Dear reader,

This updated edition of the well-known Power Engineering Guide is a manual for everyone involved in the generation, transmission and distribution of electrical energy – from system planning, to implementation and control. Our guide is designed to assist and support engineers, technicians, planners and advisors, as well as students, trainees and teachers of electrical engineering and energy technology. Beyond that, we hope the Power Engineering Guide will also be useful as a reference work for technical questions and support continuing education and training in the technical field.

Our guide covers the entire portfolio of Siemens products for the transmission and distribution of electrical power – including high, medium and low voltage, switching substations, transformers and switchgear, and is organized by product and function. It also covers solutions in the areas of Smart Grids: energy automation, energy management and network communication, as well as service and support. Key terms and abbreviations are explained in a handy appendix, and Internet addresses are provided for additional in-depth information.

Siemens AG is a global leader in electronics and electrical engineering. Siemens’ products, systems and integrated, complete solutions benefit customers by meeting a wide variety of local requirements. They represent the key technologies of the future and set global standards. All our developments and innovations – which also affect methods and processes – are distinguished by energy efficiency, economy, reliability, environmental compatibility and sustainability. The portfolio includes solutions for power transmission and distribution, for Smart Grids, for low and medium voltage as well as energy automation.

The importance of electricity is emphasized by the rapidly increasing number of electrical applications and the fact that demand will continually grow in the coming decades. To help our customers master their respective challenges and achieve success and further growth, we continue to work on selectively strengthening and optimizing our portfolio. As a result, in addition to “traditional” products for power transmission and distribution, today’s portfolio includes a wide range of additional products. We offer grid operators, electricity customers, planners and builders of electrical systems the additional benefits of integrated communications and automation technology. Our spectrum of services includes the planning, maintenance and repair of entire power supply systems.

Thanks to our vast experience in managing projects around the world, we provide power utilities, industrial companies, cities, urban planer and city hubs (airports and harbors) with cost-efficient custom-tailored solutions. Please do not hesitate to contact your local Siemens sales office. You will find the contacts to Siemens in your region at www.siemens.com/energy and www.siemens.com/infrastructure-cities.

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1 Smart Grids and the New Age of Energy

Fig. 1-1: Siemens offers complete communication solutions for the construction of Smart Grids for power utilities
Electrical energy is the backbone of our economy and supports every aspect of social and cultural life today. The comfort of always having electricity available is anything but guaranteed, however. We face major challenges in providing adequate power generation, transmission, and distribution to meet the world’s needs.

The global demand for energy is steadily increasing at the rate of three percent a year, faster than the two percent annual increase in the global demand for primary energy. There are many factors contributing to this escalation, including rapid population growth and longer life spans. The process of urbanization continues to accelerate, and growing amounts of electricity must be transported to heavily populated areas, usually over long distances. At the same time, the density and complexity of urban power supply systems are also increasing (fig. 1-1).

Fossil fuels, on the other hand, are becoming more scarce, and exploration and production of oil and gas are becoming more expensive. To slow the threat of climate change we must reduce our CO2 emissions worldwide; for power supply systems, this means increased integration of renewable energy sources such as hydro, wind, and solar power. At the same time, it also means boosting the energy efficiency of power supply systems so they contribute to our environmental and climate protection efforts and help keep energy costs under control. The growing international trade in energy, fueled by the liberalization of energy markets, and the integration of power grids across regions requires investment in more transmission power supply systems to ensure system stability and guarantee power supplies.

To meet all these challenges, an intelligent and flexible system infrastructure, smart generation, and smart buildings are essential. Achieving this will require a fundamental shift from the traditional unidirectional flow of energy and communication to a bidirectional power flow (fig. 1-2). In traditional power supply systems, power generation follows the load – but in the future, power consumption will follow generation rather than the other way around.

Power supply systems of today and tomorrow must integrate every type of power generation to bridge the increasing distances between power generation – offshore wind farms, for example – and the consumer.

The objectives set for Smart Grids are as diverse as they are exciting and ambitious. Instead of overloads, bottlenecks, and blackouts, Smart Grids will ensure the reliability, sustainability, and efficiency of power supplies. Information and communication systems within the network will be systematically expanded
and homogenized. Automation will increase considerably, and appropriately equipped smart substations will help reduce the cost and labor intensity of planning and operation. Ongoing, comprehensive monitoring will improve the way that plants and the grid are run.

Distributed power generation and storage units will be combined into virtual power plants so they can also participate in the development of the market. Susceptibility to failure will be considerably reduced by "self-healing" systems that manage and redundantly compensate for faults at the local level. Consumers will participate as end customers through smart meters that offer them better control of their own consumption, and this will make load management easier because peak loads can be avoided through price benefits. The potential of Smart Grids is enormous, and includes the use of buildings and electric vehicles linked into the network as controllable power consumers, generation, and even storage units.

Information and communication technology forms the crucial links between power generation, transmission, distribution, and consumption. The Smart Grid will create consistent structures, optimize power generation, and balance fluctuating power production with consumption (fig. 1-3).

Siemens plays a leading role in the creation and expansion of Smart Grids. Not only is Siemens uniquely positioned to trans-
Network planning
Building Smart Grids is a highly complex task that begins with a detailed quantitative assessment of the system requirements, definition of actual targets and their required performance levels, and specification of system concepts and equipment. As a result, a comprehensive strategy for building Smart Grids is necessary – including the part of the network that addresses power supply systems.

The foundation for designing an efficient Smart Grid is a detailed analysis of the system’s required performance. This is the key task for strategic network planning. Keeping a rigorous focus on the system as a whole ensures that the architecture and configuration deliver the necessary performance levels, and meet other requirements as well. The solution will integrate the most innovative technologies for power generation, transmission, distribution and consumption, while taking into account each system’s individual history and current condition. In most cases, the transition from today’s power supply system to the future Smart Grid cannot be made in one step; instead it requires step-by-step modification plans.

See chapter 9, page 478.

Power electronics (HVDC/FACTS)
Siemens power electronic solutions for High Voltage Direct Current transmission (HVDC) and Flexible Alternating Current Transmission Systems (FACTS) address the greatest challenges in power transmission.

FACTS devices can significantly increase the power transmission capacity of existing alternating current (AC) systems and extend maximum AC transmission distances by balancing the variable reactive power demand of the system. Reactive power compensation is used to control AC voltage, increase system stability, and reduce power transmission losses.

State-of-the-art FACTS devices include Fixed Series Compensators (FSC) and Thyristor Controlled Series Compensators (TCSC), or Static VAR Compensators (SVC) for dynamic shunt compensation. The latest generation of Siemens SVC devices is called SVC PLUS. These are highly standardized compact devices that can easily be implemented in demanding network environments; for example, to allow connection of large offshore wind farms.

AC technology has proven very effective in the generation, transmission and distribution of electrical power. Nevertheless, there are tasks that cannot be performed economically or with technical precision using AC. These include power transmission over very long distances, as well as between networks operating asynchronously or at different frequencies. In contrast, a unique feature of HVDC systems is their ability to feed power into grids that cannot tolerate additional increases in short-circuit currents.

The transmission capacity of a single HVDC transmission system has recently been extended by the Siemens Ultra High Voltage Direct Current transmission system (UHVDC). With a capacity of more than seven gigawatts and low rate of loss, UHVDC trans-

mission is the best way to ensure highly efficient power transmission of 2,000 kilometers or more. Electrical Super Grids based on UHVDC transmission can interconnect regions across climate and time zones, allowing seasonal changes, time of day and geographical features to be used to maximum advantage.

Siemens’ most recent development in HVDC transmission is called HVDC PLUS. Its key component is an innovative Modular Multilevel Converter (MMC) that operates virtually free of harmonics. HVDC PLUS converter stations are highly compact because there is no need for complex filter branches. This feature makes HVDC PLUS perfectly suited for installation on offshore platforms; for example, to connect offshore wind farms.

See section 2.2, page 19 (HVDC), and section 2.4, page 27 (FACTS).

Bulk renewable integration
In order to begin fulfilling the climate protection requirements of 2020, we need to use energy efficiently and reduce CO₂ emissions. Power generation needs to change accordingly. Large power plants will continue to ensure basic supplies, but there will also be renewable energy sources that fluctuate locally depending on weather and other conditions.

Energy Management System (EMS)
At power plants, the focus is on ensuring reliable supply, using generation resources efficiently, and reducing transmission losses. An Energy Management System (EMS) handles these by balancing the demands of the transmission system, generating units, and consumption. Intelligent Alarm Processors (IAPs) reduce the critical time needed to analyze faults in the grid and take corrective action, as well as the risk of incorrect analysis. Innovative Voltage Stability Analysis (VSA) applications running automatically and independently alert the operator before critical situations that jeopardize static system voltage stability occur, giving the operator time to take preventive action rather than having to react under stress. Increased grid reliability is provided by Optimal Power Flow (OPF) applications that continuously work to keep the system’s voltage level high and eliminate invalid voltage conditions. Any control measures that must be taken can be automatically executed in a closed-loop-control procedure.

Using the most efficient resources is a challenge under today’s more stringent environmental restrictions, increasingly competitive markets, and growing contractual complexity. An integrated set of closely interacting applications – ranging from back office-based, year-ahead resource optimization and maintenance planning to week- or day-ahead unit commitment and hydro-scheduling to online closed-loop control of generating units – ensures maximum efficiency grounded in powerful optimization algorithms and models. Security Constrained Unit Commitment (SCUC) has become the essential application for managing the world’s most complex energy market in California at California ISO. SCUC increases grid and market efficiency, reduces barriers to alternative power resources like demand-response and green...
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generation, and gives the operators new tools for managing transmission bottlenecks and dispatching the lowest-cost power plants.

See chapter 7, page 402.

Smart substation automation and protection

The automation and protection of substations must be enhanced to securely meet the extended requirements of future Smart Grids. The substation is in the process of becoming a node on the utility IT network for all information from the distribution substation to the customer. For example, data from the feeder automation units, power quality, meters, decentralized energy resources and home automation systems will be collected and analyzed to improve the system. Besides the new Smart Grid challenges, the usual tasks of protection, control and automation have to remain as reliable and efficient as ever. The objectives for substations are beginning to cross departmental boundaries, encompassing operations, maintenance and security requirements. Smart substation solutions and their individual components should be designed with this overarching vision and framework in mind. The use of intelligent feeder devices, an open IEC 61850 communication architecture, powerful substation computers, equipment knowledge modules and local storage all support this approach. The automated substation for Smart Grids must integrate all aspects of intelligence, from protection, automation and remote control to operational safety and advanced data collection. Going beyond the traditional concept of substation control and protection, the new automated substation must reflect the point of view of operators and maintenance personnel to become a best-in-class system that is simple both to operate and maintain. Smart Substation Automation ensures rapid and – more importantly – correct responses to unpredictable system events. The ability to reliably supply electrical power on demand can only be guaranteed by considering the power supply system in its entirety (fig. 1-4).

Smart Substation Automation Systems from Siemens support the following goals:

- Secure and reliable power supply
- Guaranteed high levels of protection for facilities and people
- Reduction of manual interactions to enhance rapid self-healing operations
- Implementation of intelligent remote error monitoring, detection, reporting
- Enabling condition-based predictive maintenance
- Support for engineering and testing through plug-and-play functionality
- Proactively distributing substation information to all relevant stakeholders
- Reduced costs for installation and maintenance.

Siemens Smart Substation Automation Systems are always customized to meet each customer’s specific requirements. The use of standard components allows the system to scale in every respect. Siemens solutions offer a fully integrated and fully automated way to operate substations under normal and emergency conditions. The system is flexible and open for future
modifications, making it easy to expand the substation while allowing the addition of new Smart Grid functions.

See chapter 6, page 262.

**Integrated Substation Condition Monitoring (ISCM)**
Integrated Substation Condition Monitoring (ISCM) is a modular system for monitoring all relevant substation components, from the transformer and switchgear to the overhead line and cable. Based on known, proven telecontrol units and substation automation devices, ISCM provides a comprehensive solution perfectly suited to substation environments. It integrates seamlessly into the existing communication infrastructure so that monitoring information from the station and the control center is displayed.

See section 10.1.3, page 496.

**Communication solutions**
The new Age of Electricity is characterized by a mix of both central and decentralized power generation, which requires bidirectional energy flows— including power from smart buildings and residential areas where consumers are becoming “prosumers.” A key prerequisite for this paradigm shift is a homogeneous, end-to-end communication network that provides sufficient bandwidth between all grid elements.

Telecommunication systems for power grid transmission have a long history in the utility industry. In today’s transmission grids, almost all substations are integrated into a communication network that allows online monitoring and controlling by an Energy Management System (EMS).

In a distribution grid, the situation is quite different. Whereas high-voltage substations are often equipped with digital communication, the communication infrastructure at lower distribution levels is weak. In most countries, fewer than ten percent of transformer substations and ring-main units (RMUs) are monitored and controlled remotely.

Communication technologies have continued to develop rapidly over the past few years, and the Ethernet has become the established standard in the power supply sector. International communication standards like IEC 61850 will further simplify the exchange of data between different communication partners. Serial interfaces will, however, continue to play a role in the future for small systems.

Because of the deregulation of energy markets, unbundling of vertically integrated structures, sharp increases in decentralized power production, and growing need for Smart Grid solutions, the demand for communications is rapidly increasing. And this applies not just to higher bandwidths, but also to new Smart Grid applications, such as the integration of RMUs and private households into power utilities.

For these complex communication requirements, Siemens offers customized, rugged communication network solutions for fiber optic, power line and wireless infrastructures based on energy industry standards.

An important element in creating and operating Smart Grids is comprehensive, consistent communication using sufficient bandwidth and devices with IP/Ethernet capability. Networks of this kind must eventually extend all the way to individual consumers, who will be integrated into them using smart metering. Consistent end-to-end communication helps meet the requirement for online monitoring of all grid components and, among other things, creates opportunities to develop new business models for smart metering and integrating distributed power generation.

See chapter 8, page 442.

**Distribution Management System (DMS)**
Today’s distribution grid operation is primarily characterized by manual procedures that rely on the expertise of an aging workforce. Using Spectrum Power Distribution Management Systems (DMS) will create a smart, self-healing grid by providing the following enhancements:

- Reduction of the occurrence and duration of outages through the application of advanced fault location and network reconfiguration algorithms.
- Minimization of losses through improved monitoring.
- Optimized utilization of assets through management of demand and distributed generation.
- Reduction of maintenance costs through online condition monitoring.

The smart management of power distribution grids is one of the key success factors for achieving ambitious Smart Grid goals.

See section 7.1, page 404, and section 7.2, page 420.

**Distribution automation and protection**
The prerequisite for comprehensive automation and protection design is determining the required levels of automation and functionality for distribution substations and RMUs. This could differ among the RMUs in one distribution grid or in the same feeder because of different primary equipment or communication availability. However, with or without limited communication access, a certain level of automation and Smart Grid functionality can still be realized, as can a mix of functions in one feeder automation system. The following levels of distribution automation can serve as a roadmap for grid upgrades moving toward the implementation of a Smart Grid:

- **Local Automation (without communication)**
  - Sectionalizer (automated fault restoration by using switching sequences)
  - Voltage regulator (automated voltage regulation for long feeders)
  - Recloser controller (auto reclose circuit-breaker for overhead lines)
Monitoring only (one-way communication to distribution substation or control center)
- Messaging box (for example, short-circuit indicators with one-way communication to distribution substation or control center for fast fault location)

Control, monitoring, and automation (two-way communication to distribution substation or control center)
- Distribution Automation RTU (DA-RTU) with powerful communication and automation features applicable to Smart Grid functions, for instance:
  - Automated self-healing routines
  - Node station for power quality applications
  - Data concentrator for smart metering systems
  - Node station for decentralized power generation
  - Node station for demand-response applications

Protection, control, monitoring, and automation (two-way communication to distribution substation or control center)
- Recloser controller for overhead lines, plus auto reclose breaker with enhanced protection functionality and advanced communication and automation features

To fulfill all these requirements in a Smart Grid feeder automation system, a modular approach to protection, monitoring, automation and communication equipment is needed. Siemens offers a complete portfolio for each level of Smart Grid application:

- Robust primary and secondary equipment to withstand tough outdoor conditions
- Flexible IO-modules adapted to the requirements of the specific RMU type, for example, for direct output to motor-driven switches or input from RMU sensors
- Optimized CPUs with advanced automation and protection functions to secure a safe and reliable power supply, with automated system recovery functions and convenient remote access
- Reliable (emergency) power supplies for all components in the RMU, for example, to operate the switchgear motor drive, to run a heating system for outdoor application, or to power the controller and communication units
- Future-oriented, fast communication via different infrastructures, for example, GPRS-/GSM modem, fiber optic, and power line carrier
- Multiple communication protocols like IEC61850 and DNP3 to connect the RMU with the distribution substation, control center, or end-user applications
- Modular, sustainable controller functions to fulfill specific Smart Grid requirements like fault detection and isolation, automatic reclosing functions, voltage or load-flow regulation, and more
- A user-friendly, powerful engineering tool with seamless integration in the overall engineering process of the distribution automation system to enable maximum re-use of data
- Open interfaces for all system components, enabling the integration of other applications; in other words, a system that is equipped for future Smart Grid modifications

Fig. 1-5: Siemens refers to its Smart Grid portfolio as Smart Grid Suite. The Suite contains everything necessary for a Smart Grid: hardware, software, IT solutions, and services for the development of intelligent grids. This refers not only to power supply grids, but also gas, water, and district heating networks. In power supply grids, Siemens also includes networks for railway electrification.

**Smart Grids and the New Age of Energy**
To manage these tasks with a global perspective, it is crucial to fully understand the overall structure of distribution grids: primary and secondary equipment, voltage levels (from high voltage via medium voltage to low voltage), indoor and outdoor applications, and multiple local regulations and standards. A big advantage derives from the use of flexible components in the same system family for the diverse feeder automation applications. Siemens provides this and more with our comprehensive Advanced Energy Automation portfolio, which transforms a Smart Grid vision into reality.

**Distributed Energy Resources (DER)**
The integration of distributed energy resources (DER) calls for a completely new concept: the virtual power plant. A virtual power plant connects many small plants that participate in the energy market in a completely new way. It makes it possible to use sales channels that otherwise would not be available to the operators of individual plants. Linked together in the network, the plants can be operated even more efficiently – and therefore more economically – than before, benefiting the operators of decentralized generating facilities.

In the virtual power plant, decentralized energy management and communication with the generating facilities play a special role, and thanks to the Siemens products Decentralized Energy Management System (DEMS) and DER Controller, are optimally supported. The centerpiece is DEMS, which enables the intelligent, economical and environmentally friendly linkage of decentralized energy sources. The DER Controller facilitates communications, and is specifically tailored to the requirements of decentralized energy sources.

See section 7.2.2, page 436.

**Decentralized Energy Management System (DEMS)**
DEMS, the core of the virtual power plant, is equally appropriate for utilities, industrial operations, operators of functional buildings, energy self-sufficient communities, regions and energy service providers. DEMS uses three tools – predictions, operational planning and real-time optimization – to optimize power. The prediction tool anticipates electrical and heat loads; for example, as a function of the weather and the time of day. Predicting generation from renewable energy sources is also important, and is based on weather forecasts and the unique characteristics of the plants. Short-term planning to optimize operating costs of all installed equipment must comply with technical and contractually specified background conditions every 15 minutes for a maximum of one week in advance. The calculated plan minimizes the costs of generation and operation, while DEMS also manages cost efficiency and environmental considerations.

See section 7.2.2, page 436.

**Smart metering solutions**
The Automated Metering and Information System (AMIS) records the power consumption of each individual consumer over time, and in turn, consumers are given detailed information about their power consumption. Experts estimate that the use of smart meters can save up to ten terawatt-hours of electricity, or almost two percent of total energy consumption. For the expansion of Smart Grids, Siemens has developed a Smart Grid solution based on its AMIS system, which covers both smart metering and the automation of distribution systems. In addition, Siemens has for the first time integrated in this application the energy automation, power quality and multimedia functions. For example, the power snapshot analysis is the first Smart Grid application worldwide, which provides synchronous grid information via AMIS smart meters. Power quality data supplements this information, with the aid of which grid stability and supply security can be enhanced. Open interfaces for tablet computers or smart phones, via which consumption and energy data can be graphically displayed, are also available. Since Siemens acquired eMeter, a California-based MDM company, in January 2012, the Metering Data Management System (MDM) EnergyIP also has been part of Siemens’ Smart Grid portfolio.

See section 10.3, page 502.

There is no doubt that the future belongs to the Smart Grid, and that power generation will change significantly by the time it becomes a reality. Large power plants will continue to ensure the basic supply, but there will also be renewable energy sources, causing fluctuations in the grid. In the not too distant future, flexible intermediate storage of temporary excess power in the grid will be possible using electric vehicles and stationary storage units. Sensors and smart meters will switch these units on or off, ensuring efficient load management. From generating large offshore wind farms to delivering smart metering in homes, Siemens is one of the worldwide leading providers of products, systems, technology and solutions for Smart Grids.
## Power Transmission and Distribution Solutions

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2 Power Transmission and Distribution Solutions

2.1 Overview of Technologies and Services

Feeding the power generated at different locations over long distances into power systems often calls for extraordinary power transmission and distribution solutions. Despite the challenges it poses, however, interconnecting of different regions, countries or even continents remains a viable option for providing these areas with economical access to power (fig. 2.1-1). As a solution provider with extensive experience in every aspect of power transmission and distribution, Siemens has already implemented a large number of projects linking power systems or connecting decentralized generating units to the grid. In each case, conditions were unique. And because Siemens strives to provide its customers with the most cost-efficient results, the implemented solutions using different technologies were also unique.

2.1.1 Solutions for Smart and Super Grids with HVDC and FACTS

The power grid of the future must be secure, cost-effective and environmentally compatible. The combination of these three tasks can be tackled with the help of ideas, intelligent solutions as well as advanced technologies.

Innovative solutions with HVDC (High-Voltage Direct Current Transmission) and FACTS (Flexible AC Transmission Systems) have the potential to cope with the new challenges. By means of power electronics, they provide features which are necessary to avoid technical problems in the power systems, they increase the transmission capacity and system stability very efficiently and help to prevent cascading disturbances.

The vision and enhancement strategy for the future electricity networks are, for example, depicted in the program for “Smart Grids”, which was developed within the European Technology Platform.

Features of a future smart grid such as this can be outlined as follows:
- Flexible: fulfilling operator needs whilst responding to the changes and challenges ahead
- Accessible: granting connection access to all network users, particularly for RES and high-efficiency local generation with zero or low carbon emissions
- Reliable: assuring and improving security and quality of supply
- Economic: providing best value through innovation, efficient energy management and “level playing field” competition and regulation

Smart grids will help achieve a sustainable development. It is worthwhile mentioning that the smart grid vision is in the same way applicable to the system developments in other regions of the world. Smart grids will help achieve a sustainable development.

An increasingly liberalized market will encourage trading opportunities to be identified and developed. Smart grids are a necessary response to the environmental, social and political demands placed on energy supply.

2.1.2 AC/DC Transmission and Distribution

HVDC, FACTS and SIPLINK

Today’s power transmission systems have the task of transmitting power from point A to point B reliably, safely and efficiently. It is also necessary to transmit power in a manner that is not harmful to the environment. Siemens offers comprehensive solutions, technical expertise and worldwide experience to help customers meet these challenges.

For each application and technical transmission stage, Siemens offers optimized solutions with SIPLINK (Siemens Multifunctional Power Link), HVDC transmission or FACTS for the most efficient use of AC power systems and lines.

Typical applications for FACTS include fast voltage control, increased transmission capacity over long lines, power flow control in meshed systems, and power oscillation damping. With FACTS, more power can be transmitted within the power system. When technical or economical feasibility of conventional three-phase technology reaches its limit, HVDC will be the solution (fig. 2.1-2). Its main application areas are economical transmission of bulk power over long distances and interconnection of asynchronous power grids. Siemens’s latest innovation in high-voltage direct current technology is HVDC PLUS. The advantages of the new system, which employs voltage-sourced converters, include a compact layout of the converter stations and advanced control features such as independent active and reactive power control, and black start capability.

For medium-voltage DC transmission, Siemens offers the SIPLINK system. Depending on the application and the configuration of the existing system, SIPLINK will reduce investment, system and lifecycle costs. The system controls the active power and optimizes voltage stability by providing reactive power (section 2.3).
Power lines
Since the very beginning of electric power supply, overhead lines have constituted the most important component for transmission and distribution systems. Their portion of the overall length of electric circuits depends on the voltage level and on local conditions and practice. When environmental or structural factors make overhead lines impossible, Siemens’s “underground” transmission path is the ideal solution. Siemens gas-insulated transmission lines (GIL) are an economically viable alternative to conventional power cables (section 2.5).

Grid access
Decentralized generating units are custom-engineered, which involves reconciling contrasting parameters, such as high reliability, low investment costs and efficient transmission, in the best possible solution. Specific attention is paid to intelligently designing the “collection systems” at the medium-voltage level, which is followed by the high-voltage transmission system offering the grid access. By relying on both transmission technologies, Siemens can offer AC as well as DC solutions at both the high and medium-voltage levels (section 2.6).

Solar power
As an alternative power supply for rural electrification, Siemens integrates solar power in the low-voltage distribution system for private consumers, as stand-alone systems or even with grid connection (section 2.7).
2.1.3 Managing Entire Projects

Project management
Supplying power is more than just combining a number of individual components. It calls for large-scale projects, such as transmission systems or industrial complexes, especially in countries where the demand for power is growing at an accelerated pace. The best partner to handle such large projects is an expert who can carefully analyze the demand, take an integrated approach to project planning and consider all the general conditions. A qualified project partner is one that can provide high-quality components and services for both power transmission tasks and power system management. Such a partner also can ensure that the systems are installed expertly.

Turnkey solutions
Siemens’s many years of experience allow it to offer turnkey power transmission solutions that are tailored to individual requirements. Siemens supplies all components, including power plants, AC or DC transmission systems and high-voltage interconnected power systems with high, medium and low voltage that finally reach the individual customers. What makes these turnkey solutions so attractive is that one party is responsible for coordinating the entire project, thereby reducing the number of interfaces between system operator and supplier to a bare minimum. Turnkey projects also reduce the operator’s own share in project risks, since Siemens is responsible for delivering a system that is ready for operation.

Engineering, procurement, production and construction
In addition to comprehensive planning and management services, engineering is one of Siemens’s special strengths. Siemens can produce or procure all necessary components and perform all construction work up to testing, commissioning and putting an entire system into operation. With Siemens as a partner, companies can benefit from Siemens’s extensive manufacturing expertise and from the work of experienced Siemens engineers who have already participated in a wide range of projects worldwide. Working on this basis, Siemens can provide the best technology for projects based on proprietary Siemens components and additional hardware purchased from reputable vendors. Siemens experts have the important task of determining which of the various technical options are best suited for implementing the project. They consider transmission capacity, transmission efficiency and the length of the transmission line, and after the best technical solution has been determined, they assess its long-term cost efficiency for the operator. Only then can the actual implementation begin for installation and on-time commissioning.

Maintenance
Systems will operate at their best, when equipment lasts a long time and provides continuous trouble-free operation. The Siemens maintenance service ensures that all components are always running safely and reliably. Siemens continuously maintains operator systems through regular inspections including all switchgear and secondary technology. If a malfunction occurs during operation, Siemens is immediately on the job; support is available 24 hours a day, 365 days a year. And with the increased use of state-of-the-art online monitoring and remote diagnosis systems, Siemens offers additional possibilities for keeping operating costs to a minimum.

Optimization and modernization
No company can replace its equipment and systems fast enough to keep pace with technological progress. But all companies can take advantage of the latest technological opportunities through the variety of optimization options provided by the Siemens retrofit and upgrade service. This fast and economical solution allows customers to invest their capital wisely and take full advantage of Siemens’s experience in adapting older systems to new technical standards.

2.1.4 Partners Throughout the System Life Cycle

Siemens is with system operators every step of the way to help them develop their projects, to create financing solutions and to provide project management (fig. 2.1-3), and supports them beyond engineering, production and construction. This support continues as the system is commissioned, as customers need maintenance services and even when it is time to modernize. The partnership between Siemens and the system operators does not stop when a turnkey job is finished: Siemens accompanies the system operators throughout the entire life cycle of their systems, offering a wide range of services with products of the highest quality that are always based on the most durable technologies.

For further information:
http://www.siemens.com/energy/power-transmission-solutions
http://www.siemens.com/energy/hvdc-facts-newsletter
2.2 High-Voltage Direct-Current Transmission

Siemens HVDC transmission is used when technical and/or economical feasibility of conventional high-voltage AC transmission technology have reached their limits. The limits are overcome by the basic operation principle of an HVDC system, which is the conversion of AC into DC and vice versa by means of high power converters.

Featuring its fast and precise controllability, a Siemens HVDC can serve the following purposes:
- Transmission of power via very long overhead lines or via long cables where an AC transmission scheme is not economical or even not possible
- Transmission of power between asynchronous systems
- Exact control of power flow in either direction
- Enhancement of AC system stability
- Reactive power control and support of the AC voltage
- Frequency control
- Power oscillation damping

2.2.1 Siemens HVDC Technologies

Depending on the converter type used for conversion between AC and DC, two technologies are available:
- Line Commutated Converter technology (LCC) based on thyristor valves
- Voltage Sourced Converter technology (VSC) based on IGBT valves, also known as HVDC PLUS

Both technologies enable Siemens to provide attractive solutions for most challenging transmission tasks ranging from extra high voltage bulk power transmission to the connection of systems in remote locations to main grids; from long distance overhead line or cable to interconnection of two systems at one location.

2.2.2 Main Types of HVDC Schemes

The main types of HVDC converters are distinguished by their DC circuit arrangements (fig. 2.2-1), as follows:

**Back-to-back**: Rectifier and inverter are located in the same station. These converters are mainly used:
- To connect asynchronous high-voltage power systems or systems with different frequencies
- To stabilize weak AC links
- To supply more active power where the AC system already is at the limit of its short circuit capability
- For grid power flow control within synchronous AC systems

**Cable transmission**: DC cables are the most feasible solution for transmitting power across the sea to supply islands/offshore platforms from the mainland and vice versa.

**Long-distance transmission**: Whenever bulk power is to be transmitted over long distances, DC transmission is the more economical solution compared to high-voltage AC.
2.2.3 LCC HVDC – The “Classical” Solution

After more than 50 year’s history with Siemens constantly contributing to its development, LCC HVDC is still the most widely used DC transmission technology today.

Technology

Thyristor valves

The thyristor valves are used to perform the conversion from AC into DC and thus make up the central component of the HVDC converter station. The valves are described by the following features:

- Robust design
- Safe with respect to fire protection due to consequent use of fire-retardant, self-extinguishing material
- Minimum number of electrical connections and components avoiding potential sources of failure
- Parallel cooling for the valve levels using de-ionized cooling water for maximum utilization of the thyristors
- Earthquake-proof design as required (fig. 2.2-2)
- Direct Light-Triggered Thyristors (LTT) with wafer-integrated overvoltage protection – the standard solution for transmission ratings up to 5,000 MW
- Electrically triggered thyristors for bulk power transmission up to 7,200 MW and above

Filter technology

Filters are used to balance the reactive power of HVDC and power system and to meet high harmonic performance standards.

- Single-tuned, double-tuned and triple-tuned as well as high-pass passive filters, or any combination thereof, can be installed depending on the specific requirements of a station.
- Active AC and DC filters are available for highest harmonic performance.
- Wherever possible, identical filters are selected maintaining the high performance even when one filter is switched off.

Applications

The primary application areas for LCC HVDC are:

- Economical power transmission over long distances
- Interconnection of asynchronous power grids without increase in short-circuit power
- Submarine DC cable transmission
- Hybrid integration of HVDC into a synchronous AC system for stability improvement
- Increase in transmission capacity by conversion of AC lines into DC lines

Power ratings

Typical ratings for HVDC schemes include:

- Back-to-back: up to typically 1,200 MW
- Cable transmission: up to 800 MW per HVDC cable
- Long-distance transmission: up to typically 5,000 MW
2.2.4 Ultra-HVDC Transmission (UHV DC) Bulk Power

UHV DC from Siemens is the answer to the increasing demand for bulk power transmission from remote power generation to large load centers. After having been awarded the contract in 2007, Siemens has successfully commissioned the world’s first ±800 kV UHV DC system with 5,000 MW in China Southern Power Grid in 2010 (fig. 2.2-3).

Technology
The high DC voltage imposes extreme requirements to the insulation of the equipment and leads to huge physical dimensions (fig. 2.2-4). The capability to withstand high electrical and mechanical stresses is thoroughly investigated during the design. All components are extensively tested to assure that they withstand most severe operating conditions and meet highest quality standards.

The thyristor valves are equipped with either 5” or 6” thyristors depending on the transmission rating (fig. 2.2-5).

Applications
UHV DC transmission is the solution for bulk power transmission of 5,000 MW or higher over some thousand kilometers. Compared to a 500 kV LCC HVDC system, the Siemens 800 kV UHV DC reduces line losses by approx. 60 % – an important aspect with respect to CO₂ reduction and operational cost.

Special attention has to be paid to the corresponding AC networks that have to supply or absorb the high amounts of electric power.

Power ratings
The Siemens 800 kV HVDC systems are designed to transmit up to 7,200 MW over long distances.

2.2.5 HVDC PLUS – One Step Ahead

VSC technology offers unique advantages for HVDC transmission which become more and more important for applications like connecting remote renewable energy sources, oil and gas platforms or mines to an existing grid.

Using the latest modular IGBT (Insulated Gate Bipolar Transistor) technology in a pioneering Modular Multilevel Converter (MMC) design, Siemens engineers have developed HVDC PLUS as a landmark product in the evolution of HVDC transmission.

The high power ratings available today make HVDC PLUS increasingly attractive also for projects where LCC HVDC could be used from a technical perspective.

Features
HVDC PLUS provides important technical and economical advantages compared to LCC:
- HVDC technology in the smallest possible space:
  An HVDC PLUS station does not require any filters (fig. 2.2-6).
Together with a compact design of the MMC, this makes HVDC PLUS perfectly suitable for offshore platforms or stations with limited space (fig. 2.2-7, fig. 2.2-8).

- Independence from short-circuit capacity:
  HVDC PLUS can operate in networks with very low short-circuit capacity or even in isolated systems with or without own generation using its black-start capability.
- Unipolar DC voltage
  The DC voltage polarity is fixed independently from the direction of power flow. This allows integration into multi-terminal systems or DC grids. HVDC PLUS can operate with extruded XLPE or mass-impregnated DC cables.
- Economical design and standardization:
  The modularly designed HVDC PLUS converter stations can be perfectly adapted to the required power rating (fig. 2.2-7).
- Standard AC transformers can be used, whereas LCC transformers require special design due to additional stresses from DC voltage and harmonics.

**Applications**
HVDC PLUS can be applied in all fields of HVDC transmission – there are no technical restrictions. The advantages of HVDC PLUS will be most apparent in circumstances that require the following capabilities:
- Black start of AC networks
- Operation in AC networks with low short-circuit capacity
- Compact design, e.g., for offshore platforms
- Operation in DC multi-terminal systems or in a DC grid

**Power ratings**
The design of HVDC PLUS is optimized for power applications in the range from 30 MW up to 1,000 MW or higher, depending on the DC voltage.

### 2.2.6 Siemens HVDC Control System: Win-TDC

The control and protection system is an important element in an HVDC transmission. The Siemens control and protection system for HVDC has been designed with special focus on high flexibility and high dynamic performance, and benefits from the knowledge gained from over 30 years of operational experience in HVDC and related fields of other industries (fig. 2.2-9).

High reliability is achieved with a redundant and robust design. All control and protection components from the human-machine interface (HMI), control and protection systems down to the measuring equipment for DC current and voltage quantities have been designed to take advantage of the latest software and hardware developments. These control and protection systems are based on standard products with a product lifecycle of 25 years or more.

The name Win-TDC reflects the combination of the PC-based HMI system SIMATIC WinCC and the high-performance industrial control system SIMATIC TDC.

SIMATIC WinCC (Windows Control Centre) is a PC-based HMI software for Microsoft Windows that is used for operator control and monitoring of HVDC systems.

SIMATIC TDC (Technology and Drive Control) is a high-performance automation system which allows the integration of both open-loop and high-speed closed-loop controls within this single system. It is especially suitable for HVDC (and other power electronics applications) demanding high-performance closed-loop control. For extremely fast control functions as required in HVDC PLUS systems, SIMATIC TDC is complemented by the
2.2 High-Voltage Direct-Current Transmission

dedicated PLUSCONTROL comprising the fast Current Control System (CCS) and the Module Management System (MMS).

SIMATIC WinCC and SIMATIC TDC are used in a wide range of industrial applications including power generation and distribution.

In Siemens LCC HVDC systems, the DC currents and voltages are measured with a hybrid electro-optical system: DC current with a shunt located at HV potential, DC voltage with a resistive/capacitive voltage divider. Both systems use laser-powered measuring electronics so that only optical connections are made to the ground level controls – this provides the necessary HV isolation and noise immunity.

For HVDC PLUS, the DC currents are measured with a zero flux measuring system, which provides the required accuracy and dynamic response for fast control during grid transients. The zero flux cores are located at ground level on suitable locations, e.g., converter hall bushings or cable sealing ends.

Siemens provides proven hardware and software systems built around state-of-the-art technologies. Their performance and reliability fulfills the most demanding requirements for both new installations and control system replacement (fig. 2.2-10).

2.2.7 Services

The following set of services completes the Siemens HVDC portfolio.

Turnkey service
Experienced staff designs, installs and commissions the HVDC system on a turnkey basis.

Project financing
Siemens is ready to assist customers in finding proper project financing.

General services
Extended support is provided to customers of Siemens from the very beginning of HVDC system planning, including:

- Feasibility studies
- Drafting the specification
- Project execution
- System operation and long-term maintenance
- Consultancy on upgrading/replacement of components/redesign of older schemes, e.g., retrofit of mercury-arc valves or relay-based controls

Studies during contract execution are conducted on system engineering, power system stability and transients:

- Load-flow optimization
- HVDC systems basic design
- System dynamic response
- Harmonic analysis and filter design for LCC HVDC
- Insulation and protection coordination
- Radio and PLC interference
- Special studies, if any

For further information:
http://www.siemens.com/energy/hvdc
http://www.siemens.com/energy/hvdc-plus
http://www.siemens.com/energy/uhvdc
2.3 Medium-Voltage DC Links with SIPLINK

Just like HVDC systems in transmission networks, medium-voltage distribution networks with different frequency, voltage or phase can also be interconnected flexibly. An innovative medium-voltage link of this type for distribution networks is the Siemens Multifunctional Power Link (SIPLINK). This converter-based Back-to-back link (fig. 2.3-1, fig. 2.3-2) is able to selectively control energy flows between subnetworks, and at the same time can improve the voltage quality by providing reactive power.

SIPLINK provides a means of interlinking different power generators or networks with different frequency or power capacity without impairing system stability or increasing the fault currents. Integration of distributed and independent power generators in existing networks is also improved. SIPLINK can cut investment, system and lifecycle costs for the following applications in particular:

- Connection of ships berthed in port to the more environment-friendly shoreside power supply system (SIHARBOR shore-to-ship connection)
- Energy transfer between different distribution networks (urban networks) through interconnected operation
- Increasing the availability and voltage quality of industrial networks

2.3.1 Shore-to-Ship Connection

Cost pressure and increasingly stringent environmental regulations are forcing many ports to supply ships in port with electrical power from an onshore source. To address this need, Siemens has developed SIHARBOR, a shore-to-ship connection system that meets the requirements of port operators, shipping companies, dockyards and power supply companies. Thanks to SIHARBOR, ships can shut down their diesel generating sets that
would otherwise be needed, and that not only produce electricity but also produce exhaust gases, soot, fine dust and noise, thus contributing to “harbor smog” (fig. 2.3-3).

SIPLINK is the core element of this supply system. It consists of two self-commutated IGBT pulse-controlled converters that are interconnected through a DC intermediate circuit. The converters are connected on one side to the local power supply network and on the other side to the ship’s onboard system. SIPLINK is thus able not only to feed the onboard system from the distribution network, but also to match the various different parameters to one another and to interlink them. Up to 5 MVA of power can be transmitted with a medium-voltage plug and socket connection.

Both the port and the ship must be equipped with such a plug-in connection system in order to use SIHARBOR. After connecting the plug-in connector in the ship, the automation system installed on shore automatically initiates the system start-up. The user dialog for this process is conducted from the ship. The ship’s power supply is not interrupted. SIPLINK is self-synchronizing and takes over the power supply within a few minutes. The diesel generators for the onboard power supply can then be shut down, and the complete onboard network can be supplied in an environmentally friendly way from the shore-based power distribution system.

Advantages of this system include:
- Flexible connection of all types of onboard systems, regardless of voltage or frequency
- A single MV cable connection instead of several LV connections
- Electrical separation of shoreside and onboard network, to keep the respective protection schemes and avoid galvanic corrosion

The system also takes into account the different types of ships, such as passenger ships, container ships and ferries. Thanks to its modular basis, any combination of 50 Hz and 60 Hz power supply systems is possible, as are all voltage levels.

### 2.3.2 Power Transfer Between Distribution Networks

Another application area for SIPLINK is the linking of distribution networks (urban networks) where SIPLINK controls the exchange of electrical energy between independent networks. The particular advantage here is that in the event of supply bottlenecks in one network, available power reserves in another network can be used to make up for the shortfall (fig. 2.3-4). The amount of costly energy that needs to be brought in “from outside,” especially during periods of peak demand is decreased. This allows significant cost savings. Other advantages, aside from minimizing energy purchases, include the following:
- The reliability of the supply and voltage quality are improved.
- Especially in population centers, SIPLINK offers an alternative to extending the network and thus saves investment costs.

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**Fig. 2.3-2:** System configuration of SIPLINK with two self-commutated IGBT pulse-controlled converters for controlling the active power flow and for rapid reactive power regulation

**Fig. 2.3-3:** An innovative solution to counter “harbor smog”: Siemens technology supplies ships in port with environmentally friendly electricity from the public network

**Fig. 2.3-4:** Lower daily peaks in the distribution system of a population center as a result of procuring power from another distribution network linked via SIPLINK
2.3.3 High Availability of Industrial Networks

SIPLINK can also provide a reliable power supply to complex plants and equipment, for example, in the oil and gas industry or chemical industry.

SIPLINK provides unlimited options for switching electricity between two or more networks at a medium-voltage level exactly according to the individual requirements in the particular network. This capability ensures improved supply reliability and better voltage quality at the distribution level. The protection afforded acts in both directions. Sensitive loads are protected against "unclean" networks, and conversely, networks are protected against problematical consumers. Power generation costs can also be reduced substantially through intelligent resource management, thanks to SIPLINK. It is possible under certain circumstances to avoid using additional diesel generators to cover peak loads if less power is needed in another subnetwork at that particular moment. Using SIPLINK cuts costs and reduces pollution of the environment.

A high-availability power supply is essential for certain industrial processes. In such cases, two independent incoming feeders can jointly supply one load (Y-circuit). If one of these feeders fails, the second takes over without interruption so that the changeover is not noticeable at the consumer load (fig. 2.3-5). It is also possible to divide the load between the two feeders in any desired ratio, thus balancing the two feeders.

The SIPLINK Multi Feed configuration is specially suitable for industrial processes where a high-availability power supply is needed but very short interruptions in the millisecond range are permissible (no voltage dips > 70 ms allowed) (fig. 2.3-6). In the case of a short circuit or other fault in one of the power feeding busbars, SIPLINK seamlessly takes over the power supply. SIPLINK is short-circuit-proof and feeds its rated power to short circuit. At the same time, an OPEN command is sent to the normal feeding switch on the busbar. As soon as the contacts of the switch are opened (about 50 ms), the voltage on the busbar increases immediately to the rated voltage (fig. 2.3-7). The Multi Feed configuration is simpler in design than the Y-circuit and is used where short voltage dips are acceptable.
2.4 Flexible AC Transmission Systems

Flexible AC Transmission Systems (FACTS) have been evolving to a mature technology with high power ratings. The technology, proven in numerous applications worldwide, became a first-rate, highly reliable one. FACTS, based on power electronics, have been developed to improve the performance of weak AC systems and to make long distance AC transmission feasible and are an essential part of smart grid and super grid developments (refer to chapter 1).

FACTS can also help solve technical problems in the interconnected power systems. FACTS are available in parallel connection:
- Static Var Compensator (SVC)
- Static Synchronous Compensator (STATCOM)
- or in series connection:
  - Fixed Series Compensation (FSC)
  - Thyristor Controlled/Protected Series Compensation (TCSC/TPSC)

2.4.1 Parallel Compensation

Parallel compensation is defined as any type of reactive power compensation employing either switched or controlled units that are connected in parallel to the transmission network at a power system node.

Mechanically Switched Capacitors/Reactors (MSC/MSR)
Mechanically switched devices are the most economical reactive power compensation devices (fig. 2.4-1a).
- Mechanically switched capacitors are a simple but low-speed solution for voltage control and network stabilization under heavy load conditions. Their utilization has almost no effect on the short-circuit power but it increases the voltage at the point of connection.
- Mechanically switched reactors have exactly the opposite effect and are therefore preferable for achieving stabilization under low load conditions.
- An advanced form of mechanically switched capacitor is the MSCDN. This device is an MSC with an additional damping circuit for avoidance of system resonances.

Static Var Compensator (SVC)
Static Var Compensators are a fast and reliable means of controlling voltage on transmission lines and system nodes (fig. 2.4-1b, fig. 2.4-2). The reactive power is changed by switching or controlling reactive power elements connected to the secondary side of the transformer. Each capacitor bank is switched ON and

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Parallel compensation

<table>
<thead>
<tr>
<th>a)</th>
<th>b)</th>
<th>c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSC (DN)/MSR (DN = Damping network)</td>
<td>SVC</td>
<td>SVC PLUS</td>
</tr>
<tr>
<td>52 kV &lt; 1,000</td>
<td>52 kV &lt; 800</td>
<td>±8 kV &lt; 800</td>
</tr>
<tr>
<td>50 MVAR &lt; 500</td>
<td>50 MVAR &lt; 800</td>
<td>±25 MVAR &lt; ±100 (and more)</td>
</tr>
</tbody>
</table>

1 Switchgear 2 Capacitor 3 Reactor 4 Thyristor valve(s) 5 Transformer 6 IGBT valves 7 DC capacitors

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Fig. 2.4-1a: Mechanically switched capacitors (MSC) and mechanically switched reactors (MSR) connected to the transmission system
Fig. 2.4-1b: Static Var Compensator (SVC) with three branches (TCR, TSC, filter) and coupling transformer
Fig. 2.4-1c: SVC PLUS connected to the transmission system
OFF by thyristor valves (TSC). Reactors can be either switched (TSR) or controlled (TCR) by thyristor valves.

When system voltage is low, the SVC supplies capacitive reactive power and rises the network voltage. When system voltage is high, the SVC generates inductive reactive power and reduces the system voltage.

Static Var Compensators perform the following tasks:
• Improvement in voltage quality
• Dynamic reactive power control
• Increase in system stability
• Damping of power oscillations
• Increase in power transfer capability
• Unbalance control (option)

The design and configuration of an SVC, including the size of the installation, operating conditions and losses, depend on the system conditions (weak or strong), the system configuration (meshed or radial) and the tasks to be performed.

SVC PLUS – new generation of STATCOM
SVC PLUS is an advanced STATCOM which uses Voltage-Sourced Converter (VSC) technology based on Modular Multilevel Converter (MMC) design.

• The MMC provides a nearly ideal sinusoidal-shaped waveform on the AC side. Therefore, there is only little – if any – need for high-frequency filtering and no need for low order harmonic filtering.
• MMC allows for low switching frequencies, which reduces system losses.
• SVC PLUS uses robust, proven standard components, such as typical AC power transformers, reactors and switchgear.
• The footprint of an SVC PLUS installation is up to 50 % smaller than that of a conventional SVC installation of the same rating.

Applications
SVC PLUS fulfills the same task as conventional SVCs. Due to the advanced technology, SVC PLUS is the preferred solution for grid access solutions (e.g., wind parks).

Modular system design
The modular SVC PLUS is equipped with industrial class IGBT (Insulated Gate Bipolar Transistors) power modules and DC capacitors.
• A very high level of system availability, thanks to the redundancy of power modules.
• Standard WinCC and SIMATIC TDC control and protection hardware and software are fully proven in practice in a wide range of applications worldwide.

Portfolio
• Standardized configurations are available: ± 25, ± 35, and ± 50 MVAr as containerized solutions. Up to four of these units can be configured as a fully parallel operating system.
• Easily expendable and relocatable
• Open rack modular system configuration enables transformerless grid connection up to 36 kV and ± 100 MVAr.

For higher system voltages, standard AC transformers are used.
• Hybrid solutions with mechanically switched capacitors (MSC) or reactors (MSR) are available.
2.4.2 Series Compensation

Series compensation is defined as insertion of reactive power elements into transmission lines. The most common application is the fixed series capacitor (FSC). Thyristor-valve controlled systems (TCSC) and thyristor-valve protected systems (TPSC) may also be installed.

Fixed Series Capacitor (FSC)
The simplest and most cost-effective type of series compensation is provided by FSCs. FSCs comprise the actual capacitor banks, and for protection purposes, parallel arresters (metal-oxide varistors, MOVs), spark gaps and a bypass switch for isolation purposes (fig. 2.4-7a).

Fixed series compensation provides the following benefits:
• Increase in transmission capacity
• Reduction in transmission angle

Thyristor-Controlled Series Capacitor (TCSC)
Reactive power compensation by means of TCSCs can be adapted to a wide range of operating conditions. It is also possible to control the current and thus the load flow in parallel transmission lines, which simultaneously improves system stability. Another important application for TCSC is power oscillation damping.

Additional benefits of thyristor-controlled series compensation:
• Damping of power oscillations (POD)
• Load flow control
• Increase in system stability
• Thyristor-Protected Series Capacitor (TPSC)

When high power thyristors are used, there is no need to install conventional spark gaps or surge arresters. Due to the very short cooling-down times of the special thyristor valves, TPSCs can be quickly returned to service after a line fault, allowing the transmission lines to be utilized to their maximum capacity. TPSCs are the first choice whenever transmission lines must be returned to maximum carrying capacity as quickly as possible after a failure (fig. 2.4-7c).

For further information:
http://www.siemens.com/energy/facts
2.5 Power Transmission Lines

2.5.1 Gas-Insulated Transmission Lines

For high-power transmission systems where overhead lines are not suitable, alternatives are gas-insulated transmission lines (GIL). GIL exhibit the following differences to cables:
- High-power ratings (transmission capacity up to 3,700 MVA per system)
- High overload capability
- Auto-reclosing functionality without overheating risk
- Suitable for long distances (70 km and more without compensation of reactive power)
- High short-circuit withstand capability (even in the theoretical case of internal arc faults)
- Possibility of direct connection to gas-insulated switchgear (GIS) and gas-insulated arresters without cable entrance fitting
- Non-flammable; no fire risk in case of failures
- Lowest electromagnetic field

History/Siemens’ experience

When SF₆ was introduced in the 1960s as an insulating and switching gas, it became the basis for the development of gas-insulated switchgear. On basis of the experience collected with GIS, Siemens started to develop SF₆ gas-insulated lines to transmit electrical energy. The aim was to create alternatives to air insulated overhead lines with decisively smaller clearances. In the early 1970s initial projects were implemented. More installations in tunnels and above ground followed. In the course of product optimization, the initially used insulating medium SF₆ was replaced by a gas mixture where the majority of the insulating gas is nitrogen, a non toxic natural gas. Only a comparatively small portion of sulfur hexafluoride (SF₆) is still needed. Thus, the way was free for environmentally friendly long transmission projects with GIL. The latest innovation of Siemens GIL is the directly buried laying technique, which was a further milestone for long distance transmission with GIL.

Challenges now and in the future

Continuously growing world population and urbanization lead to a strongly increased demand for bulk power transmission at extra high voltage, right into the heart of cities. At the same time, the available space for transmission systems has been restricted more and more, and environmental requirements such as EMC and fire protection have gained increased importance. GIL fulfil these requirements perfectly. Meanwhile power generation is undergoing a conceptual change as well. As natural resources are limited, regenerative power generation is becoming more important. Offshore wind parks and solar power plants are being installed, providing a huge amount of energy at remote places. Consequently, transmission systems are needed which allow to transport this bulk power with utmost reliability and with the least possible losses.

The transmission systems of the future will be measured by their overall CO₂ balance, asking for the minimum possible environmental impact from production of the equipment through...
Power Transmission and Distribution Solutions

2.5 Power Transmission Lines

operational while in service until its end of service life. Due to its properties and low losses, the overall CO₂ impact of GIL is clearly lower than that of traditional overhead-lines, proving the GIL's environment friendliness.

Reliable technology
The gas-insulated transmission line technique is highly reliable in terms of mechanical and electrical design. Experience over the course of 35 years shows that after a GIL system is commissioned and in service, it runs safely without dielectrical or mechanical failures. Consequently, Siemens GIL – in service for decades – did not have to undergo their initially planned revision after 20 years of operation. Instead, a mere inspection was sufficient as there was no sign of any weak point. From the operational experience gained with Siemens GIL and GIB, the Mean Time Between Failure (MTBF) was estimated > 213 years for a 1-km-long GIL system.

Basic design
In order to meet electrical and mechanical design criteria, gas-insulated lines have considerable cross-sections of enclosure and conductor, which ensures high-power transmission ratings and low losses. Because of the geometry and the gaseous insulating medium, the systems create only low capacitive loads, so that compensation of reactive power is not needed, not even for longer distances. The typical technical data of the GIL are shown in table 2.5-1.

Testing
GIL systems are tested according to the international standard IEC 62271-204 "Rigid high-voltage, gas-insulated transmission lines for voltages of 72.5 kV and above" (fig. 2.5-3, fig. 2.5-4).

The long-term performance of GIL has been proven by tests at the independent test laboratory IPH, Berlin, Germany, and the former Berlin power utility BEWAG (now ELIA). The test pattern was set by adopting long-term test procedures for power cables. The test procedure consisted of load cycles with doubled voltage and increased current as well as frequently repeated high-voltage tests. The results confirmed the meanwhile more than 35 years of field experience with GIL installations worldwide. The Siemens GIL was the first in the world to have passed these long-term tests without any problems. Fig. 2.5-3 shows the test setup arranged in a tunnel of 3 m diameter.

Fault containment
Tests have proven that the arcing behavior of GIL is excellent. It is even further improved by using mixed-gas insulations. Consequently there would be no external damage or fire caused by an internal fault.

Electromagnetic compatibility allows flexible route planning
The construction of the GIL results in much smaller electromagnetic fields than with conventional power transmission systems. A reduction by a factor of 15 to 20 can be achieved. This makes GIL suitable to follow new routings through populated areas (e.g., next to hospitals or residential areas, in the vicinity of flight monitoring systems, etc.). GIL can be laid in combined
infrastructure tunnels together with foreign elements (e.g., close to telecommunication equipment and similar). Thus, GIL provides maximum flexibility for the planning of transmission networks in EMC-sensitive environments, where magnetic fields have to be avoided. Siemens GIL systems can satisfy the most stringent magnetic flux density requirements, for example, the Swiss limit of 1 μT (fig. 2.5-2).

**Jointing technique**
In order to perfectionize gas tightness and to facilitate laying of long straight lines, flanges may be avoided as a jointing technique. Instead, welding the various GIL construction units ensures highest quality (fig. 2.5-5). Siemens’ welding process is highly automated by using orbital welding machines. This as well contributes to high productivity in the welding process and a short overall installation time. To ensure quality, the welds are controlled by a new sophisticated ultrasonic testing system which exceeds even X-ray test standards.

**Laying**
During the installation process, climatic influences such as rain, dust, seasons of the year, etc. need to be taken into account. To meet Siemens’ requirements for cleanness and quality, the laying techniques of GIL differ from pipeline technology. To protect the assembly area against dust, particles, humidity and other environmental factors, a temporary installation tent is set up for the installation period. In this way, working conditions are created which meet the standards of modern GIS factories. After the GIL is installed, these supporting installations are removed completely, and the entire area is re-naturalized. Thus, GIL are well suitable for use in environmentally protected areas. Due to the small width of GIL routes, the system is specifically compatible with the landscape.

**Above ground installation**
GIL installation above ground are a trouble-free option for use in properties with restricted public access. The open air technology is proven under all climatic conditions in numerous installations all over the world. GIL are unaffected by high ambient temperatures, intensive solar radiation or severe atmospheric pollution (such as dust, sand or moisture). Due to the use of corrosion resistant alloys, corrosion protection can be omitted in most application cases (fig. 2.5-6).

**Tunnel installation**
Tunnels made up of prefabricated structural elements provide a quick and easy method of GIL installation especially in densely populated areas. The tunnel elements are assembled in a dig-and-cover trench, which is backfilled immediately. The GIL is installed once the tunnel has been completed. Thus, the open trench time is minimized. With this method of installation, the land above the tunnel can be fully restored to other purpose of use (fig. 2.5-7).

**Vertical Installation**
Gas-insulated tubular lines can be installed without problems at any gradient, even vertically. This makes them a top solution especially for cavern power plants, where large amounts of

![Fig. 2.5-5: Orbital welding of GIL pipes](image)

![Fig. 2.5-6: Above ground installation](image)

![Fig. 2.5-7: GIL laying technique for tunnel installation](image)

![Fig. 2.5-8: Directly buried GIL](image)
energy have to be transmitted from the bottom of the cavern (e.g., the machine transformer / switchgear) to the surface (overhead line). As GIL systems pose no fire risk, they can be integrated without restriction into tunnels or shafts that are accessible to man, and can also be used for ventilation at the same time. Thus, cost for tunnelling works can be reduced clearly.

**Direct burying**

Especially when used in lesser populated areas, directly buried GIL are a perfect solution. For that purpose, the tubes are safeguarded by a passive and active corrosion protection. The passive system comprises a HDPE coating which ensures at least 40 years of protection. The active system additionally provides cathodic DC protection potential for the aluminum tubes. Magnetic fields measured at the surface above the line are minimal. The high transmission power of GIL minimizes the width of trench. The land consumption is lower by approx. 1/3 related to comparable cable installations (fig. 2.5-8).

**References**

Siemens has gained experience with gas-insulated transmission lines at rated voltages of up to 550 kV, and with phase lengths totalling more than 85 km (2011). Implemented projects include GIL in tunnels, sloping galleries, vertical shafts, open-air installations, as well as directly buried. Flanging as well as welding has been applied as jointing technique.

The first GIL stretch built by Siemens was the connection of the turbine generator pumping motor of the pumped storage power station of Wehr in the Black Forest in Southern Germany with the switchyard. The 420 kV GIL is laid in a tunnel through a mountain and has a single-phase length of ~4,000 m (fig. 2.5-1). This connection was commissioned in 1975. One of the later installations is the Limberg II pumped-storage power station in Kaprun, Austria, which was commissioned in 2010. Here a GIL system was laid in a shaft with a gradient of 42°. It connects the cavern power plant with the 380 kV overhead line at an altitude of about 1,600 meters. The GIL tunnel is used for ventilation purposes, and serves for emergency exit as well. That resulted in substantial cost reduction by eliminating the need for a second shaft in this project (fig. 2.5-10).

A typical example for a city link is the PALEXPO project in Geneva, Switzerland. A GIL system in a tunnel substitutes 500 meters of a former 300 kV double circuit overhead line, which had to move for the raised exhibition centre building. The line owner based his decision to opt for a GIL over a cable solution on the GIL’s much better values with respect to EMC. Thus, governmental requirements are met, and high sensitive electronic equipment can be exhibited and operated in the new hall without any danger of interference from the 300 kV connection located below it (fig. 2.5-11).

A typical example for a directly buried GIL is the reference project at Frankfurt Airport at Kelsterbach, which was commissioned in April 2011. The GIL solution allows to continue one phase of the OHL in one phase of GIL, thus reducing the size of both trench and transition area at the connection points (fig. 2.5-8).
2.5 Power Transmission Lines

2.5.2 Overhead Lines

Since the very beginning of electric power generation, overhead transmission lines (OHL) have constituted the most important component for transmission and distribution of electric power. The portion of overhead transmission lines within a transmission and distribution network depends on the voltage level as well as on local conditions and practice. In densely populated areas like Central Europe, underground cables prevail in the distribution sector, and overhead power lines in the high-voltage transmission sector. In other parts of the world, for example, in North America, overhead lines are often also used for distribution purposes within cities. Siemens has planned, designed and erected overhead power lines for all important voltage levels in many parts of the world.

Selection of line voltage

For the distribution and transmission of electric power, standardized voltages according to IEC 60038 are used worldwide. For 3-phase AC applications, three voltage levels prevail:

- Low voltage (up to 1 kV AC)
- Medium voltage (between 1 kV and 36 kV AC)
- High voltage (between 52 kV and 765 kV AC) and higher

Low-voltage lines serve households and small business consumers. Lines on the medium-voltage level supply small settlements, individual industrial plants and large consumers; the transmission capacity is typically less than 10 MVA per circuit. The high-voltage circuits up to 145 kV serve for subtransmission of the electric power regionally, and feed the medium-voltage network. This level is often chosen to support the medium-voltage level even if the electric power is below 10 MVA. Moreover, some of these high-voltage lines also transmit the electric power from medium-sized generating stations, such as hydro plants on small and medium rivers, and supply large-scale consumers, such as sizable industrial plants or steel mills. They constitute the connection between the interconnected high-voltage grid and the local distribution networks. The bandwidth of electrical power transported corresponds to the broad range of utilization, but rarely exceeds 100 MVA per circuit, while the surge impedance load is 35 MVA (approximately).

In Central Europe, 245 kV lines were used for interconnection of power supply systems before the 420 kV level was introduced for this purpose. Long-distance transmission, for example, between the hydro power plants in the Alps and consumers, was done by 245 kV lines. Nowadays, the importance of 245 kV lines is decreasing due to the existence of the 420 kV transmission network. The 420 kV level represents the highest operation voltage used for AC transmission in Central Europe. It typically interconnects the power supply systems and transmits the energy over long distances. Some 420 kV lines connect the national grids of the individual European countries enabling interconnected network operation (UCTE = Union for the Coordination of Transmission of Electricity) throughout Europe. Large power plants such as nuclear stations feed directly into the 420 kV network. The thermal capacity of the 420 kV circuits may reach 2,000 MVA, with a surge impedance load of approximately 600 MVA and a transmission capacity up to 1,200 MVA.

Overhead power lines with voltages higher than 420 kV AC will be required in the future to economically transmit bulk electric power over long distances, a task typically arising when utilizing hydro, wind and solar energy potentials far away from consumer centers. Fig. 2.5-12 depicts schematically the range of application for the individual AC voltage levels based on the distance of transmission and the power rating. The voltage level has to be selected based on the task of the line within the network or on the results of network planning. Siemens has carried out such studies for power supply companies all over the world.

High-voltage direct current

However, when considering bulk power transmission over long distances, a more economical solution is the high-voltage direct current (HVDC) technology. Siemens is in the position to offer complete solutions for such interconnections, starting with network studies and followed by the design, assistance in project development and complete turnkey supply and construction of such plants. For DC transmission no standard is currently available. The DC voltages vary from the voltage levels recommended in the above-mentioned standardized voltages used for AC.

HVDC transmission is used for bulk power transmission and for system interconnection. The line voltages applied for projects worldwide vary between ± 300 kV, ± 400 kV, ± 500 kV, ± 600 kV and recently (2007), ± 800 kV. The selection of the HVDC line voltage is ruled by the following parameters:

- Amount of power to be transferred
- Length of the overhead power line
- Permissible power losses
- Economical conductor size

The advantages of DC transmission over AC transmission are:

- A DC link allows power transfer between AC networks with different frequencies or networks that cannot be synchronized.
- Inductive and capacitive parameters do not limit the transmission capacity or the maximum length of a DC overhead transmission line.
- The conductor cross-section can be more or less fully utilized because there is no skin effect caused by the line frequency.
- DC overhead power lines are much more economical to built and require less right-of-way.

Economical considerations/evaluation of DC voltages

Fig. 2.5-13 shows the economical application of DC voltages in relation to overhead transmission line length and transmitted power. This graph must be seen as a general guideline. Any project should be separately evaluated on a case-by-case basis. The budgets established for this evaluation are based on 2007 figures.
Conclusions:

- **300 kV voltage level:**
The range of 750 and 1,000 km with a power transfer of 600 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per MW power and km of transmission line. The result shows that for long-distance HVDC transmission, the 300 kV voltage level is not the optimal solution (refer to 400 kV below). However, this voltage level is useful in short HVDC interconnectors such as the Thailand-Malaysia Interconnector, which has a line length of 113 km.

- **400 kV voltage level:**
The range 750, 1,000 and 1,500 km with a power transfer of 600, 1,000 and 2,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 400 kV voltage level is a suitable solution for line lengths of 750 to 1,000 km with transmitted power of 600 to 1,000 MW.

- **500 kV voltage level:**
The range 1,000 and 1,500 km with a power transfer of 1,000, 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 500 kV voltage level is a suitable solution for the line lengths of 1,000 km to 1,500 km with transmitted power of 1,000 to 2,000 MW. However, the 400 kV voltage level can also be competitive in this range of power and line length.

- **600 kV voltage level:**
The range 1,500, 2,000 and 3,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 600 kV voltage level is a suitable solution for the line lengths of 1500 km to 3,000 km with transmitted power of 2,000 MW, and 3,000 MW for lines up to 2,000 km. However, the 500 kV voltage level can still be competitive in parts of this range.

- **800 kV voltage level:**
The range 2,000, 3,000 and 4,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line. The result shows that the 800 kV voltage level is a suitable solution for the line lengths of 2,000 km and above with transmitted power of 2,000 and 3,000 MW. However, shorter line lengths of 1,500 to 3,000 km with power rating of 3,000 to 7,000 MW can be economically covered with an 800 kV solution.
Selection of conductors and earth wires

Conductors represent the most important component of an overhead power line because they have to ensure economical and reliable transmission and contribute considerably to the total line costs. For many years, aluminum and its alloys have been the prevailing conducting materials for power lines due to the favorable price, the low weight and the necessity of certain minimum cross-sections. However, aluminum is a very corrosive metal. But a dense oxide layer is formed that stops further corrosive attacks. Therefore, up to a certain level, aluminum conductors are well-suited for areas in which corrosion is a problem, for example, a maritime climate.

For aluminum conductors, there are a number of different designs in use. All-aluminum conductors (AAC) have the highest conductivity for a given cross-section; however, they possess only a low mechanical strength, which limits their application to short spans and low tensile forces. To increase the mechanical strength, wires made of aluminum-magnesium-silicon alloys are adopted. Their strength is approximately twice that of pure aluminum. But single-material conductors like all-aluminum and aluminum alloy conductors have shown susceptibility to eolian vibrations. Compound conductors with a steel core, so-called aluminum conductor, steel-reinforced (ACSR), avoid this disadvantage. The ratio between aluminum and steel ranges from 4.3:1 to 11:1. An aluminum-to-steel ratio of 6.0 or 7.7 provides an economical solution. Conductors with a ratio of 4.3 should be used for lines installed in regions with heavy wind and ice loads. Conductors with a ratio higher than 7.7 provide higher conductivity. But because of lower conductor strength, the sags are bigger, which requires higher towers.

Experience has shown that ACSR conductors, just like aluminum and aluminum alloy conductors, provide the most economical solution and offer a life span greater than 40 years. Conductors are selected according to electrical, thermal, mechanical and economic aspects. The electric resistance as a result of the conductivity for a given cross-section; however, they possess only a low mechanical strength, which limits their application to short spans and low tensile forces. To increase the mechanical strength, wires made of aluminum-magnesium-silicon alloys are adopted. Their strength is approximately twice that of pure aluminum. But single-material conductors like all-aluminum and aluminum alloy conductors have shown susceptibility to eolian vibrations. Compound conductors with a steel core, so-called aluminum conductor, steel-reinforced (ACSR), avoid this disadvantage. The ratio between aluminum and steel ranges from 4.3:1 to 11:1. An aluminum-to-steel ratio of 6.0 or 7.7 provides an economical solution. Conductors with a ratio of 4.3 should be used for lines installed in regions with heavy wind and ice loads. Conductors with a ratio higher than 7.7 provide higher conductivity. But because of lower conductor strength, the sags are bigger, which requires higher towers.

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High-voltage results in correspondingly high-voltage gradients at the conductor’s surface, and in corona-related effects such as visible discharges, radio interference, audible noise and energy losses. When selecting the conductors, the AC voltage gradient has to be limited to values between 15 and 17 kV/cm. Since the sound of the audible noise of DC lines is mainly caused at the positive pole and this sound differs from those of AC lines, the subjective feeling differs as well. Therefore, the maximum surface voltage gradient of DC lines is higher than the gradient for AC lines. A maximum value of 25 kV/cm is recommended. The line voltage and the conductor diameter are one of the main factors that influence the surface voltage gradient. In order to keep this gradient below the limit value, the conductor can be divided into subconductors. This results in an equivalent conductor diameter that is bigger than the diameter of a single conductor with the same cross-section. This aspect is important for lines with voltages of 245 kV and above. Therefore, so-called bundle conductors are mainly adopted for extra-high-voltage lines. Table 2.5-2 shows typical conductor configurations for AC lines.

From a mechanical point of view, the conductors have to be designed for everyday conditions and for maximum loads exerted on the conductor by wind and ice. As a rough figure, an everyday stress of approximately 20% of the conductor rated tensile stress can be adopted, resulting in a limited risk of con-

<table>
<thead>
<tr>
<th>Rated voltage [kV]</th>
<th>20</th>
<th>110</th>
<th>220</th>
<th>380</th>
<th>700</th>
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<tr>
<td>Highest system voltage [kV]</td>
<td>24</td>
<td>123</td>
<td>245</td>
<td>420</td>
<td>765</td>
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<tr>
<td>Nominal cross-section [mm²]</td>
<td>50</td>
<td>120</td>
<td>150</td>
<td>300</td>
<td>bundle 2x240</td>
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<tr>
<td>Conductor diameter [mm]</td>
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<td>15.5</td>
<td>17.1</td>
<td>24.5</td>
<td>28.8</td>
</tr>
<tr>
<td>Ampacity (at 80 °C conductor temperature) [A]</td>
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<td>410</td>
<td>470</td>
<td>740</td>
<td>900</td>
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<tr>
<td>Thermal capacity [MVA]</td>
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<td>14</td>
<td>90</td>
<td>140</td>
<td>340</td>
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<td>Resistance at 20 °C [Ω/km]</td>
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<td>0.24</td>
<td>0.19</td>
<td>0.10</td>
<td>0.067</td>
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<td>Reactance at 50 Hz [Ω/km]</td>
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<td>0.34</td>
<td>0.41</td>
<td>0.38</td>
<td>0.4</td>
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<td>Effective capacitance [nF/km]</td>
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<td>11.2</td>
<td>9.3</td>
<td>10</td>
<td>9.5</td>
</tr>
<tr>
<td>Capacitance to earth [nF/km]</td>
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<td>3.6</td>
<td>4.0</td>
<td>4.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Charging power [kVA/km]</td>
<td>1.2</td>
<td>1.4</td>
<td>35</td>
<td>38</td>
<td>145</td>
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<tr>
<td>Earth-fault current [A/km]</td>
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<td>0.04</td>
<td>0.25</td>
<td>0.25</td>
<td>0.58</td>
</tr>
<tr>
<td>Surge impedance [Ω]</td>
<td>360</td>
<td>310</td>
<td>375</td>
<td>350</td>
<td>365</td>
</tr>
<tr>
<td>Surge impedance load [MVA]</td>
<td>–</td>
<td>–</td>
<td>32</td>
<td>35</td>
<td>135</td>
</tr>
</tbody>
</table>

Table 2.5-2: Electric characteristics of AC overhead power lines (data refer to one circuit of a double-circuit line)
ductor damage. The maximum working tensile stress should be limited to approximately 40% of the rated tensile stress.

Earth wires, also called shieldwire or earthwire, can protect a line against direct lightning strikes and improve system behavior in the event of short-circuits; therefore, lines with single-phase voltages of 110 kV and above are usually equipped with earth wires. Earth wires made of ACSR conductors with a sufficiently high aluminum cross-section satisfy both requirements.

Since the beginning of the 1990s, more and more earth wires for extra-high-voltage overhead power lines have been executed as optical earth wires (OPGW). This type of earth wire combines the functions just described for the typical earth wire with the additional facility for large data transfer capacity via optical fibers that are integrated into the OPGW. Such data transfer is essential for the communication between two converter stations within an HVDC interconnection or for remote controlling of power stations. The OPGW in such a case becomes the major communication link within the interconnection. OPGW are mainly designed in one or more layers of aluminum alloy and/or aluminum-clad steel wires. One-layer designs are used in areas with low keraunic levels (small amount of possible lightning strikes per year) and small short-circuit levels.

Selection of insulators
Overhead line insulators are subject to electrical and mechanical stresses, because they have to isolate the conductors form potential to earth and must provide physical supports. Insulators must be capable of withstanding these stresses under all conditions encountered in a specific line.

The electrical stresses result from:
- The steady-state operating power-frequency voltage (highest operation voltage of the system)
- Temporary overvoltages at power frequency
- Switching and lightning overvoltages

Insulator types
Various insulator designs are in use, depending on the requirements and the experience with certain insulator types:
- Cap-and-pin insulators (fig. 2.5-14) are made of porcelain or pre-stressed glass. The individual units are connected by fittings of malleable cast iron or forged iron. The insulating bodies are not puncture-proof, which is the reason for a relatively high number of insulator failures.
- In Central Europe, long-rod insulators made from aluminous porcelain (fig. 2.5-15) are most frequently adopted. These insulators are puncture-proof. Failures under operation are extremely rare. Long-rod insulators show superior behavior, especially in polluted areas. Because porcelain is a brittle material, porcelain long-rod insulators should be protected from bending loads by suitable fittings.
- Composite insulators are the third major type of insulator for overhead power line applications (fig. 2.5-16). This insulator type provides superior performance and reliability, particularly because of improvements over the last 20 years, and has been in service for more than 30 years.
The composite insulator is made of a glass fiber reinforced epoxy rod. The glass fibers applied are ECR glass fibers that are resistant to brittle fracture (ECR = electrical grade corrosion resistant glass fibers). In order to avoid brittle fracture, the glass fiber rod must additionally be sealed very carefully and durably against moisture. This is done by application of silicone rubber. Nowadays, high temperature vulcanized (HTV) silicone is used.

The silicone rubber has two functions within this insulator type:
- Sealing the glass fiber rod
- Molding into insulator sheds to establish the required insulation

Metal fittings are compressed onto the glass fiber rod at both ends of the insulator, either with a ball socket or clevis connection fitting. Since the 1980s, compression fittings have been the prevailing type. The sealing of the area between fitting and silicone housing protecting the rod is most important, and is nowadays done with special silicone elastomer, which offers after vulcanization the characteristic of a sticky solid, similar to a fluid of high viscosity.

Advantages of the composite long-rod insulator are:
- Light weight, less volume and less damages
- Shorter string length compared to cap-and-pin – and porcelain long-rod – insulator strings
- Up to 765 kV AC and 600 kV DC, only one unit of insulator (practical length is only limited by the ability of the production line) is required
- High mechanical strength
- Vandalism resistance
- High performance in polluted areas, based on the hydrophobicity (water repellency) of the silicone rubber

Advantages of hydrophobicity are:
- Silicone rubber offers outstanding hydrophobicity over the long term; most other polymeric housing material will lose this property over time
- Silicone rubber is able to recover its hydrophobicity after a temporary loss of it
- The silicone rubber insulator is able to make pollution layers on its surface water-repellent, too (hydrophobicity transfer)
- Low surface conductivity, even with a polluted surface and very low leakage currents, even under wetted conditions.

Suspension string sets
Suspension insulator sets carry the conductor weight, including additional loads such as ice and wind, and are arranged more or less vertically. There are I-shaped (fig. 2.5-17a) and V-shaped sets in use. Tension insulator sets (fig. 2.5-17b, fig. 2.5-17c) terminate the conductors and are arranged in the direction of the conductors. They are loaded by the conductor tensile force and have to be rated accordingly. Multiple single, double, triple or more sets handle the mechanical loadings and the design requirements.

Design of creepage distance and air gaps
The general electrical layout of insulation is ruled by the voltages to be withstood and the pollution to which the insulation is subjected. The standards IEC 60071-1 and IEC 60071-2 as well as the technical report IEC 60815, which provides four pollution classes (the new version will have five classes), give guidance for the design of the insulation.

Because IEC 60815 is applicable to AC lines, it should be noted that the creepage distances recommended are based on the phase-to-phase AC voltage ($U_{ph-ph}$). When transferring these creepage distances recommended by IEC 60815 to a DC line, it should be noted that the DC voltage is a pole-to-earth value ($U_{LP}$). Therefore, these creepage distances have to be multiplied by the factor $\sqrt{3}$. Furthermore, it should be noted that the AC voltage value refers to a mean value, while the DC voltage is comparable to a peak value, which requires a further multiplication with factor $\sqrt{2}$.

Insulators under DC voltage operation are subjected to a more unfavorable conditions than they are under AC, due to a higher collection of surface contamination caused by the constant unidirectional electric field. Therefore, a DC pollution factor has to be applied. Table 2.5-3 shows specific creepage distances for different insulator materials under AC and DC application, and is based on industry experience published by power supply companies in South Africa and China. The results shown were confirmed by an experienced insulator manufacturer in Germany. The correction factors shown are valid for porcelain insulators only. When taking composite insulators into consideration, an additional reduction factor of 0.75 can be applied. The values for a DC system must be seen as a guideline only, that must be verified on a case-by-case basis for new HVDC projects.

To handle switching and lightning overvoltages, the insulator sets have to be designed with respect to insulation coordination according to IEC 60071-1 and IEC 60071-2. These design aspects determine the gap between the earthed fittings and the live part. However, for HVDC application, switching impulse levels are of minor importance because circuit-breaker operations from AC lines do not occur on DC Back-to-back lines. Such lines are controlled via their valve control systems. In order to coordinate the insulation in a proper way, it is recommended to apply and use the same SIL and BIL as is used for the equivalent AC insulation (determined by the arcing distance).

Selection and design of supports
Together with the line voltage, the number of circuits (AC) or poles (DC) and type of conductors, the configuration of the circuits poles determines the design of overhead power lines. Additionally, lightning protection by earth wires, the terrain and the available space at the tower sites have to be considered. In densely populated areas like Central Europe, the width of right-of-way and the space for the tower sites are limited. In the case of extra-high-voltages, the conductor configuration affects the electrical characteristics, the electrical and magnetic field and the transmission capacity of the line. Very often there are contradicting requirements, such as a tower height as low as pos-
I-shaped suspension insulator set for 245 kV

Double tension insulator set for 245 kV (elevation, top)

Double tension insulator set for 245 kV (plan, bottom)

Table 2.5-3: Guideline for specific creepage distances for different insulator materials

<table>
<thead>
<tr>
<th>IEC 60815 level</th>
<th>Porcelain and glass insulators</th>
<th>Composite insulators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AC system</td>
<td>DC system</td>
</tr>
<tr>
<td>I Light [mm/kV]</td>
<td>16</td>
<td>39</td>
</tr>
<tr>
<td>II Medium [mm/kV]</td>
<td>20</td>
<td>47</td>
</tr>
<tr>
<td>III Heavy [mm/kV]</td>
<td>25</td>
<td>59</td>
</tr>
<tr>
<td>IV Very Heavy [mm/kV]</td>
<td>31</td>
<td>72</td>
</tr>
</tbody>
</table>
Possible and a narrow right-of-way, which can only be met by compromises. The minimum clearance of the conductors depends on the voltage and the conductor sag. In ice-prone areas, conductors should not be arranged vertically, in order to avoid conductor clashing after ice shedding.

For low-voltage and medium-voltage lines, horizontal conductor configurations prevail; these configurations feature line post insulators as well as suspension insulators. Poles made of wood, concrete or steel are preferred. Fig. 2.5-18 shows some typical line configurations. Earth wires are omitted at this voltage level.

For high-voltage and extra-high-voltage power lines, a large variety of configurations are available that depend on the number of circuits (AC) or poles (DC) and on local conditions. Due to the very limited right-of-way, more or less all high-voltage AC lines in Central Europe comprise at least two circuits. Fig. 2.5-19 shows a series of typical tower configurations. Arrangement "e" is called the "Danube" configuration and is often adopted. It represents a fair compromise with respect to width of right-of-way, tower height and line costs.

For AC lines comprising more than two circuits, there are many possibilities for configuring the supports. In the case of circuits with differing voltages, those circuits with the lower voltage should be arranged in the lowermost position (fig. 2.5-19g).

DC lines are mechanically designed according to the normal practice for typical AC lines. The differences from AC Line layout are the:

- Conductor configuration
- Electric field requirements
- Insulation design

For DC lines, two basic outlines (monopole and bipole), with variations should be considered. Fig. 2.5-19i–l show examples for HVDC line configurations that are valid for all voltage levels.

The arrangements of insulators depend on the application of a support within the line. Suspension towers support the conductors in straight-line sections and at small angles. This tower type offers the lowest costs; special attention should therefore be paid to using this tower type as often as possible. Angle towers have to carry the conductor tensile forces at angle points of the line. The tension insulator sets permanently transfer high forces from the conductors to the supports. Finally, dead-end towers are used at the terminations of a transmission line. They carry the total conductor tensile forces on the line side (even under unbalanced load condition, e.g., when conductors of one tower side are broken) and a reduced tension into the substations (slack span).

Various loading conditions specified in the respective national and international standards have to be met when designing towers. The climatic conditions, the earthquake requirements and other local environmental factors are the next determining factors for the tower design.

When designing the support, a number of conditions have to be considered. High wind and ice loads cause the maximum forces to act on suspension towers. In ice-prone areas, unbalanced

Fig. 2.5-18: Configurations of medium-voltage supports
Fig. 2.5-19: (a–h): tower configurations for high-voltage lines (AC); (i–l): tower configurations for high-voltage lines (DC)
Conductor tensile forces can result in torsional loading. Additionally, special loading conditions are adopted for the purpose of failure containment, that is, to limit the extent of damage. Finally, provisions have to be made for construction and maintenance.

Depending on voltage level and the acting forces of the overhead line, differing designs and materials are adopted. Poles made of wood, concrete or steel are very often used for low-voltage and medium-voltage lines. Towers with lattice steel design, however, prevail at voltage levels of 110 kV and above (fig. 2.5-20). Guyed lattice steel structures are used in some parts of the world for high-voltage AC and DC lines. Such design requires a relatively flat topography and a secure environment where there is no threat from vandalism and theft. Guyed lattice steel structures offer a substantial amount of cost savings with respect to tower weight and foundation quantities. However, a wider right-of-way has to be considered.

**Foundations for the supports**
Overhead power line supports are mounted on concrete foundations. The foundations have to be designed according to the national or international standard applicable for the particular project.

The selection of foundation types and the design is determined by the:
- Loads resulting from the tower design
- Soil conditions on the site
- Accessibility to the line route
- Availability of machinery
- Constraints of the particular country and the site

Concrete blocks or concrete piers are in use for poles that exert bending moments on the foundation. For towers with four legs, a foundation is provided for each individual leg (fig. 2.5-21). Pad and chimney and concrete block foundations require good bearing soil conditions without groundwater.

Driven or augured piles and piers are adopted for low-bearing soil, for sites with bearing soil at a greater depth and for high groundwater level. In case of groundwater, the soil conditions must permit pile driving. Concrete slabs can be used for good bearing soil, when subsoil and groundwater level prohibit pad and chimney foundations as well as piles.

**Route selection and tower spotting**
Route selection and planning represent increasingly difficult tasks, because the right-of-way for transmission lines is limited and many aspects and interests have to be considered.

Route selection and approval depend on the statutory conditions and procedures prevailing in the country of the project. Route selection nowadays involves preliminary desktop studies with a variety of route alternatives, environmental impact studies, community communication hearings and acceptance approval from the local authorities.
After the route design stage and approval procedure, the final line route is confirmed. Following this confirmation and approval, the longitudinal profile has to be surveyed, and all crossings over roads, rivers, railways, buildings and other overhead power lines have to be identified. The results are evaluated with a specialized computer program developed by Siemens that calculates and plots the line profile. The towers are spotted by means of the same program, which takes into account the conductor sags under different conditions, the ground clearances, objects crossed by the line, technical data of the available tower family, specific cost for towers and foundations and cost for compensation of landowners.

The result is an economical design of a line that accounts for all the technical, financial and environmental conditions. Line planning forms the basis for material acquisition and line erection. Fig. 2.5-22 shows a line profile established by computer.

**Siemens’s activities and experience**

Siemens has been active in the overhead power line field for more than 100 years. The activities comprise design and construction of rural electrification schemes, low-voltage and medium-voltage distribution lines, high-voltage lines and extra-high-voltage installations.

To give an indication of what has been carried out by Siemens, approximately 20,000 km of high-voltage lines up to 245 kV and 10,000 km of extra-high-voltage lines above 245 kV have been set up so far. Overhead power lines have been erected by Siemens in Germany and Central Europe as well as in the Middle East, Africa, the Far East and South America.

**Outstanding AC projects have been:**

- The 420 kV transmission lines across the Elbe River in Germany comprising four circuits and requiring 235 m tall towers
- The 420 kV line across the Bosphorus (Crossing II) in Turkey (1983) with a crossing span of approximately 1,800 m (fig. 2.5-23).
- The 500 kV Suez Crossing (1998); height of suspension tower 220 m
- The 420/800 kV Bosporus Crossing III in Turkey (1999)

Furthermore, Siemens has constructed two HVDC interconnectors as turnkey projects that include HVDC overhead transmission lines. The two projects are the 300 kV HVDC interconnector from Thailand to Malaysia (bipole transmission line, fig. 2.5-24) and the 400 kV HVDC Basslink project in Australia (monopole transmission line, fig. 2.5-25a–c).
Fig. 2.5-22: Line profile established by computer
Earth wire: ACSR 265/35 * 80.00 N/mm²
Conductor: ACSR 265/35 * 80.00 N/mm²
Equivalent sag: 11.21 m at 40 °C
Equivalent span: 340.44 m
Conductor: 4x3x1 AACSR/AW 1802/226 mm² on 420 kV
Upgradeable to 2x3x2 AACSR/AW 1802/226 mm² on 800 kV
Shieldwire: 2x (ASLH-DBBB 1x22E8/125 - A W 33)

Fig. 2.5-23: 420/800 kV line across the Bosphorus, longitudinal profile

Fig. 2.5-24: 300kV HVDC interconnector from Thailand to Malaysia (bipole transmission line)

Fig. 2.5-25a: 400 kV HVDC Basslink project in Australia (monopole transmission line)
Fig. 2.5-25b, c: 400 kV HVDC Basslink project in Australia (monopole transmission line)

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2.6 Grid Access Solutions for Decentralized Power Generation

Grid access solutions are custom-engineered solutions for decentralized generating units and remote loads. They are an essential part of Smart Grid and Super Grid developments (refer to chapter 1). Grid access solutions involve reconciling contrasting parameters, such as high reliability, low investment costs and efficient transmission, in the best possible solution. For example, in the design of high-voltage offshore platforms for offshore wind farm connections to the grid (fig. 2.6-1), special attention is paid to intelligent collection systems at the medium-voltage level, followed by the design of the high-voltage transmission system and the onshore receiving substation and its reactive compensation to meet local grid code requirements.

Turnkey proposition and project execution
By offering a turnkey solution (fig. 2.6-2), Siemens provides a holistic setup of a complex project involving project administration, design and engineering services, subcontracting, procurement and expediting of equipment, inspection of equipment prior to delivery, shipment, transportation, control of schedule and quality, pre-commissioning and completion, performance-guarantee testing, and training of owner’s operating and/or maintenance personnel.

For both AC and DC transmission technologies, Siemens offers a broad range of solutions. The technical constraints of a decentralized generating unit or remote loads in connection with AC or DC transmission systems are well known and addressed accordingly. The engineering expertise of Siemens is all inclusive from the conceptual and basic design to digital and real-time simulations, therefore assuming responsibility for presenting the solution to the grid owner which is essential in executing such projects.

System and design studies, engineering
The final design and specification of all equipment to be installed are verified by system and design studies. Important steps to achieve final design criteria include determining an optimized economical network within a system of generating units, integrating this system within the grid, defining and configuring grid components, carrying out load flow studies and short-circuit calculations for the entire system.

Moreover, an earthing concept and coordination of the insulation for the entire grid connection must also be defined. The static and dynamic characteristics must be checked and the reactive power compensation defined (static and dynamic). The resonance phenomenon for all elements should be investigated, from the transmission system itself to cables, transformers, reactors, wind turbines and capacitor banks. Compatibility and conformity with grid code requirements must be established, as well as a control and protection system.

High-Voltage Offshore Platform
Siemens Wind Power Offshore Substation (WIPOS™) is the optimal solution that ensures long-term offshore operation. With WIPOS, Siemens marks an innovative role in the design, engineering and installation of offshore platforms (see section 2.6.1 References).

In the offshore wind industry, the word ‘platform’ reflects two construction entities, namely the ‘topside’ where all the high-voltage, medium-voltage and operational equipment are installed, and the ‘foundation’ entity which serves as the base for the topside. Siemens offers optimized designs for both entities by joining workforces with offshore, maritime and shipyard experts.

WIPOS (fig. 2.6-3) serves as an interface between the wind turbines and the mainland, whereby power harvested from wind is bundled and then passes through the export cables to reach the point of connection onshore.

Fig. 2.6-1: A comprehensive overview for both AC and DC offshore wind grid connections
A typical topside comprises a multi-deck construction with the main deck, where all electro-technical equipment is installed, as well as a helideck for helicopter landing designed to meet aviation regulations.

From a complete platform approach, Siemens also offers the self-lifting platform concept due to its versatility in function, and the possibility for transportations and installation without exorbitant efforts by avoiding heavy crane vessels.

Siemens offers a family of WIPOS designs with the flexibility to meet various offshore weather, tide and seabed conditions with three main configurations:

- WIPOS self-lifting solution
- WIPOS topside solution (topside/jacket)
- WIPOS floating solution
2.6.1 References

Fig. 2.6-4: The offshore wind farm Lillgrund, consisting of 48 wind turbines, each 2.3 MW, from Siemens Wind Power, is installed in Oresund. Its location is on Swedish national waters, roughly 7 km away from the Swedish coast line near the City of Malmö. The owner is Vattenfall AB, Sweden. The 33/138 kV transformer substation with its 120 MVA transformer is mounted on an offshore platform located within the wind farm area. Power transmission is realized via one three-phase 138 kV XLPE submarine cable towards the existing substation in Bunkello (Sweden).

Besides the transformer substation on the platform, Siemens Energy Transmission performed the grid studies as well as the design and performance studies for the entire wind farm and its grid connection.

In service since late 2007, the Lillgrund Offshore Wind Farm provides enough energy for approximately 80,000 homes and reduces the CO₂ emissions by 300,000 tons a year.

Fig. 2.6-5: The offshore wind farms Lynn and Inner Dowsing, consisting of 54 wind turbines, each 3.6 MW, from Siemens Wind Power, are located in the Greater Wash area, on Great Britain national waters. This is roughly 5 km away from the coast line of Skegness, Lincolnshire. The owner is Centrica Renewable Energy Ltd., U.K.

The 33/132 kV onshore transformer substation with its two 100 MVA transformers is located at Middle Marsh, approximately 5 km away from the sea wall. Power transmission from the offshore wind farms is realized via six submarine three-phase 33 kV XLPE cables. Further on to the grid, two 132 kV cables are used. Besides the transformer substation and the cable system, Siemens Energy Transmission also performed the grid studies as well as the design and performance studies for the entire wind farm and its grid connection.

The grid connection was energized in January 2008. Both wind farms were in full service in autumn 2008. They provide enough energy for approximately 130,000 homes, and reduce the CO₂ emissions by 500,000 tons.

Fig. 2.6-6: The Thanet Offshore Wind Farm, consisting of 100 wind turbines, each 3 MW, from Vestas (Denmark), is located in the North Sea. It is roughly 11 km away from the coast line of Kent, Foreness Point. The owner is Thanet Offshore Wind Ltd., U.K.

The 33/132 kV transformer substation with its two 180 MVA transformers is mounted on an offshore platform located within the wind farm area. Power transmission is realized via two three-phase 132 kV XLPE submarine cables. The point of coupling to the grid is a specific switchgear in Richborough, Kent.
Apart from the offshore transformer substation, the onshore substation with its compensation systems (two SVC PLUS) and harmonic filters, as well as the cable system, Siemens Energy Transmission also performed the grid studies as well as the design and performance studies for the entire wind farm and its grid connection.

The grid connection was energized in autumn 2009, with all 100 wind turbines running by autumn 2010. Now the offshore wind farm provides enough energy for approximately 215,000 homes, and reduces the CO₂ emissions by 830,000 tons a year.

The owner is Greater Gabbard Offshore Winds Ltd., U.K. The 33/132 kV transformer substation with its three 180 MVA transformers is mounted on two offshore platforms (Inner Gabbard and Galloper) located within the wind farm area. Power transmission is realized via three three-phase 132 kV XLPE submarine cables.

The point of coupling to the grid is realized in Sizewell Village, Suffolk, where Siemens built a reactive power compensation substation to allow the wind farm to meet the requirements of the GB grid code. SVC PLUS multilevel technology is used for all of the three export circuits.

Now the offshore wind farm provides enough energy for approximately 350,000 homes and reduces the CO₂ emissions by 1,350,000 tons a year.

The grid access project was completed in two phases. In phase one, two offshore substations (each with two 150 MVA transformers) will be delivered to collect the 630 MW of power generated from 175 wind turbines – also supplied by Siemens – before transferring it to shore via the main 150 kV export cables.

Siemens is responsible for the turnkey construction of the onshore substation. As for the two offshore substations, Siemens is responsible for the overall layout design to ensure that the facility functions as a substation, including all primary and secondary equipment as well as testing and commissioning.
BorWin2

800 MW offshore HVDC PLUS link BorWin2, Germany
For the BorWin2 project, Siemens will supply the voltage-sourced converter (VSC) system – using Siemens HVDC PLUS technology – with a rating of 800 MW. The wind farms Veja Mate and Global Tech 1 are designed to generate 800 MW and is connected through Siemens’ HVDC PLUS link to shore. The converter is installed on an offshore platform, where the voltage level is stepped up and then converted to ±300 kV DC. The platform will accommodate all electrical equipment required for the HVDC converter station, two transformers, four AC cable compensation reactors and high-voltage gas-insulated switchgear (GIS). The Siemens wind power offshore substation (WIPOS) is designed as a floating, self-lifting platform. Power is transmitted via subsea and land cable to Diele close to Papenburg, where an onshore converter station will reconvert the DC back to AC and feed it into the 380 kV AC network.

HelWin1

576 MW offshore HVDC PLUS link HelWin1, Germany
For the project HelWin1, Siemens is supplying a voltage-sourced converter (VSC) system with a rating of 576 MW using Siemens HVDC PLUS technology. The wind farms Nordsee Ost and Meerwind are designed to generate 576 MW and is connected through a Siemens’ HVDC PLUS link to shore. The converter is installed on an offshore platform, where the voltage level is stepped up and then converted to ±250 kV DC. The platform will accommodate all the electrical high-voltage AC and DC equipment required for the converter station. Similar to the BorWin2 project, the Siemens wind power offshore substation (WIPOS) will also be designed as a floating, self-lifting platform. Energy is transmitted via subsea and land cable to Büttel, northwest of Hamburg, Germany, where an onshore converter station will reconvert the DC back to AC and transmit it into the high-voltage grid.
SylWin1

864 MW offshore HVDC PLUS link SylWin1, Germany
Siemens will supply the world’s largest voltage-sourced converter (VSC) offshore system with a rating of 864 MW for the SylWin1 project. Siemens’ HVDC PLUS link will connect the Danish Tysk wind farm to the German shore. The converter is installed on an offshore platform, where the voltage level is stepped up and converted to ±320 kV DC. The platform will accommodate all electrical equipment required for the HVDC converter station: two transformers, four AC cable compensation reactors, and high-voltage gas-insulated switchgear (GIS). Similar to the BorWin2 and HelWin1 projects, the Siemens wind power offshore substation (WIPOS®) is designed as a floating, self-lifting platform. The energy is transmitted via subsea and land cable to Büttel, where an onshore converter station will reconvert the DC to AC and feed it into the 380 kV AC grid.

Fig. 2.6-11: SylWin1, 864 MW HVDC PLUS, North Sea

HelWin2

690 MW offshore HVDC PLUS link HelWin2, Germany
Siemens Energy in consortium with the Italian cable manufacturer Prysmian is erecting HelWin 2, the link between the North Sea offshore wind farm Amrumbank West and the onshore grid. The customer is TenneT TSO GmbH of Bayreuth, Germany. The grid connection, designed as a high-voltage direct-current transmission link, has a rating of 690 megawatts (MW). Amrumbank West is built in the North Sea, about 55 kilometers from the mainland, 35 kilometers north of Helgoland, and 37 kilometers west of the North Frisian island of Amrum. The wind farm will have a power capacity between 300 and 400 MW. Together with the Meerwind and North Sea East offshore windfarms, Amrumbank West is part of the North Sea cluster HelWin.

Fig. 2.6-12: HelWin2, 690 MW HVDC PLUS, North Sea
2.7 Solar Power Solutions

Photovoltaic (PV) systems convert sunlight directly into electrical energy without any environmentally harmful emissions, and thus reduce dependence on expensive and ending fossil energy sources. Government stimulation programs and the increase in efficiency are making PV systems more and more attractive for investors as well as power supply companies. Yields can be obtained by feeding solar electricity into the grid.

The three main application areas are:
- Grid-connected photovoltaic systems:
  These photovoltaic systems (from 5 kWp to 50 MWp) are connected to the grid and generate alternating current that is fed into the grid or used directly on the site.
- Stand-alone photovoltaic systems:
  Stand-alone photovoltaic systems equipped with batteries for storing electricity are used to supply power to areas that have no connection to the grid.
- Hybrid systems for back-up supply in regions where the public supply is unreliable.

Components and mode of operation
A grid-connected PV system typically consists of the following components:
- Solar modules
- Inverters and switchgears
- Cabling
- Metering
- Connection to the public grid

Solar cells absorb sunlight and transform it into electrical energy, thereby generating direct current. Several solar cells wired together form a solar module. Solar cells are usually manufactured from either monocrystalline or polycrystalline silicon. The use of thin-layer modules is also becoming increasingly common. The modules are connected in series and combined into arrays. The arrays are connected to the inverter via several connection boxes. Centralized inverter combinations convert the direct current generated by the solar modules into alternating current that than can be fed into the grid. Optimum electrical and structural engineering forms the basis for maximum efficiency and a high degree of reliability.

SINVERTsolar inverter units
The core elements of grid-connected PV systems are the power inverters. With its SINVERTsolar range of inverter units, Siemens offers certified series-manufactured products that comply with all important national and international safety standards. Thanks to their electromagnetic compatibility (EMC) compliant construction, they are even suitable for operation in areas susceptible to electromagnetic interference.

Large subsystems up to 1.6 MVA peak capacity (master/slave combination) can also be implemented with SINVERTsolar inverters. The devices, which are based on IGBT technology, can attain an efficiency of up to 97%, because they are optimized for extremely low losses. Master/slave operation has the advantage that the inverters can always be operated close to the optimum efficiency range. If, for example, solar irradiation decreases, superfluous inverters can be switched off automatically and the remaining inverters loaded more effectively so that the maximum possible electricity yield can flow into the grid. At night the inverters are switched off, to reduce their time of operation and increase the lifetime.

Requirements for PV systems for buildings
When planning a photovoltaic system, numerous structural engineering requirements must be taken into account, because often no allowance was made for installing photovoltaic systems when a building was first constructed. For many years, Siemens has been developing highly flexible structural and electrical engineering solutions for specific applications for the production of solar electricity. The following factors directly influence efficiency and hence cost-effectiveness when planning and installing a PV system:
- Location of the system (maximum solar irradiation)
- Orientation of the system (due south is optimal)
- Quality of the products (optimally matched)
- Engineering excellence (electrical/mechanical combination)

The following building integrated systems are available:
- Facade-mounted system (fig. 2.7-1a)
- Roof-mounted system (fig. 2.7-1c)
- Flat-roof installation
- Special structural engineering solutions (fig. 2.7-1b)

Planning guidelines
When planning a grid-connected PV system (fig. 2.7-2), the following points must be clarified in advance:
- Choice of the ideal application and orientation (solar irradiation)
- Choice of the ideal system:
  - Deciding on the total capacity of the system, depending on the investment volume and the area available for the installation
  - Drawing up a financing plan
  - Statical calculation of the load-bearing capacity of the roof or facade
  - Electrical and mechanical engineering
  - Determining whether feeding into the grid is possible and making an application to the local distribution network operator

Electricity from roof and facade-mounted systems is usually fed into the low-voltage or medium-voltage system of the local distribution network operator as a 3-phase current. The type of current that is fed into the grid should be clarified with the local distribution network operator in each individual case.

Planning process
Siemens supports the planning process with advice from experts about economical and technical aspects and basic and detailed engineering. Siemens can also help to devise the financing plan. Projects, located in the Netherlands, can offer the following
Power Transmission and Distribution Solutions

2.7 Solar Power Solutions

system solutions, based on many years of experience in the installation of grid-connected PV systems:
• (Lightweight construction) flat-roof photovoltaic system
• Building-integrated photovoltaic system (BIPV)
• Facade-mounted system (fig. 2.7-1a)
• Special structural engineering solutions (fig. 2.7-1b)
• Roof-mounted system (fig. 2.7-1c)
• Solar roofing SolarPark™

Turnkey solutions
Siemens is a one-stop shop for efficient and reliable system solutions. Its service comprises the turnkey installation of grid-connected PV systems covering everything from planning, procurement and technical realization to site acceptance testing, monitoring and service. The Center of Competence works in close cooperation with local Siemens representatives. Most projects are at this moment implemented in Germany, Italy, Spain, Belgium and France.

For further information:
www.siemens.com/solar

Fig. 2.7-1: Example of photovoltaic system:
a) Facade-integrated PV system in Italy
b) Installation of a earth-based PV system of 1 MWp in Italy
c) Example of a 30 m high stadium roof system
2.8 SIESTORAGE

2.8.1 The Modular Energy Storage System for a Sustainable Energy Supply

The challenge: reliable energy supply! Distributed, renewable energy sources, such as wind turbines and photovoltaic plants, are making a bigger and bigger contribution to the energy mix of the public power supply (fig. 2.8-1). However, as the amount of electrical power they generate cannot be predicted, their increasing use is creating new challenges in terms of system stability, integration into the power supply system, operating reserves, quality of voltage and supply, as well as peak load management.

The answer: SIESTORAGE – Siemens Energy Storage – the sustainable and eco-friendly solution! Energy storage systems are the right solution in all these cases. SIESTORAGE ensures a sufficient amount of available reserve power for balancing and regulation purposes, especially of renewable energy sources, and creates higher system stability for industry, buildings and infrastructure. Energy that is stored by the system can be regained in case of demand. Generation outages can be compensated for minutes and even for hours on end. SIESTORAGE combines cutting-edge power electronics for power system applications with high-performance lithium-ion-batteries. With a compact battery and converter cabinet as the smallest unit, the capacity of the SIESTORAGE system can be expanded to up to 2 megawatt hours, and its output up to 8 megawatts (fig. 2.8-2).

The advantages at a glance
The SIESTORAGE energy storage system from Siemens is ideally suited to various applications. Compared to other energy storage solutions, it has a number of additional advantages, such as:

- High degree of availability and reliability thanks to modular design
- Suitable for all requirements due to highest flexibility
- Easy handling of battery modules (safe low voltage) ensures the highest degree of safety for system an persons
- Completely integrated turnkey solution throughout the entire life cycle
- Parallel connection of energy storage cabinets on AC side ensures the highest flexibility
- Prowen expertise in power electronics for power system applications
- Black start capability for microgrid application
- Emissions-free solution and improvement of CO₂ footprint

Always the right storage solution

Modular design (fig. 2.8-3)
SIESTORAGE is a modular energy storage solution. Batteries and control electronics are inserted in cabinets as plug-in units. One energy storage cabinet contains up to 16 battery modules, each with a maximum voltage of 60 V DC. The individual battery modules can be pulled out, inserted and moved safely. The required power and capacity are achieved through a parallel connection of several cabinets on their AC side. Both parameters can be adapted to fit the particular requirements of a project.

The intelligent Battery Management System (BMS) monitors state of charge, voltage and temperature of the individual battery modules, among others. SIESTORAGE’s core is the SIPLINK converter product platform. The batteries are charged and discharged at the AC system using SIPLINK active front ends. The SIPLINK power electronics were developed especially for sophisticated system applications such as MVDC system couplings, and are the basis of the various SIESTORAGE applications.

The control components for the entire storage unit are accommodated in a separate cabinet. A combined control and system connection cabinet is used for up to four energy storage cabinets. The system is controlled with SIMATIC S7, either on site or over the Internet. Information on the system’s operating state, for instance on batteries, auxiliary systems, medium-voltage switchgear and error messages, are displayed on the human machine interface (HMI).
Combined energy storage cabinet (batteries + converter) for up to 16 battery modules up to 24 kWh / 144 kWp

Fully equipped energy storage cabinet including power electronics

Drawer for up to 8 battery modules

Battery module

Battery management

SIPLINK converter

Fig. 2.8-3: Batteries and control electronics are inserted in cabinets as plug-in units, thus facilitates the exchange of individual units

Up to 12 energy storage cabinets are connected to one control cabinet and one system connection cabinet. This results in additional redundancy in the control system of larger units (tab 2.8-1).

Integrated containerized solution

Up to 24 energy storage cabinets can be installed in a container. Systems larger than 2 MVA/500 kWh can be scaled with several containers. The storage unit can be connected to the MV system with a medium-voltage transformer and switchgear. The integration of the cabinets into a containerized enclosure ensures a particularly easy application (fig. 2.8-4). It is easy to transport the containers, and they can be positioned flexibly. An air-conditioning system makes smooth operation possible even at extreme ambient temperatures. Comprehensive safety functions ensure the safety of the system and the operators.

Modular structure: various configurations and storage sizes possible

| Usable capacity* | 16 kWh to 24 kWh depending on battery type |
| Rated power     | 32 kW to 96 kW depending on battery type  |
| Usable capacity* | 48 kWh to 72 kWh depending on battery type |
| Rated power     | 96 kW to 288 kW depending on battery type  |
| Usable capacity* | 80 kWh to 120 kWh depending on battery type |
| Rated power     | 160 kW to 480 kW depending on battery type  |
| Usable capacity* | 80 kWh to 120 kWh depending on battery type |
| Rated power     | 1 MVA to 2 MVA depending on battery type   |

*The usable capacity is guaranteed to the end of the service life

Tab. 2.8-1: A modular solution for each application
2.8.2 Spot-on for a Wide Variety of Applications

Thanks to its modularity, SIESTORAGE can be customized and therefore used for a wide variety of applications such as stabilizing distribution systems with a high proportion of distributed, renewable power generating plants. Other applications include supplying emergency power to vulnerable industrial production processes (fig. 2.8-6), computer centers and hospitals. There are also energy storage solutions for energy-efficient buildings, island networks, smaller, independent auxiliary power systems, public transport, and electric mobility applications (fig. 2.8-5).

Integration of renewables

Ever more renewable energy sources are connected to the distribution system. Their performance fluctuates naturally. This can disturb the balance between generation and load. SIESTORAGE can compensate for those imbalances. SIESTORAGE stores power when generation is high, and delivers it in case of insufficient power generation. The power supply systems are relieved, and renewable energy becomes more calculable (fig. 2.8-7).

Microgrids

Microgrids with renewable generation require a self-sufficient, reliable supply of energy. SIESTORAGE stores energy in case of high generation, and releases it on demand. This makes the system an eco-friendly alternative to diesel generators. Thanks to SIESTORAGE's black start capability, the power supply can be re-established without difficulties after an outage. A reliable power supply for microgrids is ensured.

T & D deferral

The growing demand for energy and the rising share of renewables can make power supply systems reach the limits of their transmission capacity. This makes the costly extension of power supply systems necessary. In case of imminent overloads, SIESTORAGE stores energy that cannot be transmitted over the power supply system. It is fed back into the system during low load levels to avoid a system overload. This means that existing system capacities can be utilized better, and that a costly extension of the power supply system can be avoided.

Power quality

System operators have to ensure a uniformly high quality of power. Short drops and variations of power have to be compensated. SIESTORAGE reliably compensates for voltage fluctuations. This is how system operators can ensure a uniformly high power quality.

Critical power

Data centers, hospitals and industrial processes require an absolutely reliable power supply. An outage of only a few milliseconds can have serious consequences. SIESTORAGE helps to preserve this reliably. In case of outages, single consumers or parts of the power supply system are supplied with previously stored energy. SIESTORAGE ensures secure power supply for critical facilities.

Frequency regulation

Imbalances between generation and load lead to fluctuations in power frequency. This can lead to unstable power systems. System operators have to keep the power frequency stable and provide short-term compensation for generation failures. SIESTORAGE stores energy during peak generation, and provides it as balancing power in case it is required. SIESTORAGE contributes to frequency regulation. This means that system operators can ensure a secure power supply.

Peak load management

Industrial businesses and utilities agree on fixed prices for power and maximum load. However, production factors can cause peak loads. Even a single case of exceeding the agreed maximum load causes high costs. The high purchase costs can be avoided with SIESTORAGE. SIESTORAGE stores energy in times of low energy consumption. It can provide energy for peak loads with next to no delay. This means that industrial businesses can avoid the expensive exceeding of the agreed maximum load.
2.8.3 The Solution Provider for Energy Storage Solutions

**Complete integration from a single source**
Siemens is a provider of turnkey solutions – from engineering and network planning to project management and all the way to installation, commissioning and additional services. Siemens supports the local creation of value, and ensures that a competent contact person is in close reach of every project around the globe (see also fig. 2.9-7, page 54).

**Eco-friendly and sustainable**
Siemens’s comprehensive approach contributes to the maximization of returns and the optimization of energy consumption. Damages to the environment are minimized, and the long-term profitability of operations is ensured. The cooperation with certified regional partners makes sure that a consistent recycling concept for battery modules is available. SIESTORAGE adheres to the highest standards and environmental requirements (according to SN 36650 (1997-6), Part 1).

**Safe in every respect**
Assessments that were carried out by an independent testing institute prove that the modular SIESTORAGE offers the highest degree of safety in every respect. Safe operation is confirmed on the basis of a risk assessment. The safety of persons who work with SIESTORAGE is ensured because the maximum voltage is less than 60 V DC during handling of individual battery modules. Dangerous direct current voltages remain safely inaccessible inside the battery cabinet. The cabinets do not have to be synchronized on the battery side thanks to their parallel connection on the AC side. This ensures an extremely high availability of the systems, and a very low maintenance effort.

**First reference in Italy**
SIESTORAGE has been installed with a performance of 1 MVA and a capacity of 500 kWh in the medium-voltage distribution system of Enel, the biggest power utility of Italy. Enel uses it to study new Smart Grid solutions for voltage regulation, the integration of renewable energy sources into the medium-voltage system, the integration of an electric vehicle charging station into the medium-voltage system, as well as to study black start capabilities (fig. 2.8-8).

Fig. 2.8-8: SIESTORAGE has been installed with a performance of 1 MVA and a capacity of 500 kWh in the medium-voltage distribution system of Enel, the biggest power utility of Italy
2.9 SIEHOUSE

2.9.1 Compact, Mobile Plug-and-Play E-Houses for Power Distribution

In an E-house, a broad range of power, control and communication equipment is installed and connected in a single enclosure. This secures a reliable, flexible supply of power, as well as the protection of operating staff and equipment (fig. 2.9-1). A SIEHOUSE E-house from Siemens is a prefabricated, modular enclosure that is completely engineered, manufactured, assembled and tested at the Siemens factory, and then joined on site (fig. 2.9-3).

Flexible and reliable power supply solution
E-houses have been a standard in the oil and gas industry for many years. They are used ever more frequently for the installation of equipment in other industries, by utilities, and in infrastructure facilities. A solid building is often too expensive for many projects. In other cases, the project schedule does not allow for a site-built construction, and sometimes building permits are not available. SIEHOUSE E-houses are the ideal solution in all these cases. They can be installed in next to no time, and are easily adaptable to almost any situation and application. They are a solution that provides reliable power, uses the available space optimally, enables extended power distribution, can be relocated and used as an interim solution, and keeps on site activities at a minimum. SIEHOUSE ensures hereby minimum interference with other activities, and increases the overall flexibility of the project. Depending on environmental conditions and other project requirements, SIEHOUSE E-houses can be a highly efficient and cost effective alternative to conventional, site-built substations.

Advantages of SIEHOUSE compared to classical site-built substations
- Quick installation and commissioning after site preparation
- No additional work on site thanks to pre-commissioning at factory
- High flexibility through modular design: ease of expansion and change of location, fast de-commissioning and removal
- Better HSE performance through reduced manpower on site
- Reduced civil work risks and possible delays (e.g., weather)
- Easier permitting
- Shorter depreciation

Various types to suit any project and application
The modular and flexible concept makes possible various types of SIEHOUSE to suit any project and application requirement. A standard containerized substation consists of one module on a pre-cast foundation (fig. 2.9-2). A mobile containerized substation is a module on wheels or support that can be relocated with its foundation. Multiple modular containerized substations are also available. They consist of several modules that are placed on top of or next to each other on a foundation. This enables transportation of large E-houses and optimum use of the available space.
2.9.2 Spot-on for a Broad Range of Applications

Customized solutions for individual project requirements
SIEHOUSE E-houses are designed with an eye to individual requirements, and to all environmental as well as Health and Safety Environment (HSE) conditions. All over the world, they meet and exceed the requirements of the most ambitious projects and withstand harsh environmental conditions. Plus, projects that use E-houses suffer from fewer delays and construction risks that are caused by the weather than projects that use conventional brick buildings.

SIEHOUSE E-houses can be installed on raised platforms to protect them from flooding. This also makes it possible to install cable tray and bus duct systems under the E-house without excavation. SIEHOUSE even reduces the need for additional buildings, because facilities such as offices, battery rooms, bathrooms and maintenance rooms can be included in an E-house on request.

Resistant to environmental impact
In some industries, it is not enough to simply install electrical equipment inside a building in order to protect it from external influences. A number of reasons make it advisable to accommodate the equipment separately, for example, a high degree of particles in the air, as well as potential dangers in case of direct contact with hazardous environments and substances. In such cases, SIEHOUSE E-houses are a simple, efficient and economical solution. The interlocking wall and roof panels are a barrier against environmental influences. External particles are kept outside thanks to HVAC overpressures. Enclosure integrity can be enhanced with additional weatherproofing. The coating provides outstanding resistance to chemicals, moisture and abrasion. The enclosure can also be customized for extreme ambient temperatures and humid environments. E-houses can be designed for high wind speeds (up to 240 km/h), the use in seismic zone 4, and high snow loads. Fireproof exterior walls that protect switchgear from transformer failures are also available. Special exterior finishes help match the E-houses to its surroundings.

References in various fields of application
SIEHOUSE is employed in a multitude of situations related to:
- Plant balancing for fossil and renewable energy
- Reliable power supply for critical power
- Cost effective answer for space restricted application
- Temporary power supplies
- Power distribution system extension
- Energy storage
- Power electronics for power system application.

SIEHOUSE is also employed in a multitude of industries and facilities. The fast and uncomplicated installation, as well as the possibility to adapt them precisely to the individual application and situation, makes them the most suitable option for a wide variety of applications (fig. 2.9-4, fig. 2.9-5, fig. 2.9-6), especially in:

- Oil and gas
- Metal and mining industry
- Data centers
- Chemical industry
- Automotive and aerospace
- Food and beverage
- Infrastructure
- Utility power plants and substations.
2.9.3 It is All about the Best Design

The SIEHOUSE design starts with structural analyses and calculations. The most widely used designs use self-framing, interlocking wall and roof panels that are installed on a structural steel base. Every variable is taken into account—from the raw materials used to the weight of the installed equipment and all the way to the project requirements. The structural design, calculations and 3D-simulations are performed on the basis of this data (fig. 2.9-7, fig. 2.9-8).

Equipment from a single solution provider
SIEHOUSE can be fitted with a wide range of equipment that ensures a high degree of functionality and reliability. This system is a completely integrated one-stop solution from one supplier with design and engineering responsibility. The equipment that is installed in an SIEHOUSE includes low and medium-voltage switchgear (GIS and AIS) up to 52 kV that meets the relevant ANSI, GOST, and IEC standards, low-voltage and medium-voltage motor control centers (MCC), variable frequency drives (VFD), oil and dry type transformers, control and protection panel boards, PLC I/Os, relay panels, instrumentation, analyzers, bus ducts, pressure relief, arc suppression ducts, batteries, uninterruptible power supply (UPS), and power compensation devices (fig. 2.9-9).

Equipment options for customized solutions
There is a wide range of auxiliary equipment that can be selected according to the local, individual and HSE requirements, standards and regulations. It includes lighting and earthing systems, sockets, distribution boards, cable trays, electrical metallic tubing, and plug accessories.

Specially fitted E-houses that ensure safe operation are available for hazardous areas, fire and smoke detection, fire fighting systems, emergency exits, and access control. A heating, ventilation and air conditioning (HVAC) system can be installed on the roof of any E-house.
2.9.4 Completely Integrated Solutions from a Single Source

Turnkey solutions all over the world
To deliver an E-house that is perfectly suited to its purpose is the one thing. But it is equally important to ensure its reliable operation throughout the entire lifecycle, even if it is exposed to the most adverse conditions. Siemens provides a single-source solution for E-houses and electrical equipment requirements. Siemens’s know-how in energy supply is based on decades of experience and constant innovation. We provide integrated solutions all over the world – from engineering and network planning to project management and all the way to installation, pre-commissioning, commissioning and additional services. Siemens supports the local creation of value and ensures that a reliable contact person is in close reach of every project. The Siemens experts bring their experience in project management, financial services, and lifecycle management to every project. This enables them to consider all aspects of safety, logistics and environmental protection.

The benefits of SIEHOUSE solutions
- Comprehensive, integrated range of products
- Application expertise
- Global experience
- Proven Siemens products
- Reliability and safety
- One contact for the entire project
- Financing support

Fig. 2.9-10: From engineering to after sales service: complete integration from a single source
3 Switchgear and Substations

3.1 High-Voltage Substations

3.1.1 Turnkey Substations

Introduction
High-voltage substations are interconnection points within the power transmission and distribution systems between regions and countries. Different applications of substations lead to high-voltage substations with and without power transformers:
- Step up from a generator-voltage level to a high-voltage system (MV/HV)
  - Power plants (in load centers)
  - Renewable power plants (e.g., windfarms)
- Transform voltage levels within the high-voltage system (HV/HV)
- Step down to a medium-voltage level of a distribution system (HV/MV)
- Interconnection in the same voltage level.

Scope
High-voltage substations comprise not only the high-voltage equipment which is relevant for the functionality in the power supply system. Siemens plans and constructs high-voltage substations comprising high-voltage switchgear, medium-voltage switchgear, major components such as high-voltage equipment and transformers, as well as all ancillary equipment such as auxiliaries, control systems, protective equipment and so on, on a turnkey basis or even as general contractor. The installations supplied worldwide range from basic substations with a single busbar to interconnection substations with multiple busbars, or a breaker-and-a-half arrangement for rated voltages up to 800 kV, rated currents up to 8,000 A and short-circuit currents up to 100 kA. The services offered range from system planning to commissioning and after-sales service, including training of customer personnel.

Project management
The process of handling such a turnkey installation starts with preparation of a quotation, and proceeds through clarification of the order, design, manufacture, supply and cost-accounting until the project is finally billed. Processing such an order hinges on methodical data processing that in turn contributes to systematic project handling.

Engineering
All these high-voltage installations have in common their high standard of engineering which covers all system aspects such as power systems, steel structures, civil engineering, fire precautions, environmental protection and control systems (fig. 3.1-1). Every aspect of technology and each work stage is handled by experienced engineers. With the aid of high-performance computer programs, e.g., the finite element method (FEM), installations can be reliably designed even for extreme stresses, such as those encountered in earthquake zones.

Fig. 3.1-1: Engineering of high-voltage switchgear

All planning documentation is produced on modern CAD/CAE systems; data exchange with other CAD systems is possible via interfaces. By virtue of their active involvement in national and international associations and standardization bodies, our engineers are always fully informed of the state of the art, even before a new standard or specification is published.

Certification of the integrated quality management system
At the beginning of the 1980s, a documented QM system was already introduced. The basis of the management system is the documentation of all processes relevant for quality, occupational safety and environmental protection.

The environment protection was implemented on the basis of the existing QM system and was certified in accordance with DIN ISO 14001 in 1996. Occupational safety and health have always played an important role for Siemens AG and for the respective Business Units. When the BS OHSAS 18001 standard was introduced, the conditions for a certification analogous to the existing management systems were created.

Know-how, experience and worldwide presence
A worldwide network of liaisons and sales offices, along with the specialist departments in Germany, support and advise system operators in all matters of high-voltage substations technology.
3.1.2 High-Voltage Switchgear – Overview

High-voltage substations comprising high-voltage switchgear and devices with different insulating systems, air or gas (SF₆). When planning high-voltage substations, some basic questions have to be answered to define the type of high-voltage switchgear:

What is the function and location within the power supply system?
What are the climatic and environmental conditions?
Are there specific requirements regarding locations?
Are there space/cost restrictions?

Depending on the answers, either AIS or GIS can be the right choice, or even a compact or hybrid solution.

Air-insulated switchgear (AIS)
AIS are favorably priced high-voltage substations for rated voltages up to 800 kV, which are popular wherever space restrictions and environmental circumstances are not severe. The individual electrical and mechanical components of an AIS installation are assembled on site. Air-insulated outdoor substations of open design are not completely safe to touch, and are directly exposed to the effects of the climate and the environment (fig. 3.1-2).

Gas-insulated switchgear (GIS)
The compact design and small dimensions of GIS make it possible to install substations of up to 550 kV right in the middle of load centers of urban or industrial areas. Each switchgear bay is factory-assembled and includes the full complement of disconnecting switches, earthing switches (regular or make-proof), instrument transformers, control and protection equipment, and interlocking and monitoring facilities commonly used for this type of installation. The earthed metal enclosures of GIS assure not only insensitivity to contamination but also safety from electric shock (fig. 3.1-3).

Mixed technology (compact/hybrid solutions)
Beside the two basic (conventional) designs, there are also compact solutions available that can be realized with air-insulated and/or gas-insulated components.
3.1.3 Circuit Configuration

High-voltage substations are points in the power system where power can be pooled from generating sources, distributed and transformed, and delivered to the load points. Substations are interconnected with each other, so that the power system becomes a meshed network. This increases reliability of the power supply system by providing alternate paths for flow of power to take care of any contingency, so that power delivery to the loads is maintained and the generators do not face any outage. The high-voltage substation is a critical component in the power system, and the reliability of the power system depends upon the substation. Therefore, the circuit configuration of the high-voltage substation has to be selected carefully.

Busbars are the part of the substation where all the power is concentrated from the incoming feeders, and distributed to the outgoing feeders. That means that the reliability of any high-voltage substation depends on the reliability of the busbars present in the power system. An outage of any busbar can have dramatic effects on the power system. An outage of a busbar leads to the outage of the transmission lines connected to it. As a result, the power flow shifts to the surviving healthy lines that are now carrying more power than they are capable of. This leads to tripping of these lines, and the cascading effect goes on until there is a blackout or similar situation. The importance of busbar reliability should be kept in mind when taking a look at the different busbar systems that are prevalent.

**Single-busbar scheme (1 BB)**
The applications of this simple scheme are distribution and transformer substations, and feeding industrial areas (fig. 3.1-4). Because it has only one busbar and the minimum amount of equipment, this scheme is a low-cost solution that provides only limited availability. In the event of a busbar failure and during maintenance periods, there will be an outage of the complete substation. To increase the reliability, a second busbar has to be added.

**Double-busbar scheme (2 BB)**
The more complex scheme of a double-busbar system gives much more flexibility and reliability during operation of the substation (fig. 3.1-5). For this reason, this scheme is used for distribution and transformer substations at the nodes of the power supply system. It is possible to control the power flow by using the busbars independently, and by switching a feeder from one busbar to the other. Because the busbar disconnectors are not able to break the rated current of the feeder, there will be a short disruption in power flow.
Double circuit-breaker scheme (2 CB)
To have a load change without disruption, a second circuit-breaker per feeder has to be used. This is the most expensive way to solve this problem. In very important feeders, the 2 CB solution will be used (fig. 3.1-6).

One-breaker-and-a-half scheme (1.5 CB)
The one-breaker-and-a-half is a compromise between the 2 BB and the 2 CB scheme. This scheme improves the reliability and flexibility because, even in case of loss of a complete busbar, there is no disruption in the power supply of the feeders (fig. 3.1-7).
Fig. 3.1-8: 3-phase busbar scheme (3 BB)

3-phase busbar scheme (3 BB)
For important substations at the nodes of transmission systems for higher voltage levels, the 3-phase busbar scheme is used. It is a common scheme in Germany, utilized at the 380 kV level (fig. 3.1-8).
3.1.4 Air-Insulated Substations

In outdoor installations of open design, all live parts are insulated by air and not covered. Therefore, air-insulated substations (AIS) are always set up in a fenced area. Only authorized personnel have access to this operational area. Relevant national and international specifications that apply to outdoor substations and equipment have to be considered. The IEC 61936 standard is valid for European countries. Insulation coordination, including minimum phase-to-phase and phase-to-earth clearances, is effected in accordance with IEC 60071.

Outdoor switchgear is directly exposed to the effects of the environmental conditions. Therefore, they have to be designed both for electrical and environmental specifications. There is currently no common international standard covering the setup of air-insulated outdoor substations of open design. Siemens designs AIS in accordance with IEC standards, in addition to national standards or customer specifications. The standard IEC 61936-1, “Erection of power installations with rated voltages above 1 kV,” demonstrates the typical protective measures and stresses that have to be taken into consideration for air-insulated switchyards.

Protective measures
The protective measures can be categorized as personal protection and functional protection of substations (S/S).

- **Personal protection**
  - Protective measures against direct contact, i.e., through appropriate covering, obstruction, through sufficient clearance, appropriately positioned protective devices, and minimum height
  - Protective measures against indirect touching by means of relevant earthing measures in accordance with IEC 61936/ DIN VDE 0101 or other required standards
  - Protective measures during work on equipment, i.e., installation must be planned so that the specifications of DIN EN 50110 (VDE 0105) (e.g., five safety rules) are observed

- **Functional protection**
  - Protective measures during operation, e.g., use of switchgear interlocking equipment
  - Protective measures against voltage surges and lightning strikes
  - Protective measures against fire, water and, if applicable, noise

- **Stresses**
  - Electrical stresses, e.g., rated current, short-circuit current, adequate creepage distances and clearances
  - Mechanical stresses (normal stressing), e.g., weight, static and dynamic loads, ice, wind
  - Mechanical stresses (exceptional stresses), e.g., weight and constant loads in simultaneous combination with maximum switching forces or short-circuit forces, etc.
  - Special stresses, e.g., caused by installation altitudes of more than 1,000 m above sea level, or by earthquakes.

Variables affecting switchgear installation
The switchyard design is significantly influenced by:

- Minimum clearances (depending on rated voltages) between various active parts and between active parts and earth
- Rated and short-circuit currents
- Clarity for operating staff
- Availability during maintenance work; redundancy
- Availability of land and topography
- Type and arrangement of the busbar disconnectors.

The design of a substation determines its accessibility, availability and clarity. It must therefore be coordinated in close cooperation with the system operator. The following basic principles apply: Accessibility and availability increase with the number of busbars. At the same time, however, clarity decreases. Installations involving single busbars require minimum investment, but they offer only limited flexibility for operation management and maintenance. Designs involving one-breaker-and-a-half and double-circuit-breaker arrangements ensure a high redundancy, but they also entail the highest costs.

Systems with auxiliary or bypass busbars have proved to be economical. The circuit-breaker of the coupling feeder for the auxiliary bus allows uninterrupted replacement of each feeder circuit-breaker. For busbars and feeder lines, mostly standard aluminum conductors are used. Bundle conductors are required where currents are high. Because of the additional short-circuit forces between the subconductors (the pinch effect), however, bundle conductors cause higher mechanical stresses at the terminal points. When conductors (particularly standard bundle conductors) are used, higher short-circuit currents cause a rise not only in the aforementioned pinch effect, also in further force maxima in the event of swinging and dropping of the conductor bundle (cable pull). This in turn results in higher mechanical stresses on the switchyard components. These effects can be calculated in an FEM (finite element method) simulation (fig. 3.1-9).

![Fig. 3.1-9: FEM calculation of deflection of wire conductors in the event of short circuit](image-url)
Switchgear and Substations

3.1 High-Voltage Substations

Computer-aided engineering/design (CAE/CAD)
A variety of items influence the design of air-insulated substations. In the daily engineering work, database-supported CAE tools are used for the primary and secondary engineering of the substations. The database speeds up all the engineering processes by using predefined solutions and improves the quality (fig. 3.1-10).

Design of air-insulated substations
When rated and short-circuit currents are high, aluminum tubes are increasingly used to replace wire conductors for busbars and feeder lines. They can handle rated currents up to 8,000 A and short-circuit currents up to 80 kA without difficulty. Other influences on the switchyard design are the availability of land, the lie of the land, the accessibility and location of incoming and outgoing overhead-lines, and the number of transformers and voltage levels. A one-line or two-line arrangement, and possibly a U-arrangement, may be the proper solution. Each outdoor switchgear installation, especially for step-up substations in connection with power stations and large transformer substations in the extra-high-voltage transmission system, is therefore unique, depending on the local conditions. HV/MV transformer substations of the distribution system, with repeatedly used equipment and a scheme of one incoming and one outgoing line as well as two transformers together with medium-voltage switchgear and auxiliary equipment, are usually subject to a standardized design.

Preferred designs
Conceivable designs include certain preferred versions that are often dependent on the type and arrangement of the busbar disconnectors.

H-arrangement
The H-arrangement is preferred for use in applications for feeding industrial consumers. Two overhead-lines are connected with two transformers and interlinked by a double-bus sectionalizer. Thus, each feeder of the switchyard can be maintained without disturbance of the other feeders (fig. 3.1-11, fig. 3.1-12).
The H-arrangement is preferred for use in applications for feeding industrial consumers. Two overhead-lines are connected with two transformers and interlinked by a double-bus sectionalizer. Thus, each feeder of the switchyard can be maintained without disturbance of the other feeders (fig. 3.1-13, fig. 3.1-14).
Fig. 3.1-15: In-line arrangement, 110 kV

In-line longitudinal arrangement (Kiellinie®), with center-break disconnectors, preferably 110 to 220 kV

The busbar disconnectors are lined up one behind the other and parallel to the longitudinal axis of the busbar. It is preferable to have either wire-type or tubular busbars. Where tubular busbars are used, gantries are required for the outgoing overhead lines only. The system design requires only two conductor levels and is therefore clear. The bay width is quite large (in-line arrangement of disconnectors), but the bay length is small (fig. 3.1-15, fig. 3.1-16).

Fig. 3.1-16: Busbar disconnectors "in line", 110 kV, Germany
Central/center arrangement (Classical arrangement) layout with center-break disconnectors, normally only for 245 kV

The busbar disconnectors are arranged side-by-side and parallel to the longitudinal axis of the feeder. Wire-type busbars located at the top are commonly used; tubular busbars are also possible. This arrangement enables the conductors to be easily jumpered over the circuit-breakers, and the bay width to be made smaller than that of in-line designs. With three conductor levels, the system is relatively clear, but the cost of the gantries is high (fig. 3.1-17, fig. 3.1-18).

Fig. 3.1-17: Central/center tower arrangement, 220 kV

Fig. 3.1-18: Central/center tower arrangement, 220 kV, Egypt
Diagonal layout with pantograph disconnectors, preferably 110 to 420 kV

The pantograph disconnectors are placed diagonally to the axis of the busbars and feeder. This results in a very clear and most space-saving arrangement. Wire and tubular conductors are customary. The busbars can be located above or below the feeder conductors (fig. 3.1-19, fig. 3.1-20).
One-breaker-and-a-half layout, preferably up to 220 to 800 kV

The one-breaker-and-a-half arrangement ensures high supply reliability; however, the expenditure for equipment is high as well. The busbar disconnectors are of the pantograph, rotary or vertical-break type. Vertical-break disconnectors are preferred for the feeders. The busbars located at the top can be either the wire or tubular type. Two arrangements are customary:

- Internal busbar, feeders in H-arrangement with two conductor levels
- External busbar, feeders in-line with three conductor levels (fig. 3.1-21, fig. 3.1-22)
Fig. 3.1-23: One-circuit-breaker-and-a half arrangement, 800 kV

One-breaker-and-a-half layout, preferably 220 to 800 kV
The one-breaker-and-a-half arrangement ensures high supply reliability; however, the expenditure for equipment is high as well. The busbar disconnectors are of the pantograph, rotary or vertical-break type. Vertical-break disconnectors are preferred for the feeders. The busbars located at the top can be either the wire or tubular type. Two arrangements are customary:
- Internal busbar, feeders in H-arrangement with two conductor levels
- External busbar, feeders in-line with three conductor levels (fig. 3.1-23, fig. 3.1-24)

Fig. 3.1-24: One-breaker-and-a-half arrangement, 800 kV, India
3.1.5 Mixed Technology (Compact/Hybrid Solutions)

Wherever there is a lack of space, system operators have to rely on space-saving outdoor switchgear, especially in regions where smaller-scale transformer substations prevail and in industrial plants. For rated voltages from 72.5 to 170 kV, Siemens Energy offers two different conventional switchgear versions for a reliable and cost-effective power supply:

- SIMOBREAKER, outdoor switchyard featuring a side-break disconnector
- SIMOVER, outdoor switchyard featuring a pivoting circuit-breaker
- HIS, highly integrated switchgear
- DTC, dead-tank compact

**SIMOBREAKER – Substation with rotary disconnector**

The design principle of SIMOBREAKER provides for the side-break disconnector blade to be located on the rotating post insulator, which establishes the connection between the circuit-breaker and the transformer. Because the circuit-breaker, the disconnector, the earthing switch and the instrument transformer are integrated into SIMOBREAKER, there is no need for a complex connection with cables and pipes, or for separate foundations, steel, or earthing terminals for each individual device. This means that the system operator gets a cost-effective and standardized overall setup from one source and has no need to provide any items. Coordination work is substantially reduced, and interface problems do not even arise.

SIMOBREAKER can also be used as indoor switchgear. Installation inside a building ensures protection against the elements. This can be an enormous advantage, particularly in regions with extreme climates, but it is also relevant in industrial installations exposed to excessive pollution, e.g., in many industrial plants (fig. 3.1-25, fig. 3.1-26).

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**Fig. 3.1-25: SIMOBREAKER module**

**Fig. 3.1-26: SIMOBREAKER (schematic)**
SIMOVER – Switchgear with withdrawable circuit-breaker

The compact SIMOVER switchgear, specially conceived for substations with single busbars, features a pivoting circuit-breaker. It is excellent for use in small transformer substations such as windfarms or any plants where space is restricted. It integrates all components of a high-voltage bay. There are no busbar and outgoing disconnectors for the feeders. The cabling is simple, and the switching status is clear. Drive technology is improved and the drive unit is weatherproofed. Pre-assembled components reduce installation times. In SIMOVER, all components of a high-voltage outdoor switchgear bay, including the isolating distances, are integrated in one unit. The instrument transformers and the local control cubicle are part of this substation design.

The concept behind SIMOVER is based on customary design verified standard components. This ensures high reliability. Thanks to economizing on the disconnectors, and to the integration of the instrument transformers and the local control cubicle, implementation costs are considerably reduced. All components needed for the full scope of functioning of the movable circuit-breaker can be obtained from a single source, so there is no need for customer-provided items, coordination work is greatly reduced and interface problems do not even arise (fig. 3.1-27, fig. 3.1-28).

Fig. 3.1-27: SIMOVER H-arrangement (schematic)

Fig. 3.1-28: H-arrangement with SIMOVER, 145 kV, Czech Republic
Dead-tank compact (DTC)
The dead-tank compact is another compact solution for the 145 kV voltage level: a dead-tank circuit-breaker together with GIS modules for disconnectors (fig 3.1-29, fig. 3.1-30). For more information, please refer to section 4.1.4.

Highly integrated switchgear (HIS)
Highly integrated switchgear (HIS), fig. 3.1-31 and fig. 3.1-32 combines the advantages of air-insulated installations with those of gas-insulated switchgear technology. HIS switchgear is available up to 550 kV. The compact HIS switchgear is especially suited
- for new substations in a limited space
- where real estate prices are high
- where environmental conditions are extreme
- where the costs of maintenance are high.

HIS arrangements are compact solutions used mainly for renewal or expansion of air-insulated outdoor and indoor substations, particularly if the operator wants to carry out modifications while the switchgear is in service. In new construction projects, high site prices and increasingly complex approval procedures mean that the space requirement is the prime factor in costing. With the HIS solution, the circuit-breakers, disconnectors, earthing switches and transformers are accommodated in compressed gastight enclosures, thus rendering the switchgear extremely compact.
3.1 High-Voltage Substations

Planning principles
For air-insulated outdoor substations of open design, the following planning principles must be taken into account:

- High reliability
  - Reliable mastering of normal and exceptional stresses
  - Protection against surges and lightning strikes
  - Protection against surges directly on the equipment concerned (e.g., transformer, HV cable)
- Good clarity and accessibility
  - Clear conductor routing with few conductor levels
  - Free accessibility to all areas (no equipment located at inaccessible depth)
  - Adequate protective clearances for installation, maintenance and transportation work
  - Adequately dimensioned transport routes
- Positive incorporation into surroundings
  - As few overhead conductors as possible
  - Tubular instead of wire-type busbars
  - Unobtrusive steel structures
  - Minimal noise and disturbance level
  - EMC earthing system for modern control and protection
- Fire precautions and environmental protection
  - Adherence to fire protection specifications and use of flame-retardant and non-flammable materials
  - Use of environmentally compatible technology and products.

Fig. 3.1-31: H-arrangement outdoor GIS

Fig. 3.1-32: HIS for renewal of AIS space relations

Space saving > 70%; AIS 1,300 m² – HIS 360 m²
3.1.6 Gas-Insulated Switchgear for Substations

Characteristic features of switchgear installations
Since 1968, the concept of Siemens gas-insulated metal-enclosed high-voltage switchgear has proved itself in more than 28,000 bay installations in all regions of the world (table 3.1-1). Gas-insulated metal-enclosed high-voltage switchgear (GIS) is constantly gaining on other types of switchgear because it offers the following outstanding advantages

- Minimum space requirements:
  Where the availability of land is low and/or prices are high, e.g., in urban centers, industrial conurbations, mountainous regions with narrow valleys or in underground power stations, gas-insulated switchgear is replacing conventional switchgear because of its very small space requirements.

- Full protection against contact with live parts:
  The surrounding metal enclosure affords maximum safety for personnel under all operating and fault conditions.

- Protection against pollution:
  Its metal enclosure fully protects the switchgear interior against environmental effects such as salt deposits in coastal regions, industrial vapors and precipitates, and sandstorms.

- Free choice of installation site:
  The small site area required for gas-insulated switchgear saves expensive grading and foundation work, e.g., in permafrost zones. Another advantage is the short erection time because of the use of prefabricated and factory tested bay units.

- Protection of the environment:
  The necessity to protect the environment often makes it difficult to erect outdoor switchgear of conventional design. Gas-insulated switchgear, however, can almost always be designed to blend well with the surroundings. Gas-insulated metal-enclosed switchgear is, because of the modular design, very flexible and meets all requirements for configuration that exist in the network design and operating conditions.

Each circuit-breaker bay includes the full complement of disconnecting and earthing switches (regular or make-proof), instrument transformers, control and protection equipment, and interlocking and monitoring facilities commonly used for this type of installation.

Besides the traditional circuit-breaker bay, other circuits, such as single busbar, single-busbar arrangement with bypass busbar, coupler and bay for double and triple busbar, can be supplied.

(Main) product range of GIS for substations
The Siemens product range covers GIS from 66 up to 800 kV rated voltage – the main range covers SF₆ switchgear up to 550 kV (table 3.1-2).

The development of this switchgear has been based on two overall production concepts: meeting the high technical standards required of high-voltage switchgear and providing maximum customer benefit.

More than 45 years of experience with gas-insulated switchgear

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>Start of fundamental studies in research and development of SF₆ technology</td>
</tr>
<tr>
<td>1964</td>
<td>Delivery of first SF₆ circuit-breaker</td>
</tr>
<tr>
<td>1968</td>
<td>Delivery of first GIS</td>
</tr>
<tr>
<td>1974</td>
<td>Delivery of first GIL (420 kV)</td>
</tr>
<tr>
<td>1997</td>
<td>Introduction of intelligent, bay integrated control, monitoring and diagnostic</td>
</tr>
<tr>
<td>1999</td>
<td>Introduction of newest GIS generation: Self-compression interrupter unit and spring-operated mechanism</td>
</tr>
<tr>
<td>2000</td>
<td>Introduction of the trendsetting switchgear concept HIS (Highly Integrated Switchgear) for extension, retrofit and new compact AIS substations</td>
</tr>
<tr>
<td>2005</td>
<td>First GIS with electrical endurance capability (class E2)</td>
</tr>
<tr>
<td>2009</td>
<td>New generation of cast resin insulators for GIS</td>
</tr>
<tr>
<td>2010</td>
<td>New 420 kV/80 kA GIS – powerful and compact</td>
</tr>
<tr>
<td>2011</td>
<td>New 170 kV/63 kA GIS – powerful and compact</td>
</tr>
<tr>
<td>2011</td>
<td>New generation of 420 kV/63 kA GIS – powerful and compact</td>
</tr>
</tbody>
</table>

Table 3.1-1: Siemens experience with gas-insulated switchgear

This objective is attained only by incorporating all processes in the quality management system, which has been introduced and certified according to EN 29001/DIN EN ISO 9001.

Siemens GIS switchgear meets all performance, quality and reliability demands, including:

- Compact and low-weight design:
  Small building dimensions and low floor loads, a wide range of options in the utilization of space, and less space taken up by the switchgear.

- Safe encapsulation:
  An outstanding level of safety based on new manufacturing methods and optimized shape of enclosures.

- Environmental compatibility:
  No restrictions on choice of location due to minimum space requirement; extremely low noise and EMC emission as well as effective gas sealing system (leakage < 0.1 % per year per
3.1 High-Voltage Substations

Modern spring mechanisms that are currently available for the whole GIS 8D product spectrum eliminates the need for hydraulic oil.

• Economical transport:
  Simplified fast transport and reduced costs, because of a minimum of shipping units.

• Low operating costs:
  The switchgear is practically maintenance-free, e.g., contacts of circuit-breakers and disconnectors are designed for extremely long endurance, motor operating mechanisms are lubricated for life, the enclosure is corrosion-free. This ensures that the first inspection is required only after 25 years of operation.

• High reliability:
  The longstanding experience of Siemens in design, production and commissioning – more than 330,000 bay operating years in over 28,000 bay installations worldwide – is testament to the fact that the Siemens products are highly reliable. The mean time between failures (MTBF) amounts to > 900 bay years for major faults. A quality management system certified according to ISO 9001, which is supported by highly qualified employees, ensures high quality throughout the whole process chain from the offer/order process to the on-site commissioning of the GIS.

• Smooth and efficient installation and commissioning:
  Transport units are fully assembled, tested at the factory and filled with SF₆ gas at reduced pressure. Coded plug connectors are used to cut installation time and minimize the risk of cabling failures.

• Routine tests:
  All measurements are automatically documented and stored in the electronic information system, which provides quick access to measured data for years.

SF₆-insulated switchgear for up to 170 kV, type 8DN8 3-phase enclosures are used for switchgear type 8DN8 in order to achieve small and compact component dimensions. The low bay weight ensures low floor loading, and helps to reduce the cost of civil works and to minimize the footprint. The compact low-weight design allows installing it almost anywhere. Capital cost is reduced by using smaller buildings or existing ones, e.g., when replacing medium-voltage switchyards with the 145 kV GIS.

The bay is based on a circuit-breaker mounted on a supporting frame (fig. 3.1-33). A special multifunctional cross-coupling module combines the functions of the disconnector and earthing switch in a 3-position switching device. It can be used as:

• An active busbar with an integrated disconnector and work-in-progress earthing switch (fig. 3.1-33, pos. 3 and 5)
• An outgoing feeder module with an integrated disconnector and work-in-progress earthing switch (fig. 3.1-33, pos. 9)
• A busbar sectionalizer with busbar earthing.

Cable termination modules can be equipped with either conventional sealing ends or the latest plug-in connectors (fig. 3.1-33, pos. 10). Flexible 1-pole modules are used to connect overhead-lines and transformers with a splitting module that links the 3-phase enclosed switchgear to the 1-pole connections.

Thanks to their compact design, the completely assembled and factory-tested bays can be shipped as a single transport unit. Fast erection and commissioning on site ensure the highest possible quality.

<table>
<thead>
<tr>
<th>Switchgear type</th>
<th>8DN8</th>
<th>8DN9</th>
<th>8DQ1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage (kV) up to 170</td>
<td>up to 245</td>
<td>up to 420/550</td>
<td></td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage (kV) up to 325</td>
<td>up to 460</td>
<td>up to 650/740</td>
<td></td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage (kV) up to 750</td>
<td>up to 1,050</td>
<td>up to 1,425/1,800</td>
<td></td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage (kV) –</td>
<td>up to 850</td>
<td>up to 1,050/1,250</td>
<td></td>
</tr>
<tr>
<td>Rated current, busbar (A) up to 4,000</td>
<td>up to 4,000</td>
<td>up to 6,300</td>
<td></td>
</tr>
<tr>
<td>Rated current, feeder (A) up to 4,000</td>
<td>up to 4,000</td>
<td>up to 5,000</td>
<td></td>
</tr>
<tr>
<td>Rated short-circuit breaking current (kA) up to 63</td>
<td>up to 50</td>
<td>up to 63</td>
<td></td>
</tr>
<tr>
<td>Rated short-time withstand current (kA) up to 63</td>
<td>up to 50</td>
<td>up to 63</td>
<td></td>
</tr>
<tr>
<td>Rated peak withstand current (kA) up to 170</td>
<td>up to 135</td>
<td>up to 170</td>
<td></td>
</tr>
<tr>
<td>Inspection (years) &gt; 25</td>
<td>&gt; 25</td>
<td>&gt; 25</td>
<td></td>
</tr>
<tr>
<td>Bay width (mm) 650/800/1,000</td>
<td>1,500</td>
<td>2,200/3,600</td>
<td></td>
</tr>
</tbody>
</table>

Values in accordance with IEC; other values available on request

Table 3.1-2: Main product range of GIS
The feeder control and protection can be installed in a bay-integrated local control cubicle mounted to the front of each bay (fig. 3.1-33, pos. 1). Moreover, state-of-the-art monitoring devices are available at the customer’s request, e.g., for partial discharge online monitoring.
3.1 High-Voltage Substations

**SF₆-insulated switchgear for up to 245 kV, type 8DN9**

The clear bay configuration of the lightweight and compact 8DN9 switchgear is evident at first glance. Control and monitoring facilities are easily accessible despite the switchgear’s compact design.

The horizontally arranged circuit-breaker forms the basis of every bay configuration. The operating mechanism is easily accessible from the operator area. The other bay modules – of 1-phase enclosed switchgear design, like the circuit-breaker module – are located on top of the circuit-breaker. The 1-phase encapsulated passive busbar is partitioned off from the active equipment (fig. 3.1-36).

Thanks to “single-function” assemblies (assignment of just one task to each module) and the versatile modular structure, even unconventional arrangements can be set up from a pool of only 20 different modules. The modules are connected to each other with a standard interface that allows implementing an extensive range of bay structures. Switchgear design with standardized modules and the scope of services ensure that all types of bay structures can be set up in a small area. The compact design allows supplying of complete bays that are fully assembled and tested at the factory, which makes for smooth and efficient installation and commissioning.

**Fig. 3.1-36: 8DN9 switchgear bay**

**Fig. 3.1-37: 8DN9 switchgear for a rated voltage of 245 kV, with a 3-phase encapsulated passive busbar**
SF₆-insulated switchgear for up to 550 kV, type 8DQ1
GIS type 8DQ1 is a 1-phase enclosed switchgear system for high-power switching stations with individual enclosure of all modules of the 3-phase system.

The base unit for the switchgear is a horizontally arranged circuit-breaker on top of which the housing containing the disconnectors, earthing switches, current transformers and so on are mounted. The busbar modules are partitioned off from the active equipment (fig. 3.1-38, fig. 3.1-39).

Some other characteristic features of switchgear installation are:

- Circuit-breakers with single interrupter unit up to operating voltages of 420 kV, with two interrupter units up to operating voltages of 550 kV
- Short-circuit breaking currents up to 63 kA within 2 cycles for 50 Hz / 60 Hz and 80 kA up to 420 kV
- Horizontal arrangement of the circuit-breakers in the lower section provides low center of gravity for the switchgear
- Utilization of the circuit-breaker transport frame as a supporting device for the entire bay
- Reduced length of sealing surfaces, and thus, decreased risk of leakage through use of only a few modules and equipment combinations in one enclosure.
Special arrangements
Gas-insulated switchgear – usually accommodated in buildings (such as a tower-type substation) – is expedient wherever land is very expensive or restricted, or where necessitated by ambient conditions. When it comes to smaller switching stations, or in cases of expansion where installation in a building does not provide any advantage, installing the substation in a container is a good solution.

Mobile containerized switchgear
At medium-voltage levels, mobile containerized switchgear is the state of the art. Even high-voltage switching stations can be built this way and are economically operated in many applications. At the core is the metal-enclosed SF₆-insulated switchgear, installed either in a sheet-steel container or in a block house made of prefabricated concrete elements. In contrast to conventional stationary switchgear, there is no need for complicated constructions, as mobile switching stations come with their own “building” (fig. 3.1-40, fig. 3.1-41).

Mobile containerized switching stations can be of single-bay or multi-bay design with a large number of different circuits and arrangements. All of the usual connection components can be employed, among them outdoor bushings, cable adapter boxes and SF₆ tubular connections. If necessary, all control and protection equipment as well as that for local supply can be
accommodated in the container. This allows largely independent operation of the installation on site. Containerized switchgear is pre-assembled at the factory and ready for operation. The only on-site work required is setting up the containers, fitting the exterior system parts and making the external connections. Shifting the switchgear assembly work to the factory enhances quality and operational reliability. Mobile containerized switchgear has a small footprint, and usually fits well within the environment. For operators, prompt availability and short commissioning times are a further significant advantage. Considerable cost reductions are achieved in planning, construction work and assembly.

Approvals from building authorities are either not required or required in a simplified form. The installation can also be operated at various locations in succession. Adaptation to local circumstances is not a problem. The following are the possible applications for containerized stations:

- Interim solutions during the modernization of switching stations
- Low-cost transitional solutions where new construction of transformer substations involves tedious formalities, such as the procurement of land or the establishment of cable routes
- Quick erection as an emergency station in the event of malfunctioning of the existing switchgear
- Switching stations for movable geothermal power plants.

**GIS for up to 245 kV in a standard container**

The dimensions of the BDN9 switchgear make it possible to accommodate all active components of the switchgear (circuit-breaker, disconnector, earthing switch) and the local control cubicle in a standard container. The floor area of 6.1 m x 2.44 m complies with the ISO 668 standard. Although the container exceeds the standard dimension of 2.44 m, this will not cause any problem during transportation, a fact that has already been proven by several equipment deliveries. German Lloyd, an approval authority, already issued a test certificate for an even higher container construction. The standard dimensions and ISO corner fittings facilitate handling during transport in the 6.1 m frame of a container ship and on a low-loader truck. Two doors provide the operating staff with access to the container.

**Rent a GIS**

Siemens also offers containerized gas-insulated high-voltage substations for rent to fill every gap, instantly and in a remarkably cost-effective manner. The Siemens Instant Power Service offers an economical power supply solution for time periods from a few weeks up to 3 years.

**Specification guide for metal-enclosed SF₆-insulated switchgear**

Note: The points below are not considered exhaustive, but are a selection of the important. These specifications cover the technical data applicable to metal-enclosed SF₆-insulated switchgear for switching and distributing power in cable and/or overhead-line systems and transformers. Key technical data are contained in the data sheet and the single-line diagram (SLD) attached to the inquiry.

A general SLD and a sketch showing the general arrangement of the substation will be part of a proposal. Any switchgear quoted will be complete and will form a functional, safe and reliable system after installation, even if certain parts required to achieve this have not been specifically been included in the inquiry.

- **Applicable standards**
  - All equipment is designed, built, tested and installed according to the latest issues of the applicable IEC standards, which are:
    - IEC 62271-1 “High-voltage switchgear and controlgear: Common specifications”
    - IEC 62271-203 “High-voltage switchgear and controlgear: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV”
    - IEC 62271-100 “High-voltage switchgear and controlgear: Alternating-current circuit-breakers”
    - IEC 62271-102 “High-voltage switchgear and controlgear: Alternating current disconnectors and earthing switches”
    - IEC 60044 “Instrument transformers: Current transformers”
    - National standards on request.

**Local conditions**

The equipment is tested for indoor and outdoor applications. All the buyer has to provide is a flat concrete floor with the cutouts for cable installation – if this is required. The switchgear comes equipped with adjustable supports (feet). If steel support structures are required for the switchgear, Siemens will provide these as well. For design purposes, the indoor temperatures should be between -5 °C and + 40 °C, and outdoor temperatures should be between -30 °C and + 40 °C (+50 °C). For parts to be installed outdoors (overhead-line connections), the conditions described in IEC 62271-203 will be observed.

For the enclosures, aluminum or aluminum alloys are preferred. A minimum of on-site erection work will ensure maximum reliability. Any subassemblies will be erected and tested at the factory. Subassembly size is restricted only by transport requirements. Siemens will provide the enclosure in a material and thickness suited to withstand an internal arc and prevent burn-throughs or punctures within the first stage of protection, referred to the rated short-circuit current of the given GIS type.

All assemblies are designed to allow absorption of thermal expansion and contraction caused by varying temperatures. Adjustable metal bellow compensators are installed for this purpose. Density monitors with electrical contacts for at least two pressure levels are installed to allow monitoring the gas in the enclosures. The circuit-breakers can be monitored with density gauges that are fitted in the circuit-breaker control units.

Siemens can assure that the pressure loss for each individual gas compartment – i.e., not just for the complete switchgear installation – will not exceed 0.5 % per year and gas compartment. Each gas-filled compartment comes equipped with static filters that are capable of absorbing any water vapor that penetrates into the switchgear installation for a period of at least 25 years. Intervals between required inspections are long, which keeps maintenance costs to a minimum. The first minor inspection is due after ten years. The first major inspection is usually required.
Switchgear and Substations

3.1 High-Voltage Substations

Fig. 3.1-42: Special arrangement for limited space. Sectional view of a building showing the compact nature of gas-insulated substations

after more than 25 years of operation unless the permissible number of operations is reached before that date.

Arrangement and modules

Arrangement
The system is of the enclosed 1-phase or 3-phase type. The assembly consists of completely separate pressurized sections, and is thus designed to minimize any danger to the operating staff and risk of damage to adjacent sections, even if there should be trouble with the equipment. Rupture diaphragms are provided to prevent the enclosures from bursting discs in an uncontrolled manner. Suitable deflectors provide protection for the operating personnel. For maximum operating reliability, internal relief devices are not installed, because these would affect adjacent compartments. The modular design, complete segregation, arc-proof bushing and plug-in connections allow speedy removal and replacement of any section with only minimal effects on the remaining pressurized switchgear.

Busbars
All busbars of the enclosed 3-phase or the 1-phase type are connected with plugs from one bay to the next.

Circuit-breakers
The circuit-breakers operate according to the dynamic self-compression principle. The number of interrupting units per phase depends on the circuit-breaker’s performance. The arcing chambers and circuit-breaker contacts are freely accessible. The circuit-breaker is suitable for out-of-phase switching and designed to minimize overvoltages. The specified arc interruption performance has to be consistent across the entire operating range, from line-charging currents to full short-circuit currents.

The circuit-breaker is designed to withstand at least 10 operations (depending on the voltage level) at full short-circuit rating. Opening the circuit-breaker for service or maintenance is not necessary. The maximum tolerance for phase displacement is 3 ms, that is, the time between the first and the last pole’s opening or closing. A standard station battery that is required for control and tripping may also be used for recharging the operating mechanism. The drive and the energy storage system are provided by a stored-energy spring mechanism that holds sufficient energy for all standard IEC close-open duty cycles. The control system provides alarm signals and internal interlocks but inhibits tripping or closing of the circuit-breaker when the energy capacity in the energy storage system is insufficient or the SF₆ density within the circuit-breaker drops below the minimum permissible level.

Disconnectors
All disconnectors (isolators) are of the single-break type. DC motor operation (110, 125, 220 or 250 V), which is fully suited to remote operation, and a manual emergency operating mechanism are provided. Each motor operating mechanism is self-contained and equipped with auxiliary switches in addition to the mechanical indicators. The bearings are lubricated for life.

Earthing switches
Work-in-progress earthing switches are generally provided on either side of the circuit-breaker. Additional earthing switches may be used to earth busbar sections or other groups of the assembly. DC motor operation (110, 125, 220 or 250 V) that is fully suited for remote operation and a manual emergency operating mechanism are provided. Each motor operating mechanism is self-contained and equipped with auxiliary position switches in addition to the mechanical indicators. The bearings are lubricated for life. Make-proof high-speed earthing switches are generally installed at the cable and overhead-line terminals. They are equipped with a rapid closing mechanism to provide short-circuit making capacity.
**Instrument transformers**
Current transformers (CTs) are of the dry-type design. Epoxy resin is not used for insulation purposes. The cores have the accuracies and burdens that are shown on the SLD. Voltage transformers are of the inductive type, with ratings of up to 200 VA.

**Cable terminations**
1-phase or 3-phase, SF₆ gas-insulated, metal-enclosed cable end housings are provided. The cable manufacturer has to supply the stress cone and suitable sealings to prevent oil or gas from leaking into the SF₆ switchgear. Siemens will supply a mating connection piece to be fitted to the cable end. The cable end housing is suitable for oil-type, gas-pressure-type cables with plastic insulation (PE, PVC, etc.) as specified on the SLD or the data sheets. Additionally, devices for safely isolating a feeder cable and connecting a high-voltage test cable to the switchgear or cable will be provided (fig. 3.1-44, fig. 3.1-45).

**Overhead-line terminations**
The terminations for connecting overhead-lines come complete with SF₆-to-air bushings but without line clamps (fig. 3.1-46).

**Control and monitoring**
As a standard, an electromechanical or solid-state interlocking control board is supplied for each switchgear bay. This fault-tolerant interlocking system prevents all operating malfunctions. Mimic diagrams and position indicators provide the operating personnel with clear operating instructions. Provisions for remote control are included. Gas compartments are constantly monitored by density monitors that provide alarm and blocking signals via contacts.

**Required tests**

**Partial discharge tests**
All solid insulators fitted in the switchgear are subjected to a routine partial discharge test prior to installation. At 1.2 times the line-to-line voltage, no measurable discharge is allowed. This test ensures maximum safety with regard to insulator failure, good long-term performance and thus a very high degree of reliability.

**Pressure tests**
Each cast-aluminum enclosure of the switchgear is pressure-tested for at least twice the service pressure.

**Leakage tests**
Leakage tests performed on the subassemblies ensure that the flanges and cover faces are clean, and that the guaranteed leakage rate is not be exceeded.

**Power frequency tests**
Each assembly is subjected to power-frequency withstand tests, including sensitive partial discharge detection, to verify correct installation of the conductors, and to make sure that the insulator surfaces are clean and the switchgear as a whole is not subject to internal faults.

**Additional technical data**
Siemens will point out any dimensions, weights or other switchgear data that may affect local conditions and handling of the equipment. Any quotation includes drawings showing the switchgear assembly.
Instructions
Detailed instruction manuals on the installation, operation and maintenance of the equipment are supplied with all equipment delivered by Siemens.

Scope of supply
Siemens supplies the following items for all GIS types and interfaces as specified:

- The switchgear bay, including circuit-breakers, disconnectors and earthing switches, instrument transformers and busbar housings, as specified. For the different feeder types, the following limits apply:
  - Overhead-line feeder:
    The connecting stud at the SF₆-to-air bushing is supplied without the line clamp.
  - Cable feeder:
    According to IEC 60859, the termination housing, conductor coupling and connecting plate are part of the GIS delivery, while the cable stress cone with the matching flange is part of the cable supply (fig. 3.1-45).
  - Transformer feeder:
    Siemens supplies the connecting flange at the switchgear bay and the connecting bus ducts to the transformer, including any expansion joints. The SF₆-to-oil bushings plus terminal enclosures are part of the transformer delivery unless otherwise agreed (fig. 3.1-47, fig. 3.1-48).
    Note: This point always requires close coordination between the switchgear manufacturer and the transformer supplier.

- Each feeder bay is equipped with earthing pads. The local earthing network and the connections to the switchgear are included in the installation contractor's scope.

- Initial SF₆ gas filling for the entire switchgear supplied by Siemens is included. Siemens will also supply all gas interconnections from the switchgear bay to the integral gas service and monitoring panel.

- Terminals and circuit protection for auxiliary drives and control power are provided with the equipment. Feeder circuits and cables as well as the pertaining installation material will be supplied by the installation contractor.

- The local control, monitoring and interlocking panels are supplied for each circuit-breaker bay to form completely operational systems. Terminals for remote monitoring and control are also provided.

- Siemens will supply the above-ground mechanical support structures; embedded steel and foundation work are part of the installation contractor’s scope.

For further information, please contact:
e-mail: h-gis.ptd@siemens.com
Fig. 3.1-46: Outdoor termination module: High-voltage bushings are used for the SF₆-to-air transition. The bushings can be matched to specific requirements with regard to clearance and creepage distances. They are connected to the switchgear by means of angular-type modules of variable design.

Fig. 3.1-47: Transformer/reactor termination module: These termination modules form the direct connection between the GIS and oil-insulated transformers or reactance coils. Standardized modules provide an economical way of matching them to various transformer dimensions.

Fig. 3.1-48: Transformer termination modules

Fig. 3.1-49: 8DQ1 GIS for 550 kV, one-breaker-and-a-half arrangement.
3.2 Medium-Voltage
Switchgear

3.2.1 Introduction

According to international rules, there are only two voltage levels:
• Low-voltage: up to and including 1 kV AC (or 1,500 V DC)
• High-voltage: above 1 kV AC (or 1,500 V DC)

Most electrical appliances used in household, commercial and industrial applications work with low-voltage. High-voltage is used not only to transmit electrical energy over very large distances, but also for regional distribution to the load centers via fine branches. However, because different high-voltage levels are used for transmission and regional distribution, and because the tasks and requirements of the switchgear and substations are also very different, the term "medium-voltage" has come to be used for the voltages required for regional power distribution that are part of the high-voltage range from 1 kV AC up to and including 52 kV AC (fig. 3.2-1). Most operating voltages in medium-voltage systems are in the 3 kV AC to 40.5 kV AC range.

The electrical transmission and distribution systems not only connect power stations and electricity consumers, but also, with their "meshed systems," form a supraregional backbone with reserves for reliable supply and for the compensation of load differences. High operating voltages (and therefore low currents) are preferred for power transmission in order to minimize losses. The voltage is not transformed to the usual values of the low-voltage system until it reaches the load centers close to the consumer.

In public power supplies, the majority of medium-voltage systems are operated in the 10 kV to 30 kV range (operating voltage). The values vary greatly from country to country, depending on the historical development of technology and the local conditions.

Medium-voltage equipment

Apart from the public supply, there are still other voltages fulfilling the needs of consumers in industrial plants with medium-voltage systems; in most cases, the operating voltages of the motors installed are decisive. Operating voltages between 3 kV and 15 kV are frequently found in industrial supply systems.

In power supply and distribution systems, medium-voltage equipment is available in:
• Power stations, for generators and station supply systems
• Transformer substations of the primary distribution level (public supply systems or systems of large industrial companies), in which power supplied from the high-voltage system is transformed to medium-voltage
• Local supply, transformer or customer transfer substations for large consumers (secondary distribution level), in which the power is transformed from medium to low-voltage and distributed to the consumer.

---

Fig. 3.2-1: Voltage levels from the power plant to the consumer
3.2.2 Basics of Switching Devices

What are switching devices?
Switching devices are devices used to close (make) or open (break) electrical circuits. The following stress can occur during making and breaking:
- No-load switching
- Breaking of operating currents
- Breaking of short-circuit currents

What can the different switching devices do?
- **Circuit-breakers:** Make and break all currents within the scope of their ratings, from small inductive and capacitive load currents up to the full short-circuit current, and this under all fault conditions in the power supply system, such as earth faults, phase opposition, and so on.
- **Switches:** Switch currents up to their rated normal current and make on existing short-circuits (up to their rated short-circuit making current).
- **Disconnectors (isolators):** Used for no-load closing and opening operations. Their function is to “isolate” downstream devices so they can be worked on.
- **Three-position disconnectors:** Combine the functions of disconnecting and earthing in one device. Three-position disconnectors are typical for gas-insulated switchgear.
- **Switch-disconnectors (load-break switches):** The combination of a switch and a disconnect, or a switch with isolating distance.
- **Contactors:** Load breaking devices with a limited short-circuit making or breaking capacity. They are used for high switching rates.
- **Earthing switches:** To earth isolated circuits.
- **Make-proof earthing switches (earthing switches with making capacity):** Are used for the safe earthing of circuits, even if voltage is present, that is, also in the event that the circuit to be earthed was accidentally not isolated.
- **Fuses:** Consist of a fuse-base and a fuse-link. With the fuse-base, an isolating distance can be established when the fuse-link is pulled out in de-energized condition (like in a disconnector). The fuse-link is used for one single breaking of a short-circuit current.
- **Surge arresters:** To discharge loads caused by lightning strikes (external overvoltages) or switching operations and earth faults (internal overvoltages). They protect the connected equipment against impermissibly high-voltages.

Selection of switching devices
Switching devices are selected both according to their ratings and according to the switching duties to be performed, which also includes the switching rates. The following tables illustrate these selection criteria: table 3.2-1, next page, shows the selection according to ratings. Table 3.2-2 through table 3.2-5 show the endurance classes for the devices.

Selection according to ratings
The system conditions, that is, the properties of the primary circuit, determine the required parameters. The most important of these are:
- **Rated voltage:** The upper limit of the system voltage the device is designed for. Because all high-voltage switching devices are zero-current interrupters – except for some fuses – the system voltage is the most important dimensioning criterion. It determines the dielectric stress of the switching device by means of the transient recovery voltage and the recovery voltage, especially while switching off.
- **Rated insulation level:** The dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance. The dielectric strength is the capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages). The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2/50 µs and a power-frequency withstand voltage test (50 Hz/1 min).
### Table 3.2-1: Device selection according to data of the primary circuit

<table>
<thead>
<tr>
<th>Device</th>
<th>Withstand capability, rated ...</th>
<th>Switching capacity, rated ...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>insulation level</td>
<td>voltage</td>
</tr>
<tr>
<td>Circuit-breaker</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Switch(-disconnector)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Disconnector</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Earthing switch</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Make-proof earthing switch</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Contactor</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fuse-link</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fuse-base</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Surge arrester*</td>
<td>x 2)</td>
<td>x 3)</td>
</tr>
<tr>
<td>Current limiting reactor</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Bushing</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Post insulator (insulator)</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

*Selection parameter
1) Limited short-circuit making and breaking capacity
2) Applicable as selection parameter in special cases only, e.g., for exceptional pollution layer
3) For surge arresters with spark gap: rated voltage
4) Rated discharge current for surge arresters
5) For surge arresters: short-circuit strength in case of overload
6) For bushings and insulators: Minimum failing loads for tension, bending and torsion

*See also section 3.3

(Parameters of the secondary equipment for operating mechanisms, control and monitoring are not taken into consideration in this table.)

### Table 3.2-2: Classes for switches

<table>
<thead>
<tr>
<th>Class</th>
<th>Switching cycles</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>1,000</td>
<td>Mechanical endurance</td>
</tr>
<tr>
<td>M2</td>
<td>5,000</td>
<td>Increased mechanical endurance</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1</td>
<td>$10 \times I_{load}$</td>
<td>$10 \times I_{load}$</td>
</tr>
<tr>
<td></td>
<td>$2 \times I_{nom}$</td>
<td>$10 \times I_{nom}$</td>
</tr>
<tr>
<td></td>
<td>$I_{nom}$</td>
<td>$I_{nom}$</td>
</tr>
<tr>
<td></td>
<td>$I_{nom}$</td>
<td>$I_{nom}$</td>
</tr>
<tr>
<td></td>
<td>$I_{nom}$</td>
<td>$I_{nom}$</td>
</tr>
<tr>
<td>E2</td>
<td>$30 \times I_{load}$</td>
<td>$20 \times I_{load}$</td>
</tr>
<tr>
<td>E3</td>
<td>$100 \times I_{load}$</td>
<td>$20 \times I_{load}$</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>$10 \times I_{nom}$</td>
<td>$10 \times I_{nom}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$I_{nom}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No restrikes</td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No restrikes</td>
</tr>
</tbody>
</table>

### Table 3.2-3: Classes for circuit-breakers

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>2,000 switching cycles</td>
</tr>
<tr>
<td>M2</td>
<td>10,000 switching cycles</td>
</tr>
<tr>
<td>E</td>
<td></td>
</tr>
<tr>
<td>E1</td>
<td>$2 \times C$ and $3 \times O$ with 10%, 30%, 60% and 100% $I_{sc}$</td>
</tr>
<tr>
<td>E2</td>
<td>$26 \times C$ and $130 \times O$ with 10% $I_{sc}$</td>
</tr>
<tr>
<td></td>
<td>$26 \times C$ and $130 \times O$ with 30% $I_{sc}$</td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>$24 \times O$ per 10...40% $I_{pu}$</td>
</tr>
<tr>
<td></td>
<td>$24 \times CO$ per 10...40% $I_{pu}$</td>
</tr>
<tr>
<td></td>
<td>$128 \times CO$ per 10...40% $I_{pu}$</td>
</tr>
<tr>
<td></td>
<td>$128 \times CO$ per 10...40% $I_{pu}$</td>
</tr>
<tr>
<td></td>
<td>$128 \times CO$ per 10...40% $I_{pu}$</td>
</tr>
<tr>
<td>S</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>Circuit-breaker used in a cable system</td>
</tr>
<tr>
<td>S2</td>
<td>Circuit-breaker used in a line-system, or in a cable-system with direct connection (without cable) to overhead lines</td>
</tr>
</tbody>
</table>

* Class C1 is recommendable for infrequent switching of transmission lines and cables
** Class C2 is recommendable for capacitor banks and frequent switching of transmission lines and cables
• Rated normal current:
The current that the main circuit of a device can continuously carry under defined conditions. The temperature increase of components – especially contacts – must not exceed defined values. Permissible temperature increases always refer to the ambient air temperature. If a device is mounted in an enclosure, it may be advisable to load it below its full rated current, depending on the quality of heat dissipation.

• Rated peak withstand current:
The peak value of the major loop of the short-circuit current during a compensation process after the beginning of the current flow, which the device can carry in closed state. It is a measure for the electrodynamic (mechanical) load of an electrical component. For devices with full making capacity, this value is not relevant (see the previous item in this list).

• Rated short-circuit making current:
The root-mean-square value of the breaking current in case of short-circuit at the terminals of the switching device.

Selection according to endurance and switching rates
If several devices satisfy the electrical requirements and no additional criteria have to be taken into account, the required switching rate can be used as an additional selection criterion. Table 3.2-1 through table 3.2-5 show the endurance of the switching devices, providing a recommendation for their appropriate use. The respective device standards distinguish between classes of mechanical (M) and electrical (E) endurance, whereby they can also be used together on the same switching device; for example, a switching device can have both mechanical class M1 and electrical class E3.

• Switches:
Standard IEC 62271-103/VDE 0671-103 only specifies classes for the so-called general-purpose switches. There are also “special switches” and “switches for limited applications.”**
  – General-purpose switches:
    General-purpose switches must be able to break different types of operating currents (load currents, ring currents, currents of unloaded transformers, charging currents of unloaded cables and overhead-lines), as well as to make on short-circuit currents.
    General-purpose switches that are intended for use in systems with isolated neutral or with earth earth-fault compensation, must also be able to switch under earth-fault conditions. The versatility is mirrored in the very exact specifications for the E classes.
  – SF₆ switches:
    SF₆ switches are appropriate when the switching rate is not more than once a month. These switches are usually classified as E3 with regard to their electrical endurance.
  – Air-break or hard-gas switches:
    Air-break or hard-gas switches are appropriate when the switching rate is not more than once a year. These switches are simpler and usually belong to the E1 class. There are also E2 versions available.
  – Vacuum switches:
    The switching capacity of vacuum switches is significantly higher than that of the M2/E3 classes. They are used for special tasks – mostly in industrial power supply systems – or when the switching rate is at least once a week.

• Circuit-breakers:
Whereas the number of mechanical operating cycles is specifically stated in the M classes, the circuit-breaker standard IEC 62271-100/VDE 0671-100 does not define the electrical endurance of the E classes by specific numbers of operating cycles; the standard remains very vague on this.

The test duties of the short-circuit type tests provide an orientation as to what is meant by “normal electrical endurance” and “extended electrical endurance.” The number of make and break operations (Close, Open) is specified in table 3.2-3.

* Disconnectors up to 52 kV may only switch negligible currents up to 500 mA (e.g., voltage transformer), or larger currents only when there is an insignificant voltage difference (e.g., during busbar transfer when the bus coupler is closed).
3.2 Medium-Voltage Switchgear

Modern vacuum circuit-breakers can generally make and break the rated normal current up to the number of mechanical operating cycles. The switching rate is not a determining selection criterion, because circuit-breakers are always used where short-circuit breaking capacity is required to protect equipment.

- **Disconnectors:**
  Disconnectors do not have any switching capacity (switches for limited applications must only control some of the switching duties of a general-purpose switch). Switches for special applications are provided for switching duties such as switching of single capacitor banks, paralleling of capacitor banks, switching of ring circuits formed by transformers connected in parallel, or switching of motors in normal and locked condition. Therefore, classes are only specified for the number of mechanical operating cycles.

- **Earthing switches:**
  With earthing switches, the E classes designate the short-circuit making capacity (earthing on applied voltage). E0 corresponds to a normal earthing switch; switches of the E1 and E2 classes are also-called make-proof or high-speed earthing switches.
  The standard does not specify how often an earthing switch can be actuated purely mechanically; there are no M classes for these switches.

- **Contactors:**
  The standard has not specified any endurance classes for contactors yet. Commonly used contactors today have a mechanical and electrical endurance in the range of 250,000 to 1,000,000 operating cycles. They are used wherever switching operations are performed very frequently, e.g., more than once per hour.

Regarding capacitor applications IEC 62271-106 introduced classes for capacitice current breaking. If contactors are used for capacitor banks it is recommended to only install class C2 contactors.

### 3.2.3 Requirements of Medium-Voltage Switchgear

The major influences and stress values that a switchgear assembly is subjected to result from the task and its rank in the distribution system. These influencing factors and stresses determine the selection parameters and ratings of the switchgear (fig. 3.2-4).

#### Influences and stress values

- **System voltage**
  The system voltage determines the rated voltage of the switchgear, switching devices and other installed components. The maximum system voltage at the upper tolerance limit is the deciding factor.

- **Assigned configuration criteria for switchgear**
  - Rated voltage $U_r$
  - Rated insulation level $U_{di}, U_p$
  - Rated primary voltage of voltage transformers $U_{pr}$

- **Short-circuit current**
  The short-circuit current is characterized by the electrical values of peak withstand current $I_p$ (peak value of the initial symmetrical short-circuit current) and sustained short-circuit current $I_k$.
  The required short-circuit current level in the system is predetermined by the dynamic response of the loads and the power quality to be maintained, and determines the making and breaking capacity and the withstand capability of the switching devices and the switchgear (table 3.2-7).

  **Important note:** The ratio of peak current to sustained short-circuit current in the system can be significantly larger than the standardized factor $I_{p}/I_k = 2.5$ (50 Hz) used for the construction of the switching devices and the switchgear. A possible cause, for example, are motors that feed power back to the system when a short circuit occurs, thus increasing the peak current significantly.

- **Normal current and load flow**
  The normal current refers to current paths of the incoming feeders, busbar(s) and outgoing consumer feeders. Because of the spatial arrangement of the panels, the current is also distributed, and therefore there may be different rated current values next to one another along a conducting path; different values for busbars and feeders are typical.

  Reserves must be planned when dimensioning the switchgear:
  - In accordance with the ambient air temperature
  - For planned overload
  - For temporary overload during faults
Fig. 3.2-4: Influencing factors and stresses on the switchgear

Assigned configuration criteria for switchgear
- Rated peak withstand current $I_p$
- Rated short-time withstand current $I_{t}$

Switching devices
- Rated short-circuit making current $I_{ma}$
- Rated short-circuit breaking current $I_{cb}$

Current transformers
- Rated peak withstand current $I_{pk}$
- Rated short-time thermal current $I_{th}$

Table 3.2-7: Configuration criteria for short-circuit current

Large cable cross sections or several parallel cables must be connected for high normal currents; the panel connection must be designed accordingly.

Assigned configuration criteria for switchgear
- Rated current of busbar(s) and feeders
- Number of cables per phase in the panel (parallel cables)
- Current transformer ratings

Table 3.2-8: Loss of service continuity categories

<table>
<thead>
<tr>
<th>Type of accessibility to a compartment</th>
<th>Access features</th>
<th>Type of construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interlock-controlled</td>
<td>Opening for normal operation and maintenance, e.g., fuse replacement</td>
<td>Access is controlled by the construction of the switchgear, i.e., integrated interlocks prevent impermissible opening.</td>
</tr>
<tr>
<td>Procedure-based</td>
<td>Opening for normal operation or maintenance, e.g., fuse replacement</td>
<td>Access control via a suitable procedure (work instruction of the operator) combined with a locking device (lock).</td>
</tr>
<tr>
<td>Tool-based</td>
<td>Opening not for normal operation and maintenance, e.g., cable testing</td>
<td>Access only with tool for opening; special access procedure (instruction of the operator).</td>
</tr>
<tr>
<td>Not accessible</td>
<td>Opening not possible not intended for operator; opening can destroy the compartment. This applies generally to the gas-filled compartments of gas-insulated switchgear.</td>
<td>Because the switchgear is maintenance-free and climate-independent, access is neither required nor possible.</td>
</tr>
</tbody>
</table>

Table 3.2-9: Accessibility of compartments

The notation IAC A FLR, and contains the abbreviations for the following values:
- IAC: Internal Arc Classification
- A: Distance between the indicators 300 mm, i.e., installation in rooms with access for authorized personnel; closed electrical service location.
- FLR: Access from the front (F), from the sides (L = Lateral) and from the rear (R).
- $I$: Test current = Rated short-circuit breaking current (in kA)
- $t$: Arc duration (in s)

Table 3.2-10: Internal arc classification according to IEC 62271-200
### 3.2.4 Medium-Voltage Switchgear

<table>
<thead>
<tr>
<th>Distribution level</th>
<th>Insulation</th>
<th>Type of construction</th>
<th>Loss of service continuity</th>
<th>Partition class</th>
<th>Internal arc classification*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Gas-insulated</td>
<td>Extendable</td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FLR 31.5 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FLR 25 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FL 25 kA, 1 s **</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FL 25 kA, 1 s ***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FLR 31.5 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FLR 40 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FLR 40 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td>Air-insulated</td>
<td>Extendable</td>
<td>LSC 2B</td>
<td>PM</td>
<td>IAC A FLR 40 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2B</td>
<td>PM</td>
<td>IAC A FLR 50 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2B</td>
<td>PM</td>
<td>IAC A FLR 50 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2A</td>
<td>PM</td>
<td>IAC A FLR 25 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 2B</td>
<td>PM</td>
<td>IAC A FLR 31.5 kA, 1 s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LSC 1</td>
<td>PM</td>
<td>IAC A FL 16 kA, 1 s</td>
</tr>
<tr>
<td>Secondary</td>
<td>Gas-insulated</td>
<td>Non-extendable</td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FL 21 kA, 1 s **</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IAC A FL 21 kA, 1 s ***</td>
</tr>
<tr>
<td></td>
<td>Extendable</td>
<td></td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FL 21 kA, 1 s **</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IAC A FL 21 kA, 1 s ***</td>
</tr>
<tr>
<td></td>
<td>Air-insulated</td>
<td>Extendable</td>
<td>LSC 2</td>
<td>PM</td>
<td>IAC A FLR 21 kA, 1 s</td>
</tr>
</tbody>
</table>

* Maximum possible IAC classification  ** Wall-standig arrangement  *** Free-standig arrangement  **** Depending on HV HRC fuse-link

Table 3.2-11: Overview of Siemens medium-voltage switchgear
<table>
<thead>
<tr>
<th>Switchgear type</th>
<th>Busbar system</th>
<th>Rated voltage (kV)</th>
<th>Rated short-time withstand current (kA)</th>
<th>Rated current, busbar (A)</th>
<th>Rated current, feeder (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NXPLUS C</td>
<td>Single</td>
<td>15 24.0</td>
<td>31.5 25 31.5 25</td>
<td>2,500 2,000</td>
<td>2,500 2,000</td>
</tr>
<tr>
<td>NXPLUS C</td>
<td>Double</td>
<td>24</td>
<td>25 25</td>
<td>2,500 1,250</td>
<td></td>
</tr>
<tr>
<td>NXPLUS C Wind</td>
<td>Single</td>
<td>36</td>
<td>25 20</td>
<td>1,000 630/1,000</td>
<td></td>
</tr>
<tr>
<td>NXPLUS</td>
<td>Single</td>
<td>40.5</td>
<td>31.5 31.5</td>
<td>2,500 2,500</td>
<td></td>
</tr>
<tr>
<td>NXPLUS</td>
<td>Double</td>
<td>36</td>
<td>40 40</td>
<td>2,500 2,500</td>
<td></td>
</tr>
<tr>
<td>8DA10</td>
<td>Single</td>
<td>40.5 40</td>
<td>40 40</td>
<td>5,000 2,500</td>
<td></td>
</tr>
<tr>
<td>8DB10</td>
<td>Double</td>
<td>40.5 40</td>
<td>40 40</td>
<td>5,000 2,500</td>
<td></td>
</tr>
<tr>
<td>NXAIR</td>
<td>Single</td>
<td>17.5 24</td>
<td>40 25</td>
<td>4,000 2,500</td>
<td></td>
</tr>
<tr>
<td>NXAIR</td>
<td>Double</td>
<td>24</td>
<td>25 25</td>
<td>2,500 2,500</td>
<td></td>
</tr>
<tr>
<td>NXAIR P</td>
<td>Single</td>
<td>17.5 24</td>
<td>50 20</td>
<td>4,000 2,500</td>
<td></td>
</tr>
<tr>
<td>NXAIR P</td>
<td>Double</td>
<td>24</td>
<td>50 20</td>
<td>4,000 2,500</td>
<td></td>
</tr>
<tr>
<td>8BT1</td>
<td>Single</td>
<td>24</td>
<td>25 25</td>
<td>2,000 2,000</td>
<td></td>
</tr>
<tr>
<td>8BT2</td>
<td>Single</td>
<td>36</td>
<td>31.5 20</td>
<td>3,150 3,150</td>
<td></td>
</tr>
<tr>
<td>8BT3</td>
<td>Single</td>
<td>36 24</td>
<td>16 20</td>
<td>1,250 1,250</td>
<td></td>
</tr>
<tr>
<td>8DJH Block Type</td>
<td>Single</td>
<td>17.5 24</td>
<td>25 20</td>
<td>630 630</td>
<td></td>
</tr>
<tr>
<td>8DJH Block Type</td>
<td></td>
<td></td>
<td>20 20</td>
<td>630 630</td>
<td>200 ****/250/400/630</td>
</tr>
<tr>
<td>8DJH Single Panel</td>
<td>Single</td>
<td>17.5 24</td>
<td>25 20</td>
<td>630 630</td>
<td>200 ****/250/400/630</td>
</tr>
<tr>
<td>SIMOSEC</td>
<td>Single</td>
<td>17.5 24</td>
<td>25 20</td>
<td>1,250 1,250</td>
<td></td>
</tr>
</tbody>
</table>
### NXAIR ≤ 17.5 kV

**Performance features**

The air-insulated, metal-clad switchgear type NXAIR is an innovation in the switchgear field for the distribution and process level up to 17.5 kV, 40 kA, 4,000 A.

- Design verified, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 40 kA 1 s
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel

#### Table 3.2-12: Technical data of NXAIR

<table>
<thead>
<tr>
<th>Voltage</th>
<th>kV</th>
<th>7.2</th>
<th>12</th>
<th>17.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Hz</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage (phase/phase, phase/earth)</td>
<td>kV</td>
<td>20*</td>
<td>28*</td>
<td>38</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage (phase/phase, phase/earth)</td>
<td>kV</td>
<td>60</td>
<td>75</td>
<td>95</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>max. kA</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s</td>
<td>max. kA</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Short-circuit making current</td>
<td>max. kA</td>
<td>100/104**</td>
<td>100/104**</td>
<td>100/104**</td>
</tr>
<tr>
<td>Peak withstand current</td>
<td>max. kA</td>
<td>100/104**</td>
<td>100/104**</td>
<td>100/104**</td>
</tr>
<tr>
<td>Normal current of the busbar</td>
<td>max. A</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Normal current of the feeders:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit-breaker panel</td>
<td>max. A</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Contactor panel</td>
<td>max. A</td>
<td>400***</td>
<td>400***</td>
<td>400***</td>
</tr>
<tr>
<td>Disconnecting panel</td>
<td>max. A</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Bus sectionalizer</td>
<td>max. A</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Busbar connection panel</td>
<td>max. A</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
</tbody>
</table>

* 32 kV at 7.2 kV and 42 kV at 12 kV optional for GOST standard.
** Values for 50 Hz: 100 kA; for 60 Hz: 104 kA.
*** Current values dependent on HV HRC fuses. Lightning impulse withstand voltage across open contact gap of contactor: 40 kV at 7.2 kV, 60 kV at 12 kV.

#### Dimensions

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width W</td>
<td></td>
</tr>
<tr>
<td>Circuit-breaker panel ≤ 1,000 A</td>
<td>600*</td>
</tr>
<tr>
<td>1,250 A</td>
<td>800</td>
</tr>
<tr>
<td>2,500 A / 3,150 A / 4,000 A</td>
<td>1,000</td>
</tr>
<tr>
<td>Contactor panel</td>
<td>≤ 400 A</td>
</tr>
<tr>
<td>1,250 A</td>
<td>435</td>
</tr>
<tr>
<td>Disconnecting panel</td>
<td>1,250 A</td>
</tr>
<tr>
<td>2,500 A / 3,150 A / 4,000 A</td>
<td>800</td>
</tr>
<tr>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>Bus sectionalizer</td>
<td>1,250 A</td>
</tr>
<tr>
<td>2,500 A / 3,150 A / 4,000 A</td>
<td>2 x 800</td>
</tr>
<tr>
<td>2 x 1,000</td>
<td></td>
</tr>
<tr>
<td>Metering panel</td>
<td>800</td>
</tr>
<tr>
<td>Busbar connection panel</td>
<td>≤ 4,000 A</td>
</tr>
<tr>
<td>800/1,000</td>
<td></td>
</tr>
<tr>
<td>Height H1</td>
<td>With standard low-voltage compartment, natural ventilation</td>
</tr>
<tr>
<td>Height H2</td>
<td>With high low-voltage compartment or additional compartment for busbar components</td>
</tr>
<tr>
<td>Height H3</td>
<td>With forced ventilation for 4,000 A</td>
</tr>
<tr>
<td>Height H4</td>
<td>With optional internal arc absorber</td>
</tr>
<tr>
<td>Depth D</td>
<td>Single busbar, all panel types ≤ 31.5 kA (except contactor panel)</td>
</tr>
<tr>
<td>40 kA</td>
<td>1,500</td>
</tr>
<tr>
<td>Contactor panel</td>
<td>≤ 40 kA</td>
</tr>
<tr>
<td>1,400* / 1,500</td>
<td></td>
</tr>
</tbody>
</table>

* ≤ 31.5 kA
** ≤ 32 kV at 7.2 kV and 42 kV at 12 kV optional for GOST standard.
*** Values for 50 Hz: 100 kA; for 60 Hz: 104 kA.

**Fig. 3.2-6: Dimensions of NXAIR**

- Insulating medium air is always available
- Single busbar, double busbar (back-to-back, face-to-face)
- Withdrawable vacuum circuit-breaker
- Withdrawable vacuum contactor
- Platform concept worldwide, local manufacturing presence
- Use of standardized devices
- Maximum security of operation by self-explaining operating logic
- Maintenance interval ≥ 10 years
NXAIR, 24 kV

Performance features
The air-insulated, metal-clad switchgear type NXAIR, 24 kV is the resulting further development of the NXAIR family for use in the distribution and process level up to 24 kV, 25 kA, 2,500 A.
- Design verified, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 25 kA 1s
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel
- Single busbar, double busbar (back-to-back, face-to-face)
- Insulating medium air is always available
- Withdrawable vacuum circuit-breaker
- Platform concept worldwide, local manufacturing presence
- Use of standardized devices
- Maximum security of operation by self-explaining operating logic
- Maintenance interval ≥ 10 years

### Rated

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>24 kV</td>
</tr>
<tr>
<td>Frequency</td>
<td>50/60 Hz</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage (phase/phase, phase/earth)</td>
<td>kV 50 *</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage (phase/phase, phase/earth)</td>
<td>kV 125</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>max. kA 25</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s</td>
<td>max. kA 25</td>
</tr>
<tr>
<td>Short-circuit making current</td>
<td>max. kA 63/65 **</td>
</tr>
<tr>
<td>Peak withstand current</td>
<td>max. kA 63/65 **</td>
</tr>
<tr>
<td>Normal current of busbar</td>
<td>max. A 2,500</td>
</tr>
<tr>
<td>Normal current of feeders:</td>
<td></td>
</tr>
<tr>
<td>Circuit-breaker panel</td>
<td>max. A 2,500</td>
</tr>
<tr>
<td>Disconnecting panel</td>
<td>max. A 2,500</td>
</tr>
<tr>
<td>Bus sectionalizer</td>
<td>max. A 2,500</td>
</tr>
</tbody>
</table>

* 65 kV optional for GOST standard  ** Values for 50 Hz: 63 kA; for 60 Hz: 65 kA.

### Technical data of NXAIR, 24 kV

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Voltage kV</td>
<td>24</td>
</tr>
<tr>
<td>Rated Frequency Hz</td>
<td>50/60</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage (phase/phase, phase/earth) kV</td>
<td>50 *</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage (phase/phase, phase/earth) kV</td>
<td>125</td>
</tr>
<tr>
<td>Short-circuit breaking current max. kA</td>
<td>25</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s max. kA</td>
<td>25</td>
</tr>
<tr>
<td>Short-circuit making current max. kA</td>
<td>63/65 **</td>
</tr>
<tr>
<td>Peak withstand current max. kA</td>
<td>63/65 **</td>
</tr>
<tr>
<td>Normal current of busbar max. A</td>
<td>2,500</td>
</tr>
<tr>
<td>Normal current of feeders:</td>
<td></td>
</tr>
<tr>
<td>Circuit-breaker panel max. A</td>
<td>2,500</td>
</tr>
<tr>
<td>Disconnecting panel max. A</td>
<td>2,500</td>
</tr>
<tr>
<td>Bus sectionalizer max. A</td>
<td>2,500</td>
</tr>
</tbody>
</table>

* 65 kV optional for GOST standard  ** Values for 50 Hz: 63 kA; for 60 Hz: 65 kA.

### Dimensions

<table>
<thead>
<tr>
<th>Width W</th>
<th>Circuit-breaker panel ≤ 1,250 A 2,500 A</th>
<th>800 1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disconnecting panel ≤ 1,250 A 2,500 A</td>
<td>800 1,000</td>
</tr>
<tr>
<td></td>
<td>Bus sectionalizer ≤ 1,250 A 1,600 A / 2,000 A / 2,500 A 2 × 800 2 × 1,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metering panel</td>
<td>800</td>
</tr>
<tr>
<td>Height H1</td>
<td>With standard low-voltage compartment</td>
<td>2,510</td>
</tr>
<tr>
<td>Height H2</td>
<td>With high low-voltage compartment</td>
<td>2,550</td>
</tr>
<tr>
<td>Height H3</td>
<td>With natural ventilation</td>
<td>2,680</td>
</tr>
<tr>
<td>Height H4</td>
<td>With optional internal arc absorber</td>
<td>2,750</td>
</tr>
<tr>
<td>Height H5</td>
<td>With additional compartment for busbar components</td>
<td>2,770</td>
</tr>
<tr>
<td>Depth D</td>
<td>Single busbar</td>
<td>1,600</td>
</tr>
</tbody>
</table>

Fig. 3.2-8: Dimensions of NXAIR, 24 kV
Switchgear and Substations

3.2 Medium-Voltage Switchgear

**NXAIR P**

<table>
<thead>
<tr>
<th>Rated</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage</strong></td>
<td>kV</td>
</tr>
<tr>
<td></td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>17.5</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>Hz</td>
</tr>
<tr>
<td></td>
<td>50/60</td>
</tr>
<tr>
<td></td>
<td>50/60</td>
</tr>
<tr>
<td><strong>Short-duration power-frequency withstand voltage (phase/phase, phase/earthing)</strong></td>
<td>kV</td>
</tr>
<tr>
<td></td>
<td>20*</td>
</tr>
<tr>
<td></td>
<td>28*</td>
</tr>
<tr>
<td></td>
<td>38</td>
</tr>
<tr>
<td><strong>Lightning impulse withstand voltage (phase/phase, phase/earthing)</strong></td>
<td>kV</td>
</tr>
<tr>
<td></td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>95</td>
</tr>
<tr>
<td><strong>Short-circuit breaking current</strong></td>
<td>max. kA</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td><strong>Short-time withstand current, 3 s</strong></td>
<td>max. kA</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td><strong>Short-circuit making current</strong></td>
<td>max. kA</td>
</tr>
<tr>
<td></td>
<td>125/130**</td>
</tr>
<tr>
<td></td>
<td>125/130**</td>
</tr>
<tr>
<td></td>
<td>125/130**</td>
</tr>
<tr>
<td><strong>Peak withstand current</strong></td>
<td>max. kA</td>
</tr>
<tr>
<td></td>
<td>125/130**</td>
</tr>
<tr>
<td></td>
<td>125/130**</td>
</tr>
<tr>
<td></td>
<td>125/130**</td>
</tr>
<tr>
<td><strong>Normal current of busbar</strong></td>
<td>max. A</td>
</tr>
<tr>
<td></td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>4,000</td>
</tr>
<tr>
<td><strong>Normal current of feeders:</strong></td>
<td>max. A</td>
</tr>
<tr>
<td>Circuit-breaker panel</td>
<td>4,000</td>
</tr>
<tr>
<td>Contactor panel</td>
<td>400***</td>
</tr>
<tr>
<td>Disconnecting panel</td>
<td>4,000</td>
</tr>
<tr>
<td>Bus sectionalizer</td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>4,000</td>
</tr>
</tbody>
</table>

* 32 kV at 7.2 kV and 42 kV at 12 kV optional for GOST standard.
** Values for 50 Hz: 125 kA; for 60 Hz: 130 kA, make-proof earthing switch for 17.5 kV up to 100 kA.
*** Dependent on rated current of HV HRC fuses used; dielectric strength of contactor panel: 20 kV short-duration power-frequency withstand voltage phase-to-phase, phase-to-earth, open contact gap, or 60 kV lightning impulse withstand voltage phase-to-phase, phase-to-earth, 40 kV open contact gap of the contactor.

**Performance features**
The air-insulated, metal-clad switchgear type NXAIR P is based on the construction principles of the NXAIR family and designed for use in the distribution and process level up to 17.5 kV, 50 kA, 4,000 A.
- Design verified, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 50 kA 1 s
- Insulating medium air is always available
- Single busbar, double busbar (back-to-back, face-to-face)
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earth switches inside the panel
- Withdrawable vacuum circuit-breaker
- Withdrawable vacuum contactor
- Maximum availability due to modular design
- Maximum security of operation by self-explaining operating logic
- Maintenance interval ≥ 10 years

---

**Table 3.2-14: Technical data of NXAIR P**

**Dimensions**

<table>
<thead>
<tr>
<th>Components</th>
<th>Width W</th>
<th>Height H1</th>
<th>Height H2</th>
<th>Height H3</th>
<th>Height H4</th>
<th>Depth D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit-breaker panel</td>
<td>≤ 2,000 A</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
<td>1,635</td>
</tr>
<tr>
<td></td>
<td>&gt; 2,000 A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contactor panel</td>
<td>≤ 400 A</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td>1,650</td>
</tr>
<tr>
<td>Disconnecting panel</td>
<td>≤ 2,000 A</td>
<td>800</td>
<td>1,000</td>
<td></td>
<td></td>
<td>2 × 800</td>
</tr>
<tr>
<td></td>
<td>&gt; 2,000 A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 × 1,000</td>
</tr>
<tr>
<td>Bus sectionalizer</td>
<td>≤ 2,000 A</td>
<td>2 × 800</td>
<td>2 × 1,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 2,000 A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metering panel</td>
<td></td>
<td>800</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With standard low-voltage compartment (≤ 3150 A)</td>
<td>2,225</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With high-low-voltage compartment</td>
<td>2,485</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With top-mounted pressure relief duct</td>
<td>2,550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>as standard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With forced ventilation (4000 A)</td>
<td>2,710</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single busbar (except contactor panel)</td>
<td>1,635</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contactor panel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,650</td>
</tr>
<tr>
<td>Double busbar in back-to-back arrangement (except contactor panel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,320</td>
</tr>
</tbody>
</table>

**Fig. 3.2-9: NXAIR P panel**

**Fig. 3.2-10: Dimensions of NXAIR P**
8BT1

**Performance features**
The air-insulated, cubicle-type switchgear type 8BT1 is a factory-assembled, design verified indoor switchgear for lower ratings in the distribution and process level up to 24 kV, 25 kA, 2,000 A.
- **Design verified, IEC 62271-200, cubicle-type, loss of service continuity category: LSC 2A; partition class: PM; internal arc classification: IAC A FLR ≤ 25 kA 1 s**
- **Insulating medium air is always available**
- **Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel**
- **Single busbar**
- **Withdrawable vacuum circuit-breaker**
- **All switching operations with door closed**

<table>
<thead>
<tr>
<th>Rated</th>
<th></th>
<th>12</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>kV</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hz</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage (phase/phase, phase/earth)</td>
<td>kV</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage (phase/phase, phase/earth)</td>
<td>kV</td>
<td>75</td>
<td>125</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>max. kA</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s</td>
<td>max. kA</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Short-circuit making current</td>
<td>max. kA</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Peak withstand current</td>
<td>max. kA</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Normal current of the busbar</td>
<td>max. A</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Normal current of the feeders with circuit-breaker</td>
<td>max. A</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>with switch-disconnector</td>
<td>max. A</td>
<td>630</td>
<td>630</td>
</tr>
<tr>
<td>with switch-disconnector and fuses</td>
<td>max. A</td>
<td>200 A*</td>
<td>200 A*</td>
</tr>
</tbody>
</table>

* Depending on rated current of the HV HRC fuses used.

Table 3.2-16: Technical data of 8BT1

**All panel types**

| Dimensions in mm |
|---|---|---|
| **W** | For circuit-breaker max. 1,250 A | 600 |
| For circuit-breaker 2,000 A | 800 |
| For switch-disconnector | 600 |
| **H1** | With standard low-voltage compartment | 2,050 |
| **H2** | With pressure relief system | 2,300* |
| **H3** | With lead-off duct | 2,350* |
| **D1** | Without low-voltage compartment | 1,200 |
| **D2** | With low-voltage compartment | 1,410 |

| 24 kV |

| Dimensions in mm |
|---|---|---|
| **W** | For circuit-breaker max. 1,250 A | 800 |
| For circuit-breaker 2,000 A | 1,000 |
| For switch-disconnector | 800 |
| **H1** | With standard low-voltage compartment | 2,050 |
| **H2** | With pressure relief system | 2,300* |
| **H3** | With lead-off duct | 2,350* |
| **D1** | Without low-voltage compartment | 1,200 |
| **D2** | With low-voltage compartment | 1,410 |

* For 1 s arc duration.
3.2 Medium-Voltage Switchgear

**8BT2**

**Performance features**
The air-insulated, metal-clad switchgear type 8BT2 is a factory-assembled, design verified indoor switchgear for use in the distribution and process level up to 36 kV, 31.5 kA, 3,150 A.
- Design verified, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 31.5 kA 1 s
- Insulating medium air is always available
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel
- Single busbar
- Withdrawable vacuum circuit-breaker
- All switching operations with door closed

**Rated**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage</strong></td>
<td>36 kV</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>50/60 Hz</td>
</tr>
<tr>
<td><strong>Short-duration power-frequency withstand voltage</strong> (phase/phase, phase/earth)</td>
<td>70 kV</td>
</tr>
<tr>
<td><strong>Lightning impulse withstand voltage</strong> (phase/phase, phase/earth)</td>
<td>170 kV</td>
</tr>
<tr>
<td><strong>Short-circuit breaking current</strong></td>
<td>max. 31.5 kA</td>
</tr>
<tr>
<td><strong>Short-time withstand current, 3 s</strong></td>
<td>max. 31.5 kA</td>
</tr>
<tr>
<td><strong>Short-circuit making current</strong></td>
<td>max. 80/82* kA</td>
</tr>
<tr>
<td><strong>Peak withstand current</strong></td>
<td>max. 80/82* kA</td>
</tr>
<tr>
<td><strong>Normal current of the busbar</strong></td>
<td>max. 3,150 A</td>
</tr>
<tr>
<td><strong>Normal current of the feeders with circuit-breaker</strong></td>
<td>max. 3,150 A</td>
</tr>
</tbody>
</table>

* Values for 50 Hz: 80 kA; for 60 Hz: 82 kA.

**Dimensions**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width W</td>
<td>≤ 3,150 A feeder current</td>
</tr>
<tr>
<td>Height H1 Intermediate panel</td>
<td>2,400</td>
</tr>
<tr>
<td>Height H2 End panel with side baffles</td>
<td>2,750/2,775*</td>
</tr>
<tr>
<td>Height H3 Panel with closed duct</td>
<td>2,900**</td>
</tr>
<tr>
<td>Depth D</td>
<td>Wall-standing, IAC A FL</td>
</tr>
<tr>
<td></td>
<td>Free-standing, IAC A FLR</td>
</tr>
</tbody>
</table>

* H2 indicates side baffles for internal arc protection
** Closed duct for IAC-classification A FLR

**Fig. 3.2-15: 8BT2 switchgear**

**Table 3.2-17: Technical data of 8BT2**

**Fig. 3.2-16: Dimensions of 8BT2**
8BT3

Performance features
The air-insulated, cubicle-type switchgear type 8BT3 is a factory-assembled, design verified indoor switchgear for lower ratings in the distribution and process level up to 36 kV, 16 kA, 1,250 A.
- Design verified, IEC 62271-200, cubicle-type, loss of service continuity category: LSC 1; internal arc classification: IAC A FL ≤ 16 kA 1 s
- Insulating medium air is always available
- Make-proof earthing switch
- Single busbar
- Withdrawable vacuum circuit-breaker
- All switching operations with door closed

Table 3.2-18: Technical data of 8BT3

<table>
<thead>
<tr>
<th>Rated</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>kV 36</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hz 50/60</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage (phase/phase, phase/earth)</td>
<td>kV 70</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage (phase/phase, phase/earth)</td>
<td>kV 170</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>max. kA 16</td>
</tr>
<tr>
<td>Short-time withstand current, 1 s</td>
<td>max. kA 16</td>
</tr>
<tr>
<td>Short-circuit making current</td>
<td>max. kA 40/42*</td>
</tr>
<tr>
<td>Peak withstand current</td>
<td>max. kA 40/42*</td>
</tr>
<tr>
<td>Normal current of the busbar</td>
<td>max. A 1,250</td>
</tr>
<tr>
<td>Normal current of the feeders with circuit-breaker</td>
<td>max. A 1,250</td>
</tr>
<tr>
<td>Normal current of the feeders with switch-disconnector and fuses</td>
<td>max. A 630</td>
</tr>
<tr>
<td></td>
<td>max. A 100**</td>
</tr>
</tbody>
</table>

* Values for 50 Hz: 40 kA; for 60 Hz: 42 kA
** Depending on the rated current of the HV HRC fuses used.

Fig. 3.2-17: 8BT3 switchgear

Fig. 3.2-18: Dimensions of 8BT3
8DA/8DB are gas-insulated medium-voltage circuit-breaker switchgear assemblies up to 40.5 kV with the advantages of the vacuum switching technology – for a high degree of independence in all applications. 8DA/8DB are suitable for primary distribution systems up to 40.5 kV, 40 kA, up to 5,000 A.

Performance features
- Design verified according to IEC 62271-200
- Enclosure with modular standardized housings made from corrosion-resistant aluminum alloy
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Operating mechanisms and transformers are easily accessible outside the enclosure
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2
- Internal arc classification: IAC A FLR 40 kA 1 s

### Rated

<table>
<thead>
<tr>
<th></th>
<th>12</th>
<th>24</th>
<th>36</th>
<th>40.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (kV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage (kV)</td>
<td>28</td>
<td>50</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage (kV)</td>
<td>75</td>
<td>125</td>
<td>170</td>
<td>185</td>
</tr>
<tr>
<td>Short-circuit breaking current (max. kA)</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s (max. kA)</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Short-circuit making current (max. kA)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Peak withstand current (max. kA)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Normal current of the busbar (max. A)</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Normal current of the feeders (max. A)</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
</tr>
</tbody>
</table>

Table 3.2-19: Technical data of 8DA/8DB

### Dimensions

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (spacing) W</td>
<td>600</td>
</tr>
<tr>
<td>Height H</td>
<td>Standard design Design with higher low-voltage compartment 2,350 2,700</td>
</tr>
<tr>
<td>Depth D1</td>
<td>Single-busbar switchgear 1,625</td>
</tr>
<tr>
<td></td>
<td>Double-busbar switchgear 2,665</td>
</tr>
</tbody>
</table>

Fig. 3.2-20: Dimensions of 8DA/8DB

### Advantages
- Independent of the environment and climate
- Compact
- Maintenance-free
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient
The gas-insulated medium-voltage switchgear type 8DJH is used for power distribution in secondary distribution systems up to 24 kV. Ring-main feeders, circuit-breaker feeders and transformer feeders are all part of a comprehensive product range to satisfy all requirements with the highest level of operational reliability – also for extreme ambient conditions.

**Performance features**
- Design verified according to IEC 62271-200
- Sealed pressure system with SF6 filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- 3-pole, gas-insulated switchgear vessel for switching devices and busbar
- Panel blocks and single panels available
- Switching devices: three-position load-break switch (ON – OFF – EARTH), switch-fuse combination for distribution transformer protection, vacuum circuit-breaker with three-position disconnector, earthing switch
- Earthing function of switching devices generally make-proof

### Rated

<table>
<thead>
<tr>
<th></th>
<th>7.2</th>
<th>12</th>
<th>15</th>
<th>17.5</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage</strong></td>
<td>kV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>Hz</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
</tr>
<tr>
<td><strong>Short-duration power-frequency withstand voltage</strong></td>
<td>kV</td>
<td>20</td>
<td>28*</td>
<td>36</td>
<td>38</td>
</tr>
<tr>
<td><strong>Lightning impulse withstand voltage</strong></td>
<td>kV</td>
<td>60</td>
<td>75</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td><strong>Normal current for ring-main feeders</strong></td>
<td>A</td>
<td>400 or 630</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Normal current for busbar</strong></td>
<td>max. A</td>
<td>630</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Normal current for circuit-breaker feeders</strong></td>
<td>A</td>
<td>250 or 630</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Normal current for transformer feeders</strong></td>
<td>A</td>
<td>200**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Short-time withstand current, 1 s</strong></td>
<td>max. kA</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td><strong>Short-time withstand current, 3 s</strong></td>
<td>max. kA</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td><strong>Peak withstand current</strong></td>
<td>max. kA</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td><strong>Short-circuit making current</strong> for ring-main feeders</td>
<td>max. kA</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td><strong>for circuit-breaker feeders</strong></td>
<td>max. kA</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td><strong>for transformer feeders</strong></td>
<td>max. kA</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td><strong>Short-time withstand current, 1 s</strong></td>
<td>max. kA</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td><strong>Short-time withstand current, 3 s</strong></td>
<td>max. kA</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td><strong>Peak withstand current</strong></td>
<td>max. kA</td>
<td>55</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td><strong>Short-circuit making current</strong> for ring-main feeders</td>
<td>max. kA</td>
<td>55</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td><strong>for circuit-breaker feeders</strong></td>
<td>max. kA</td>
<td>55</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td><strong>for transformer feeders</strong></td>
<td>max. kA</td>
<td>55</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
</tbody>
</table>

* 42 kV according to some national requirements
** Depending on HV HRC fuse-link

### Table 3.2-20: Technical data of 8DJH

### Dimensions

<table>
<thead>
<tr>
<th>Dimensions in mm</th>
<th>Width W</th>
<th>Number of feeders (in extracts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2 feeders (e.g., RR)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 feeders (e.g., RRT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 feeders (e.g., 3R + 1T)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panels without low-voltage compartment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panels with low-voltage compartment (option)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switchgear with pressure absorber (option)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard switchgear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switchgear with pressure absorber (option)</td>
</tr>
<tr>
<td></td>
<td>620</td>
<td>1,050</td>
</tr>
<tr>
<td></td>
<td>1,050</td>
<td>1,360</td>
</tr>
<tr>
<td></td>
<td>1,200/1,400/1,700</td>
<td>1,400–2,600</td>
</tr>
<tr>
<td></td>
<td>1,800–2,600</td>
<td>775</td>
</tr>
<tr>
<td></td>
<td>890</td>
<td></td>
</tr>
</tbody>
</table>
Switchgear and Substations

3.2 Medium-Voltage Switchgear

8DJH

![8DJH single panel](image)

**Advantages**
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2
- Internal arc classification (option):
  - IAC A FL 21 kA, 1 s
  - IAC A FLR 21 kA, 1 s

**Dimensions**

<table>
<thead>
<tr>
<th>Width (W)</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring-main feeders</td>
<td>310/500</td>
</tr>
<tr>
<td>Transformer feeders</td>
<td>430</td>
</tr>
<tr>
<td>Circuit-breaker feeders</td>
<td>430/500</td>
</tr>
<tr>
<td>Bus sectionalizer panels</td>
<td>430/620</td>
</tr>
<tr>
<td>Busbar metering panels</td>
<td>430/500</td>
</tr>
<tr>
<td>Billing metering panels</td>
<td>840</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Height (H1)</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panels without low-voltage compartment</td>
<td>1,200/1,400/1,700</td>
</tr>
<tr>
<td>Panels with low-voltage compartment</td>
<td>1,400–2,600</td>
</tr>
<tr>
<td>Switchgear with pressure absorber (option)</td>
<td>1,800–2,600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (D)</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard switchgear</td>
<td>775</td>
</tr>
<tr>
<td>Switchgear with pressure absorber (option)</td>
<td>890</td>
</tr>
</tbody>
</table>

**Typical uses**
8DJH switchgear is used for power distribution in secondary distribution systems, such as

- Public energy distribution
  - Transformer substations
  - Customer transfer substations
  - High-rise buildings
- Infrastructure facilities
  - Airports & ports
  - Railway & underground railway stations
  - Water & wastewater treatment
- Industrial plants
  - Automotive industry
  - Chemical industry
  - Open-cast mines
- Renewable power generation
  - Wind power stations
  - Solar power plants
  - Biomass power stations

*Fig. 3.2-23: 8DJH single panel*

*Fig. 3.2-24: Dimensions of 8DJH single panels*
NXPLUS is a gas-insulated medium-voltage circuit-breaker switchgear up to 40.5 kV with the advantages of the vacuum switching technology – for a high degree of independence in all applications. NXPLUS can be used for primary distribution systems up to 40.5 kV, up to 31.5 kA, up to 2,000 A (for double-busbar switchgear up to 2,500 A).

**Performance features**
- Design verified according to IEC 62271-200
- Sealed pressure system with SF₆ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Separate 3-pole gas-insulated modules for busbar with three-position disconnector, and for circuit-breaker
- Interconnection of modules with 1-pole insulated and screened module couplings
- Operating mechanisms and transformers are arranged outside the switchgear vessels and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2

**Advantages**
- Internal arc classification: IAC A FLR 31.5 kA, 1 s
- No gas work during installation or extension
- Independent of the environment and climate
- Compact
- Maintenance-free
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

### Table 3.2-22: Technical data of NXPLUS

<table>
<thead>
<tr>
<th>Rated</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>kV</td>
<td>12</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage</td>
<td>kV</td>
<td>28</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage</td>
<td>kV</td>
<td>75</td>
<td>125</td>
<td>170</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>max. kA</td>
<td>31.5</td>
<td>31.5</td>
<td>31.5</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s</td>
<td>max. kA</td>
<td>31.5</td>
<td>31.5</td>
<td>31.5</td>
</tr>
<tr>
<td>Short-circuit making current</td>
<td>max. kA</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Peak withstand current</td>
<td>max. kA</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Normal current of the busbar</td>
<td>max. A</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
</tr>
<tr>
<td>Normal current of the feeders</td>
<td>max. A</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
</tr>
</tbody>
</table>

**Dimensions**

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (spacing)</td>
<td>W</td>
</tr>
<tr>
<td>Height</td>
<td>H1</td>
</tr>
<tr>
<td>Depth</td>
<td>D1</td>
</tr>
</tbody>
</table>

**Fig. 3.2-26: Dimensions of NXPLUS**

**Fig. 3.2-25: NXPLUS switchgear for single-busbar applications (on the left), NXPLUS switchgear for double-busbar applications (on the right)**
NXPLUS C

Fig. 3.2-27: NXPLUS C panel

The compact NXPLUS C is the medium-voltage circuit-breaker switchgear that made gas insulation with the proven vacuum switching technology economical in its class. The NXPLUS C is used for secondary and primary distribution systems up to 24 kV, up to 31.5 kA and up to 2,500 A. It can also be supplied as double-busbar switchgear in a back-to-back arrangement (see catalog HA35.41).

Performance features
• Design verified according to IEC 62271-200
• Sealed pressure system with SF₆ filling for the entire service life
• Safe-to-touch enclosure and standardized connections for plug-in cable terminations
• Loss of service continuity category for switchgear:
  – Without HV HRC fuses: LSC 2
• 1-pole insulated and screened busbar
• 3-pole gas-insulated switchgear vessels with three-position switch and circuit-breaker
• Operating mechanisms and transformers are located outside the switchgear vessel and are easily accessible
• Metal-enclosed, partition class PM

Table 3.2-23: Technical data of NXPLUS C

<table>
<thead>
<tr>
<th>Rated</th>
<th>Voltage kV</th>
<th>7.2</th>
<th>12</th>
<th>15</th>
<th>17.5</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Hz</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td></td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage kV</td>
<td>20</td>
<td>28*</td>
<td>36</td>
<td>38</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Lightning impulse withstand voltage kV</td>
<td>60</td>
<td>75</td>
<td>95</td>
<td>95</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Short-circuit breaking current max. kA</td>
<td>31.5</td>
<td>31.5</td>
<td>31.5</td>
<td>25</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Short-time withstand current, 3 s max. kA</td>
<td>31.5</td>
<td>31.5</td>
<td>31.5</td>
<td>25</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Short-circuit making current max. kA</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>63</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Peak withstand current max. kA</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>63</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Normal current of the busbar max. A</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td></td>
</tr>
<tr>
<td>Normal current of the feeders max. A</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>2,000</td>
<td>2,000</td>
<td></td>
</tr>
</tbody>
</table>

* 42 kV according to some national requirements

Table 3.2-24: Technical data of NXPLUS C

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width W</td>
<td>630 A/1,000 A/1,250 A</td>
</tr>
<tr>
<td></td>
<td>2,000 A/2,500 A</td>
</tr>
<tr>
<td>Height H1</td>
<td>Standard design</td>
</tr>
<tr>
<td></td>
<td>With horizontal pressure relief duct</td>
</tr>
<tr>
<td>H2</td>
<td>For higher low-voltage compartment</td>
</tr>
<tr>
<td>H3</td>
<td>Wall-standing arrangement</td>
</tr>
<tr>
<td></td>
<td>Free-standing arrangement</td>
</tr>
<tr>
<td>Depth D</td>
<td>1,250</td>
</tr>
<tr>
<td>Wall-standing arrangement</td>
<td>1,250</td>
</tr>
<tr>
<td>Free-standing arrangement</td>
<td>1,250</td>
</tr>
</tbody>
</table>

Advantages
• No gas work during installation or extension
• Compact
• Independent of the environment and climate
• Maintenance-free
• Personal safety
• Operational reliability
• Environmentally compatible
• Cost-efficient
NXPLUS C Wind

The compact medium voltage circuit-breaker switchgear NXPLUS C Wind is especially designed for wind turbines. Due to the small dimensions it fits into wind turbines where limited space is available. The NXPLUS C Wind is available for 36 kV, up to 25 kA and busbar currents up to 1,000 A. NXPLUS C Wind offers a circuit-breaker, a disconnector and a switch-disconnector (ring-main) panel.

Performance features
- Design verified according to IEC 62271-200
- Sealed pressure system with SF₆ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- 1-pole insulated and screened busbar
- 3-pole gas-insulated switchgear vessels with three-position switch and circuit-breaker
- Operating mechanism and transformers are located outside the vessel and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category LSC 2B
- Internal arc classification for:
  - Wall-standing arrangement: IAC FL A 25 kA, 1 s
  - Free-standing arrangement: IAC FLR A 25 kA, 1 s

Advantages
- No gas work during installation or extension
- Compact
- Independent of the environment and climate
- Maintenance-free
- Personal Safety
- Operational reliability
- Environmentally compatible
- Cost efficient

Fig. 3.2-29: NXPLUS C Wind

<table>
<thead>
<tr>
<th>Rated</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>kV</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hz</td>
</tr>
<tr>
<td>Short-time power-frequency withstand voltage</td>
<td>kV</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage</td>
<td>kV</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>max. kA</td>
</tr>
<tr>
<td>Short-time withstand current, 1 s</td>
<td>max. kA</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s</td>
<td>max. kA</td>
</tr>
<tr>
<td>Short-circuit making current</td>
<td>max. kA</td>
</tr>
<tr>
<td>Peak withstand current</td>
<td>max. kA</td>
</tr>
<tr>
<td>Normal current of the busbar</td>
<td>max. A</td>
</tr>
<tr>
<td>Normal current of the circuit-breaker panel</td>
<td>max. A</td>
</tr>
<tr>
<td>Normal current of the disconnector panel</td>
<td>max. A</td>
</tr>
</tbody>
</table>

Table 3.2-24: Technical data of NXPLUS C Wind

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width W</td>
<td>Circuit-breaker panel Disconnector, switch-disconnector panel</td>
</tr>
<tr>
<td>Height H</td>
<td>600 450</td>
</tr>
<tr>
<td>Depth D</td>
<td>1,900</td>
</tr>
</tbody>
</table>

Fig. 3.2-30: Dimensions of NXPLUS C Wind
SIMOSEC

The air-insulated medium-voltage switchgear type SIMOSEC is used for power distribution in secondary and primary distribution systems up to 24 kV and up to 1,250 A. The modular product range includes individual panels such as ring-main, transformer and circuit-breaker panels or metering panels to fully satisfy all requirements for power supply companies and industrial applications.

Performance features
- Design verified according to IEC 62271-200
- Phases for busbar and cable connection are arranged one behind the other
- 3-pole gas-insulated switchgear vessel with three-position disconnector, circuit-breaker and earthing switch as a sealed pressure system with SF₆ filling for the entire service life
- Air-insulated busbar system
- Air-insulated cable connection system, for conventional cable sealing ends
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2

Table 3.2-25: Technical data of SIMOSEC

<table>
<thead>
<tr>
<th>Rated</th>
<th>Voltage</th>
<th>7.2 kV</th>
<th>12 kV</th>
<th>15 kV o.r.</th>
<th>17.5 kV</th>
<th>24 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Hz</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
<td>50/60</td>
</tr>
<tr>
<td>Short-duration power-frequency withstand voltage</td>
<td>kV</td>
<td>20</td>
<td>28*</td>
<td>36</td>
<td>38</td>
<td>50</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage</td>
<td>kV</td>
<td>60</td>
<td>75</td>
<td>95</td>
<td>95</td>
<td>125</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>max. kA</td>
<td>25</td>
<td>75</td>
<td>95</td>
<td>95</td>
<td>125</td>
</tr>
<tr>
<td>Short-time withstand current, 1 s</td>
<td>max. kA</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Short-time withstand current, 3 s</td>
<td>max. kA</td>
<td>–</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>Short-circuit making current</td>
<td>max. kA</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Peak withstand current</td>
<td>max. kA</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>50</td>
</tr>
<tr>
<td>Normal current of the busbar</td>
<td>A</td>
<td>630 or 1,250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal current of the feeders</td>
<td>max. A</td>
<td>1,250</td>
<td>1,250</td>
<td>1,250</td>
<td>1,250</td>
<td>1,250</td>
</tr>
</tbody>
</table>

* 42 kV/75 kV, according to some national requirements

Advantages
- Compact modular design
- High operating and personal safety
- Environmentally compatible
- Cost-efficient
3.2.5 High-Current and Generator Switchgear

As central components, high-current and generator switchgear provides the link between the generator and the transformer (feeding into the transmission and distribution networks). Siemens offers various generator switchgear types with rated voltages up to 17.5 kV, rated currents up to 10,000 A and rated short-circuit breaking currents up to 72 kA for indoor and outdoor installations.

The heart of the generator switchgear is the circuit-breaker. Its primary function is to withstand very high currents and to switch off extremely high short-circuit currents. Siemens generator circuit-breakers, designed using environmentally friendly vacuum switching technology, are designed to withstand maximum normal currents and meet the demanding requirements of the generator circuit-breaker standard IEEE C37.013-1997.

*Performance features*
- High mechanical stability
- Low fire load
- High operational safety

**HIGS (highly integrated generator switchgear)**

HIGS is an air-insulated, metal-enclosed generator switchgear for voltages and currents up to 13.8 kV, 63 kA, 3,150 A for indoor and outdoor installation. For the first time, the neutral treatment of the generator as well as the auxiliary feeder are integrated in a single generator switchgear (fig. 3.2-33).

*Performance features*
- Generator circuit-breaker according to IEEE C37.013 in the main transformer feeder
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors
- Integrated auxiliary feeder with disconnector and generator circuit-breaker or with switch-disconnector and fuses

The technical data of HIGS and generator switchgear is shown in the table 3.2-26.

---

<table>
<thead>
<tr>
<th>Type</th>
<th>HIGS</th>
<th>8BK40</th>
<th>HB1</th>
<th>HB1 Outdoor</th>
<th>HB3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation</td>
<td>IR, FL</td>
<td>IR</td>
<td>IR</td>
<td>FL</td>
<td>IR, FL</td>
</tr>
<tr>
<td>Dimensions L x W x H mm</td>
<td>3,430 x 1,200 x 2,500</td>
<td>2,300 x 1,100 x 2,500</td>
<td>4,000 x 1,900 x 2,500*</td>
<td>6,300 x 1,900 x 2,600*</td>
<td>2,900 x 4,040 x 2,400*</td>
</tr>
<tr>
<td>Rated voltage kV</td>
<td>13.8</td>
<td>max. 17.5</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage kV</td>
<td>110</td>
<td>95</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Rated short-duration power-frequency withstand voltage kV</td>
<td>50</td>
<td>38</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Rated short-circuit-breaking current kA</td>
<td>31.5 – 63</td>
<td>50/63</td>
<td>50/63/72</td>
<td>50/63/72</td>
<td>50/63/72</td>
</tr>
<tr>
<td>Rated normal current:</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of the busbar A</td>
<td>2,000 – 3,150</td>
<td></td>
<td>max. 6,100</td>
<td>max. 5,400</td>
<td>max 10,000</td>
</tr>
<tr>
<td>of the feeder A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Measurements may vary according to type</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 3.2-26: Technical data of HIGS and generator switchgear*
8BK40
8BK40 is an air-insulated, metal-enclosed generator switchgear with truck-type circuit-breaker for indoor installation up to 17.5 kV; 63 kA; 5,000 A (fig. 3.2-34).

Performance features
- Generator circuit-breaker according to IEEE C37.013, or circuit-breaker according to IEC 62271-100
- Disconnecting function by means of truck-type circuit-breaker
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors

HB1, HB1 Outdoor and HB3
This is an air-insulated, metal-enclosed horizontal busbar switchgear, not phase-segregated (HB1, HB1 Outdoor, fig. 3.2-35, fig. 3.2-36) or phase-segregated (HB3, fig. 3.2-37).

Performance features
- Generator circuit-breaker according to IEEE C37.013
- Disconnector
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors
- Further options
  - Integrated SFC starter
  - Integrated auxiliary feeder, with generator circuit-breaker or with switch-disconnector and fuses
  - Integrated excitation feeder
  - Brake switch
3.2.6 Industrial Load Center Substation

Introduction
Industrial power supply systems call for a maximum level of personal safety, operational reliability, economic efficiency and flexibility. And they likewise necessitate an integral approach that includes “before” and “after” customer service, that can cope with the specific load requirements and, above all, that is tailored to each individually occurring situation. With SITRABLOC® (fig. 3.2-38), such an approach can be easily turned into reality.

General
SITRABLOC is an acronym for Siemens TRAnsformer BLOC-type. SITRABLOC is supplied with power from a medium-voltage substation via a fuse/switch-disconnector combination and a radial cable. In the load center, where SITRABLOC is installed, several SITRABLOCs are connected together by means of cables or bars (fig. 3.2-39).

Features
- Due to the fuse/switch-disconnector combination, the short-circuit current is limited, which means that the radial cable can be dimensioned according to the size of the transformer.
- In the event of cable faults, only one SITRABLOC fails.
- The short-circuit strength is increased due to the connection of several stations in the load center. The effect of this is that, in the event of a fault, large loads are selectively disconnected in a very short time.
- The transmission losses are optimized because only short connections to the loads are necessary.
- SITRABLOC has, in principle, two transformer outputs:
  - 1,250 kVA during AN operation (ambient air temperature up to 40 °C)
  - 1,750 kVA during AF operation (140 % with forced cooling)

These features ensure that, if one station fails, for whatever reason, supply of the loads is maintained without interruption.

The SITRABLOC components are:
- Transformer housing with roof-mounted ventilation for AN/AF operating mode
- GEAFOL transformer
  - (Cast-resin insulated) with make-proof earthing switch
  - AN operating mode: 100 % load up to an ambient air temperature of 40 °C
  - AF operating mode: 140 % load
- LV circuit-breaker as per transformer AF load
- Automatic power factor correction equipment (tuned/detuned)
- Control and metering panel as well as central monitoring interface
- Universal connection to the LV distribution busway system (fig. 3.2-40)

Whether in the automobile or food industry, in paint shops or bottling lines, putting SITRABLOC to work in the right place considerably reduces transmission losses. The energy is transformed in the production area itself, as close as possible to the loads. For installation of the system itself, no special building or fire-protection measures are necessary.

Available with any level of output
SITRABLOC can be supplied with any level of power output, the latter being controlled and protected by a fuse/switch-disconnector combination.

A high-current busbar system into which up to four transformers can feed power ensures that even large loads can be brought onto load without any loss of energy. Due to the interconnection of units, it is also ensured that large loads are switched off selectively in the event of a fault.

Fig. 3.2-38: SITRABLOC system

Fig. 3.2-39: Example of a schematic diagram
3.2 Medium-Voltage Switchgear

Integrated automatic power factor correction
With SITRABLOC, power factor correction is integrated from the very beginning. Unavoidable energy losses – e.g., due to magnetization in the case of motors and transformers – are balanced out with power capacitors directly in the low-voltage network. The advantages are that the level of active power transmitted increases and energy costs are reduced (fig. 3.2-41).

Reliability of supply
With the correctly designed transformer output, the n-1 criterion is no longer a problem. Even if one module fails (e.g., a medium-voltage switching device or a cable or transformer), power continues to be supplied without the slightest interruption. None of the drives comes to a standstill, and the whole manufacturing plant continues to run reliably. With SITRABLOC, the power is where it is needed – and it is safe, reliable and economical.

n-1 operating mode
n-1 criteria
With the respective design of a factory grid on the MV side as well as on the LV side, the so-called n-1 criteria is fulfilled. In case one component fails on the line side of the transformer (e.g., circuit-breaker or transformer or cable to transformer) no interruption of the supply on the LV side will occur (fig. 3.2-42).

Load required 5,000 kVA = 4 x 1,250 kVA. In case one load center (SITRABLOC) is disconnected from the MV network, the missing load will be supplied via the remaining three (n-1) load centers. SITRABLOC is a combination of everything that present-day technology has to offer. The GEAFOL® cast-resin transformers are just one example of this.

Their output is 100 % load without fans plus reserves of up to 140 % with fans. The safety of operational staff is ensured – even in the direct vicinity of the installation.

Another example is the SENTRON high-current busbar system. It can be laid out in any arrangement, is easy to install and conducts the current wherever you like – With almost no losses. The most important thing, however, is the uniformity of SITRABLOC throughout, regardless of the layout of the modules.

The technology at a glance
(table 3.2-26, fig. 3.2-44, next page)
SITRABLOC can cope with any requirements. Its features include:
• A transformer cubicle with or without fans (AN/AF operation)
• GEAFOL cast-resin transformers with make-proof earthing switch – AN operation 1,250 kVA, AF operation 1,750 kVA (fig. 3.2-43, next page)
• External medium-voltage switchgear with fuse/switch-disconnectors
• Low-voltage circuit-breakers
• Automatic reactive-power compensation: up to 500 kVAR unrestricted, up to 300 kVAR restricted
• The SENTRON high-current busbar system: connection to high-current busbar systems from all directions
• SIMATIC ET 200/PROFIBUS interface for central monitoring system (if required).

<table>
<thead>
<tr>
<th>Table 3.2-26: Technical data of SITRABLOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
</tr>
<tr>
<td>Transformer rating AN/AF</td>
</tr>
<tr>
<td>Transformer operating mode</td>
</tr>
<tr>
<td>Power factor correction</td>
</tr>
<tr>
<td>Busway system</td>
</tr>
<tr>
<td>Degree of protection</td>
</tr>
<tr>
<td>Dimensions (min) (LxHxD)</td>
</tr>
<tr>
<td>Weight approx.</td>
</tr>
</tbody>
</table>

Fig. 3.2-40: Location sketch
3.2 Medium-Voltage Switchgear

How to understand this mode:
- Normal operating mode: 4 x 1,250 kVA
  ➔ AN operating mode (100 %)
- n-1 operating mode: 3 x 1,750 kVA
  ➔ AF operating mode (140 %)

Power distribution

Utilities substation

Substation

Circuit-breakers and switch-disconnectors with HV HRC fuses

Fig. 3.2-42: n-1 operating mode

- Personal safety
- Reduced costs
- Low system losses

Fig. 3.2-41: Capacitor Banks

Fig. 3.2-43: Transformer and earthing switch, LV bloc
Information distribution

PG/PC

S7-400

S7-300

S5-155U

PROFIBUS DP

COROS OP

PROFIBUS

ET 200B

ET 200C

Field devices

ET 200M

GEAFOL transformer with built-in make-proof earthing switch

LV installation with circuit-breakers and automatic reactive-power compensation

LV busbar system with sliding link (e.g., SENTRON busways)

SITRABLOC

Fig. 3.2-44: SIMATIC ET 200/PROFIBUS interface for control monitoring system

For further information please contact:
Fax: ++ 49 91 31 7-31573
3.3 Low-Voltage Switchgear

3.3.1 Requirements to Electrical Power Systems in Buildings

The efficiency of electrical power supply rises and falls with qualified planning. Especially in the first stage of planning, the finding of conceptual solutions, the planner can use his creativity for an input of new, innovative solutions and technologies. They serve as a basis for the overall solution which has been economically and technically optimized in terms of the supply task and related requirements.

The following stages of calculating and dimensioning circuits and equipment are routine tasks which involve a great effort. They can be worked off efficiently using modern dimensioning tools like SIMARIS® design, so that there is more freedom left for the creative planning stage of finding conceptual solutions (fig. 3.3-1).

When the focus is limited to power supply for infrastructure projects, useful possibilities can be narrowed down. The following aspects should be taken into consideration when designing electric power distribution systems:

- Simplification of operational management by transparent, simple power system structures
- Low costs for power losses, e.g. by medium-voltage-side power transmission to the load centers
- High reliability of supply and operational safety of the installations even in the event of individual equipment failures (redundant supply, selectivity of the power system protection, and high availability)
- Easy adaptation to changing load and operational conditions
- Low operating costs thanks to maintenance-friendly equipment
- Sufficient transmission capacity of equipment during normal operation and also in the event of a fault, taking future expansions into account
- Good quality of the power supply, i.e. few voltage changes due to load fluctuations with sufficient voltage symmetry and few harmonic distortions in the voltage
- Compliance with applicable standards and project-related stipulations for special installations

Standards

To minimize technical risks and/or to protect persons involved in handling electrotechnical components, essential planning rules have been compiled in standards. Standards represent the state of the art; they are the basis for evaluations and court decisions.

Technical standards are desired conditions stipulated by professional associations which are, however, made binding by legal standards such as safety at work regulations. Furthermore, the compliance with technical standards is crucial for any approval of operator granted by authorities or insurance coverage. While decades ago, standards were mainly drafted at a national level and debated in regional committees, it has currently been agreed that initiatives shall be submitted centrally (on the IEC level) and then be adopted as regional or national standards. Only if the IEC is not interested in dealing with the matter of if there are time constraints, a draft standard shall be prepared at the regional level.

The interrelation of the different standardization levels is illustrated in table 3.3-1. A complete list of the IEC members and further links can be obtained at www.iec.ch -> Members & Experts -> List of Members (NC); http://www.iec.ch/dyn/www/f?p=103:5:0:121:21
System Configurations
Table 3.3-2 and table 3.3-3 illustrate the technical aspects and influencing factors that should be taken into account when electrical power distribution systems are planned and network components are dimensioned.

• Simple radial system (spur line topology)
  All consumers are centrally supplied from one power source. Each connecting line has an unambiguous direction of energy flow.

• Radial system with changeover connection as power reserve – partial load:
  All consumers are centrally supplied from two to n power sources. They are rated as such that each of it is capable of supplying all consumers directly connected to the main power distribution system (stand-alone operation with open couplings). If one power source fails, the remaining sources of supply can also supply some consumers connected to the other power source. In this case, any other consumer must be disconnected (load shedding).

• Radial system with changeover connection as power reserve – full load:
  All consumers are centrally supplied from two to n power sources (stand-alone operation with open couplings). They are rated as such that, if one power source fails, the remaining power sources are capable of additionally supplying all those consumers normally supplied by this power source. No consumer must be disconnected. In this case, we speak of rating the power sources according to the \((n-1)\) principle. With three parallel power sources or more, other supply principles, e.g. the \((n-2)\) principle would also be possible. In this case, these power sources will be rated as such that two out of three transformers can fail without the continuous supply of all consumers connected being affected.

• Radial system in an interconnected grid
  Individual radial networks in which the consumers connected are centrally supplied by one power source are additionally coupled electrically with other radial networks by means of connecting couplings. All couplings are normally closed.

Depending on the rating of the power sources in relation to the total load connected, the application of the \((n-1)\) principle, \((n-2)\) principle etc. can ensure continuous and faultless power supply of all consumers by means of additional connecting lines.

The direction of energy flow through the coupling connections may vary depending on the line of supply, which must be taken into account for subsequent rating of switching/protective devices, and above all for making protection settings.

• Radial system with power distribution via busbars
  In this special case of radial systems that can be operated in an interconnected grid, busbar trunking systems are used instead of cables.

In the coupling circuits, these busbar trunking systems are either used for power transmission (from radial system A to radial system B etc.) or power distribution to the respective consumers.

<table>
<thead>
<tr>
<th>Quality criterion</th>
<th>Simple radial system</th>
<th>Radial system with changeover connection as power reserve</th>
<th>Radial system in an interconnected grid</th>
<th>Radial system with power distribution via busbars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Partial load</td>
<td>Full load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low cost of investment</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Low power losses</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>High reliability of supply</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Great voltage stability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Easy operation</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Easy and clear system protection</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>High adaptability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Low fire load</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Rating: very good (1) to poor (5) fulfillment of a quality criterion

Table 3.3-2: Exemplary quality rating dependent on the power system configuration
### Power Supply Systems according to the Type of Connection to Ground

**TN-C, TN-C/S, TN-S, IT and TT systems**

The implementation of IT systems may be required by national or international standards.

- For parts of installations which have to meet particularly high requirements regarding operational and human safety (e.g. in medical rooms, such as the OT, intensive care or post-anaesthesia care unit)
- For installations erected and operated outdoors (e.g. in mining, at cranes, garbage transfer stations and in the chemical industry).

- Depending on the power system and nominal system voltage there may be different requirements regarding the disconnection times to be met (protection of persons against indirect contact with live parts by means of automatic disconnection).

- Power systems in which electromagnetic interference plays an important part should preferably be configured as TN-S systems immediately downstream of the point of supply. Later, it will mean a comparatively high expense to turn existing TN-C or TN-C/S systems into an EMC-compatible system.

The state of the art for TN systems is an EMC-compatible design as TN-S system.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>TN-C</th>
<th>TN-C/S</th>
<th>TN-S</th>
<th>IT system</th>
<th>TT system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low cost of investment</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Little expense for system extensions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Any switchgear/protective technology can be used</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground fault detection can be implemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fault currents and impedance conditions in the system can be calculated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability of the grounding system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High degree of operational safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High degree of protection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High degree of shock hazard protection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High degree of fire safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic disconnection for protection purposes can be implemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMC-friendly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment functions maintained in case of 1st ground or enclosure fault</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fault localization during system operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of system downtimes by controlled disconnection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 = true  2 = conditionally true  3 = not true

*Table 3.3-3: Exemplary quality rating dependent on the power supply system according to its type of connection to ground*
3.3 Low-Voltage Switchgear

3.3.2 Dimensioning of Power Distribution Systems

When the basic supply concept for the electricity supply system has been established, it is necessary to dimension the electrical power system.

Dimensioning means the sizing rating of all equipment and components to be used in the power system.

The dimensioning target is to obtain a technically permissible combination of switching protective devices and connecting lines for each circuit in the power system.

**Basic rules**

In principle, circuit dimensioning should be performed in compliance with the technical rules standards listed in fig. 3.3-2.

**Cross-circuit dimensioning**

When selected network components and systems are matched, an economically efficient overall system can be designed. This cross-circuit matching of network components may bear any degree of complexity, because subsequent modifications to certain components, e.g., a switch or protective device, may have effects on the neighboring higher-level or all lower-level network sections (high testing expense, high planning risk).

**Dimensioning principles**

For each circuit, the dimensioning process comprises the selection of one or more switching protective devices to be used at the beginning or end of a connecting line, and the selection of the connecting line itself (cable/line or busbar connection) after considering the technical features of the corresponding switching protective devices. For supply circuits in particular, dimensioning also includes rating the power sources.

The objectives of dimensioning may vary depending on the circuit type. The dimensioning target of overload and short-circuit protection can be attained in correlation to the mounting location of the protective equipment. Devices applied at the end of a connecting line can ensure overload protection for this line at best, not, however, short-circuit protection.

**Circuit types**

The basic dimensioning rules and standards listed in fig. 3.3-2 principally apply to all circuit types. In addition, there are specific requirements for these circuit types that are explained in detail below.

---

**Fig. 3.3-2: Relevant standards for circuit dimensioning**

<table>
<thead>
<tr>
<th>Overload protection</th>
<th>IEC 60364-4-43</th>
<th>DIN VDE 0100-430</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-circuit protection</td>
<td>IEC 60364-4-43/ IEC 60364-5-54</td>
<td>DIN VDE 0100-430/ DIN VDE 0100-540</td>
</tr>
<tr>
<td>Protection against electric shock</td>
<td>IEC 60364-4-41</td>
<td>DIN VDE 0100-410</td>
</tr>
<tr>
<td>Voltage drop static / dynamic</td>
<td>IEC 60364-5-52 IEC 60038</td>
<td>DIN VDE 0100-520 VDE 0175</td>
</tr>
<tr>
<td>Selectivity static / dynamic</td>
<td>IEC 60364-7-710 IEC 60364-7-718 IEC 60947-2 IEC 60898-1</td>
<td>DIN VDE 0100-710 DIN VDE 0100-718 DIN EN 60947-2 DIN EN 60898-1</td>
</tr>
</tbody>
</table>
Supply circuits
Particularly stringent requirements apply to the dimensioning of supply circuits. This starts with the rating of the power sources. Power sources are rated according to the maximum load current to be expected for the power system, the desired amount of reserve power, and the degree of supply reliability required in case of a fault (overload short-circuit).

Load conditions in the entire power system are established by taking the energy balance (in an "energy report"). Reserve power and operational safety in the vicinity of the supply system are usually established by building up appropriate redundancies, for example, by doing the following:

- Providing additional power sources (transformer, generator, UPS).
- Rating the power sources according to the failure principle; n- or (n–1) principle: Applying the (n–1) principle means that two out of three supply units are principally capable of continually supplying the total load for the power system without any trouble if the smallest power source fails.
- Rating those power sources that can temporarily be operated under overload (e.g., using vented transformers).

Independent of the load currents established, dimensioning of any further component in a supply circuit is oriented to the ratings of the power sources, the system operating modes configured and all the related switching states in the vicinity of the supply system.

As a rule, switching protective devices must be selected in such a way that the planned performance maximum can be transferred. In addition, the different minimum/maximum short-circuit current conditions in the vicinity of the supply system, which are dependent on the switching status, must be determined.

When connecting lines are rated (cable or busbar), appropriate reduction factors must be taken into account; these factors depend on the number of systems laid in parallel and the installation type.

When devices are rated, special attention should be paid to their rated short-circuit breaking capacity. In addition, a high-quality tripping unit with variable settings is preferred, because this component is an important foundation for attaining the best possible selectivity toward all upstream and downstream devices.

Distribution circuit
Dimensioning of cable routes and devices follows the maximum load currents to be expected at this distribution level.

As a rule
\[ I_{b,\text{max}} = \sum \text{installed capacity} \times \text{simultaneity factor} \]

Switching/protective device and connecting line are to be matched with regard to overload and short-circuit protection.

In order to ensure overload protection, the standardized conventional (non-)tripping currents referring to the devices in application have to be observed. A verification based merely on the rated device current or the setting value \( I_r \) would be insufficient.

**Basic rules for ensuring overload protection:**

**Rated current rule**

- Non-adjustable protective equipment
  \[ I_b \leq I_n \leq I_z \]
  The rated current \( I_n \) of the selected device must be between the calculated maximum load current \( I_b \) and the maximum permissible load current \( I_z \) of the selected transmission medium (cable or busbar).

- Adjustable protective equipment
  \[ I_b \leq I_r \leq I_z \]
  The rated current \( I_r \) of the overload release must be between the calculated maximum load current \( I_b \) and the maximum permissible load current \( I_z \) of the selected transmission medium (cable or busbar).

**Tripping current rule**

\[ I_z \leq 1.45 \times I_2 \]

The maximum permissible load current \( I_z \) of the selected transmission medium (cable or busbar) must be above the conventional tripping current \( I_z/1.45 \) of the selected device.

The test value \( I_z \) is standardized and varies according to the type and characteristics of the protective equipment applied.

**Basic rules for ensuring short-circuit protection:**

**Short-circuit energy**

\[ K S^2 \geq I^2 t \]

\( K = \text{Material coefficient}; \quad S = \text{Cross-section} \)

The amount of energy that is set free when a short-circuit occurs – and up to the moment it is cleared automatically – must be less than the energy that the transmission medium can carry as a maximum or there will be irreparable damage. As a standard, this basic rule applies in the time range up to max. 5 s.

Below 100 ms of short-circuit breaking time, the let-through energy of the protective device (according to the equipment manufacturer’s specification) must be taken into account.
When devices with a tripping unit are used, observance of this rule across the entire characteristic device curve must be verified. A mere verification in the range of the maximum short-circuit current applied \( I_{k, \text{max}} \) is not always sufficient, in particular when time-delayed releases are used.

**Short-circuit time**

\[ t_a (I_{k, \text{min}}) \leq 5 \text{ s} \]

The resulting current-breaking time of the selected protective equipment must ensure that the calculated minimum short-circuit current \( I_{k, \text{min}} \) at the end of the transmission line or protected line is automatically cleared within 5 s at the most.

Overload and short-circuit protection need not necessarily be provided by one and the same device. If required, these two protection targets may be realized by a device combination. The use of separate switching protective devices could also be considered, i.e., at the start and end of a cable route. As a rule, devices applied at the end of a cable route can ensure overload protection for that line only.

**Final circuits**

The method for coordinating overload and short-circuit protection is practically identical for distribution and final circuits. Besides overload and short-circuit protection, the protection of human life is also important for all circuits.

**Protection against electric shock**

\[ t_a (I_{k1, \text{min}}) \leq t_a \text{ perm} \]

If a 1-phase fault to earth \( (I_{k1, \text{min}}) \) occurs, the resulting current breaking time \( t_a \) for the selected protective equipment must be shorter than the maximum permissible breaking time \( t_a \text{ perm} \) that is required for this circuit according to IEC 60364-4-41/ DIN VDE 0100-410 to ensure the protection of persons.

Because the required maximum current breaking time varies according to the rated system voltage and the type of load connected (stationary and non-stationary loads), protection requirements regarding minimum breaking times \( t_a \text{ perm} \) may be transferred from one load circuit to other circuits. Alternatively, this protection target may also be achieved by observing a maximum touch voltage.

Because final circuits are often characterized by long supply lines, their dimensioning is often affected by the maximum permissible voltage drop.

As far as the choice of switching protective devices is concerned, it is important to bear in mind that long connecting lines are characterized by high impedances, and thus strong attenuation of the calculated short-circuit currents.

Depending on the system operating mode (coupling open, coupling closed) and the medium of supply (transformer or generator), the protective equipment and its settings must be configured for the worst-case scenario for short-circuit currents.

In contrast to supply or distribution circuits, where the choice of a high-quality tripping unit is considered very important, there are no special requirements on the protective equipment of final circuits regarding the degree of selectivity to be achieved. The use of a tripping unit with LI characteristics is normally sufficient.

**Summary**

Basically, the dimensioning process itself is easy to understand and can be performed using simple means.

Its complexity lies in the procurement of the technical data on products and systems required. This data can be found in various technical standards and regulations as well as in numerous product catalogs.

An important aspect in this context is the cross-circuit manipulation of dimensioned components owing to their technical data. One such aspect is the above mentioned inheritance of minimum current breaking times of the non-stationary load circuit to other stationary load or distribution circuits.

Another aspect is the mutual impact of dimensioning and network calculation (short-circuit), e.g., for the use of short-circuit current-limiting devices.

In addition, the complexity of the matter increases, when different national standards or installation practices are to be taken into account for dimensioning.

For reasons of risk minimization and time efficiency, a number of engineering companies generally use advanced calculation software, such as SIMARIS design, to perform dimensioning and verification processes in electrical power systems.
### 3.3 Low-Voltage Switchgear

When developing a power distribution concept including dimensioning of the systems and devices, its requirements and feasibility have to be matched by the end user and the manufacturer.

When selecting a low-voltage main distribution board (LVMD), the prerequisite for its efficient sizing is knowledge of its use, availability and future options for extension. The demands on power distribution are extremely diverse. They start with buildings that do not place such high demands on the power supply, such as office buildings, and continue through to the high demands, for example, made by data centers, in which smooth operation is of prime importance.

Because no major switching functions in the LVMD have to be considered in the planning of power distribution systems in commercial buildings and no further extensions are to be expected, a performance-optimized technology with high component density can be used. In these cases, mainly fuse-protected equipment in fixed-mounted design is used. When planning a power distribution system for a production plant, however, system availability, extendibility, control and the visualization are important functions to keep plant downtimes as short as possible. The use of circuit-breaker protected and fuse-protected withdrawable design is an important principle. Selectivity is also of great importance for reliable power supply. Between these two extremes there is a great design variety that is to be optimally matched to customer requirements. The prevention of personal injury and damage to equipment must, however, be the first priority in all cases. When selecting appropriate switchgear, it must be ensured that it is a design verified switchgear assembly (in compliance with IEC 61439-2, resp. DIN EN 61439-2, VDE 0660-600-2) with extended testing of behavior in the event of an accidental arc (IEC 61641, VDE 0660-500, Addendum 2), and that the selection is always made in light of the regulations governing the entire supply system (full selectivity, partial selectivity).

Further information:
Siemens AG (ed.): The low-voltage power distribution board that sets new standards; SIVACON S8 – safe, flexible and cost-efficient; Order no.: E10003-E38-98-D0010-7600
For detailed planning: www.siemens.com/sivacon

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**Fig. 3.3-4: SIVACON S8 switchgear**
## Overview

The SIVACON S8 low-voltage switchgear (fig. 3.3-4) is a variable, multi-purpose and design verified low-voltage switchgear assembly that can be used for the infrastructure supply not only in administrative and institutional buildings, but also in industry and commerce. SIVACON S8 consists of standardized, modular components that can be flexibly combined to form an economical, overall solution, depending on the specific requirements. SIVACON S8 has a high level of functionality, flexibility and quality, and has compact dimensions and a high degree of safety for persons and equipment. Siemens or its authorized contracting party will perform the following:

- The customer-specific configuration
- The mechanical and electrical installation
- The testing, for which design verified function modules are used

The authorized contracting party will use the specified documentation. SIVACON S8 can be used as a design verified power distribution board system up to 7,000 A.

### Standards and regulations

SIVACON S8 is a design verified low-voltage switchgear assembly in compliance with IEC 61439-2, VDE 0660-600-2. SIVACON S8 is resistant to accidental arcs, in compliance with IEC 61641, VDE 0660-500, Addendum 2. SIVACON S8 is available in several mounting designs (fig. 3.3-5).

### Circuit-breaker design

The panels for installation of 3WL and 3VL circuit-breakers are used for the supply of the switchgear and for outgoing feeders and bus ties (bus sectionalizer and bus coupler). The rule that only one circuit-breaker is used for each panel applies to the entire circuit-breaker design (fig. 3.3-6).

The device mounting space is intended for the following functions:

- Incoming/outgoing feeders with 3WL circuit-breakers in fixed-mounted and withdrawable designs up to 6,300 A
- Bus sectionalizer and bus coupler with 3WL circuit-breakers in fixed-mounted and withdrawable designs up to 6,300 A
- Incoming/outgoing feeders with 3VL circuit-breakers in fixed-mounted design up to 1,600 A

### Universal installation design

The panels for cable feeders in fixed-mounted and plug-in designs up to 630 A are intended for the installation of the following switchgear (fig. 3.3-7):

- SIRIUS 3RV/3VL circuit-breaker
- 3K switch-disconnector
- 3NP switch-disconnector
- 3NJ6 switch-disconnector in plug-in design

The switching devices are mounted on mounting plates and connected to the vertical current distribution bars on the supply side. Plug-in 3NJ6 in-line switch-disconnectors can be installed using an adapter. The front is covered by panel doors or compartment doors.

### Plug-in 3NJ6 in-line switch-disconnector design

The panels for cable feeders in the plug-in design up to 630 A are intended for the installation of in-line switch-disconnectors. The plug-in contact on the supply side is a cost-effective alternative to the withdrawable design. The modular design of the plug-ins enables an easy and quick retrofit or replacement under operating conditions. The device mounting space is intended for plug-in, in-line switch-disconnectors with a distance between pole centers of 185 mm. The vertical plug-on bus system is arranged at the back of the panel and is covered by an optional touch protection with pick-off openings in the IP20 degree of protection. This enables the in-line switch-disconnectors to be replaced without shutting down the switchgear (fig. 3.3-8).

### Fixed-mounted design with front covers

The panels for cable feeders in fixed-mounted design up to 630 A are intended for the installation of the following switchgear (fig. 3.3-9):

- SIRIUS 3RV/3VL circuit-breaker
- 3K switch-disconnector
- 3NP switch-disconnector
- Modular devices
The switching devices are mounted on infinitely adjustable device holders and connected to the vertical current distribution bars on the supply side. The front of the panel has either covers (with or without hinges) or additional doors (with or without a window).

Fixed-mounted 3NJ4 in-line switch-disconnector design
The panels for cable feeders in fixed-mounted design up to 630 A are intended for the installation of 3NJ4 in-line fuse switch-disconnectors. With their compact design and modular structure, in-line fuse switch-disconnectors offer optimal installation conditions with regard to the achievable packing density. The busbar system is arranged horizontally at the back of the panel. This busbar system is connected to the main busbar system via cross-members. The in-line fuse switch-disconnectors are screwed directly onto the busbar system (fig. 3.3-10).

Low-voltage main distribution
When selecting a low-voltage main distribution system, the prerequisite for its efficient sizing is knowing about its use, availability and future options for extension. The requirements for power distribution are extremely diverse.

Normally, frequent switching operations need not be considered in the planning of power distribution for commercial, institutional and industrial building projects, and extensions are generally not to be expected. For these reasons, a performance-optimized technology with high component density can be used. In these cases, Siemens mainly uses circuit-breaker protected equipment in fixed-mounted design. When planning a power distribution system for a production plant, however, system availability, extendibility, control and the visualization of status information and control functions are important issues related to keeping plant downtimes as short as possible. The use of circuit-breaker protected technology in withdrawable design is important. Selectivity is also of great importance for reliable power supply. Between these two extremes there is a great design variety that should be optimally matched to customer requirements. The prevention of personal injury and damage to equipment must, however, be the first priority in any case. When selecting appropriate switchgear, it must be ensured that it is a design verified switchgear assembly (in compliance with IEC 61439-2, VDE 0660-600-2), with extended testing of behavior in the event of an internal arc fault (IEC 61641, VDE 0660-500, Addendum 2).

Low-voltage main distribution systems should be chosen among those featuring a total supply power up to 3 MVA. Up to this rating, the equipment and distribution systems are relatively inexpensive due to the maximum short-circuit currents to be encountered.

For rated currents up to 3,200 A, power distribution via busbars is usually sufficient if the arrangement of the incoming/outgoing feeder panels and coupler panels has been selected in a performance-related way. Ambient air temperatures, load on individual feeders and the maximum power loss per panel have a decisive impact on the devices to be integrated and the number of panels required, as well as their component density (number of devices per panel).
3.3.4 Planning Notes for Low-Voltage Switchgear

Installation – clearances and corridor widths
The minimum clearances between switchgear and obstacles specified by the manufacturer must be taken into account when installing low-voltage switchgear (fig. 3.3-11). The minimum dimensions for operating and servicing corridors according to IEC 60364-7-729 (DIN VDE 0100-729) must be taken into account when planning the space requirements (table 3.3-4, fig. 3.3-12, fig. 3.3-13).

Caution! If a lift truck is used to insert circuit-breakers or withdrawable units, the minimum corridor widths must be adapted to the lift truck!

Transportation units
Depending on the access routes available in the building, one or more panels can be combined into transportation units (TU). The max. length of a TU should not exceed 2,400 mm.

Space requirements

| Height: | 2,000 mm and 2,200 mm (optionally with 100 mm or 200 mm base) |
|---------------------------------|
| Width: | For data required for the addition of panels please refer to the panel descriptions |

<table>
<thead>
<tr>
<th>Depth:</th>
<th>Busbar position</th>
<th>Rated current of the main busbar</th>
<th>Type of installation</th>
<th>Cable / busbar entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 mm</td>
<td>Rear</td>
<td>4,000 A</td>
<td>Single front</td>
<td>Top &amp; bottom</td>
</tr>
<tr>
<td>800 mm</td>
<td>Rear</td>
<td>7,010 A</td>
<td>Single front</td>
<td>Top &amp; bottom</td>
</tr>
<tr>
<td>1,000 mm</td>
<td>Rear</td>
<td>4,000 A</td>
<td>Double front</td>
<td>Top &amp; bottom</td>
</tr>
<tr>
<td>1,200 mm</td>
<td>Rear</td>
<td>7,010 A</td>
<td>Double front</td>
<td>Top &amp; bottom</td>
</tr>
<tr>
<td>500 mm</td>
<td>Top</td>
<td>3,270 A</td>
<td>Single front</td>
<td>Bottom</td>
</tr>
<tr>
<td>800 mm</td>
<td>Top</td>
<td>3,270 A</td>
<td>Single front</td>
<td>Top &amp; bottom</td>
</tr>
<tr>
<td>800 mm</td>
<td>Top</td>
<td>6,300 A</td>
<td>Single front</td>
<td>Bottom</td>
</tr>
<tr>
<td>1,200 mm</td>
<td>Top</td>
<td>6,300 A</td>
<td>Single front</td>
<td>Top &amp; bottom</td>
</tr>
</tbody>
</table>

Table 3.3-4: SIVACON S8 switchgear dimensions

Fig. 3.3-11: Clearances to obstacles

A: 100 mm from the rear side of the installation
B: 100 mm from the side side panels
C: 200 mm from the rear panels with back to back installation

Fig. 3.3-12: Reduced corridor widths within the area of open doors

1) Minimum height of passage under covers or enclosures

Fig. 3.3-13: Minimum corridor width according to IEC 60364-7-729 (DIN VDE 0100-729)

1) With switchgear fronts facing each other, the space requirements only account for obstruction by open doors from one side (i.e. doors that don’t close in escape direction)

2) Take door widths into account, i.e. door can be opened at 90 ° minimum
Full door opening angle = 125 ° (Sinus 55 °)
Double-front installations
In the double-front installation, the panels are positioned in a row next to and behind one another. The main advantage of a double-front installation is the extremely economic design through the supply of the branch circuits on both operating panels from one main busbar system.

The "double-front unit" system structure is required for the assignment of certain modules.

A double-front unit (fig. 3.3-14) consists of at least 2 and a maximum of 4 panels. The width of the double-front unit is determined by the widest panel (1) within the double-front unit. This panel can be placed on the front or rear side of the double-front unit. Up to three panels (2), (3), (4) can be placed on the opposite side. The sum of the panel widths (2) to (4) must be equal to the width of the widest panel (1). The panel combination within the double-front unit is possible for all technical installations with the following exceptions.

Exceptions
The following panels determine the width of the double-front unit and may only be combined with an empty panel.
- Bus sectionalizer unit
- 5,000 A incoming/outgoing feeder
- 6,300 A incoming/outgoing feeder

Weights
The panel weights as listed in table 3.3-5 should be used for the transportation and dimensioning of building structures such as cable basements and false floors.

Environmental conditions for switchgear
The climate and other external conditions (natural foreign substances, chemically active pollutants, small animals) may affect the switchgear to a varying extent. The effect depends on the heating/air-conditioning systems of the switchgear room. If higher concentrations are present, pollutant-reducing measures are required, for example:
- Air-intake for operating room from a less contaminated point
- Slightly pressurizing the operating room (e.g. by blowing uncontaminated air into the switchgear)
- Switchgear room air conditioning (temperature reduction, relative humidity < 60 %, if necessary, use air filters)
- Reduction of temperature rise (oversizing of switchgear or components such as busbars and distribution bars)

Power losses
The power losses listed in table 3.3-5 are approximate values for a panel with the main circuit of functional units to determine the power loss to be discharged from the switchgear room.

<table>
<thead>
<tr>
<th>Circuit-breaker design with 3WL (withdrawable unit)</th>
<th>Rated current [A]</th>
<th>Size</th>
<th>Minimum panel width [mm]</th>
<th>Approx. weight [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>630–1,600 Size I</td>
<td>600</td>
<td>400</td>
<td>340</td>
<td></td>
</tr>
<tr>
<td>2,000–3,200 Size II</td>
<td>600</td>
<td>510</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4,000 Size III</td>
<td>800</td>
<td>770</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4,000–6,300 Size III</td>
<td>1,000</td>
<td>915</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Universal mounting design panel                    |                  |      |                          |
| (incl. withdrawable units, fixed mounting with front doors) |                  |      |                          |
|                                                     | 1,000             | 400  |
| 3NJ4 in-line-type switch-disconnector panel (fixed mounting) |                  | 600  | 360                      |
| 3NJ6 in-line-type switch-disconnector design panel (plugged) |                  | 1,000 | 415                      |
| Reactive power compensation panel                  | 800               | 860  |

Table 3.3-5: Average weights of the panels including busbar (without cable)
### Table 3.3-6: Power loss generated per panel (average values)

<table>
<thead>
<tr>
<th>Circuit-breaker type</th>
<th>Approx. $P_v$ [W] for % of the rated current of the switch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 %</td>
</tr>
<tr>
<td>3WL1106 630 A Size I</td>
<td>215</td>
</tr>
<tr>
<td>3WL1108 800 A Size I</td>
<td>345</td>
</tr>
<tr>
<td>3WL1110 1,000 A Size I</td>
<td>540</td>
</tr>
<tr>
<td>3WL1112 1,250 A Size I</td>
<td>730</td>
</tr>
<tr>
<td>3WL1116 1,600 A Size I</td>
<td>1,000</td>
</tr>
<tr>
<td>3WL1220 2,000 A Size II</td>
<td>1,140</td>
</tr>
<tr>
<td>3WL1225 2,500 A Size II</td>
<td>1,890</td>
</tr>
<tr>
<td>3WL1232 3,200 A Size II</td>
<td>3,680</td>
</tr>
<tr>
<td>3WL1340 4,000 A Size III</td>
<td>4,260</td>
</tr>
<tr>
<td>3WL1350 5,000 A Size III</td>
<td>5,670</td>
</tr>
<tr>
<td>3WL1363 6,300 A Size III</td>
<td>8,150</td>
</tr>
</tbody>
</table>

**Universal mounting design panel (incl. withdrawable units, fixed mounting with front doors)**

<table>
<thead>
<tr>
<th>Circuit-breaker type</th>
<th>Approx. $P_v$ [W] for % of the rated current of the switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>3NJ4 in-line-type switch-disconnector panel (fixed mounting)</td>
<td>600 W</td>
</tr>
<tr>
<td>3NJ6 in-line-type switch-disconnector design panel (plugged)</td>
<td>1,500 W</td>
</tr>
<tr>
<td>Fixed-mounted type panel with front covers</td>
<td>600 W</td>
</tr>
<tr>
<td>Reactive power compensation panel</td>
<td>non-choked</td>
</tr>
<tr>
<td></td>
<td>1.4 W / kvar</td>
</tr>
<tr>
<td></td>
<td>choked</td>
</tr>
<tr>
<td></td>
<td>6.0 W / kvar</td>
</tr>
</tbody>
</table>

**Arc resistance**

Arcing faults can be caused by incorrect dimensioning and reductions in insulation due to contamination etc., but they can also be a result of handling errors. The effects, resulting from high pressure and extremely high temperatures, can have fatal consequences for the operator, the system and even the building. SIVACON offers efficiency of personal safety through testing under arcing fault conditions with a special test in accordance with IEC 61641 (DIN VDE 0660-500 Addendum 2).

Active protection measures such as the high-quality insulation of live parts (e.g. busbars), standardized and simple operation, prevent arcing faults and the associated personal injuries. Passive protections increase personal and system safety many times over. These include: hinge and locking systems with arc resistance, the safe operation of withdrawable units or circuit breakers behind a closed door and patented swing check valves behind ventilation openings on the front, arcing fault barriers or arcing fault detection system combined with the rapid disconnection of arcing faults.

**Fig. 3.3-15:** The arcing fault levels describe the classification in accordance with the characteristics under arcing fault conditions and the restriction of the effects of the arcing fault to the system or system section.
### 3.3.5 Low-Voltage Switchgear – Example

**Table 3.3-7: Various mounting designs according to panel types**

<table>
<thead>
<tr>
<th>Panel type</th>
<th>Circuit-breaker design</th>
<th>Universal mounting design</th>
<th>3NJ6 in-line switch-disconnector design</th>
<th>Fixed-mounted design with front cover</th>
<th>3NJ4 in-line switch-disconnector design</th>
<th>Reactive power compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mounting design</td>
<td>Fixed mounting</td>
<td>Fixed mounting</td>
<td>Plug-in design</td>
<td>Fixed-mounted design with front covers</td>
<td>Fixed mounting</td>
<td>Fixed mounting</td>
</tr>
<tr>
<td>Function</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incoming feeder</td>
<td></td>
<td>Cable feeders</td>
<td>Cable feeders</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outgoing feeder</td>
<td></td>
<td>Motor feeders</td>
<td>Cable feeders</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coupling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current In</td>
<td>Up to 6,300 A</td>
<td></td>
<td>Up to 630 A</td>
<td>Up to 630 A</td>
<td>Up to 630 A</td>
<td>Up to 600 kvar</td>
</tr>
<tr>
<td>Connection</td>
<td></td>
<td></td>
<td>Front side</td>
<td>Front side</td>
<td>Front side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Front and rear side</td>
<td></td>
<td>Front side</td>
<td>Front side</td>
<td>Front side</td>
<td></td>
</tr>
<tr>
<td>Panel width [mm]</td>
<td>400/600/800/1,000/1,400</td>
<td></td>
<td>600/1,000/1,200</td>
<td>1,000/1,200</td>
<td>600/800/800</td>
<td></td>
</tr>
<tr>
<td>Internal compartmentalization</td>
<td>1, 2b, 3a, 4b</td>
<td>4a, 3b, 4b</td>
<td>4a, 3b, 4b</td>
<td>1, 2b, 3b, 4a, 4b</td>
<td>1, 2b</td>
<td>1, 2b</td>
</tr>
<tr>
<td>Busbars</td>
<td>Rear/top</td>
<td>Rear/top</td>
<td>Rear/top</td>
<td>Rear/top</td>
<td>Rear</td>
<td>Rear/top/without</td>
</tr>
</tbody>
</table>

**Fig. 3.3-16: SIVACON S8, busbar position at rear 2,200 × 4,800 × 600 (H × W × D in mm)**
3.3.6 Protective and Switching Devices for the Low-Voltage Switchgear

In the TIP planning and application manuals are the basics for the dimensioning of low-voltage main distribution boards and main components described. The following focuses on the relevant characteristics and selection criteria of the respective devices that are used in the main power distribution circuits in commercial buildings and in industry.

**Note:**
All figures apply for low-voltage power systems or distribution boards in IEC applications. Different regulations and criteria apply for systems according to UL standards.

If you have questions on UL applications, please contact your local Siemens representative. We provide solutions for these applications, but they must be treated completely differently.

Depending on the country, standard specifications, local practices, planning engineer, technical threshold values, etc., low voltage power distribution systems are made up of various protective devices.

<table>
<thead>
<tr>
<th>Table 3.3-8: Overview of circuit-breaker-protected switchgear</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Circuit-breaker-protected switchgear (circuit-breaker)</strong></td>
</tr>
<tr>
<td>ACB</td>
</tr>
<tr>
<td>- Air circuit-breaker</td>
</tr>
<tr>
<td>- Non-current-limiting circuit-breaker</td>
</tr>
<tr>
<td>- Current-zero cut-off circuit breaker</td>
</tr>
<tr>
<td>MCCB</td>
</tr>
<tr>
<td>- Molded-case circuit-breaker</td>
</tr>
<tr>
<td>- Current-limiting circuit-breaker</td>
</tr>
<tr>
<td>MCB</td>
</tr>
<tr>
<td>- Miniature circuit-breaker</td>
</tr>
<tr>
<td>MSP</td>
</tr>
<tr>
<td>MPCB</td>
</tr>
<tr>
<td>- Circuit-breaker for motor protection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3.3-9: Overview of fuse-protected switchgear</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuse-protected switchgear (fuse switch disconnector / switch disconnector)</strong></td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td><strong>Operator-dependent</strong></td>
</tr>
<tr>
<td>- Without breaker latching mechanism, with protection (fuse); with these devices, the fuse is also moved when making and breaking (= fuse switch disconnector)</td>
</tr>
<tr>
<td>- With breaker latching mechanism, with protection (fuse); with these devices, the fuse is not moved when making and breaking (= switch disconnector with fuse)</td>
</tr>
<tr>
<td><strong>Operator-independent</strong></td>
</tr>
<tr>
<td>- With breaker latching mechanism, without protection (without fuse); these devices are only used to interrupt the circuit, similar to a main switch (= switch disconnector without fuse)</td>
</tr>
</tbody>
</table>

Table 3.3-8: Overview of circuit-breaker-protected switchgear

Table 3.3-9: Overview of fuse-protected switchgear
Circuits and Device Assignment
(see also section 3.3.2 “Dimensioning of Power Distribution Systems”)

Basic configuration of a low-voltage power distribution system and assignment of the protective devices including core functions

Core functions in the respective circuits
Supply circuit
Task: System protection
Protective device
– ACB (air circuit-breaker)

Distribution circuit
Task: System protection
Protective devices:
– ACB (air circuit-breaker)
– MCCB (molded-case circuit-breaker)
– SD (switch disconnector)

Final circuit
Task: Motor protection
Protective devices:
– MCCB (circuit-breaker for motor protection)
– SD (switch disconnector)
– MSP (3RT contactor, 3RU overload relay, 3UF motor protection and control devices)

Criteria for Device Selection
A protective device is always part of a circuit and must satisfy the corresponding requirements (see also section 3.3.2 “Dimensioning of Power Distribution Systems”). The most important selection criteria are shown in the following.

Main selection criteria
Fig. 3.3-18 shows the seven most important selection criteria that must be at least taken into account for the device selection.
3.3.7 Requirements on the Switchgear in the Three Circuit Types

**Device Application in the Supply Circuit**

The system infeed is the most "sensitive" circuit in the entire power distribution. A failure here would result in the entire network and therefore the building or production being without power. This worst-case scenario must be considered during the planning. Redundant system supplies and selective protection setting are important preconditions for a safe network configuration. The selection of the correct protective devices is therefore of elementary importance in order to create these preconditions. Some of the key dimensioning data is addressed in the following.

**Rated current**

The feeder circuit-breaker in the LVMD must be dimensioned for the maximum load of the transformer/generator. When using ventilated transformers, the higher operating current of up to 1.5 x Iₙ of the transformer must be taken into account.

**Short-circuit strength**

The short-circuit strength of the feeder circuit-breaker is determined by (n–1) x Iₙ max of the transformer or transformers (n = number of transformers). This means that the maximum short-circuit current that occurs at the installation position must be known in order to specify the appropriate short-circuit strength of the protective device (Iₙ max). Exact short-circuit current calculations including attenuations of the medium-voltage levels or the laid cables can be made, for example, with the aid of the SIMARIS design dimensioning software. SIMARIS design determines the maximum and minimum short-circuit currents and automatically dimensions the correct protective devices.

**Utilization category**

When dimensioning a selective network, time grading of the protective devices is essential. When using time grading up to 500 ms, the selected circuit-breaker must be able to carry the short-circuit current that occurs for the set time. Close to the transformer, the currents are very high. This current carrying capacity is specified by the Iₙcw value (rated short-time withstand current) of the circuit-breaker; this means the contact system must be able to carry the maximum short-circuit current, i.e. the energy contained therein, until the circuit-breaker is tripped. This requirement is satisfied by circuit-breakers of utilization category B (e.g. air circuit-breakers, ACB). Current-limiting circuit-breakers (molded-case circuit breakers, MCCB) trip during the current rise. They can therefore be constructed more compactly.

**Release**

For a selective network design, the release (trip unit) of the feeder circuit-breaker must have an LSI characteristic. It must be possible to deactivate the instantaneous release (I). Depending on the curve characteristic of the upstream and downstream protective devices, the characteristics of the feeder circuit-breaker in the overload range (L) and also in the time-lag short-circuit range (S) should be optionally switchable (Iₜₘₗ or Iₜₜ characteristic curve). This facilitates the adaptation of upstream and downstream devices.

**Internal accessories**

Depending on the respective control, not only shunt releases (previously: f releases), but also undervoltage releases are required.

**Communication**

Information about the current operating states, maintenance, error messages and analyses, etc. is being increasingly required, especially from the very sensitive supply circuits. Flexibility may be required with regard to a later upgrade or retrofit to the desired type of data transmission.

**Device Application in Supply Circuits (Coupling)**

If the coupling (connection of Network 1 to Network 2) is operated open, the circuit-breaker (tie breaker) only has the function of an isolator or main switch. A protective function (release) is not absolutely necessary.

The following considerations apply to closed operation:

**Rated current**

Must be dimensioned for the maximum possible operating current (load compensation). The simultaneity factor can be assumed to be 0.9.

**Short-circuit strength**

The short-circuit strength of the feeder circuit-breaker is determined by the sum of the short-circuit components that flow through the coupling. This depends on the configuration of the component busbars and their supply.

**Utilization category**

As for the system supply, utilization category B is also required for the current carrying capacity (Iₙcw value).

**Release**

Partial shutdown with the couplings must be taken into consideration for the supply reliability. As the coupling and the feeder circuit-breakers have the same current components when a fault occurs, similar to the parallel operation of two transformers, the LSI characteristic is required. The special “Zone Selective Interlocking (ZSI)” function should be used for larger networks and/or protection settings that are difficult to determine.

**Device Application in the Distribution Circuit**

The distribution circuit receives power from the higher level (supply circuit) and feeds it to the next distribution level (final circuit).

Depending on the country, local practices, etc., circuit-breakers and fuses can be used for system protection; in principle, all protective devices described in this chapter.

The specifications for the circuit dimensioning must be fulfilled. The ACB has advantages if full selectivity is required. However for cost reasons, the ACB is only frequently used in the distribu-
As no clear recommendations can otherwise be given, Table 3.3-10 shows the major differences and limits of the respective protective devices.

**Device Application in the Final Circuit**

The final circuit receives power from the distribution circuit and supplies it to the consumer (e.g. motor, lamp, non-stationary load (power outlet), etc.). The protective device must satisfy the requirements of the consumer to be protected by it.

**Note:**

All protection settings, comparison of characteristic curves, etc. always start with the load. This means that no protective devices are required with adjustable time grading in the final circuit.

---

### Table 3.3-10: Overview of the protective devices

<table>
<thead>
<tr>
<th>Standards</th>
<th>IEC</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>System protection</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Power supply system</td>
</tr>
<tr>
<td>Installation</td>
<td>Fixed mounting</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Availability</td>
</tr>
<tr>
<td></td>
<td>Plug-in</td>
<td>–</td>
<td>up to 800 A</td>
<td>–</td>
<td>Partly</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Withdrawable unit</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Rated current</td>
<td>$I_{n}$</td>
<td>6,300 A</td>
<td>1,600 A</td>
<td>630 A</td>
<td>630 A</td>
<td>125 A</td>
<td>Operating current $I_{g}$</td>
</tr>
<tr>
<td>Short-circuit breaking capacity</td>
<td>$I_{cu}$</td>
<td>up to 150 kA</td>
<td>up to 100 kA</td>
<td>up to 120 kA</td>
<td>up to 25 kA</td>
<td>Maximum short-circuit current $I_{k_{max}}$</td>
<td></td>
</tr>
<tr>
<td>Current carrying capacity</td>
<td>$I_{cw}$</td>
<td>up to 80 kA</td>
<td>up to 5 kA</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Circuit</td>
</tr>
<tr>
<td>Number of poles</td>
<td>3-pole</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4-pole</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>Partly</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Tripping characteristic</td>
<td>ETU</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Power supply system</td>
</tr>
<tr>
<td></td>
<td>TM</td>
<td>–</td>
<td>up to 630 A</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Power supply system</td>
</tr>
<tr>
<td>Tripping function</td>
<td>LI</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes</td>
<td>Power supply system</td>
</tr>
<tr>
<td></td>
<td>LSI</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Characteristics</td>
<td>Fixed</td>
<td>–</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Power supply system</td>
</tr>
<tr>
<td></td>
<td>Adjustable</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Protection against electric shock, tripping condition</td>
<td>Detection of $I_{k_{min}}$</td>
<td>No limitation</td>
<td>No limitation *)</td>
<td>Depends on cable length</td>
<td>Depends on cable length</td>
<td>Depends on cable length</td>
<td>Minimum short-circuit current $I_{k_{min}}$</td>
</tr>
<tr>
<td>Communication (data transmission)</td>
<td>High</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Customer specification</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Activation</td>
<td>Local</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Customer specifications</td>
</tr>
<tr>
<td></td>
<td>Remote (motor)</td>
<td>Yes</td>
<td>Yes</td>
<td>–</td>
<td>Partly</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Derating</td>
<td>Full rated current up to</td>
<td>60 °C</td>
<td>50 °C</td>
<td>30 °C</td>
<td>30 °C</td>
<td>30 °C</td>
<td>Switchgear</td>
</tr>
<tr>
<td>System synchronization</td>
<td>Yes</td>
<td>up to 800 A</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Power supply system</td>
<td></td>
</tr>
</tbody>
</table>

*) with ETU: No limitation / with TMTU: depends on cable length
### 3.3.8 Busbar Trunking Systems

#### General

When a planning concept for power supply is developed, it is not only imperative to observe standards and regulations, it is also important to discuss and clarify economic and technical interrelations. The rating and selection of electric equipment, such as distribution boards and transformers, must be performed in such a way that an optimum result for the power system as a whole is kept in mind rather than focusing on individual components.

All components must be sufficiently rated to withstand normal operating conditions as well as fault conditions. Further important aspects to be considered for the creation of an energy concept are:

- Type, use and shape of the building (e.g. high-rise building, low-rise building, multi-storey building)
- Load centers and possible power transmission routes and locations for transformers and main distribution boards
- Building-related connection values according to specific area loads that correspond to the building’s type of use
- Statutory provisions and conditions imposed by building authorities
- Requirements of the power distribution network operator

The result will never be a single solution. Several options must be assessed in terms of their technical and economic impacts. The following requirements are the main points of interest:

- Easy and transparent planning
- Long service life
- High availability
- Low fire load
- Flexible adaptation to changes in the building

Most applications suggest the use of suitable busbar trunking systems to meet these requirements. For this reason, engineering companies increasingly prefer busbar trunking to cable installation for power transmission and distribution. Siemens offers busbar trunking systems ranging from 25 A to 6,300 A.

#### Planning Notes

Considering the complexity of modern building projects, transparency and flexibility of power distribution are indispensable requirements. In industry, the focus is on continuous supply of energy as an essential prerequisite for multi-shift production. Busbar trunking systems meet all these requirements on efficient power distribution by being easily planned, quickly installed and providing a high degree of flexibility and safety. The advantages of busbar trunking systems are:

- Straightforward network configuration
- Low space requirements
- Easy retrofitting in case of changes of locations and consumer loads
- High short-circuit strength and low fire load
- Increased planning security

#### Power transmission

Power from the transformer to the low-voltage switchgear is transmitted by suitable components in the busbar trunking system. These components are installed between transformer and main distribution board, then branching to sub-distribution systems.

Trunking units without tap-off points are used for power transmission. These are available in standard lengths. Besides the standard lengths, the customer can also choose a specific length from various length ranges to suit individual constructive requirements.

#### Power distribution

Power distribution is the main area of application for busbar trunking systems. This means that electricity cannot just be tapped from a permanently fixed point as with a cable installation. Tapping points can be varied and changed as desired within the entire power distribution system.

In order to tap electricity, you just have plug a tap-off unit on the busbar at the tap-off point. This way a variable distribution system is created for linear and/or area-wide, distributed power supply. Tap-off points are provided on either or just one side on the straight trunking units.

For each busbar trunking system, a wide range of tap-off units is available for the connection of equipment and electricity supply.
### Table 3.3-11: Cable/Busbar Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cable</th>
<th>Busbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning, calculation</td>
<td>High determination and calculation expense, the consumer locations must be fixed</td>
<td>Flexible consumer locations, only the total load is required for the planning</td>
</tr>
<tr>
<td>Expansions, changes</td>
<td>High expense, interruptions to operation, calculation, risk of damage to the insulation</td>
<td>Low expense as the tap-off units are hot pluggable</td>
</tr>
<tr>
<td>Space requirements</td>
<td>More space required because of bending radii and the spacing required between parallel cables</td>
<td>Compact directional changes and fittings</td>
</tr>
<tr>
<td>Temperature responses and derating</td>
<td>Limits depend on the laying method and cable accumulation. The derating factor must be determined/calculated</td>
<td>Design verified switchgear assembly, limits from catalog</td>
</tr>
<tr>
<td>Free from halogen</td>
<td>PVC cables are not free from halogen; halogen-free cable is very expensive</td>
<td>Principally free from halogen</td>
</tr>
<tr>
<td>Fire load</td>
<td>Fire load with PVC cable is up to 10 times greater, with PE cable up to 30 times greater than with busbars</td>
<td>Very low, see catalog</td>
</tr>
<tr>
<td>Design verified switchgear assembly</td>
<td>The operational safety depends on the version</td>
<td>Tested system, non-interchangeable assembly</td>
</tr>
</tbody>
</table>

**Benefits**

**System CD-K up to 40 A**

The versatile busbar trunking system for area-wide power distribution to lighting systems:
- Versatile thanks to high degree of protection IP55
- Lower planning costs through simple configuration
- Quick-release plug-in connection for fast assembly
- Variable changes of direction
- Optimum utilization of the busbar line through tap-off points fitted to both sides
- Uniform current loading of the conductors through splitting of the tap-off plugs among the individual phases
- Tap-off plugs allow fast and flexible load relocation
- Transmission of the KNX, DALI protocol for intelligent lighting control directly via the busbar

**System BD01 up to 160 A**

The busbar trunking system for power distribution in trade and commerce:
- High degree of protection up to IP55
- Flexible power supply
- Easy and fast planning
- Time-saving installation
- Reliable mechanical and electrical cables and connections
- High stability, low weight
- Small number of basic modules
- Modular system reduces stock-keeping
- Variable changes of direction
- Multi-purpose tap-off units
- Forced opening and closing of the tap-off point

**System BD2 up to 1,250 A**

The busbar trunking system for power distribution in the aggressive industrial environment:
- High degree of protection up to IP55
- Easy and fast planning
- Time-saving and economic installation
- Safe and reliable operation
- Flexible, modular system providing simple solutions for every application
• Advance power distribution planning without precise knowledge of device locations
• Ready to use in no time thanks to fast and easy installation
• Innovative construction: expansion units to compensate for expansion are eliminated.
• Tap-off units and tap-off points can be coded at the factory
• Uniformly sealable

System LD up to 5,000 A
The perfect busbar trunking system for power distribution in industrial environments:
• High degree of protection up to IP54
• Easy and rapid installation
• Safe and reliable operation
• Space-saving, compact design, up to 5,000 A in one casing
• Load feeders up to 1,250 A
• Design verified connection to distribution board and transformers

System LX up to 6,300 A
The busbar trunking system for power transmission and distribution in buildings:
• High degree of protection up to IP55
• Easy and rapid installation
• Safe and reliable operation
• Load feeders up to 1,250 A
• Design verified connection to distribution board and transformers

System LR up to 6,150 A
The busbar trunking system for power transmission under extreme ambient conditions (IP68):
• Reliable and safe operation
• Quick and easy installation
• Cast resin system up to 6,150 A
• Safe connection to distribution boards and transformers
• High degree of protection IP68 for outdoor applications

Communication-capable busbar trunking system
Communication-capable functional extensions to be combined with known tap-off units:
• For use with the systems BD01, BD2, LD and LX
• Applications:
  – Large-scale lighting control
  – Remote switching and signaling in industrial environments
  – Consumption metering of distributed load feeders
• Interfacing to KNX/EIB, AS-Interface and PROFIBUS bus systems
• Easy contacting of the bus line with insulation displacement method
• Easy and fast planning
• Flexible for extension and modification
• Modular system
• Retrofitting to existing installations possible

Further information

Busbar trunking system selection guide (MobileSpice)
You can order busbar trunking systems up to 1,250 A with the selection guide.

The following configurators are available:
• SIVACON 8PS system CD-K, 25 … 40 A
• SIVACON 8PS system BD01, 40 … 160 A
• SIVACON 8PS system BD2, 160 … 1,250 A

This selection guide is available via the Industry Mall (www.siemens.com/industrymall) and contained on DVD in Catalog CA 01. This DVD is available free-of-charge from your Siemens sales office.

Manual
Busbar trunking system SIVACON 8PS – Planning with SIVACON 8PS
• German: Order no. ASE 01541017-02
• English: Order no. ASE 01541117-02

Brochure
So that energy flows safely– SIVACON 8PS busbar trunking systems
• German: Order no. E10003-E38-9B-D0010
• English: Order no. E10003-E38-9B-D0010-7600

For further information:
http://www.siemens.com/sentron
http://www.siemens.com/sivacon
http://www.siemens.com/tip
Fig. 3.3-21: Overview of busbar trunking systems

1. CD-K system
2. BD01 system
3. BD2 system
4. LR system
5. Communication-capable busbar trunking systems
6. LX system
7. LD system
# Products and Devices

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4 Products and Devices

4.1 High Voltage Circuit Breakers

4.1.1 Circuit Breakers for 72.5 kV up to 800 kV

Circuit breakers are the central part of AIS and GIS switchgear. They have to meet high requirements in terms of:
• Reliable opening and closing
• Consistent quenching performance with rated and short-circuit currents even after many switching operations
• High-performance, reliable, maintenance-free operating mechanisms.

Technology reflecting the latest state of the art and years of operating experience are put to use in constant further development and optimization of Siemens circuit breakers. This makes Siemens circuit breakers able to meet all the demands placed on high-voltage switchgear.

The comprehensive quality system is certified according to DIN EN ISO 9001. It covers development, manufacturing, sales, commissioning and after-sales service. Test laboratories are accredited to EN 45001 and PEHLA/STL.

The modular design

Circuit breakers for air-insulated switchgear are individual components, and are assembled together with all individual electrical and mechanical components of an AIS installation on site.

Due to the consistent application of a modular design, all Siemens circuit breaker types, whether air-insulated or gas-insulated, are made up of the same range of components based on our well-proven platform design (fig. 4.1-1):
• Interrupter unit
• Operating mechanism
• Sealing system
• Operating rod
• Control elements.

Interrupter unit – self-compression arc-quenching principle

The Siemens product range from 72.5 kV up to 800 kV includes high-voltage circuit breakers with self-compression interrupter units – for optimum switching performance under every operating condition for every voltage level.

Self-compression circuit breakers

3AP high-voltage circuit breakers for the complete voltage range ensure optimum use of the thermal energy of the arc in the contact cylinder. This is achieved by the self-compression interrupter unit.

Siemens patented this method for arc quenching in 1973. Since that time, Siemens has continued to develop the technology of the self-compression interrupter unit. One of its technical innovations is that the arc energy is increasingly used to extinguish the arc. In short-circuit breaking operations, the actuating energy required is reduced to the energy needed for mechanical contact movement.

That means that the operating energy is truly minimized. The self-compression interrupter unit allows the use of a compact stored-energy spring mechanism that provides unrestricted high dependability.

Stored-energy spring mechanism – for the complete product range

The operating mechanism is a central part of the high-voltage circuit breakers. The drive concept of the 3AP high-voltage circuit breakers is based on the stored-energy spring principle. The use of such an operating mechanism for voltage ranges of up to 800 kV became appropriate as a result of the development of a self-compression interrupter unit that requires minimal actuating energy.

Advantages of the stored-energy spring mechanism are:
• Highest degree of operational safety: It is a simple and sturdy design and uses the same principle for rated voltages from 72.5 kV up to 800 kV with just a few moving parts. Due to the self-compression design of the interrupter unit, only low actuating forces are required.
• Availability and long service life: Minimal stressing of the latch mechanisms and rolling-contact bearings in the operating mechanism ensure reliable and wear-free transmission of forces.
• Maintenance-free design: The spring charging gear is fitted with wear-free spur gears, enabling load-free decoupling.

Siemens circuit breakers for rated voltage levels from 72.5 kV up to 800 kV are equipped with self-compression interrupter units and stored-energy spring mechanisms.

For special technical requirements such as rated short-circuit breaking currents of 80 kA, Siemens can offer twin-nozzle circuit breaker series 3AQ or 3AT with an electrohydraulic mechanism.
Fig. 4.1-1: Circuit-breaker parts: circuit-breaker for air-insulated switchgear (top), circuit-breaker in SF₆-insulated switchgear (bottom)
The interrupter unit: self-compression system

The conducting path
The current conducting path of the interrupter unit consists of the contact support (2), the base (7) and the movable contact cylinder (6). In the closed position, the current flows via the main contact (4) and the contact cylinder (6); (fig. 4.1-2).

Breaking operating currents
During the opening operation, the main contact (4) opens first, and the current commutates to the still closed arcing contact. During the further course of opening, the arcing contact (5) opens and an arc is drawn between the contacts. At the same time, the contact cylinder (6) moves into the base (7) and compresses the SF₆ gas located there. This gas compression creates a gas flow through the contact cylinder (6) and the nozzle (3) to the arcing contact, extinguishing the arc.

Breaking fault currents
In the event of interrupting high short-circuit breaking currents, the SF₆ gas is heated up considerably at the arcing contact due to the energy of the arc. This leads to a pressure increase in the contact cylinder. During the further course of opening, this increased pressure initiates a gas flow through the nozzle (3), extinguishing the arc. In this case, the arc energy is used to interrupt the fault current. This energy needs not be provided by the operating mechanism.

Major features:
• Self-compression interrupter unit
• Use of the thermal energy of the arc
• Minimized energy consumption
• High reliability for a long time.

The operating mechanism

Stored-energy spring mechanism
Siemens circuit breakers for voltages up to 800 kV are equipped with stored-energy spring mechanisms. These operating mechanisms are based on the same principle that has been proving its worth in Siemens low-voltage and medium-voltage circuit breakers for decades. The design is simple and robust, with few moving parts and a vibration-isolated latch system of the highest reliability. All components of the operating mechanism, the control and monitoring equipment and all terminal blocks are arranged in a compact and convenient way in one cabinet.

Depending on the design of the operating mechanism, the energy required for switching is provided by individual compression springs (i.e., one per pole) or by springs that function jointly on a 3-pole basis.
The principle of the operating mechanism with charging gear and latching is identical on all types (fig. 4.1-3, fig. 4.1-4). Differences between mechanism types are in the number, size and arrangement of the opening and closing springs.

Main features at a glance:
- Uncomplicated, robust construction with few moving parts
- Maintenance-free
- Vibration-isolated latches
- Load-free uncoupling of charging mechanism
- Easy access
- 10,000 operating cycles.

![Operating mechanism](image1)

![Control cubicle](image2)

---

**Fig. 4.1-3: Operating mechanism**

**Fig. 4.1-4: Control cubicle**
4.1.2 Live-Tank Circuit Breakers for 72.5 kV up to 800 kV

Live-tank circuit breakers for air-insulated switchgear

All live-tank circuit breakers are of the same general modular design, as shown in fig. 4.1-5 to fig. 4.1-9.

They consist of the following main components based on our well established platform concept:
- Self-compression interrupter unit
- Stored-energy spring mechanism
- Insulator column (AIS)
- Operating rod
- Circuit breaker base
- Control unit.

The uncomplicated design of the circuit breakers and the use of many similar components, such as interrupter units, operating rods, control cubicles and operating mechanisms, ensure high reliability. The experience Siemens has gained from the use of the many circuit breakers in service has been applied in improvement of the design. The self-compression interrupter unit, for example, has proven its reliability in more than 100,000 installations all over the world.

The control unit includes all necessary devices for circuit breaker control and monitoring, such as:
- Pressure/SF₆ density monitors
- Relays for alarms and lockout
- Operation counters (upon request)
- Local circuit breaker control (upon request)
- Anti-condensation heaters.

Transport, installation and commissioning are performed with expertise and efficiency. The routine-tested circuit breaker is dismantled into a few subassemblies for transportation.

If desired, Siemens can provide appropriately qualified personnel for installation and commissioning.
Products and Devices

4.1 High Voltage Circuit Breakers

**Fig. 4.1-6: 550 kV circuit breaker 3AP2FI**

**Fig. 4.1-7: Sectional view of pole column**

**Fig. 4.1-8: 145 kV circuit breaker 3AP1FG with 3-pole stored-energy spring mechanism**

**Fig. 4.1-9: 3AP1FG on site**
4.1 High Voltage Circuit Breakers

**Table 4.1-1: Technical data of circuit breakers 3AP1, 3AP2 and 3AP4**

<table>
<thead>
<tr>
<th>Type</th>
<th>3AP1</th>
<th>3AP2</th>
<th>3AP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage [kV]</td>
<td>72.5</td>
<td>123</td>
<td>145</td>
</tr>
<tr>
<td>Number of interrupter units per pole</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage/min [kV]</td>
<td>140</td>
<td>230</td>
<td>275</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage/min [kV]</td>
<td>325</td>
<td>550</td>
<td>650</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage/min [kV]</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rated normal current, up to [A]</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Rated short-time withstand current (1 s – 3 s), up to [kA (rms)]</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Rated peak withstand current, up to [kA (peak)]</td>
<td>108</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>Rated short-circuit breaking current, up to [kA (rms)]</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Rated short-circuit making current, up to [kA (peak)]</td>
<td>108</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>Temperature range [°C]</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rated operating sequence</td>
<td>0-0.3 s-CO-3 min-CO or CO-15 s-CO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated break time</td>
<td>3 cycles</td>
<td>2 cycles</td>
<td></td>
</tr>
<tr>
<td>Rated frequency [Hz]</td>
<td>50/60</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Type of operating mechanism</td>
<td>Stored-energy spring mechanism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control voltage [V, DC]</td>
<td>48 ... 250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor voltage [V, DC]</td>
<td>48/60/110/125/220/250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flashover distance [mm]</td>
<td>3,810</td>
<td>3,880</td>
<td>4,360</td>
</tr>
<tr>
<td>Min. creepage distance [mm]</td>
<td>3,180</td>
<td>3,880</td>
<td>3,880</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Height [mm]</td>
<td>3,810</td>
<td>3,880</td>
</tr>
<tr>
<td>Phase spacing (min.) [mm]</td>
<td>3,180</td>
<td>3,880</td>
<td>3,880</td>
</tr>
<tr>
<td>Circuit breaker mass [kg]</td>
<td>1,350</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td>Maintenance after</td>
<td>25 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in accordance with IEC; other values available on request
4.1.3 Dead-Tank Circuit Breakers for 72.5 kV up to 550 kV

Circuit breakers in dead-tank design
For certain substation designs, dead-tank circuit breakers might be required instead of the standard live-tank circuit breakers. The main feature of dead-tank technology is that the interrupter unit is accommodated in an earthed metal housing. The dead-tank circuit breaker offers particular advantages if the protection design requires the use of several current transformers per pole assembly. For this purpose, Siemens can offer dead-tank circuit breaker types (fig. 4.1-10, fig. 4.1-11).

Main features at a glance:
• Reliable opening and closing
  – Proven contact and self-compression arc-quenching system
  – Consistent quenching performance with rated and short-circuit currents – even after many switching operations
  – Similar uncomplicated design for all voltage levels
• High-performance, reliable operating mechanisms
  – Easy-to-actuate spring operating mechanisms
  – Low maintenance, economical and long service life
• Economy
  – Perfect finish
  – Simplified, quick installation process
  – Long maintenance intervals
  – High number of operating cycles
  – Long service life.
• Individual service
  – Close proximity to the customer
  – Order-specific documentation
  – Solutions tailored to specific problems
  – After-sales service available promptly worldwide
• The right qualifications
  – Expertise in all power supply matters
  – More than 40 years of experience with SF₆-insulated circuit breakers
  – A quality system certified to ISO 9001, covering development, manufacture, sales, installation and after-sales service
  – Our dead tank circuit breakers are developed according to the latest version of IEC 62271-1, IEC 62271-100 and ANSI C37.04, ANSI C37.06, C37.09
  – Test laboratories accredited to EN 45001 and PEHLA/STL.
Dead-tank circuit breaker

Type SPS2 and 3AP DT

The type SPS2 power circuit breakers (table 4.1-2) are used for the US and ANSI markets, and the 3AP DT breaker types are offered in IEC markets. Both types are designed as general, definite-purpose circuit breakers for use at maximum rated voltages of 72.5 kV up to 550 kV.

The design

Dead-tank circuit breakers (except for the 550 kV version) consist of three identical pole units mounted on a common support frame. The opening and closing spring of the FA-type operating mechanism is transferred to the moving contacts of the interrupter unit through a system of connecting rods and a rotating seal at the side of each phase.

The connection to the overhead lines and busbars is realized by SF₆-insulated air bushings. The insulators are available in either porcelain or composite (epoxy-impregnated fiberglass tube with silicone rubber sheds) materials.

The tanks and the bushings are charged with SF₆ as at a rated pressure of 6.0 bar. The SF₆ is used for insulation and arc-quenching purposes.

The 3AP2/3 DT for 550 kV (fig. 4.1-13, fig. 4.1-14) consists of two interrupter units in a series that features a simple design. The proven Siemens arc-quenching system ensures faultless operation, consistently high arc-quenching capacity and a long service life, even at high switching frequencies.

Thanks to constant further development, optimization and consistent quality assurance, Siemens self-compression arc-quenching systems meet all the requirements placed on modern high-voltage technology.

A control cubicle mounted at one end of the circuit breaker houses the spring operating mechanism and circuit breaker control components. The interrupter units are located in the aluminum housing of each pole unit. The interrupters use the latest Siemens self-compression arc-quenching system.

The stored-energy spring mechanism is the same design as used within the Siemens 3AP live-tank circuit breakers, GIS and compact switchgear. This design has been documented in service for more than 10 years, and has a well-documented reliability record.

Operators can specify up to four (in some cases, up to six) bushing-type current transformers (CT) per phase. These CTs, mounted externally on the aluminum housings, can be removed without dismantling the bushings.

<table>
<thead>
<tr>
<th>Type</th>
<th>3AP1 DT / SPS2</th>
<th>3AP2/3 DT / SPS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage [kV]</td>
<td>72.5</td>
<td>123</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage [kV]</td>
<td>140/160</td>
<td>230/260</td>
</tr>
<tr>
<td>Rated lighting impulse withstand voltage [kV]</td>
<td>325/350</td>
<td>550</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage [kV]</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rated nominal current up to [A]</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Rated breaking current up to [kA]</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

Operating mechanism type

| Stored-energy spring mechanism |

Table 4.1-2: Technical data of dead-tank circuit breaker
Operating mechanism
The mechanically and electrically trip-free spring mechanism type FA is used on type SPS2 and 3AP1/2 DT circuit breakers. The closing and opening springs are loaded for “O-C-O” operations.

A weatherproofed control cubicle (degree of protection IP55) has a large door, sealed with rubber gaskets, for easy access during inspection and maintenance. Condensation is prevented by heaters that maintain a difference in inside/outside temperature, and by ventilation.

The control system includes all the secondary technical components required for operating the circuit breaker, which are typically installed in the control cubicle. The current transformer connections are also located in the control cubicle.

The control, tripping, motor and heating power supplies are selectable in a great extent. Depending on customer requirements, two standard control versions are available.

Basic version
The basic variant includes all control and monitoring elements that are needed for operation of the circuit breaker. In addition to the elementary actuation functions, it includes:
• 19 auxiliary switch contacts (9 normally open, 9 normally closed, 1 passing contact)
• Operations counter
• Local actuator.

Compact version
In addition to the basic version, this type includes:
• Spring monitoring by motor runtime monitoring
• Heating monitoring (current measuring relay)
• Luminaire and socket attachment with a common circuit breaker to facilitate servicing and maintenance work
• Overvoltage attenuation
• Circuit breaker motor
• Circuit breaker heating.

For further information:
Fax: +49 30 386-20231
Email: support.energy@siemens.com or circuit-breaker@siemens.com
4.1.4. The DTC – Dead Tank Compact – a Compact Switchgear up to 245 kV

The hybrid concept
The hybrid concept combines SF₆-encapsulated components and air-insulated devices. The application of gas-insulated components increases availability of switchgear. According to CIGRE analyses, gas-insulated components are four times more reliable than air-insulated components. The level of encapsulation can be defined in accordance with the requirements of the individual substation layout and the system operator’s project budget. This leads to optimized investments and can be combined with further air-insulated devices.

The modular design
Based on the well-proven modular design, the core components of the main units are based on the same technology that is used in the well-established high-voltage circuit breakers, disconnectors and GIS product family of Siemens.

These components are:
- Self-compression arc-quenching interrupter unit of the AIS 3AP circuit breaker
- Stored-energy spring mechanism
- SF₆-insulated disconnector/earthing switch from the GIS type 8DN8
- Outdoor earthing switch from the disconnector product range (fig. 4.1-15 and fig. 4.1-16).

This allows for providing flexible solutions according to different substation configurations:
- Circuit breaker with single-pole or three-pole operating mechanism
- Disconnector, earthing switch, high-speed earthing switch
- Current transformer, voltage transformer and voltage detecting system
- Cable connections possible at various positions
- Bushings available as porcelain or composite insulators
- Additional separations of gas compartment, with SF₆ density monitor on request
- Double breaker modules for ultra compact substation designs
- Possibility of combination with stand-alone components, e.g. disconnector module with voltage transformer (fig. 4.1-17).

Fig. 4.1-15: Possible components for the 3AP1 DTC
1. Bushing
2. Current transformer
3. Circuit breaker with self-compression principle
4. Three-position disconnector and earthing switch
5. Voltage transformer
6. Cable connection assembly
7. High-speed earthing switch

Fig. 4.1-16: 3AP1 DTC 145 kV
**Highlights and characteristics**

- Simple SF₆ filling and monitoring, one gas compartment possible (separation optional)
- Flexibility in confined spaces and extreme environmental conditions, e.g. low temperature applications down to –55 °C
- Single-pole encapsulation: no 3-phase fault possible and fast replacement of one pole (spare part: one pole)
- Safety can be enhanced by separated gas compartments, e.g. between circuit breaker and disconnector.
- Complete module can be moved with a fork-lift truck
- Fast installation and commissioning: easy assembly of fully manufactured and tested modular units
- Less maintenance effort: first major inspection after 25 years
- Service life minimum 50 years
- Single-pole and three-pole operated drive system for 145 kV and 245 kV (fig. 4.1-18).

**Standard**

The international IEC 62271-205 standard treats compact switchgear assemblies for rated voltages above 52 kV. The used terminology for the hybrid concept is the so-called mixed technology switchgear (MTS).

Our compact switchgear is fully type-tested in accordance with this standard.

We have one of the most modern testing laboratories available which are certified and part of the European network of independent testing organizations (PEHLA).

Also other international testing laboratories (KEMA, CESI) certify our circuit breakers’ high quality standards (fig. 4.1-19, table 4.1-3).

---

**Table 4.1-3: Technical data of 3AP1 DTC**

<table>
<thead>
<tr>
<th></th>
<th>3AP1 DTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage [kV]</td>
<td>145</td>
</tr>
<tr>
<td>Rated normal current [A]</td>
<td>3,150</td>
</tr>
<tr>
<td>Rated frequency [Hz]</td>
<td>50/60</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage [kV]</td>
<td>650</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage [kV]</td>
<td>275</td>
</tr>
<tr>
<td>Rated short-time withstand current (3 s) [kA]</td>
<td>40</td>
</tr>
<tr>
<td>Rated peak withstand current [kA]</td>
<td>108</td>
</tr>
</tbody>
</table>
4.1.5. The DCB – Disconnecting Circuit Breaker

ONE device – TWO functions
In switchgear, isolating distances in air combined with circuit breakers are used to protect the circuit state in the grid.

Siemens developed a combined device in which the isolating distance has been integrated in the SF₆ gas compartment on the basis of an SF₆-insulated circuit breaker in order to reduce environmental influence. The combined device (DCB – Disconnecting Circuit breaker) is used as a circuit breaker and additionally as a disconnector – two functions combined in one device (fig. 4.1-20, fig. 4.1-21).

The DCB was developed on the basis of a higher-rated standard 3AP circuit breaker to provide the higher dielectric properties required and type-tested in accordance with IEC 62271-108 for disconnecting circuit breakers. Due to the SF₆-insulated disconnector function there is no visible opening distance anymore. The proper function of the kinematic chain has been most thoroughly verified. The closest attention was paid to developing a mechanical interlock which guarantees that the circuit breaker remains in open position when used as a disconnector. When this mechanical interlock is activated, it is impossible to close the breaker. The current status of the DCB can also be controlled electrically and is shown by well visible position indicators.

In addition, an air-insulated earthing switch could be mounted onto the supporting structure. Its earthing function was implemented by a well-established earthing switch with a maintenance-free contact system from Ruhrtal, a Siemens Company.

The disconnecting circuit breakers are type tested according to class M2 and C2 of IEC 62271-108, a specific standard for combined switching devices.

Combining the strengths of our well proven product portfolio, we can provide a new type of device which fulfills the system operator’s needs for highest reliability and safety, while saving space and costs at the same time (table 4.1-4).
### 4.1 High Voltage Circuit Breakers

#### Highlights and characteristics
- Maximum reliability by applying well-proven and established components from Siemens circuit breakers and Ruhrtal earthing switches
- Maximum availability due to longer maintenance intervals
- Economical, space-saving solution by combining the circuit breaker and the disconnector in one device
- Minimized costs for transportation, maintenance, installation and commissioning as well as civil works (foundation, steel, cable ducts, etc.)
- Compact and intelligent interlocking and position indicating device
- Optionally available without earthing switch
- Porcelain or composite insulators obtainable (fig. 4.1-20).

#### Table 4.1-4: Technical data of 3AP DCB

<table>
<thead>
<tr>
<th>Feature</th>
<th>3AP1 DCB</th>
<th>3AP2 DCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage [kV]</td>
<td>145</td>
<td>420</td>
</tr>
<tr>
<td>Number of interrupter units per pole</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Rated power frequency withstand voltage [kV]</td>
<td>275/315</td>
<td>520/610</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage [kV]</td>
<td>650/750</td>
<td>1,425/1,665</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage [kV]</td>
<td>n.a.</td>
<td>1,050/1,245</td>
</tr>
<tr>
<td>Rated normal current up to [A]</td>
<td>3,150</td>
<td>4,000</td>
</tr>
<tr>
<td>Rated short-circuit breaking current [kA\text{rms}]</td>
<td>40 (31.5)</td>
<td>40</td>
</tr>
<tr>
<td>Ambient air temperature *) [°C]</td>
<td>–40 … +40</td>
<td>–40 … +40</td>
</tr>
<tr>
<td>Insulating medium</td>
<td>SF₆</td>
<td>SF₆</td>
</tr>
<tr>
<td>Classification CB</td>
<td>M2, C2</td>
<td>M2, C2</td>
</tr>
<tr>
<td>Classification DS</td>
<td>M2</td>
<td>M2</td>
</tr>
<tr>
<td>Insulators</td>
<td>composite **)</td>
<td>composite</td>
</tr>
<tr>
<td>Attached earthing switch (optional)</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Type-tested according to</td>
<td></td>
<td>IEC 62271-108</td>
</tr>
<tr>
<td>(*) Other ambient temperature values on request</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(**) Or porcelain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Fig. 4.1-22: 3AP2 DCB 420 kV*
4.2 High VoltageDisconnectors

4.2.1 Disconnectors andEarthing Switches

General
 Disconnectors are an essential part of electrical power substations. They indicate a visible isolating distance in air isolated gap.

Modern production technologies and investments in our production sites worldwide ensure sustained product and process quality in accordance with the high standards of Siemens.

Siemens disconnectors fulfil the system operators’ requirements for low life-cycle costs with maximum availability and continuous economic service by:

- Delivery of completely routine-tested and pre-adjusted assembly groups
- Easy erection and commissioning
- Maintenance-free bearings and contact systems
- Lifetime technical support
- The contact systems have proved their reliability through decades of service.

The most important features are:

- Self-resilient contact fingers – no further spring elements are necessary to generate the contact force
- Silver-plated contact surface provides maximum conductivity without regular greasing lubrication
- Factory set contact forces; no re-adjustments required during service life
- Ice layers up to 20 mm can be broken without difficulties
- Maintenance-free contact system for up to 25 years.

The reliability of Siemens disconnectors and earthing switches over many decades is ensured by a comprehensive testing and quality assurance system certified according to DIN EN ISO 9001.

Center-break disconnectors

The center-break disconnector is the most frequently used disconnector type. The disconnector base supports the operating mechanism and two rotating porcelain support insulators. The current path arms which are fixed to the insulators open in the center. Each rotating unit comprises two high-quality ball bearings and is designed for high mechanical loads. They are lubricated and maintenance-free for the entire service life (fig. 4.2-1).

The current path of the center-break disconnector consists of only a few components, thus the number of contact resistances is reduced to a minimum. The main contact system of block contact and spread contact fingers assures a steady contact force even after decades of operation (fig. 4.2-2).
Pantograph disconnectors
This type is generally used in double-busbar systems to connect the two busbars or a busbar to a line.

The main components of a pantograph disconnector are (fig. 4.2-3):
- Scissor arms (1)
- Bearing frame (2)
- Support insulator (3)
- Rotating insulator (4)
- Motor operating mechanism (5).

Rotary contact systems inside the joints, which have thermal and dynamic current carrying capacity, are used for current transfer. The geometry of the pantograph ensures optimum operational behavior.

The specific contact force is adjusted in the factory and remains unchanged during service life. Ice loads of up to 20 mm can be broken without difficulties.

In both end positions of the disconnector, the rotary arm in the bearing frame is switched beyond the dead center point. The switch position cannot be changed by external forces. The rigidity of the scissor arms prevents opening during a short-circuit.

Pantograph disconnectors with rated voltages from 123 kV up to 362 kV are optionally equipped with group operating mechanisms or 1-pole operating mechanisms. All pantograph disconnectors for higher rated voltages are equipped with 1-pole operating mechanisms.

Vertical-break disconnectors
The current path of the vertical-break disconnector opens vertically and requires a minimum phase distance (fig. 4.2-4).

The current path performs two movements:
- A vertical swinging movement
- A rotary movement around its own longitudinal axis.

The rotary movement generates the contact force and breaks possible ice layers.

In both end positions, the rotary arm is switched beyond the dead center point. This locks the current path in the short-circuit-proof CLOSED position, and prevents the current path from switching to the OPEN position under external forces.

The ample distance between support insulator and rotating insulator ensures dielectric strength of the parallel insulation even under saline fog conditions.

The movable part of the current path is one single subassembly which is pre-adjusted and routine-tested at the factory. This allows for easy and quick installation and commissioning on site.
Double-side break disconnectors
The double-side break disconnector features three support insulators. The support insulator in the center is mounted on a rotating unit and carries the current path. Both end support insulators are fixed.

The main application of double-side break disconnectors are substations with limited phase distances and where vertical opening of the current path is not possible. High mechanical terminal loads are possible due to the compact and stable design. It can also be combined with an integrated surge arrester (fig. 4.2-5).

For voltage levels up to 245 kV, the contact fingers of the double-side break disconnectors are integrated into the current path tube, and the fixed contacts consist of contact blocks. The current path performs a horizontal swinging movement, and the contact force is generated by spreading the contact fingers while sliding on the contact blocks.

For voltage levels higher than 245 kV, contact strips are attached to the ends of the current path tubes. The contact fingers are part of the fixed contacts. In this design, the current path performs a combined swinging and rotary movement. After completion of the swinging movement, the contact force is generated by the rotation of the current path around its own axis.

Knee-type disconnectors
This disconnector type has the smallest horizontal and vertical space requirements. The knee-type disconnector has two fixed and one rotating insulator. Thanks to its folding-arm design, only limited overhead clearance is required, which results in lower investment costs (fig. 4.2-6).

Earthing switches
The use of earthing switches (fig. 4.2-7) ensures absolute de-energization of high-voltage components in a circuit or switchgear.

Free-standing earthing switches are available for all voltage levels up to 800 kV.

Suitable built-on earthing switches are available for all disconnector types of the Siemens scope of supply.

According to the system operators’ requirements, built-on earthing switches can be arranged laterally or in integrated arrangement with respect to the position of the main current path of the disconnector when needed.

Optionally, all earthing switches can be designed for switching induced inductive and capacitive currents according to IEC 62271-102, Class A or Class B.

**Motor operating mechanisms**

The motor operating mechanisms consist of three main subassemblies:
- Corrosion-resistant housing
- Gear unit with motor
- Electrical equipment with auxiliary switch.

The motor operating mechanism can also be operated manually by a hand crank which can be inserted in the cubicle. The insertion of the hand crank automatically isolates the motor circuit for safety purposes. Heaters are provided to prevent condensation (fig. 4.2-8).

The auxiliary switch is custom-fit to the gear unit and signals the switch position with absolute reliability. This ensures safe substation operation.

After the motor starts, the auxiliary switch moves and the switch position signal is cancelled. The disconnector operates thereafter until the end position is reached.

The auxiliary switch then moves again and issues the switch position signal.

This sequence ensures that the CLOSED position is indicated only after the disconnector is locked and short-circuit-proof, and the rated current can be carried. The OPEN position is indicated only after the opened current path has reached the nominal dielectric strength.

An overview of Siemens disconnectors is shown in table 4.2-1 to table 4.2-5.
## Technical data

<table>
<thead>
<tr>
<th>Design</th>
<th>Center break</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>72.5 123 145 170 245 300 362 420 550</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage 50 Hz/1 min</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases [kV]</td>
<td>140 160 230 265 275 315 325 460 530 435 450 520 520 620 610 800</td>
</tr>
<tr>
<td>Across the isolating distance [kV]</td>
<td>140 160 230 265 275 315 325 460 530 435 450 520 520 620 610 800</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage 1.2/50 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases [kV]</td>
<td>325 375 550 630 650 750 860 1,050 1,050 (+170) 1,175 1,175 (+205) 1,425 1,425 (+240) 1,550 1,550 (+315)</td>
</tr>
<tr>
<td>Across the isolating distance [kV]</td>
<td>325 375 550 630 650 750 860 1,050 1,050 (+170) 1,175 1,175 (+205) 1,425 1,425 (+240) 1,550 1,550 (+315)</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage 250/2,500 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases [kV]</td>
<td>– – – – – 850 950 1,050 (+245) 1,050 900 (+345) 1,175 900 (+450)</td>
</tr>
<tr>
<td>Across the isolating distance [kV]</td>
<td>– – – – – 700 (+245) 800 (+295) 900 (+345) 900 (+450)</td>
</tr>
<tr>
<td>Rated normal current up to [A]</td>
<td>4,000</td>
</tr>
<tr>
<td>Rated peak withstand current up to [kA]</td>
<td>160</td>
</tr>
<tr>
<td>Rated short-time withstand current up to [kA]</td>
<td>63</td>
</tr>
<tr>
<td>Rated duration of short circuit [s]</td>
<td>1/3</td>
</tr>
<tr>
<td>Icing class</td>
<td>10/20</td>
</tr>
<tr>
<td>Temperature range [°C]</td>
<td>–50/+50</td>
</tr>
<tr>
<td>Operating mechanism type</td>
<td>Motor operation/Manual operation</td>
</tr>
<tr>
<td>Control voltage [V, DC]</td>
<td>60/110/125/220</td>
</tr>
<tr>
<td>[V, AC]</td>
<td>220…230, 1~, 50/60 Hz</td>
</tr>
<tr>
<td>Motor voltage [V, DC]</td>
<td>60/110/125/220</td>
</tr>
<tr>
<td>[V, AC]</td>
<td>110/125/220, 1~, 50/60 Hz</td>
</tr>
<tr>
<td>220/380/415, 3~, 50/60 Hz</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>25 years</td>
</tr>
</tbody>
</table>

Table 4.2-1: Center-break disconnector
### Technical data

<table>
<thead>
<tr>
<th>Design</th>
<th>Pantograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>145</td>
</tr>
<tr>
<td>170</td>
<td>245</td>
</tr>
<tr>
<td>300</td>
<td>362</td>
</tr>
<tr>
<td>420</td>
<td>550</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage 50 Hz/1 min</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>230</td>
<td>265</td>
</tr>
<tr>
<td>275</td>
<td>315</td>
</tr>
<tr>
<td>325</td>
<td>375</td>
</tr>
<tr>
<td>460</td>
<td>435</td>
</tr>
<tr>
<td>450</td>
<td>520</td>
</tr>
<tr>
<td>520</td>
<td>620</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>226</td>
<td>265</td>
</tr>
<tr>
<td>256</td>
<td>315</td>
</tr>
<tr>
<td>325</td>
<td>375</td>
</tr>
<tr>
<td>411</td>
<td>450</td>
</tr>
<tr>
<td>411</td>
<td>520</td>
</tr>
<tr>
<td>465</td>
<td>520</td>
</tr>
<tr>
<td>519</td>
<td>620</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage 1.2/50 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>550</td>
<td>630</td>
</tr>
<tr>
<td>650</td>
<td>750</td>
</tr>
<tr>
<td>750</td>
<td>860</td>
</tr>
<tr>
<td>1,050</td>
<td>1,200</td>
</tr>
<tr>
<td>1,050 (+170)</td>
<td>1,175 (+205)</td>
</tr>
<tr>
<td>1,175 (+240)</td>
<td>1,425 (+315)</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>519</td>
<td>620</td>
</tr>
<tr>
<td>541</td>
<td>650</td>
</tr>
<tr>
<td>550</td>
<td>620</td>
</tr>
<tr>
<td>750</td>
<td>860</td>
</tr>
<tr>
<td>1,050 (+170)</td>
<td>1,175 (+205)</td>
</tr>
<tr>
<td>1,175 (+240)</td>
<td>1,425 (+315)</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage 250/2,500 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>850 (+245)</td>
</tr>
<tr>
<td>–</td>
<td>950 (+295)</td>
</tr>
<tr>
<td>–</td>
<td>1,050 (+345)</td>
</tr>
<tr>
<td>–</td>
<td>1,175 (+450)</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>800 (+295)</td>
</tr>
<tr>
<td>–</td>
<td>900 (+345)</td>
</tr>
<tr>
<td>–</td>
<td>900 (+450)</td>
</tr>
<tr>
<td>Rated normal current up to</td>
<td>[A]</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>5,000</td>
</tr>
<tr>
<td>Rated peak withstand current up to</td>
<td>[kA]</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>200</td>
</tr>
<tr>
<td>Rated short-time withstand current up to</td>
<td>[kA]</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>80</td>
</tr>
<tr>
<td>Rated duration of short circuit</td>
<td>[s]</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>1/3</td>
</tr>
<tr>
<td>Icing class</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>10/20</td>
</tr>
<tr>
<td>Temperature range</td>
<td>[°C]</td>
</tr>
<tr>
<td>–</td>
<td>–50/+50</td>
</tr>
<tr>
<td>Operating mechanism type</td>
<td></td>
</tr>
<tr>
<td>Motor operation/Manual operation</td>
<td></td>
</tr>
<tr>
<td>Control voltage</td>
<td>[V, DC]</td>
</tr>
<tr>
<td>60/110/125/220</td>
<td>220...230, 1~, 50/60 Hz</td>
</tr>
<tr>
<td>[V, AC]</td>
<td></td>
</tr>
<tr>
<td>Motor voltage</td>
<td>[V, DC]</td>
</tr>
<tr>
<td>60/110/125/220</td>
<td>110/125/220, 1~, 50/60 Hz</td>
</tr>
<tr>
<td>[V, AC]</td>
<td>220/380/415, 3~, 50/60 Hz</td>
</tr>
<tr>
<td>Maintenance</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>25 years</td>
</tr>
</tbody>
</table>

*Table 4.2-2: Pantograph disconnector*
### Technical data

<table>
<thead>
<tr>
<th>Design</th>
<th>Vertical break</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>123 145 170 245 300 362 420 550</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage 50 Hz/1 min</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases [kV]</td>
<td>230 265 275 315 325 460 435 450 520 610 620</td>
</tr>
<tr>
<td>Across the isolating distance [kV]</td>
<td>230 265 275 315 325 460 435 450 520 610 620</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage 1.2/50 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases [kV]</td>
<td>550 630 650 750 750 1,050 1,050 (+170) 1,175 1,425 1,550 (+315)</td>
</tr>
<tr>
<td>Across the isolating distance [kV]</td>
<td>550 630 650 750 750 1,050 1,050 (+170) 1,175 1,425 1,550 (+315)</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage 250/2,500 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases [kV]</td>
<td>– – – – – 850 700 (+245) 950 800 (+295) 1,050 900 (+345) 1,175 900 (+450)</td>
</tr>
<tr>
<td>Across the isolating distance [kV]</td>
<td>– – – – – 850 700 (+245) 950 800 (+295) 1,050 900 (+345) 1,175 900 (+450)</td>
</tr>
<tr>
<td>Rated normal current up to [A]</td>
<td>4,000</td>
</tr>
<tr>
<td>Rated peak withstand current up to [kA]</td>
<td>160</td>
</tr>
<tr>
<td>Rated short-time withstand current up to [kA]</td>
<td>160</td>
</tr>
<tr>
<td>Rated duration of short circuit [s]</td>
<td>1/3</td>
</tr>
<tr>
<td>Icing class</td>
<td>10/20</td>
</tr>
<tr>
<td>Temperature range [°C]</td>
<td>−50/+50</td>
</tr>
<tr>
<td>Operating mechanism type</td>
<td>Motor operation/Manual operation</td>
</tr>
<tr>
<td>Control voltage [V, DC]</td>
<td>60/110/125/220</td>
</tr>
<tr>
<td>[V, AC]</td>
<td>220...230, 1~ 50/60 Hz</td>
</tr>
<tr>
<td>Motor voltage [V, DC]</td>
<td>60/110/125/220</td>
</tr>
<tr>
<td>[V, AC]</td>
<td>110/125/230, 1~ 50/60 Hz</td>
</tr>
<tr>
<td></td>
<td>220/380/415, 3~ 50/60 Hz</td>
</tr>
<tr>
<td>Maintenance</td>
<td>25 years</td>
</tr>
</tbody>
</table>

*Table 4.2-3: Vertical-break disconnector*
### Technical data

<table>
<thead>
<tr>
<th>Design</th>
<th>Knee-type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>123</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage 50 Hz/1 min</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage 1.2/50 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage 250/2,500 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>Rated normal current up to</td>
<td>[A]</td>
</tr>
<tr>
<td>Rated peak withstand current up to</td>
<td>[kA]</td>
</tr>
<tr>
<td>Rated short-time withstand current up to</td>
<td>[kA]</td>
</tr>
<tr>
<td>Rated duration of short circuit</td>
<td>[s]</td>
</tr>
<tr>
<td>Icing class</td>
<td>–</td>
</tr>
<tr>
<td>Temperature range</td>
<td>[°C]</td>
</tr>
<tr>
<td>Operating mechanism type</td>
<td>Motor operation/Manual operation</td>
</tr>
<tr>
<td>Control voltage</td>
<td>[V, DC]</td>
</tr>
<tr>
<td></td>
<td>[V, AC]</td>
</tr>
<tr>
<td>Motor voltage</td>
<td>[V, DC]</td>
</tr>
<tr>
<td></td>
<td>[V, AC]</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>–</td>
</tr>
</tbody>
</table>

*Table 4.2-4: Knee-type disconnector*
### Technical data

<table>
<thead>
<tr>
<th>Design</th>
<th>Double-side break</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>123 145 170 245 300 420 550 800</td>
</tr>
<tr>
<td>Rated power-frequency withstand voltage 50 Hz/1 min</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage 1.2/50 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage 250/2,500 µs</td>
<td></td>
</tr>
<tr>
<td>To earth and between phases</td>
<td>[kV]</td>
</tr>
<tr>
<td>Across the isolating distance</td>
<td>[kV]</td>
</tr>
<tr>
<td>Rated normal current up to</td>
<td>[A]</td>
</tr>
<tr>
<td>Rated peak withstand current up to</td>
<td>[kA]</td>
</tr>
<tr>
<td>Rated short-time withstand current up to</td>
<td>[kA]</td>
</tr>
<tr>
<td>Rated duration of short circuit</td>
<td>[s]</td>
</tr>
<tr>
<td>Icing class</td>
<td>–50/+50</td>
</tr>
<tr>
<td>Operating mechanism type</td>
<td>Motor operation/Manual operation</td>
</tr>
<tr>
<td>Control voltage</td>
<td>[V, DC]</td>
</tr>
<tr>
<td></td>
<td>[V, AC]</td>
</tr>
<tr>
<td>Motor voltage</td>
<td>[V, DC]</td>
</tr>
<tr>
<td></td>
<td>[V, AC]</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>25 years</td>
</tr>
</tbody>
</table>

*Table 4.2-5: Double-side break*

For further information, please contact:
Fax: +49 30 386-25867
Email: support.energy@siemens.com
4.3 Vacuum Switching Technology and Components for Medium Voltage

4.3.1 Overview of Vacuum Switching Components

Medium-voltage equipment is available in power stations (in generators and station supply systems) and in transformer substations (of public systems or large industrial plants) of the primary distribution level. Transformer substations receive power from the high-voltage system and transform it down to the medium-voltage level. Medium-voltage equipment is also available in secondary transformer or transfer substations (secondary distribution level), where the power is transformed down from medium to low voltage and distributed to the end consumer.

The product line of the medium-voltage switching devices contains (fig. 4.3-1):
- Circuit-breakers
- Switches
- Contactors
- Disconnectors
- Switch-disconnectors
- Earthing switches

Requirements

In CLOSED condition, the switching device has to offer minimum resistance to the flow of normal and short-circuit currents. In OPEN condition, the open contact gap must withstand the appearing voltages safely. All live parts must be sufficiently isolated to earth and between phases when the switching device is open or closed.

The switching device must be able to close the circuit if voltage is applied. For disconnectors, however, this condition is only requested for the de-energized state, except for small load currents.

The switching device should be able to open the circuit while current is flowing. This is not requested for disconnectors. The switching device should produce switching overvoltages as low as possible.
### 4.3 Vacuum Switching Technology and Components for Medium Voltage

#### 4.3.2 Selection of Components by Ratings

The switching devices and all other equipment must be selected for the system data available at the place of installation. This system data defines the ratings of the components (table 4.3-1).

**Rated insulation level**

The rated insulation level is the dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance.

The dielectric strength is the capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages). The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2/50 µs and a power-frequency withstand voltage test (50 Hz/1 min).

**Rated voltage**

The rated voltage is the upper limit of the highest system voltage the device is designed for. Because all high-voltage switching devices are zero-current interrupters – except for some fuses – the system voltage is the most important dimensioning criterion. It determines the dielectric stress of the switching device by means of the transient recovery voltage and the recovery voltage, especially while switching off.

**Rated normal current**

The rated normal current is the current that the main circuit of a device can continuously carry under defined conditions. The heating of components – especially of contacts – must not exceed defined values. Permissible temperature rises always refer to the ambient air temperature. If a device is mounted in an enclosure, it is possible that it may not be loaded with its full rated current, depending on the quality of heat dissipation.

**Rated peak withstand current**

The rated peak withstand current is the peak value of the first major loop of the short-circuit current during a compensation process after the beginning of the current flow that the device

<table>
<thead>
<tr>
<th>Circuit-breakers</th>
<th>Disconnectors</th>
<th>Switch-disconnectors</th>
<th>Earthing switches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit-breakers must make and break all currents within the scope of their ratings, from small inductive and capacitive load currents up to the short-circuit current, and this must occur under all fault conditions in the power supply system, including earth faults and phase opposition. Outdoor circuit-breakers have the same applications, but are also exposed to weather influences.</td>
<td>Disconnectors are used for no-load closing and opening operations. Their function is to “isolate” downstream equipment so they can be worked on.</td>
<td>A switch-disconnector is to be understood as the combination of a switch and a disconnector, or a switch with isolating distance.</td>
<td>Earthing switches earth isolated circuits. Make-proof earthing switches earth circuits without danger, even if voltage is present, that is, also in the event that the circuit to be earthed was accidentally not isolated.</td>
</tr>
<tr>
<td>Switches</td>
<td>Fig. 4.3-1: Product line of medium-voltage switching devices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switches must make and break normal currents up to their rated normal current, and be able to make on existing short circuits (up to their rated short-circuit making current). However, they cannot break any short-circuit currents.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contactors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contactors are load breaking devices with a limited making and breaking capacity. They are used for high switching rates but can neither make nor break short-circuit currents.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
can carry in closed state. It is a measure for the electrodynamic (mechanical) load of an electrical component. For devices with full making capacity, this value is not relevant (see the paragraph “Rated short-circuit making current” later in this section).

**Rated breaking current**
The rated breaking current is the load breaking current in normal operation. For devices with full breaking capacity and without a critical current range, this value is not relevant (see the paragraph “Rated short-circuit breaking current” later in this section).

**Rated short-circuit breaking current**
The rated short-circuit breaking current is the root-mean-square value of the breaking current in the event of short-circuit at the terminals of the switching device.

<table>
<thead>
<tr>
<th>Component designation</th>
<th>Rated insulation level</th>
<th>Rated voltage</th>
<th>Rated normal current</th>
<th>Rated peak withstand current</th>
<th>Rated breaking current</th>
<th>Rated short-circuit breaking current</th>
<th>Rated short-circuit making current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching devices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit-breaker</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>–</td>
<td>–</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Switch</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>–</td>
<td>■</td>
<td>■ 1)</td>
<td>■</td>
</tr>
<tr>
<td>Switch-disconnector</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>–</td>
<td>–</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Disconnector</td>
<td>■</td>
<td>–</td>
<td>■</td>
<td>■</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Earthing switch</td>
<td>■</td>
<td>–</td>
<td>–</td>
<td>■</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Make-proof earthing switch</td>
<td>■</td>
<td>■</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>■</td>
</tr>
<tr>
<td>Contactor</td>
<td>■</td>
<td>■</td>
<td>–</td>
<td>■</td>
<td>■</td>
<td>■ 1)</td>
<td>■ 1)</td>
</tr>
</tbody>
</table>

■ Influence on selection of component – No influence on selection of component

1) Limited short-circuit making capacity

Table 4.3-1: Table of switching devices according to ratings

**Rated short-circuit making current**
The rated short-circuit making current is the peak value of the making current in the event of short-circuit at the terminals of the switching device. This stress is greater than that of the rated peak withstand current, because dynamic forces may work against the contact movement.

**Standards**
The switching devices, and also non-switching components, are subject to national and international standards.
4.3.3 Vacuum Circuit-Breakers

Siemens medium-voltage vacuum circuit-breakers are available with rated voltages up to 36 kV and rated short-circuit breaking currents up to 72 kA (table 4.3-3). They are used:
- For universal installation in all customary medium-voltage switchgear types
- As 1-pole or multi-pole medium-voltage circuit-breakers for all switching duties in indoor switchgear
- For breaking resistive, inductive and capacitive currents
- For switching generators
- For switching contact lines (1-pole traction circuit-breakers).

Switching duties

The switching duties of the circuit-breaker depend partly upon its type of operating mechanism:
- Stored-energy mechanism
- For synchronizing and rapid load transfer
- For auto-reclosing
- Spring-operated mechanism (spring CLOSED, stored-energy OPEN) for normal closing and opening.

Switching duties in detail

Synchronizing
The closing times during synchronizing are so short that, when the contacts touch, there is still sufficient synchronism between the systems to be connected in parallel.

Rapid load transfer
The transfer of consumers to another incoming feeder without interrupting operation is called rapid load transfer. Vacuum circuit-breakers with stored-energy mechanisms feature the very short closing and opening times required for this purpose. Beside other tests, vacuum circuit-breakers for rapid load transfer have been tested with the operating sequence O-3 min-CO-3 min-CO at full rated short-circuit breaking current according to the standards. They even control the operating sequence O-0.3 s-CO-3 min-CO up to a rated short-circuit breaking current of 31.5 kA.

Auto-reclosing
This is required in overhead lines to clear transient faults or short-circuits that could be caused by, for example, thunder-storms, strong winds or animals. Even at full short-circuit current, the vacuum circuit-breakers for this switching duty leave such short dead times between closing and opening that the de-energized time interval is hardly noticeable to the power supply to the consumers. In the event of unsuccessful auto-reclosing, the faulty feeder is shut down definitively. For vacuum circuit-breakers with the auto-reclosing feature, the operating sequence O-0.3 s-CO-3 min-CO must be complied with according to IEC 62 271-100, whereas an unsuccessful auto-reclosing only requires the operating sequence O-0.3 s-CO.

Auto-reclosing in traction line systems
To check the traction line system via test resistors for the absence of short-circuits after a short-circuit shutdown, the operating sequence is O-15 s-CO.

Multiple-shot reclosing
Vacuum circuit-breakers are also suitable for multiple-shot reclosing, which is mainly applicable in English-speaking countries. The operating sequence O-0.3 s-CO-15 s-CO-15 s-CO is required.

Switching of transformers
In the vacuum circuit-breaker, the chopping current is only 2 to 3 A due to the special contact material used, which means that no hazardous overvoltages will appear when unloaded transformers are switched off.

Breaking of short-circuit currents
While breaking short-circuit currents at the fault location directly downstream from transformers, generators or current-limiting reactors, the full short-circuit current can appear first; second, the initial rate of rise of the transient recovery voltage can be far above the values according to IEC 62 271-100. There may be initial rates of rise up to 10 kVs, and while switching off short-circuits downstream from reactors, these may be even higher. The circuit-breakers are also adequate for this stress.

Switching of capacitors
Vacuum circuit-breakers are specifically designed for switching capacitive circuits. They can switch off capacitors up to the maximum battery capacities without restrikes, and thus without overvoltages. Capacitive current breaking is generally tested up to 400 A. These values are technically conditioned by the testing laboratory. Operational experience has shown that capacitive currents are generally controlled up to 70 % of the rated normal current of the circuit-breaker. When capacitors are connected in parallel, currents up to the short-circuit current can appear, which may be hazardous for parts of the system due to their high rate of rise. Making currents up to 20 kA (peak value) are permissible; higher values are can be achieved if specifically requested.

Switching of overhead lines and cables
When unloaded overhead lines and cables are switched off, the relatively small capacitive currents are controlled without restrikes, and thus without overvoltages.
Switching of motors
When small high-voltage motors are stopped during start-up, switching overvoltages may arise. This concerns high-voltage motors with starting currents up to 600 A. The magnitude of these overvoltages can be reduced to harmless values by means of special surge limiters. For individually compensated motors, no protective circuit is required.

Switching of generators
When generators with a short-circuit current of < 600 A are operated, switching overvoltages may arise. In this case, surge limiters or arresters should be used.

Switching of filter circuits
When filter circuits or inductor-capacitor banks are switched off, the stress for the vacuum circuit-breaker caused by the recovery voltage is higher than when switching capacitors. This is due to the series connection of the inductor and the capacitor, and must be taken into account for the rated voltage when the vacuum circuit-breaker is selected.

Switching of arc furnaces
Up to 100 operating cycles are required per day. The vacuum circuit-breaker type 3AH4 is especially adequate for this purpose. Due to the properties of the load circuit, the currents can be asymmetrical and distorted. To avoid resonance oscillations in the furnace transformers, individually adjusted protective circuits are necessary.
### Portfolio of vacuum circuit-breakers

<table>
<thead>
<tr>
<th>Rated short-circuit breaking current</th>
<th>Rated normal current</th>
<th>Rated voltage and frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 kA</td>
<td>800 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>1,250 A</td>
<td></td>
</tr>
<tr>
<td>13.1 kA</td>
<td>800 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>1,250 A</td>
<td>3AH5</td>
</tr>
<tr>
<td>16 kA</td>
<td>800 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>1,250 A</td>
<td>3AH5</td>
</tr>
<tr>
<td></td>
<td>2,000 A</td>
<td>SION</td>
</tr>
<tr>
<td>20 kA</td>
<td>800 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>1,250 A</td>
<td>3AH5</td>
</tr>
<tr>
<td></td>
<td>2,000 A</td>
<td>3AH5</td>
</tr>
<tr>
<td></td>
<td>2,500 A</td>
<td></td>
</tr>
<tr>
<td>25 kA</td>
<td>800 A</td>
<td>SION</td>
</tr>
<tr>
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<td>1,250 A</td>
<td>3AH5</td>
</tr>
<tr>
<td></td>
<td>2,000 A</td>
<td>3AH5</td>
</tr>
<tr>
<td></td>
<td>2,500 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>3,150 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>4,000 A</td>
<td></td>
</tr>
<tr>
<td>40 kA</td>
<td>1,250 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>2,000 A</td>
<td>3AH4</td>
</tr>
<tr>
<td></td>
<td>2,500 A</td>
<td>3AH4</td>
</tr>
<tr>
<td></td>
<td>3,150 A</td>
<td>3AH4</td>
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<tr>
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<td>3AH4</td>
</tr>
<tr>
<td></td>
<td>5,000 A</td>
<td>SION</td>
</tr>
<tr>
<td></td>
<td>6,300 A</td>
<td></td>
</tr>
<tr>
<td>50 kA</td>
<td>1,250 A</td>
<td>3AH3</td>
</tr>
<tr>
<td></td>
<td>2,500 A</td>
<td>3AH3</td>
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<tr>
<td></td>
<td>3,150 A</td>
<td>3AH3</td>
</tr>
<tr>
<td></td>
<td>4,000 A</td>
<td>3AH3</td>
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<tr>
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<td>6,300 A</td>
<td></td>
</tr>
<tr>
<td>63 kA</td>
<td>1,250 A</td>
<td>3AH3</td>
</tr>
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<td>5,000 A</td>
<td>3AH3</td>
</tr>
<tr>
<td></td>
<td>6,300 A</td>
<td></td>
</tr>
<tr>
<td>72 kA</td>
<td>3,150 A</td>
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</tr>
<tr>
<td></td>
<td>4,000 A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5,000 A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6,300 A</td>
<td></td>
</tr>
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</table>

Table 4.3-3: Portfolio of vacuum circuit-breakers
<table>
<thead>
<tr>
<th>Rated short-circuit breaking current</th>
<th>Rated normal current</th>
<th>Rated voltage and frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17.5 kV 50/60 Hz</td>
<td>24 kV 50/60 Hz</td>
</tr>
<tr>
<td>12.5 kA 800 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>1,250 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>13.1 kA 800 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>1,250 A</td>
<td>3AH5</td>
<td></td>
</tr>
<tr>
<td>16 kA 800 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>1,250 A</td>
<td>3AH5</td>
<td>3AH5</td>
</tr>
<tr>
<td>2,000 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>20 kA 800 A</td>
<td>SION</td>
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</tr>
<tr>
<td>1,250 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>2,000 A</td>
<td>3AH5</td>
<td></td>
</tr>
<tr>
<td>2,500 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>25 kA 800 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>1,250 A</td>
<td>SION, 3AH4, 3AH5</td>
<td></td>
</tr>
<tr>
<td>2,000 A</td>
<td>SION, 3AH4, 3AH5</td>
<td></td>
</tr>
<tr>
<td>2,500 A</td>
<td>SION, 3AH5</td>
<td></td>
</tr>
<tr>
<td>31.5 kA 800 A</td>
<td>SION</td>
<td></td>
</tr>
<tr>
<td>1,250 A</td>
<td>3AH4</td>
<td>3AH4, 3AH3, 3AH4</td>
</tr>
<tr>
<td>2,000 A</td>
<td>3AH4</td>
<td>3AH4, 3AH3, 3AH4</td>
</tr>
<tr>
<td>2,500 A</td>
<td>3AH4</td>
<td>3AH4, 3AH3, 3AH4</td>
</tr>
<tr>
<td>3,150 A</td>
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<td>3AH4, 3AH3</td>
</tr>
<tr>
<td>40 kA 1,250 A</td>
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<td>3AH3</td>
</tr>
<tr>
<td>2,000 A</td>
<td>3AH4</td>
<td>3AH3</td>
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<td>2,500 A</td>
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<td>3AH3</td>
</tr>
<tr>
<td>3,150 A</td>
<td>3AH3</td>
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<td>3AH3, 3AH3</td>
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<td>5,000 A</td>
<td>3AH3</td>
<td>3AH3</td>
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<tr>
<td>6,300 A</td>
<td>3AH3</td>
<td>3AH3</td>
</tr>
<tr>
<td>8,000 A</td>
<td>3AH3</td>
<td>3AH3</td>
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<tr>
<td>63 kA 1,250 A</td>
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<td>3,150 A</td>
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<tr>
<td>4,000 A</td>
<td>3AH3</td>
<td>3AH3, 3AH3</td>
</tr>
<tr>
<td>5,000 A</td>
<td>3AH3</td>
<td>3AH3</td>
</tr>
<tr>
<td>6,300 A</td>
<td>3AH3</td>
<td>3AH3</td>
</tr>
<tr>
<td>8,000 A</td>
<td>3AH3</td>
<td>3AH3</td>
</tr>
<tr>
<td>72 kA 3,150 A</td>
<td>3AH3</td>
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<td>4,000 A</td>
<td>3AH3</td>
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<td>5,000 A</td>
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<td>3AH3</td>
</tr>
<tr>
<td>6,300 A</td>
<td>3AH3</td>
<td>3AH3</td>
</tr>
<tr>
<td>8,000 A</td>
<td>3AH3</td>
<td>3AH3</td>
</tr>
</tbody>
</table>
### Portfolio of circuit-breakers

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
</table>
| **SION** | The standard circuit-breaker for variable application:  
- Available as standard circuit-breaker or complete slide-in module  
- Up to 30,000 operating cycles  
- Retrofit solution possible |

| **3AH5** | The standard circuit-breaker for small switching capacities:  
- Up to 10,000 operating cycles. |

| **3AH3** | The circuit-breaker for high switching capacities:  
- Rated short-circuit breaking currents of up to 63 kA  
- Rated normal currents of up to 4,000 A  
- Up to 10,000 operating cycles |

| **3AH4** | The circuit-breaker for a high number of operating cycles, i.e. for arc furnace switching:  
- Up to 120,000 operating cycles  
- Rated normal currents of up to 4,000 A  
- Rated short-circuit breaking currents of up to 40 kA |

| **3AH37/3AH38** | The circuit-breaker for high-current and generator applications  
- Rated short-circuit breaking currents of up to 72 kA  
- (according to IEEE C37.013)  
- Rated normal currents up to 6,300 A  
- Up to 10,000 operating cycles  
- Design for phase segregation  
- up to 24 kV, 80 kA, 12,000 A  
- up to 24 kV, 90 kA, 6,300 A |

| **3AH47** | The circuit-breaker for applications in traction systems  
- System frequency 16 ⅔, 25, 50 or 60 Hz  
- 1-pole or 2-pole  
- Up to 60,000 operating cycles |

| **3AK7** | The compact, small circuit-breaker for high-current and generator applications  
- Rated short-circuit breaking currents of up to 40 kA  
- (according to IEEE C37.013)  
- Rated normal currents up to 4,000 A |

Table 4.3-2: Different types of vacuum circuit-breakers
4.3.4 Vacuum Circuit-Breaker for Generator Switching Application

In numerous power stations around the world, the 3AH38 high-current and generator circuit-breaker has become the standard for switching rated operating currents up to 4,000 A.

The circuit-breakers have been modularly constructed in order to be able to use the best materials for the current circuit, magnetic flux and cooling. In this way, features such as low resistance of the main circuit, high mechanical stability and ideal cooling behavior have been combined in the 3AH37.

The 3AH37 is the first 72 kA vacuum circuit-breaker in the world that has been type-tested in accordance with the criteria of the generator circuit-breaker guideline IEEE Std C37.013. The 3AH37 high-current and generator circuit-breaker has a classic VCB design and is available to extend the product portfolio to master operating currents up to 6,300 A on a sustained basis up to 24 kV without forced cooling. With forced cooling the 3AH37 is able to carry operating currents up to 8,000 A.

For generator switching application with phase segregation the VCB's are designed for pole simultaneity and have been tested with ratings up to 80 kA with 12,000 A continuing current and 90 kA.

Advantages in daily operation:
- High mechanical stability through the column construction
- Compact dimensions through vertical arrangement of the vacuum interrupters
- Low fire load as solid insulation is not required
- High normal current possible without forced cooling due to free convection also in horizontal installation
- Secondary equipment can be easily retrofitted
- Maintenance-free throughout its entire service life
- Suitable for horizontal and vertical installation

3AK, 3AH37 and 3AH38 are type-tested according to IEEE Std C37.013

Fig. 4.3-2: Vacuum circuit-breaker for generator switching application up to 24 kV
4.3.5 Outdoor Vacuum Circuit-Breakers

Outdoor vacuum circuit-breakers perform the same functions as indoor circuit-breakers (table 4.3-3) and cover a similar product range. Due to their special design, they are preferred for use in power supply systems with a large extent of overhead lines. When using outdoor vacuum circuit-breakers, it is not necessary to provide for closed service locations for their installation.

The design comprises a minimum of moving parts and a simple structure in order to guarantee a long electrical and mechanical service life. At the same time, these circuit-breakers offer all advantages of indoor vacuum circuit-breakers.

In live-tank circuit-breakers (fig. 4.3-3), the vacuum interrupter is housed inside a weatherproof insulating enclosure, e.g., made of porcelain. The vacuum interrupter is at electrical potential, which means live.

The significant property of the dead-tank technology is the arrangement of the vacuum interrupter in an earthed metal enclosure (fig. 4.3-4).

The portfolio of outdoor vacuum circuit-breakers is shown in table 4.3-4.

<table>
<thead>
<tr>
<th>Type</th>
<th>3AG01 / 3AF01 / 3AF03</th>
<th>3AF04 / 3AF05 for AC traction power supply</th>
<th>SDV6 / SDV7</th>
<th>SDV7M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>12 – 40.5 kV</td>
<td>27.5 kV</td>
<td>15.5 – 38 kV</td>
<td>15.5 – 27.6 kV</td>
</tr>
<tr>
<td>Rated short-duration power frequency withstand voltage</td>
<td>28 – 70 kV</td>
<td>95 kV</td>
<td>50 – 80 kV</td>
<td>50 – 60 kV</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage</td>
<td>75 – 200 kV</td>
<td>200 kV</td>
<td>110 – 200 kV</td>
<td>110 – 150 kV</td>
</tr>
<tr>
<td>Rated normal current</td>
<td>1,250 – 2,500 A</td>
<td>2,000 A</td>
<td>1,200 – 3,000 A</td>
<td>1,200 – 2,000 A</td>
</tr>
<tr>
<td>Rated short-circuit breaking current</td>
<td>20 – 31.5 kA</td>
<td>31.5 kA</td>
<td>20 – 40 kA</td>
<td>20 – 25 kA</td>
</tr>
<tr>
<td>Number of poles</td>
<td>3</td>
<td>1 or 2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Operating mechanism</td>
<td>Spring</td>
<td>Spring</td>
<td>Spring</td>
<td>Magnetic</td>
</tr>
<tr>
<td>Design</td>
<td>Live-tank</td>
<td>Live-tank</td>
<td>Dead-tank</td>
<td>Dead-tank</td>
</tr>
</tbody>
</table>

Table 4.3-4: Portfolio of outdoor vacuum circuit-breakers
4.3.6 Reclosers

Vacuum reclosers offer dependable protection for overhead lines in order to provide improved reliability of the distribution network. At the core of the system, the controller provides a high level of protection, easiest operation, and high operating efficiency.

Up to 90% of the faults in overhead line networks are temporary in nature. In case of a fault, a vacuum recloser trips to interrupt the fault current. After a few cycles, it recloses again and will remain closed if a transient fault has disappeared. This cycle is performed up to five times in order to bring the line back to service before the device finally switches to a lockout state should a permanent network fault be present.

Siemens vacuum reclosers can easily be installed anywhere on the overhead line, so network operators can choose an easily accessible location. The reclosers will be parameterized to sequentially protect the feeder in either star, ring or meshed networks.

The included trouble-free operating features are:
- Advanced vacuum switching technology
- A sophisticated solid epoxy insulation system with integrated sensors
- A dual-coil low-energy magnetic actuator
- The advanced Siemens controller
- A weatherproof control cubicle
- Reliable operation due to self-monitoring and standby.

Controller
The controller (fig. 4.3-5) – the “brain” of the recloser – comprises indicators and control elements, communication interfaces, and a USB port for convenient connection of a laptop. Access to the user level is protected by multi-level password authentication. The controller is mounted in a cubicle which also contains the auxiliary power supply and a battery-backed UPS unit, fuses, and a general purpose outlet to power a laptop.

The controller provides comprehensive protection functions as:
- Earth fault and sensitive earth fault detection along with overcurrent-time protection (definite and inverse)
- Inrush restraint
- Load shedding.

Further features of the controller are:
- A multitude of inputs and outputs for customer use
- Additional communication modules for data transfer
- Self-monitoring and measuring functions.

Switch unit
The switch unit (fig. 4.3-6) contains integrated current transformers and optionally also voltage sensors. It consists of one or three poles and the actuator housing. The poles are made of weatherproof epoxy resin which holds the vacuum interrupter. A switching rod connects the vacuum interrupter with the magnetic actuator.

A mechanical lockout handle, which allows for mechanical tripping and lockout, sticks out of the actuator housing. As long as this handle is extended, the unit can neither be closed electrically nor mechanically. The lockout handle needs to be reset manually to activate the unit.

For switchover tasks in open ring networks (so-called loop automation), reclosers with voltage sensors on both sides (source and load side) are available. In the open state, they are able to detect voltage on either side of the recloser individually. A position indicator is located underneath the housing. Thanks to its size and the application of reflective materials, the indicator is highly visible from the ground and the switching state can be clearly recognized even at night.

<table>
<thead>
<tr>
<th>Rated operating current</th>
<th>400 A to 800 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage acc. to ANSI C37-60</td>
<td>12 kV; 15.5 kV; 27 kV; 38 kV</td>
</tr>
<tr>
<td>Short-circuit breaking current</td>
<td>12.5 kA; 16 kA</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage</td>
<td>95 kV to 190 kV</td>
</tr>
<tr>
<td>Number of operating cycles</td>
<td>10,000</td>
</tr>
<tr>
<td>Number of short circuit operations</td>
<td>up to 200</td>
</tr>
<tr>
<td>Number of phases</td>
<td>three-phases; single-phases; single-tipple</td>
</tr>
<tr>
<td>Standards</td>
<td>ANSI C37.60; IEC 62271-111; IEC 60255; IEC 62271-100</td>
</tr>
</tbody>
</table>

Table 4.3-5: Technical data and ratings
4.3.7 Vacuum Contactors

3TL vacuum contactors (fig. 4.3-8 to fig. 4.3-10) are 3-pole contactors with electromagnetic operating mechanisms for medium-voltage switchgear. They are load breaking devices with a limited short-circuit making and breaking capacity for applications with high switching rates of up to 1 million operating cycles. Vacuum contactors are suitable for operational switching of alternating current consumers in indoor switchgear.

They can be used, e.g., for the following switching duties:
- AC-3: Squirrel-cage motors: Starting, stopping of running motor
- AC-4: Starting, plugging and inching
- Switching of three-phase motors in AC-3 or AC-4 operation (e.g., in conveying and elevator systems, compressors, pumping stations, ventilation and heating)
- Switching of transformers (e.g., in secondary distribution switchgear, industrial distributions)
- Switching of reactors (e.g., in industrial distribution systems, DC-link reactors, power factor correction systems)
- Switching of resistive consumers (e.g., heating resistors, electrical furnaces)
- Switching of capacitors (e.g., in power factor correction systems, capacitor banks).

Further switching duties are:
- Switching of motors
- Switching of transformers
- Switching of capacitors.

In contactor-type reversing starter combinations (reversing duty), only one contactor is required for each direction of rotation if high-voltage high-rupturing capacity fuses are used for short-circuit protection.

The portfolio of the vacuum contactors is shown in table 4.3-6.

<table>
<thead>
<tr>
<th>Type</th>
<th>3TL81</th>
<th>3TL61</th>
<th>3TL65</th>
<th>3TL68</th>
<th>3TL71</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>7.2 kV</td>
<td>7.2 kV</td>
<td>12 kV</td>
<td>15 kV</td>
<td>24 kV</td>
</tr>
<tr>
<td>Rated frequency</td>
<td>50/60 Hz</td>
<td>50/60 Hz</td>
<td>50/60 Hz</td>
<td>50/60 Hz</td>
<td>50/60 Hz</td>
</tr>
<tr>
<td>Rated normal current</td>
<td>400 A</td>
<td>450 A</td>
<td>400 A</td>
<td>320 A</td>
<td>800 A</td>
</tr>
<tr>
<td>Rated making current*</td>
<td>4,000 A</td>
<td>4,500 A</td>
<td>4,000 A</td>
<td>3,200 A</td>
<td>4,500 A</td>
</tr>
<tr>
<td>Rated breaking current*</td>
<td>3,200 A</td>
<td>3,600 A</td>
<td>3,200 A</td>
<td>2,560 A</td>
<td>3,600 A</td>
</tr>
<tr>
<td>Mechanical endurance of the contactor*</td>
<td>1 million operating cycles</td>
<td>3 million operating cycles</td>
<td>1 million operating cycles</td>
<td>1 million operating cycles</td>
<td>1 million operating cycles</td>
</tr>
<tr>
<td>Electrical endurance of the vacuum interrupter (rated current)*</td>
<td>0.25 million operating cycles</td>
<td>1 million operating cycles</td>
<td>0.5 million operating cycles</td>
<td>0.25 million operating cycles</td>
<td>0.5 million operating cycles</td>
</tr>
</tbody>
</table>

* Switching capacity according to utilization category AC-4 (cos φ = 0.35)
4.3.8 Contactor-Fuse Combination

Contactor-fuse combinations 3TL62/63/66 are type-tested units comprising contactors and HV HRC (high-voltage high-rupturing capacity) fuses. They have been specially developed for flexible use in restricted spaces and do not require any additional room for HV HRC fuses or any additional conductors between contactor and fuse. The components are laid out on the base plate so as to enable optimum ventilation, thereby allowing a high normal current. This design even meets the high dielectric strength standards required in countries such as China.

A number of different designs are available for integration in the switchgear panel, for example with different pole-center distances and widths across flats. A choice of single and double fuse holders, control transformer and an extensive range of other accessories are available as delivery versions (table 4.3-7).

Construction

The contactor-fuse combination (fig. 4.3-11, fig. 4.3-12) consists of the components vacuum contactor (1), insulating cover with fuse holder (2), fuse-links (3), contacts (4) and optionally a control transformer (5). These are accommodated on a base plate (6).

In normal operation, the vacuum contactor (1) breaks the corresponding currents reliably. To do this, the vacuum switching technology, proven for nearly 40 years, serves as arc-quenching principle by using vacuum interrupters. The vacuum interrupters are operated by the magnet system through an integral rocker.

The insulating cover with fuse holder (2) is mounted on one side of the contactor. On the other side it stands on a cross-member (7) under which there is room for the optional control transformer. The holders, which are especially conceived for the use of two HV HRC fuse-links, ensure a homogeneous distribution of the current to the two fuse-links of one phase.

The contactor-fuse combination is optimized for using 3GD2 fuses. But also fuse links from other manufacturers can be used (3). When selecting the fuses for an operational scenario, the technical limit values such as heating due to power dissipation, the limit switching capacity and the maximum let-through current must be taken into account.

The contacts (4) are used to establish the connection to the busbar compartment and the cable compartment via bushings, which can also be delivered optionally.

The optional control transformer (5) is connected to the high-voltage terminals of the contactor-fuse combination on its primary part, so that no additional cables are required. To protect the transformer, a separate upstream fuse is series-connected on the primary side and accommodated in the cross-member. Due to its different versions, the control transformer can be optimally selected to the existing power system.
Mode of operation

Basically, there are three different modes or states of operation: normal operation, short circuit and overload.

During normal operation, the combination behaves like a contactor. To close the contactor, the magnetic system can be operated with a control current, optional taken out of the control transformer. The DC magnet system operates as an economy circuit, proving a high mechanical endurance and a low pickup and holding power. An optional latch may hold the vacuum contactor in closed position even without excitation of the magnet system. The vacuum contactor is released electrically by means of a latch release solenoid or mechanically by an optional cable operated latch release.

In case of short circuit, the HV HRC fuse melts already during the current rise. The released thermal striker activates an indication and operates the vacuum contactor. In the optimum time sequence, the fuse has already interrupted the short-circuit current at this time.

In case of overload, a high continuous current overloads the fuse-link thermally, thus tripping the thermal striker. The contactor already operates within the arcing time of the fuse, making a take-over current flow through the vacuum interrupters. The take-over current must not exceed maximum switching capability, as this could damage the vacuum interrupter. This is prevented by selecting the correct fuse.

Application examples

Contactor-fuse combinations are suitable for operational switching of alternating-current consumers in indoor switchgear. They are used, for example, for the following switching functions:

- Starting of motors
- Plugging or reversing the direction of rotation of motors
- Switching of transformers and reactors
- Switching of resistive consumers (e.g., electric furnaces)
- Switching of capacitors and compressors.

With these duties, contactor-fuse combinations are used in conveyor and elevator systems, pumping stations, air conditioning systems as well as in systems for reactive power compensation, and can therefore be found in almost every industrial sector.

Standards

Contactor-fuse combinations 3TL62/63/66 are designed in open construction, with degree of protection IP00, according to IEC 60470. They conform to the standards for high-voltage alternating current contactors above 1 kV to 12 kV:

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 62271-1</td>
<td>DIN EN 62271-1</td>
</tr>
<tr>
<td>IEC 60470 – Issue 2000</td>
<td>DIN EN 60470</td>
</tr>
<tr>
<td>IEC 62271-1 – 106 CDV 01’2010</td>
<td></td>
</tr>
<tr>
<td>IEC 60529</td>
<td>DIN EN 60529</td>
</tr>
<tr>
<td>IEC 60721</td>
<td>DIN EN 60721</td>
</tr>
<tr>
<td>IEC 60282-1</td>
<td>DIN EN 60282-1</td>
</tr>
<tr>
<td>Test voltage according to D/L 404, GB 14808, DL/T 593</td>
<td></td>
</tr>
</tbody>
</table>

Advantages at a glance

- Up to one million electrical operating cycles
- Usable for all kinds of switching duties
- Maintenance-free, reliable operation of vacuum interrupter and magnetic operating mechanism for maximum cost-efficiency
- Wide range of types for the most varied requirements
- Type-tested, compact construction (also for installation in narrow switchgear panels)
- Specially developed fuse holders for homogeneous current distribution
- Optimized construction for high power density
- Reliable for optimized availability
- Excellent environmental compatibility
- Over 35 years experience with vacuum contactors.
### Table 4.3-7: Portfolio of contactor-fuse combination 3TL6

<table>
<thead>
<tr>
<th>Type</th>
<th>3TL62</th>
<th>3TL63</th>
<th>3TL66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>7.2 kV</td>
<td>7.2 kV</td>
<td>12 kV</td>
</tr>
<tr>
<td>Standard</td>
<td>IEC 60470</td>
<td>IEC 60470/</td>
<td>IEC 60470</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High dielectric</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>strength</td>
<td></td>
</tr>
<tr>
<td>Rated normal current (depending on</td>
<td>450 A</td>
<td>400 A</td>
<td>400 A</td>
</tr>
<tr>
<td>installation and coordination with the</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>selected fuses)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal current $I_{th}$</td>
<td></td>
<td></td>
<td>Depending on</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>installation and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>coordination with</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>the selected fuses</td>
</tr>
<tr>
<td>Rated short-circuit breaking current</td>
<td>50 kA</td>
<td>50 kA</td>
<td>40 kA</td>
</tr>
<tr>
<td>$I_{sc}$ (prospective)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. let-through current $I_{D}$</td>
<td>46 kA</td>
<td>46 kA</td>
<td>46 kA</td>
</tr>
<tr>
<td>Short-circuit capability of the contractor</td>
<td>5 kA</td>
<td>4.6 kA</td>
<td>4.6 kA</td>
</tr>
<tr>
<td>(limit switching capacity)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage</td>
<td>60 kV/40 kV</td>
<td>60 kV/40 kV</td>
<td>75 kV/60 kV</td>
</tr>
<tr>
<td>(to earth/open contact gap)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated short-duration power-frequency</td>
<td>20 kV</td>
<td>32 kV</td>
<td>28 kV</td>
</tr>
<tr>
<td>withstand voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching rate</td>
<td>1,200 operating</td>
<td>600 operating</td>
<td>600 operating</td>
</tr>
<tr>
<td></td>
<td>cycles/h</td>
<td>cycles/h</td>
<td>cycles/h</td>
</tr>
<tr>
<td>Mechanical endurance</td>
<td>1 mio. operating</td>
<td>1 mio. operating</td>
<td>1 mio. operating</td>
</tr>
<tr>
<td></td>
<td>cycles</td>
<td>cycles</td>
<td>cycles</td>
</tr>
<tr>
<td>Max. number of fuses per phase</td>
<td>$1 \times 315$ A or $2 \times 250$ A</td>
<td>$1 \times 315$ A or $2 \times 250$ A</td>
<td>$1 \times 200$ A or $2 \times 200$ A</td>
</tr>
<tr>
<td>Pole-center distances</td>
<td>120 mm</td>
<td>120 mm</td>
<td>120 mm</td>
</tr>
<tr>
<td>Widths across flats</td>
<td>205 mm, 275 mm,</td>
<td>205 mm, 275 mm,</td>
<td>205 mm, 275 mm,</td>
</tr>
<tr>
<td></td>
<td>310 mm</td>
<td>310 mm</td>
<td>310 mm</td>
</tr>
</tbody>
</table>

Various different contact systems and comprehensive accessories are available.
4.3.9 Disconnectors and Switch-Disconnectors

Disconnectors (also called isolators) are used for almost no-load opening and closing of electrical circuits. While doing so, they can break negligible currents (these are currents up to 500 mA, e.g., capacitive currents of busbars or voltage transformers), or higher currents if there is no significant change of the voltage between the terminals during breaking, e.g., during busbar transfer in double-busbar switchgear, when a bus coupler is closed in parallel.

The actual task of disconnectors is to establish an isolating distance in order to work safely on other operational equipment that has been “isolated” by the disconnector (fig. 4.3-14). For this reason, stringent requirements are placed on the reliability, visibility and dielectric strength of the isolating distance.

The different disconnectors and their properties are shown in table 4.3-9.

Switch-disconnectors (table 4.3-9, fig. 4.3-13) combine the functions of a switch with the establishment of an isolating distance (disconnector) in one device, and they are therefore used for breaking load currents up to their rated normal current.

While connecting consumers, making on an existing short circuit cannot be excluded. That is why switch-disconnectors today feature a short-circuit making capacity. In combination with fuses, switches (switch-disconnectors) can also be used to break short-circuit currents. The short-circuit current is interrupted by the fuses. Subsequently, the fuses trip the three poles of the switch (switch-disconnector), disconnecting the faulty feeder from the power system.

<table>
<thead>
<tr>
<th>Type</th>
<th>Rated short-time withstand current</th>
<th>Rated normal current</th>
<th>Rated voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 kV</td>
<td>17.5 kV</td>
<td>24 kV</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>28 kV/32 kV</td>
<td>38 kV/45 kV</td>
<td>50 kV/60 kV</td>
</tr>
<tr>
<td>Rated short-duration power-frequency withstand voltage</td>
<td>75 kV/85 kV</td>
<td>95 kV/110 kV</td>
<td>125 kV/145 kV</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage</td>
<td>400 A</td>
<td>400 A</td>
<td>400 A</td>
</tr>
<tr>
<td>Rated normal current</td>
<td>630 A/1000 A</td>
<td>630 A</td>
<td>630 A/1000 A</td>
</tr>
<tr>
<td>Rated normal current – without fuse-link</td>
<td>25 kA</td>
<td>25 kA</td>
<td>25 kA</td>
</tr>
<tr>
<td>Rated short-time withstand current (1 sec)</td>
<td>63 kA</td>
<td>63 kA</td>
<td>50 kA</td>
</tr>
<tr>
<td>Rated closed-loop breaking current</td>
<td>400 A/630 A</td>
<td>400 A/630 A</td>
<td>400 A/630 A</td>
</tr>
<tr>
<td>Rated cable-charging breaking current</td>
<td>50 A</td>
<td>75 A</td>
<td>50 A</td>
</tr>
<tr>
<td>Rated earth-fault breaking current</td>
<td>150 A</td>
<td>200 A</td>
<td>150 A</td>
</tr>
<tr>
<td>Rated cable-charging breaking current under earth-fault conditions</td>
<td>86 A</td>
<td>100 A</td>
<td>86 A</td>
</tr>
<tr>
<td>Number of mechanical operating cycles</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
</tr>
<tr>
<td>Torque of spring-operated/stored-energy mechanism</td>
<td>44/60</td>
<td>54/62</td>
<td>64/64</td>
</tr>
<tr>
<td>Torque of earthing switch</td>
<td>60</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>Standard fuse reference dimension “e”</td>
<td>292</td>
<td>362</td>
<td>442</td>
</tr>
</tbody>
</table>
Earthing switches (table 4.3-10) are used in order to earth and short-circuit switchgear parts, cables and overhead lines. They make it possible to work without danger on the previously earthed operational equipment. Their design is similar to that of vertical-break disconnectors. They are often mounted on disconnectors or switch-disconnectors and then interlocked with these devices in order to prevent earthing on applied voltages.

If earthing switches with making capacity (make-proof earthing switches) are used instead of the normal earthing switches, earthing and short-circuiting presents no danger even if the circuit was accidentally not isolated before (fig. 4.3-16, fig. 4.3-17).

**Fig. 4.3-16: Earthing switch in OPEN position with closed disconnector**

**Fig. 4.3-17: Earthing switch in CLOSED position with open disconnector**

### 4.3.10 Earthing Switches

Earthing switches are used in order to earth and short-circuit switchgear parts, cables and overhead lines. They make it possible to work without danger on the previously earthed operational equipment. Their design is similar to that of vertical-break disconnectors. They are often mounted on disconnectors or switch-disconnectors and then interlocked with these devices in order to prevent earthing on applied voltages.

If earthing switches with making capacity (make-proof earthing switches) are used instead of the normal earthing switches, earthing and short-circuiting presents no danger even if the circuit was accidentally not isolated before (fig. 4.3-16, fig. 4.3-17).

#### Arc-extinguishing principle

Switch-disconnectors operate according to the principle of a hard-gas switch, and so the arc is not extinguished in a vacuum interrupter. The arc splits off some gas from an insulating material that surrounds the arc closely and this gas quenches the arc.

Because the material providing the gas cannot regenerate itself, the number of operating cycles is lower than in vacuum interrupters. Nevertheless, switch-disconnectors that use the hard-gas principle are used most frequently because of their good cost/performance ratio.

3CJ2 switch-disconnectors operate with a flat, hard-gas arcing chamber, (1) in fig. 4.3-15. During the opening movement, the contact blade, (2) in fig. 4.3-15, is separated first. Because the auxiliary blade, (3) in fig. 4.3-15, guided in the arcing chamber is still touching, the current now flows through the auxiliary blade. When the switching blades reach the isolating distance, the auxiliary blade opens the connection suddenly. The opening arc burns in a small gap, and the thermal effect releases enough gas to extinguish the arc rapidly and effectively.

**Fig. 4.3-14: Switch-disconnector**

**Fig. 4.3-15: 3CJ2 switch-disconnector: (1) flat hard-gas arcing chamber, (2) contact blade, (3) auxiliary blade**

### Table 4.3-10: Portfolio of earthing switches

<table>
<thead>
<tr>
<th>Earthing switches</th>
<th>Rated voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated short-time withstand current</td>
<td>Rated peak withstand current</td>
</tr>
<tr>
<td>20 kA</td>
<td>50 kA</td>
</tr>
<tr>
<td>31.5 kA</td>
<td>80 kA</td>
</tr>
<tr>
<td>50 kA</td>
<td>125 kA</td>
</tr>
<tr>
<td>63 kA</td>
<td>160 kA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Make-proof earthing switches</th>
<th>Rated voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated lightning impulse withstand voltage</td>
<td>Rated power-frequency withstand voltage</td>
</tr>
<tr>
<td>60 kV</td>
<td>20 kV</td>
</tr>
<tr>
<td>60 kV</td>
<td>28 kV</td>
</tr>
<tr>
<td>75 kV</td>
<td>28 kV</td>
</tr>
<tr>
<td>95 kV</td>
<td>38 kV</td>
</tr>
<tr>
<td>95 kV</td>
<td>50 kV</td>
</tr>
<tr>
<td>125 kV</td>
<td>50 kV</td>
</tr>
</tbody>
</table>
4.4 Low-Voltage Devices

4.4.1 Requirements on the Switchgear in the Three Circuit Types

Device application in the supply circuit
The system infeed is the most “sensitive” circuit in the entire power distribution. A failure here would affect the whole network, leaving the building or the production concerned without power. This worst-case scenario must be considered during the planning. Redundant system supplies and selective protection settings are important preconditions for a safe network configuration. The selection of the correct protective devices is therefore of elementary importance in order to create these preconditions. Some of the key dimensioning data is described in the following.

Rated current
The feeder circuit-breaker in the LVMD must be dimensioned for the maximum load of the transformer/generator. When using ventilated transformers, the higher normal current of up to 1.5 x I₀ of the transformer must be taken into account.

Short-circuit strength
The short-circuit strength of the feeder circuit-breaker is determined by (n–1) x Iₖ max of the transformer or transformers (n = number of transformers). This means that the maximum short-circuit current that occurs at the place of installation must be known in order to specify the appropriate short-circuit strength of the protective device (Icu). Exact short-circuit current calculations including attenuations of the medium-voltage levels or the laid cables can be made, for example, with the aid of the SIMARIS design dimensioning software. SIMARIS design determines the maximum and minimum short-circuit currents and automatically dimensions the correct protective devices.

Utilization category
When dimensioning a selective network, time grading of the protective devices is essential. When using time grading up to 500 ms, the selected circuit-breaker must be able to carry the short-circuit current that occurs for the set time. Close to the transformer, the currents are very high. This current carrying capacity is specified by the I₁ₚ value (rated short-time withstand current) of the circuit-breaker; this means the contact system must be able to carry the maximum short-circuit current, i.e., the energy contained therein, until the circuit-breaker is tripped. This requirement is satisfied by circuit-breakers of utilization category B (e.g., air circuit-breakers, ACB). Current-limiting circuit-breakers (molded-case circuit-breakers, MCCB) trip during the current rise. They can therefore be constructed more compactly.

Release
For a selective network design, the release (trip unit) of the feeder circuit-breaker must have an LSI characteristic. It must be possible to deactivate the instantaneous release (I). Depending on the curve characteristic of the upstream and downstream protective devices, the characteristics of the feeder circuit-breaker in the overload range (L) and also in the time-lag short-circuit range (S) should be optionally switchable (Iₚt or Iₚ characteristic curve). This facilitates the adaptation of upstream and downstream devices.

Internal accessories
Depending on the respective control, not only shunt releases (previously: f releases), but also undervoltage releases are required.

Communication
Information about the current operating states, maintenance, error messages and analyses, etc. is being increasingly required, especially from the very sensitive supply circuits. Flexibility may be required with regard to a later upgrade or retrofit to the desired type of data transmission.

Device application in supply circuits (coupling)
If the coupling (connection of network 1 to network 2) is operated in open condition, the circuit-breaker (tie breaker) only has the function of a disconnector or main switch. A protective function (release) is not absolutely necessary.

The following considerations apply to closed operation:
• Rated current
  must be dimensioned for the maximum possible normal current (load compensation). The simultaneity factor can be assumed to be 0.9.
• Short-circuit strength
  The short-circuit strength of the feeder circuit-breaker is determined by the sum of the short-circuit components that flow through the coupling. This depends on the configuration of the component busbars and their supply.
• Utilization category
  As for the system supply, utilization category B is also required for the current carrying capacity (Icu).
• Release
  Partial shutdown with the couplings must be taken into consideration for the supply reliability. As the coupling and the feeder circuit-breakers have the same current components when a fault occurs, similar to the parallel operation of two transformers, the LSI characteristic is required. The special zone selective interlocking (ZSI) function should be used for larger networks and/or protection settings that are difficult to determine.

Device application in the distribution circuit
The distribution circuit receives power from the higher level (supply circuit) and feeds it to the next distribution level (final circuit).

Depending on the country, local practices, etc., circuit-breakers and fuses can be used for system protection; in principle, all protective devices described in this chapter. The specifications for the circuit dimensioning must be fulfilled. The ACB has advantages if full selectivity is required. However for cost reasons, the ACB is only frequently used in the distribution circuit.
with a rated current of 630 A or 800 A. As the ACB is not a current-limiting device, it differs greatly from other protective devices such as MCCB, MCB and fuses.

Fig. 4.4-1 shows the major differences and limits of the respective protective devices.

**Device application in the final circuit**
The final circuit receives power from the distribution circuit and supplies it to the consumer (e.g., motor, lamp, non-stationary load (power outlet), etc.). The protective device must satisfy the requirements of the consumer to be protected by it.

**Note:**
All protection settings, comparison of characteristic curves, etc. always start with the load. This means that no protective devices are required with adjustable time grading in the final circuit.

| Standards | IEC | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Application | System protection | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Installation | Fixed mounting | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | Plug-in | – | Up to 800 A | – | Partly | – | – | – |
| | Withdrawable unit | Yes | Yes | – | – | – | – | – |
| Rated current | $I_{n}$ | 6,300 A | 1,600 A | 630 A | 630 A | 125 A | Normal current $I_{n}$ |
| Short-circuit breaking capacity | $I_{cu}$ | Up to 150 kA | Up to 100 kA | Up to 120 kA | Up to 120 kA | Up to 25 kA | Maximum short-circuit current $I_{cu}$ |
| Current carrying capacity | $I_{cw}$ | Up to 80 kA | Up to 5 kA | – | – | – | Circuit |
| Number of poles | 3-pole | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | 4-pole | Yes | Yes | – | Partly | – | – | – |
| Tripping characteristic | ETU | Yes | Yes | – | – | – | – | – |
| | TM | – | Up to 630 A | Yes | Yes | Yes | – | – |
| Tripping function | LI | Yes | Yes | Yes* | Yes* | Yes | – | – |
| | LSI | Yes | Yes | – | – | – | – | – |
| | N | Yes | Yes | – | – | – | – | – |
| | G | Yes | Yes | – | – | – | – | – |
| Characteristics | Fixed | – | Yes | Yes | Yes | Yes | – | – |
| | Adjustable | Yes | Yes | – | – | – | – | – |
| | Optional | Yes | Yes | – | – | – | – | – |
| Protection against electric shock, tripping condition | Detection of $I_{k_{min}}$ | No limitation | No limitation *) | Depends on cable length | Depends on cable length | Depends on cable length | Minimum short-circuit current $I_{k_{min}}$ |
| Communication (data transmission) | High | Yes | – | – | – | – | – | – |
| | Medium | Yes | Yes | – | – | – | – | – |
| | Low | Yes | Yes | Yes | Yes | Yes | – | – |
| Activation | Local | Yes | Yes | Yes | Yes | Yes | – | – |
| | Remote (motor) | Yes | Yes | – | – | – | – | – |
| Derating | Full rated current up to | 60 °C | 50 °C | 30 °C | 30 °C | 30 °C | Switchgear |
| System synchronization | Yes | Up to 800 A | – | – | – | – | Power supply system |

* According to the fuse characteristic

Fig. 4.4-1: Overview of the protective devices; *) with ETU: No limitation/with TMTU: depends on cable length
4.4.2 Low-Voltage Protection and Switching Devices

The following chapter focuses on the relevant characteristics and selection criteria of the respective devices that are used in the main power distribution circuits in commercial buildings and in industry.

Note:

All figures apply for low-voltage power systems or distribution boards in IEC applications. Different regulations and criteria apply for systems according to UL standards. Depending on the country, standard specifications, local practices, planning engineer, technical threshold values, etc., low-voltage power distribution systems are made up of various protective devices.

Circuits and device assignment
(section 3.3.2 “Dimensioning of Power Distribution Systems”)

Basic configuration of a low-voltage power distribution system and assignment of the protective devices including core functions

Core functions in the respective circuits:
• Supply circuit
  Task: System protection
  Protective device:
  – ACB (air circuit-breaker)
• Distribution circuit
  Task: System protection
  Protective devices:
  – ACB (air circuit-breaker)
  – MCCB (molded-case circuit-breaker)
  – SD (switch-disconnector)
• Final circuit
  Task: Motor protection
  Protective devices:
  MCCB (circuit-breaker for motor protection)
  – SD (switch-disconnector)
• MSP (3RT contactor, 3RU overload relay, 3UF motor protection and control devices.

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Circuit-breaker protected switchgear (circuit-breaker)

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACB</td>
<td>Air circuit-breaker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Non-current-limiting circuit-breaker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Current-zero cut-off circuit-breaker</td>
<td></td>
</tr>
<tr>
<td>MCCB</td>
<td>Molded-case circuit-breaker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Molded-case circuit-breaker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Current-limiting circuit-breaker</td>
<td></td>
</tr>
<tr>
<td>MCB</td>
<td>Miniature circuit-breaker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Miniature circuit-breaker</td>
<td></td>
</tr>
<tr>
<td>MSP</td>
<td>Motor starter protector</td>
<td></td>
</tr>
<tr>
<td>MPCB</td>
<td>Motor protector circuit-breaker</td>
<td></td>
</tr>
</tbody>
</table>

Fuse-protected switchgear
(fuse switch-disconnector/switch-disconnector)

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD</td>
<td>Switch-disconnector</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depending on the type of operation, these devices are divided into two main groups:</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Operator-dependent</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Without circuit-breaker latching system, with protection (fuse); with these devices, the fuse is also moved when making and breaking (= fuse switch-disconnector)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>With circuit-breaker latching system, with protection (fuse); with these devices, the fuse is not moved when making and breaking (= switch-disconnector with fuse)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Operator-independent</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>With circuit-breaker latching system, without protection (without fuse); these devices are only used to interrupt the circuit, similar to a main switch (= switch-disconnector without fuse)</td>
<td></td>
</tr>
</tbody>
</table>

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* If you have questions on UL applications, please contact your local Siemens representative. We provide solutions for these applications, but they must be treated completely differently.
Criteria for device selection
A protective device is always part of a circuit and must satisfy the corresponding requirements (section 3.3.2 “Dimensioning of Power Distribution Systems”). The most important selection criteria are shown in the following.

Main selection criteria
Fig. 4.4-5 shows the seven most important selection criteria that must be at least taken into account for the device selection.

Fig. 4.4-4: Core functions of the protective devices in the individual circuit types

Fig. 4.4-5: Main selection criteria

1. Application
   Plants/motors/disconnectors

2. 3-pole/4-pole

3. Fixed mounting/plug-in/withdrawable-unit design

4. Rated current $I_n$
   ACB: 6,300 A
   MCCB: 1,600 A
   Fuse: 630 A

5. Short-circuit breaking capacity $I_{cu}$

6. Release
   Influences selectivity and protection setting

7. Communication and data transfer

Fuse-protected

Circuit-breaker protected
4.4.3 Busbar Trunking Systems, Cables and Wires

Busbar trunking systems
When a planning concept for power supply is developed, it is not only imperative to observe standards and regulations, it is also important to discuss and clarify economic and technical interrelations. The rating and selection of electric equipment, such as distribution boards and transformers, must be performed in such a way that an optimum result for the power system as whole is kept in mind rather than focusing on individual components.

All components must be sufficiently rated to withstand normal operating conditions as well as fault conditions. Further important aspects to be considered for the preparation of an energy concept are:

- Type, use and shape of the building (e.g., high-rise building, low-rise building, number of story levels)
- Load centers and possible power transmission routes and locations for transformers and main distribution boards
- Building-related connection details according to specific area loads that correspond to the type of use of the building
- Statutory provisions and conditions imposed by building authorities
- Requirements by the power supply system operator.

The result will never be a single solution. Several options have to be assessed in terms of their technical and economic impacts. The following requirements are of central importance:

- Easy and transparent planning
- High service life
- High availability
- Low fire load
- Flexible adaptation to changes in the building.

Most applications suggest the use of suitable busbar trunking systems to meet these requirements. For this reason, engineering companies increasingly prefer busbar trunking to cable installation for power transmission and distribution. Siemens offers busbar trunking systems ranging from 25 A to 6,300 A:

- The CD-K busbar system from 25 to 40 A for the supply of light fixtures and micro-consumers
- The BD01 busbar system from 40 to 160 A for supplying workshops with tap-offs up to 63 A
- The BD2 busbar system from 160 to 1,250 A for supplying medium-size consumers in buildings and industry
- The ventilated LD system from 1,100 to 5,000 A for power transmission and power distribution at production sites with a high energy demand
- The LX sandwich system from 800 to 5,000 A (6,300 A on request), mainly for power transmission insensitive to position in buildings with the requirements of degree of protection IP54 and special conductor configurations such as double N or insulated PE
- The encapsulated LR system from 400 to 6,150 A for power transmission for extreme environmental conditions (IP68).

For the configuration of a busbar system, the following points are to be noted:

Calculation/dimensioning:

- Electrical parameters, such as rated current, voltage, given voltage drop and short-circuit strength at place of installation.

Technical parameters of the busbar systems:

- The conductor configuration depends on the mains system according to type of earth connection
- Reduction factors, e.g., for ambient air temperature, type of installation, (vertical) busbar position (horizontal on edge) and degree of protection
- Copper is required as conductor material; otherwise, aluminum has advantages such as weight, price, etc.
- How is the system supply to be carried out: as a TTA solution directly from the distribution board or by means of cables at the end or center of the busbar
- Max. cable connection options to infeed and tap-off units
- Power and size of the tap-off units including installation conditions
- Number of tapping points
- Use of bus systems possible
- Influence of a magnetic field (hospitals, broadcasting studios)
- Environmental conditions, especially ambient air temperature (e.g., where there are fire compartments in each floor of a vertical shaft).
Structural parameters and boundary conditions:
- Phase response (changes of direction in the busbar routing possible, differences in height, etc.)
- Functional sections (e.g., various environmental conditions or various uses)
- Check use in sprinkler-protected building sections
- Fire areas (provision of fire barriers –> what structural (e.g., type of walls) and fire fighting (local provisions) boundary conditions are there?
- Fire protection classes of the fire barriers ($S90$ and $S120$)
- Functional endurance classes ($E60$, $E90$, $E120$) and certifications of the busbar systems (observe relevant deratings)
- Fire loads/halogenes (prescribed fire loads in certain functional sections, e.g., fire escape routes, must not be exceeded).
- Maximum clearance from fixings taking into consideration location, weight of system and additional loads such as tap-off units, lighting, etc.
- Agreement on possible means of fixing with structural analyst
- Use of tested fixing accessories with busbar systems with functional endurance
- Observe derating for type of installation
- Dimensions of the distribution board, system supplies and tap-off units:
- Installation clearance from ceiling, wall and parallel systems for the purpose of heat dissipation and installation options
- Crossing with other installations (water, gas pipes, etc.)
- Swing angle for installing and operating the tap-off units
- Minimum dimensions for changes of direction in the busbar routing, fire protection compartmentalization, wall cutouts
- Space requirement for distribution connection
- Cutout planning (sizes and locations of the cutouts)
- Linear expansion (expansion units, if applicable).

More information:
Technical data, dimension drawings, components, etc. are included in the technical catalog LV 70 of Siemens AG:
- German: Order no. E86060-K1870-A101-A6
- English: Order no. E86060-K1870-A101-A6-7600

Manual:
Planning with SIVACON 8PS – Busbar Trunking Systems up to 6,300 A
- German: Order no. ASE 01541017-02
- English: Order no. ASE 01541117-02

Fig. 4.4-6: Busbar trunking systems
CD-K system 25 A – 40 A
The system is designed for applications of 25 to 40 A and serves to provide an economical and flexible power supply for lighting systems and low-consumption equipment. Typical areas of application are department stores, supermarkets, storerooms or clean room technology.

1. Trunking unit
   - 2, 3, 4, 2 x 4, (1 x 4 + 1 x 2)-conductor (PE = casing)
   - Degree of protection: IP54, IP55
   - Standard lengths: 2 m and 3 m
   - Rated current: 30 A, 40 A, 2 x 25 A, 2 x 40 A
   - Spacing of the tapping points: 0.5 m and 1 m
   - Rated operating voltage: 400 V AC

2. Feeding unit
   - Cable entry: from three sides

3. Tap-off component
   - Pluggable while energized
   - 3-pole for 10 A and 16 A
   - Equipped as L1, L2 or L3 with N and PE
   - 5-pole for 10 A and 16 A
   - Codable

4. End flange

5. Possible supplementary equipment
   - Fixing clamp
   - Suspension hook
   - Hanger
   - Cable fixing
   - Coding set

Fig. 4.4-7: System components for CD-K system
System BD01 40 A – 160 A
The BD01 busbar trunking system is designed for applications from 40 to 160 A. Five rated amperages are available for only one size, i.e., all other components can be used for all five rated currents irrespective of the power supply. The system is used primarily to supply smaller consumers, e.g., in workshops.

1. Trunking unit
   - 4-conductor (L1, L2, L3, N, PE = casing)
   - Degree of protection: IP50, IP54, IP55
   - Standard lengths: 2 m and 3 m.
   - Rated current: 40 A, 63 A, 100 A, 125 A, 160 A
   - Spacing of the tapping points: 0.5 m and 1 m
   - Rated operating voltage: 400 V AC

2. Directional change components
   - Changes of direction in the busbar routing possible: flexible, length 0.5 m, 1 m

3. Feeding unit
   - Universal system supply

4. Tap-off unit
   - Up to 63 A, with fuses or miniature circuit-breaker (MCB) and with fused outlets
   - With fittings or for customized assembly
   - For 3, 4 or 8 modules (MW)
   - With or without assembly unit

5. Device case
   - For 4 or 8 modules (MW)
   - With or without assembly unit
   - With or without outlet installed

6. Possible supplementary equipment
   - Installation sets for degree of protection IP55
   - Fixing and suspension
   - Coding set
   - Fire barrier kit S90

Fig. 4.4-8: System components for BD01 system
BD2 system 160 A – 1,250 A
The BD2A/BD2C busbar trunking system (aluminum/copper) is suitable for universal use. It has not only been designed to provide flexible power supply and distribution for consumers in trade and industry, but it can also be used for power transmission from one supply point to another. In addition, the BD2 busbar trunking system is used as rising mains in multi-storey buildings, and since a large number of changes of direction in the busbar routing are possible, it can be adapted to the building geometries perfectly.

1. **Trunking unit**
   - 5-conductor (L1, L2, L3, N, PE or with half PE)
   - Degree of protection: IP52, IP54, IP55
   - Busbar material: copper or aluminum
   - Rated current:
     - 160 A, 250 A, 400 A (68 mm x 167 mm)
     - 630 A, 800 A, 1,000 A, 1,250 A (126 mm x 167 mm)
   - Standard lengths: 3.25 m, 2.25 m and 1.25 m
   - Lengths available: from 0.5 m to 3.24 m
   - Tap-off points:
     - without
     - on both sides (0.25 or 0.5 m apart)
   - Fire protection: fire safety class S90 and S120 in accordance with DIN 4102, sheet 2 to 4

2. **Directional change components**
   - On edge or flat position
   - With or without fire protection
   - Horizontal angle unit with or without user-configurable bracket
   - Z-unit
   - T-unit

3. **Feeding unit**
   - Feeding from one end
   - Center feeding
   - Bolt terminal
   - Cable entry from 1, 2 or 3 sides
   - Distribution board feeding

4. **Tap-off unit**
   - 25 A to 630 A
   - With fuse, miniature circuit-breaker (MCB) or fused outlet installed

5. **Device case**
   - For 8 modules (MW)
   - With or without assembly unit

6. **Possible supplementary equipment**
   - End flange
   - For fixing:
     - Universal fixing clamp for on edge or flat position
     - Fixing elements for vertical phases, for fixing to walls or ceilings
   - Terminal block

---

Fig. 4.4-9: System components for BD2 system
LD system

1,100 A – 5,000 A

The LDA/LDC busbar trunking system is used both for power transmission and power distribution. A special feature of the system is a high short-circuit strength and it is particularly suitable for connecting the transformer to the low-voltage main distribution and then to the subdistribution system. When there is a high power demand, conventional current conduction by cable means that parallel cables are frequently necessary. Here, the LD system allows optimal power distribution with horizontal and vertical phase responses. The system can be used in industry as well as for relevant infrastructure projects, such as hospitals, railroad stations, airports, trade fairs, office blocks, etc.

1. Trunking unit
   - 4 and 5-conductor system
   - Busbar material: copper or aluminum
   - Rated current: 1,100 to 5,000 A
   - LDA1 to LDC3 (180 mm x 180 mm)
   - LDA4 to LDC8 (240 mm x 180 mm)
   - Degree of protection: IP34 and IP54 (IP36 and IP56 upon request)
   - Standard lengths: 1.6 m, 2.4 m and 3.2 m
   - Lengths available: from 0.5 m to 3.19 m
   - Tapping points:
     - Without
     - With user-configurable tapping points
   - Fire protection partitions: fire resistance class S120 in accordance with DIN 4102-9

2. Directional change components
   - With or without fire protection
   - Horizontal angle unit with or without user-configurable bracket
   - Z-unit
   - U-unit
   - T-unit

3. Tap-off unit
   - Degree of protection IP30 and IP54
   - With fuse switch-disconnector from 125 A to 630 A
   - With circuit-breaker from 100 A to 1,250 A

4. Feeding unit
   - Leading PEN or PE connector
   - Switching to load-free state following defined, forced-operation sequences
   - Suspension and fixing bracket

5. Universal terminal for transformers

6. Possible supplementary equipment
   - End flange
   - Terminal block

Fig. 4.4-10: System components for LDA/LDC system
LX system from 800 A – 6,300 A

The LXA/LXC bus bar trunking system is used both for power transmission and power distribution. Special features of the system include high flexibility and position insensitivity, and it is particularly suitable for power distribution in multi-story buildings. The high degree of protection IP54, which is standard for this system, and tap-off units up to 1,250 A also guarantee a safe supply if there is a high energy demand. It can be used in industry as well as for relevant infrastructure projects such as hospitals, railroad stations, airports, data centers, office blocks, etc.

1. Trunking unit
   - 4 and 5 conductor system in various conductor configurations, including separate PE or double N
   - Busbar material: copper or aluminum
   - Rated current: 800 up to 5,000 A
   - Size (mm) Aluminum Copper
     - 137 x 145 up to 1,000 A up to 1,250 A
     - 162 x 145 up to 1,250 A up to 1,600 A
     - 207 x 145 up to 1,600 A up to 2,000 A
     - 287 x 145 up to 2,500 A up to 3,200 A
     - 439 x 145 up to 3,200 A up to 4,000 A
     - 599 x 145 up to 4,500 A up to 5,000 A (up to 6,300 A on request)
   - Degree of protection: IP54 (IP55 optional)
   - Standard lengths: 1 m, 2 m and 3 m
   - Lengths available: from 0.35 m to 2.99 m
   - Layout: horizontal and vertical without derating
   - Tap-off points:
     - On one side
     - On both sides
   - Fire protection partitions: fire resistance class S120 in accordance with DIN 4102 Part 9

2. Directional change components
   - With or without fire protection
   - Horizontal angle unit with or without user-configurable bracket
   - Z-unit
   - Offset knee
   - T-unit

3. Tap-off unit
   - Degree of protection IP54 (IP55 upon request)
   - With fuse switch-disconnector from 125 A to 630 A
   - With circuit-breaker from 80 A to 1,250 A
   - Pluggable while energized up to 630 A
   - Fixed installation up to 1,250 A (on terminal block)
   - Leading PEN or PE connector
   - Switching to load-free state following defined, forced-operation sequences
   - Suspension and fixing bracket

4. Feeding unit
   - Cable feeding unit
   - Universal terminal for transformers

5. Terminal boxes for connection to distribution board
   - TTA distribution connection to the SIVACON system from the top/bottom
   - Terminals for external distribution boards

6. Possible supplementary equipment
   - End flange
   - Flange for degree of protection increased from IP54 to IP55
   - Terminal block

Fig. 4.4-11: System components for LXA/LXC system
LR system from 400 A – 6,150 A

The LRA/LRC busbar trunking system is used for power transmission. A special feature of the system is high resistance to external influences of chemical and corrosive substances, and it is particularly suitable for use in the open air and in environments with high air humidity. The high degree of protection IP68 is guaranteed with the encapsulated epoxy cast-resin casing, and serves to provide reliable power transmission when there is a high energy demand. The system can be used in industry as well as for relevant infrastructure projects such as railroad stations, airports, office blocks, etc.

1. Trunking unit
   - 4 and 5-conductor system
   - Busbar material: copper or aluminium
   - Degree of protection: IP68
   - User-configurable lengths: from 0.30 m to 3.00 m
   - Layout: horizontal and vertical without derating
   - Fire barriers: fire resistance class S120 in accordance with DIN 4102 Part 9

2. Directional change components
   - With or without fire protection
   - Horizontal angle unit with or without offset
   - Z-unit
   - T-unit

3. Feeding unit and distributor units
   - Universal terminals for transformers, external distributors and cable connection

4. Possible supplementary equipment
   - End flange
   - Terminal block
   - Junction point every 1 m, on one side; junction box on request
   - Adapters to the LX and LD systems

Fig. 4.4-12: System components for LRA/LRC system
4.4.4 Subdistribution Systems

General
Subdistribution systems, as an essential component for the reliable power supply to all consumers of a building, are used for the distributed supply of circuits. From the subdistribution boards, cables either lead directly or via ground contact outlets to the consumer. Protective devices are located within the subdistribution systems.

These are:
- Fuses
- Miniature circuit-breakers
- RCD (residual current devices)
- Circuit-breakers
- Overvoltage protection

They provide protection against personal injury and protect:
- Against excessive heating caused by non-permissible currents
- Against the effects of short-circuit currents and the resulting mechanical damage.

In addition to the protective devices, a subdistribution system also contains devices for switching, measuring and monitoring. These are:
- Disconnectors
- KNX/EIB components
- Outlets
- Measuring instruments
- Switching devices
- Transformers for extra-low-voltages
- Components of the building control systems

Configuration
The local environmental conditions and all operating data have utmost importance for the configuration of the subdistribution systems. The dimensioning is made using the following criteria:

Ambient conditions
- Dimensions
- Mechanical stress
- Exposure to corrosion
- Notes concerning construction measures
- Wiring spaces
- Environmental conditions

Electrical data
- Rated currents of the busbars
- Rated currents of the supply circuits
- Rated currents of the branches
- Short-circuit strength of the busbars
- Rating factor for switchgear assemblies
- Heat loss

Protection and installation type
- Degree of protection
- Observance of the upper temperature limit
- Protective measures
- Installation type (free-standing, floor-mounted distribution board, wall-mounted distribution board)

Accessibility, e.g., for installation, maintenance and operating

Type of construction
- Number of operating faces
- Space requirements for modular installation devices, busbars and terminals
- Supply conditions

The number of subdistribution boards in a building is determined using the following criteria:

Floors
A high-rise building normally has at least one floor distribution board for each floor. A residential building normally has one distribution system for each apartment.

Building sections
If a building consists of several sections, at least one subdistribution system is normally provided for each building section.

Departments
In a hospital, separate subdistribution systems are provided for the various departments, such as surgery, OP theater, etc.

Safety power supplies
Separate distribution boards for the safety power supply are required for supplying the required safety equipment. Depending on the type and use of the building or rooms, the relevant regulations and guidelines must be observed, such as IEC 60364-7-710 and -718, DIN VDE 0100-710 and -718 and the MLAR (Sample Directive on Fireproofing Requirements for Line Systems).

Standards to be observed for dimensioning
- IEC 60364-1, DIN VDE 0100-100 Low voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions
- IEC 60364-4-41, DIN VDE 0100-410 Protection against electric shock
- IEC 60364-4-43, DIN VDE 0100-430 Protection against overcurrent
- IEC 60364-5-51, DIN VDE 0100-510 Selection and erection of electrical equipment; common rules
- IEC 60364-5-52, DIN VDE 0100-520 Wiring systems
- DIN VDE 0298-4 Recommended values for the current carrying capacity of sheathed and non-sheathed cables
- DIN VDE 0606-1 Connecting materials up to 690 V; Part 1 – Installation boxes for accommodation of equipment and/or connecting terminals
- DIN 18015-1 Electrical systems in residential buildings, Part 1 planning principles
Selection of protective devices and connecting lines
The selection and setting of the protective devices to be used must satisfy the following three conditions:
• Protection against non-permissible contact voltage for indirect contact (electric shock)
• Overload protection
• Short-circuit protection

For detailed information on the three conditions, see section 3.3.2 “Dimensioning of Power Distribution Systems”.

An exact protective device selection and thus the dimensioning of subdistribution systems requires extensive short-circuit current and voltage drop calculations. Catalog data for the short-circuit energies, the selectivity and the backup protection of the individual devices and assemblies must also be consulted. In addition, the appropriate regulations and standards must be observed. At this point, a reference should be made to the SIMARIS design dimensioning tool that automatically takes account of the above mentioned conditions, catalog data, standards and regulations, and consequently automatically makes the device selection.

Selectivity and backup protection
Rooms used for medical purposes (IEC 60364-7-710, DIN VDE 0100-710) and meeting rooms (IEC 60364-7-718, DIN VDE 0100-718) require the selection of protective devices in subareas. For other building types, such as computer centers, there is an increasing demand for a selective grading of the protective devices, because only the circuit affected by a fault would be disabled with the other circuits continuing to be supplied with power without interruption (chapter 6 “Protection, Substation Automation, Power Quality and Measurement”).

Because the attainment of selectivity results in increased costs, it should be decided for which circuits selectivity is useful. Backup protection is the lower-cost option. In this case, an upstream protective device, e.g., an LV HRC fuse as group backup fuse, supports a downstream protective device in mastering the short-circuit current, i.e., both an upstream and a downstream protective device trip. The short-circuit current, however, has already been sufficiently reduced by the upstream protective device so that the downstream protective device can have a smaller short-circuit breaking capacity. Backup protection should be used when the expected solid short-circuit current exceeds the breaking capacity of the switching device or the consumers. If this is not the case, an additional limiting protective device unnecessarily reduces the selectivity or, indeed, removes it.

The following scheme should be followed for the selectivity or backup protection decision:
• Determine the maximum short-circuit current at the installation point,
• Check whether the selected protective devices can master this short-circuit current alone or with backup protection using upstream protective devices,
• Check at which current the downstream protective devices and the upstream protective devices are selective to each other.

Fig. 4.4-13: Subdistribution in a data center; display in SIMARIS design
Selectivity and backup protection exemplified for a data center

Computer centers place very high demands on the safety of supply. This is particularly true for the consumers attached to the uninterruptible power supply, and ensures a reliable data backup in case of a fault and service interruption. Those solutions providing selectivity and backup protection relying on the previously mentioned SIMARIS design configuration tool should be presented at this point. Fig. 4.4-13 shows a subdistribution system in SIMARIS design. A SENTRON 3WL circuit-breaker as outgoing feeder switch of the main distribution is upstream to the subdistribution system shown here. The following figures show the selectivity diagrams for the considered subdistribution system automatically generated by SIMARIS design (fig. 4.4-14).

SIMARIS design specifies the characteristic curve band of the considered circuit (red lines), the envelope curves of all upstream devices (blue line) and all downstream devices (green line). In addition to the specification of the minimum and maximum short-circuit currents, any selectivity limits for the individual circuits are also specified.

Fig. 4.4-15 shows the selective grading of the 3WL circuit-breaker from the main distribution system and the group backup fuse (100 A LV HRC fuse) of the subdistribution system. The consumers critical for functional endurance which are installed in a redundant manner in the subdistribution system should not be protected with the same backup fuse but rather be assigned to different groups.

The selectivity diagram shows the circuit diagram of a single-phase consumer in the subdistribution system. This circuit diagram is protected with a 10 A miniature circuit-breaker with characteristic B and for a maximum short-circuit current of 5,892 kA selective for the 100 A group backup fuse.

The same subdistribution system also contains an example for backup protection. Fig. 4.4-16 shows the selectivity diagram for the combination of the group backup fuse with a 13 A miniature circuit-breaker of the characteristic B. Up to the breaking capacity of the 6 kA miniature circuit-breaker, the two protective devices are selective to each other. Above this value, the current is limited by the fuse and the miniature circuit-breaker protected by a fuse; both devices trip.

SIMARIS design automatically generates these characteristic curves to provide exact information about the maximum and minimum short-circuit currents of the associated circuit. Fig. 4.4-16 also shows up to which current ($I_{sel-short-circuit}$) the protective devices are selective to each other.
4.5 Surge Arresters

The main task of an arrester is to protect equipment from the effects of overvoltages. During normal operation, an arrester should have no negative effect on the power system. Moreover, the arrester must be able to withstand typical surges without incurring any damage. Non-linear resistors with the following properties fulfill these requirements:

- Low resistance during surges so that overvoltages are limited
- High resistance during normal operation so as to avoid negative effects on the power system
- Sufficient energy absorption capability for stable operation.

With this kind of non-linear resistor, there is only a small flow of current when continuous operating voltage is being applied. When there are surges, however, excess energy can be quickly removed from the power system by a high discharge current.

4.5.1 High-Voltage Surge Arresters

Non-linear resistors

Non-linear resistors, comprising metal oxide (MO), have proved especially suitable for this use. The non-linearity of MO resistors is considerably high. For this reason, MO arresters, as the arresters with MO resistors are known today, do not need series gaps (fig. 4.5-1).

Siemens has many years of experience with arresters – with the previous gapped SiC arresters and the new gapless MO arresters – in low-voltage systems, distribution systems and transmission systems. They are usually used for protecting transformers, generators, motors, capacitors, traction vehicles, cables and substations.

There are special applications such as the protection of:

- Equipment in areas subject to earthquakes or heavy pollution
- Surge-sensitive motors and dry-type transformers
- Generators in power stations with arresters that possess a high degree of short-circuit current strength
- Gas-insulated high-voltage metal-enclosed switchgear (GIS)
- Valves in HVDC transmission installations
- Static compensators
- Airport lighting systems
- Electric smelting furnaces in the glass and metals industries
- High-voltage cable sheaths
- Test laboratory apparatus.

MO arresters are used in medium, high and extra-high-voltage power systems. Here, the very low protection level and the high energy absorption capability provided during switching surges are especially important. For high-voltage levels, the simple construction of MO arresters is always an advantage. Another very important advantage of MO arresters is their high degree of reliability when used in areas with a problematic climate, for example, in coastal and desert areas, or in regions affected by heavy industrial air pollution. Furthermore, some special applications have become possible only with the introduction of MO arresters. One instance is the protection of capacitor banks in series reactive-power compensation equipment that requires extremely high energy absorption capabilities.
Trade and innovation

Fig. 4.5-2 shows a Siemens MO arrester in a traditional porcelain housing, a well-proven technology representing decades of Siemens experience. Siemens also offers surge arresters with polymer housings for all system voltages and mechanical requirements.

These arresters are divided into two subgroups:
- Cage design™ arresters
- Tube design arresters.

Fig. 4.5-3 shows the sectional view of a tube design arrester. The housing consists of a fiberglass-reinforced plastic tube with insulating sheds made of silicone rubber. The advantages of this design, which has the same pressure relief device as an arrester with porcelain housing, are absolutely safe and reliable pressure relief characteristics, high mechanical strength even after pressure relief and excellent pollution-resistant properties. The very good mechanical features mean that Siemens arresters with a polymer housing (type 3EQ) can serve as post insulators as well. The pollution-resistant properties are the result of the water-repellent effect (hydrophobicity) of the silicone rubber, which even transfers its effects to pollution.

The newest types of polymer surge arresters also feature the cage design. While using the same MO resistors, they have the same excellent electrical characteristics as the 3EP and 3EQ types. The difference is that the 3EL (fig. 4.5-4) types get their mechanical performance from a cage built up by fiber-reinforced plastic rods. Furthermore, the whole active part is directly and completely molded with silicone rubber to prevent moisture ingress and partial discharges. The polymer-housed high-voltage arrester design chosen by Siemens and the high-quality materials used by Siemens provide a whole series of advantages, including long life and suitability for outdoor use, high mechanical stability and ease of disposal.

Another important design are the gas-insulated metal-enclosed surge arresters (GIS arresters, fig. 4.5-5). Siemens has been making these arresters for more than 25 years. There are two reasons why, when GIS arresters are used with gas-insulated switchgear, they usually offer a higher protective safety margin than when outdoor-type arresters are used: First, they can be installed closer to the item to be protected so that traveling wave effects can be limited more effectively. Second, compared with the outdoor type, inductance of the installation is lower (both that of the connecting conductors and that of the arrester itself). This means that the protection offered by GIS arresters is much better than that offered by any other method, especially in the case of surges with a very steep rate of rise or high frequency, to which gas-insulated switchgear is exceptionally sensitive.

Monitoring

Siemens also offers a wide range of products for diagnosis and monitoring of surge arresters. The innovative arrester condition monitor (fig. 4.5-7) is the heart of the future-proof (IEC 61850) monitoring product line.
### 4.5.2 Low-Voltage and Medium-Voltage Surge Arresters and Limiters

Surge arresters and limiters protect operational equipment both from external overvoltages caused by lightning strikes in overhead lines and from internal overvoltages produced by switching operations or earth faults. Normally, the arrester is installed between phase and earth. The built-in stack of non-linear, voltage-dependent resistors (varistors) made of metal oxide (MO) or zinc oxide (ZnO) becomes conductive from a defined overvoltage limit value onward, so that the load can be discharged to earth. When the power-frequency voltage underflows this limit value, called discharge voltage, the varistors return to

<table>
<thead>
<tr>
<th>Special applications</th>
<th>Railway applications</th>
<th>Medium-voltage distribution class</th>
</tr>
</thead>
<tbody>
<tr>
<td>3EF1; 3EF3; 3EF4; 3EF5</td>
<td>3E82</td>
<td>3E02</td>
</tr>
<tr>
<td>3EF8</td>
<td>3EC3</td>
<td>3E24</td>
</tr>
<tr>
<td>3EF1; 3EF3; 3EF4; 3EF5</td>
<td>3E81</td>
<td>3E04</td>
</tr>
<tr>
<td>3EF8</td>
<td>3EK4</td>
<td>3E06</td>
</tr>
<tr>
<td>3EF8</td>
<td>3EK7</td>
<td>3E08</td>
</tr>
</tbody>
</table>

**Applications**

- Motors, dry-type transformers, airfield lighting systems, sheath voltage limiters, protection of converters for drives
- DC overhead contact lines
- DC systems (locomotives, overhead contact lines)
- AC and DC systems (locomotives, overhead contact lines), for highest speed
- Distribution systems and medium-voltage switchgear

**Highest voltage for equipment ($U_{nom}$)**

- 3EF1: 12 kV
- 3EF3: 2 kV
- 3EF4: 4 kV
- 3EF5: 72.5 kV
- 3EF8: 30 kV
- 3E82: 45 kV
- 3E81: 72.5 kV

**Maximum rated voltage**

- 3EF1: 15 kV
- 3EF3: 1 kV
- 3EF4: 4 kV
- 3EF5: 8 kV

**Nominal discharge current**

- 3EF1: 10 A
- 3EF3: 10 A
- 3EF4: 10 A
- 3EF5: 10 A

**Maximum thermal energy absorption capability (per kV of $U_{nom}$)**

- 3EF1: 0.8 kJ/kV
- 3EF3: 4 kJ/kV
- 3EF4: 12.5 kJ/kV
- 3EF5: 8 kJ/kV

**Maximum long-duration current impulse, 2 ms**

- 3EF1: 1,600 A
- 3EF3: 1,600 A
- 3EF4: 1,200 A
- 3EF5: 1,200 A

**Rated short circuit current**

- 3EF1: 40 kA
- 3EF3: 40 kA
- 3EF4: 40 kA
- 3EF5: 40 kA

**Housing material**

- Polyethylene
- Silicone
- Porcelain
- Silicone
- Silicone
- Silicone

**Design principle**

- 3EF1 – polyethylene directly molded onto MO; 3EF3/3EF4/3EF5 – Hollow insulator
- Directly molded
- Hollow insulator
- Hollow insulator, silicone directly molded onto FRP tube
- Cage design, silicone directly molded onto MO

**Pressure relief device**

- No
- No
- Yes
- No
- Yes
- No

1) Energy absorption capability under the conditions of the operating duty test according to IEC 60099-4

**Tab. 4.5-1: Medium-voltage metal-oxide surge arresters and limiters (300 V to 72.5 kV)**
### 4.5 Surge Arresters

#### Tab. 4.5-2: High-voltage metal-oxide surge arresters (72.5 to 1,200 kV)

<table>
<thead>
<tr>
<th>Applications</th>
<th>Porcelain</th>
<th>Silicone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium and high-voltage systems, outdoor installations</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>High-voltage systems, outdoor installations</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>High-voltage systems, outdoor installations, HVDC, SC&amp;SVC applications</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>Medium and high-voltage systems, station and line surge arrester</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>Medium and high-voltage systems, station and line surge arrester</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>Medium and high-voltage systems, outdoor installations</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>High-voltage systems, outdoor installations, HVDC, SC&amp;SVC applications</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>High-voltage systems, outdoor installations</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
<tr>
<td>High-voltage systems, outdoor installations, HVDC applications</td>
<td>3EP5 3EP4 3EP6 3EP3</td>
<td>3EL5 3EL1 3EL2 3EQ1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties</th>
<th>Porcelain</th>
<th>Silicone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest voltage for equipment ($U_{m}$) kV</td>
<td>123 362 550 800</td>
<td>145 362 550 362 550 800 1,200</td>
</tr>
<tr>
<td>Maximum rated voltage kV</td>
<td>96 288 468 612</td>
<td>126 288 468 288 468 612 850</td>
</tr>
<tr>
<td>Maximum nominal discharge current kA</td>
<td>10 10 20 20</td>
<td>10 10 20 10 20 20 20</td>
</tr>
<tr>
<td>Maximum line discharge class</td>
<td>3 3 5 5</td>
<td>2 2 4 3 5 5 5</td>
</tr>
<tr>
<td>Maximum thermal energy absorption capability (per kV of $U_{m}$) kJ/kV</td>
<td>8 8 14 25</td>
<td>2 5 10 8 18 25 66</td>
</tr>
<tr>
<td>Maximum long-duration current impulse, 2 ms A</td>
<td>1,100 1,100 2,000 7,000</td>
<td>550 750 1,200 1,100 3,200 8,500 11,000</td>
</tr>
<tr>
<td>Rated short circuit current kA</td>
<td>40 65 65 100</td>
<td>20 65 65 50 80 80 80</td>
</tr>
<tr>
<td>Maximum permissible service load kNm</td>
<td>2.0 (SSL)1) 3 (SSL)1) 16.0 (SSL)1) 34 (SSL)1)</td>
<td>0.5 (SSL)1) 1.2 (SSL)1) 4.0 (SSL)1) 6.0 (SSL)1) 38 (SSL)1) 72 (SSL)1) 225 (SSL)1)</td>
</tr>
<tr>
<td>Housing material</td>
<td>Porcelain</td>
<td>Silicone</td>
</tr>
<tr>
<td>Design principle</td>
<td>Hollow insulator</td>
<td>Silicone directly molded onto MO</td>
</tr>
<tr>
<td>Pressure relief device</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

1) SSL = Specified short-term load
their original resistance value so that only a so-called leakage current of a few mA flows at operating voltage. Because this leakage current heats up the resistors, and thus the arrester, the device must be designed according to the neutral-point treatment of the system in order to prevent impermissible heating of the arrester.

In contrast to the normal surge arrester, the surge limiter contains a series gap in addition to the MO resistor stack. If the load generated by the overvoltage is large enough, the series gap ignites, and the overvoltage can be discharged to earth until the series gap extinguishes and the varistors return to their non-conductive state. This process is repeated again and again throughout the entire duration of the fault. This makes it possible to design the device with a considerably lower discharge voltage as a conventional surge arrester, and is especially useful for the protection of motors with – normally – a poor dielectric strength. To guarantee a sufficient protective function, the discharge voltage value of the arresters or limiters must not exceed the dielectric strength of the operational equipment to be protected.

The medium-voltage product range includes:
- The 3EB and 3EC surge arresters for railway DC as well as AC applications (fig. 4.5-6).
- The 3EF group of surge arresters and limiters for the protection of motors, dry-type transformers, airfield lighting systems and cable sheath as well as for the protection of converters for drives (fig. 4.5-6).
- The 3EK silicone-housed surge arrester for distribution systems, medium-voltage switchgear up to 72.5 kV and line surge arresters for outdoor use (fig. 4.5-8 and fig. 4.5-9).

An overview of the complete range of Siemens arresters appears in the table 4.5-1 to table 4.5-3.

<table>
<thead>
<tr>
<th></th>
<th>3ES5-CIM/N, 3ES4-K 3-phase</th>
<th>3ES2-E 1-phase</th>
<th>3ES4-L, 3ES5-H 1-phase</th>
<th>3ES9-J 1-phase</th>
<th>3ES with oil-SF₆ 1-phase</th>
<th>3ES6 3-phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications</td>
<td>High-voltage systems, protection of metal-enclosed, gas-insulated switchgear and transformers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest voltage for equipment (Uₘₘ)</td>
<td>170</td>
<td>245</td>
<td>550</td>
<td>800</td>
<td>550</td>
<td>420</td>
</tr>
<tr>
<td>Maximum rated voltage</td>
<td>kV</td>
<td>156</td>
<td>216</td>
<td>444</td>
<td>612</td>
<td>444</td>
</tr>
<tr>
<td>Maximum nominal discharge current</td>
<td>kA</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Maximum line discharge class</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Maximum thermal energy absorption capability (per kV of Uₘₘ)</td>
<td>kJ/kV</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Maximum long-duration current impulse, 2 ms</td>
<td>A</td>
<td>1,200</td>
<td>1,200</td>
<td>1,600</td>
<td>2,100</td>
<td>1,600</td>
</tr>
<tr>
<td>Rated short circuit current</td>
<td>kA</td>
<td>63</td>
<td>50</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Maximum permissible service load</td>
<td>kNm</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing material</td>
<td>Metal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure relief device</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Tab. 4.5-3: Metal-oxide surge arresters for GIS (72.5 to 800 kV)*

For further information, please contact:
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E-mail: arrester.energy@siemens.com
4.6 Instrument Transformers

4.6.1 High-Voltage Instrument Transformers

Introduction
Electrical instrument transformers transform high currents and voltages to standardized low and easily measurable values that are isolated from the high voltage. When used for metering purposes, instrument transformers provide voltage or current signals that are very accurate representations of the transmission line values in both magnitude and phase. These signals allow accurate determination of revenue billing.

When used for protection purposes, the instrument transformer outputs must accurately represent the transmission line values during both steady-state and transient conditions. These critical signals provide the basis for circuit breaker operation under fault conditions, and as such are fundamental to network reliability and security.

Instrument transformers used for network control supply important information for determining the state of the operating conditions of the network.

Reliability and security
Reliability of an instrument transformer refers to its ability to consistently satisfy prescribed performance criteria over its expected useful lifetime under specified operating conditions. Security refers to the acceptability and consequences of the instrument transformer failure mode in the event that it does fail, due either to being subjected to stresses in excess of those for which it was designed, or due to its reaching the end of its expected service life.

The reliability and security characteristics of an instrument transformer are governed by the electrical and insulation design, the manufacturing and processing technology used and the specific physical arrangement. The partial discharge performance under in-service conditions is a key determining factor in the life expectancy and long-term reliability of an instrument transformer.

IEC standards for oil-immersed or gas-filled devices require a partial discharge value of less than 10 pC at $U_{\text{max}}$. Due to the demanding requirements of today's HV and UHV networks, the Trench Group has elected to adopt even more stringent internal requirements. As such, Trench instrument transformers typically perform much better than required by these standards with proven field experience with hundreds of thousands in operation over more than 50 years in almost every country worldwide. Typical designs are oil-immersed (fig. 4.6-2), gas-insulated (fig. 4.6-1).

Oil-immersed instrument transformers
The reliability and security of Trench oil-immersed inductive instrument transformers is proven by in-service experience spanning up to 50 years and more than 100,000 units in service under a wide variety of different environmental conditions. The transformer is based on state-of-the-art design and a secure failure mode approach. In the event of unexpected stresses from the network, secure failure is achieved through the use of a “barrier construction” design in the free oil section. This approach consists of inserting insulating barriers at critical points through the free oil space, thereby preventing the formation of fiber bridges.

Furthermore a rupture of the housing, particularly of the hollow insulator with built-in finely graded capacitor bushing, is improbable because of the safe dimensioning of the bushing and the solid electrical connection between the core housing and the ground.

If over pressure occurs, the protection is guaranteed by the:
  - Welded elastic housing
  - Stainless-steel bellows for the oil expansion.

Both the welded seam, which connects the upper and lower portions of the head housing, and the metallic bellows are designed to act as pressure relief points in the event of severe internal pressure buildup.

Because the unit has a normal internal oil pressure of approximately 1 bar absolute, it is possible to design these pressure relief points to rupture at very moderate pressures. Additional safety is achieved by the selection of composite insulators, available in the whole range as an alternative to the traditional porcelain.

Pressure relief for capacitor voltage transformers is provided by a bellows puncture pin and through the use of porcelain, which is strong enough to result in any rapid pressure rise being released through the seal plates at the ends of the porcelain rather than via explosion of the porcelain itself.

Gas-insulated instrument transformers
The reliability and security of Trench gas-insulated instrument transformers is based on:
  - 50 years of experience as a manufacturer of instrument transformers covering epoxy resin and oil-paper
  - Thousands of gas-insulated instrument transformers in service under a wide variety of different environmental conditions.

Explosion-proof design
The present Trench gas-insulated instrument transformers were initially designed in 1965 at the request of customers who sought to achieve explosion-proof operation. SF6 gas insulation, combined with composite insulators, is particularly suitable for this, because in the event of an internal flashover, the pressure increase will be linear and hence technically manageable. A controlled pressure relief device at the head of the transformer (rupture disc) eliminates unacceptable mechanical stresses in
the housing; i.e., only the rupture disc is released. Gas escapes, but the complete transformer remains intact and no explosion occurs.

**Most reliable insulation properties**

$SF_6$ gas is the main insulation medium between high-voltage and earth potential. A stable quality can be guaranteed by the use of $SF_6$ gas according to IEC 60137 (2005) / ASTM 2472 D and the fact that this inert gas shows no ageing even under the highest electrical and thermal stresses. The insulation properties remain unchanged throughout its lifetime. All of these features guarantee an operation period over many years without any control of the insulation condition.

**Full functional security and monitoring**

The guaranteed $SF_6$ leakage rate is less than 0.5 % per year. The gas pressure can be checked on site or by means of a remote control device, i.e., a densimeter with contacts for remote control. In the case of loss of $SF_6$ pressure, the transformer still operates at rated pressure.

**Environmentally beneficial under extremely severe conditions**

$SF_6$ gas is absolutely safe for humans. It bears no ecologically toxic potential and its decomposition products have no deleterious effects on the environment, e.g., groundwater pollution. This $SF_6$ gas insulation medium allows easy waste management of the transformers. Furthermore, the hydrophobic features of the composite insulator result in problem-free service even under saline fog or polluted conditions. As a long-term benefit, the change of cores or windings, even after years, can be realized easily for new requirements like additional metering.

**Current transformers**

All Trench current transformer (CT) designs are based on “head type” construction. CTs are available with either oil (fig. 4.6-2) or $SF_6$ gas dielectric systems (fig. 4.6-3).

**Features of oil-immersed type**

- Low weight and minimum oil volume
- Excellent seismic performance as a consequence of the optimized design of flanges, vast choice of porcelain strengths and their interconnection and low weight
- Available for the full voltage range of 72.5 kV up to 550 kV and full current range of few Amperes up to 5,000 A with multiple-turn primaries for small primary currents. Ratio change available either on primary side or secondary side
- Short, symmetrically arranged low-reactance bar-type primary conductor permits higher short-circuit currents up to 80 kA and avoids large voltage drop across the primary winding
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
- Hermetically sealed by stainless-steel metallic bellows and high-quality gaskets
- Uniformly distributed secondary windings guarantee accurate transformation at both rated and high currents
- Essentially unaffected by stray external magnetic fields
- Stable accuracy over life-time

---

**Fig. 4.6-1:** 800 kV gas-insulated current transformers  
**Fig. 4.6-2:** 550 kV oil-immersed current transformers  
**Fig. 4.6-3:** 420 kV gas-insulated current transformers
• Perfect transient performance
• Exclusive use of corrosion-resistant materials
• Full range of products available with composite insulator.

Features of gas-insulated transformer
• Explosion-proof design by the compressible insulation medium SF₆ gas and rupture disc
• Excellent seismic performance due to the properties of the composite insulator
• Available for the full voltage range of 72.5 kV up to 800 kV and full current range of 100 A up to 4,800 A
• Low-reactance, bar-type primary providing optimal short-circuit performance
• Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
• Multiple-turn primaries for small primary currents and uniformly distributed secondary windings guarantee accurate transformation at both rated and high currents
• Stable accuracy over life-time
• Perfect transient performance
• Exclusive use of corrosion-resistant materials
• Replacing cores on assembled units is possible without affecting the integrity of the high-voltage insulation.

Inductive voltage transformers
Inductive voltage transformers are designed for 72.5 kV to 800 kV systems and are used to provide voltage for metering and protection applications. They are available with either oil (fig. 4.6-4) or SF₆ gas dielectric systems (fig. 4.6-5).

Features of oil-immersed type
• Low weight and minimum oil volume
• Excellent seismic performance as a consequence of optimized designs of flanges, large choice of porcelain strengths and their interconnection and low weight
• Available for the full voltage range of 72.5 kV up to 550 kV
• Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
• Optimized high-voltage coil ensures identical electric stresses under both transient and steady-state conditions
• Essentially unaffected by stray external magnetic fields
• Hermetically sealed stainless-steel metallic bellows for units rated 123 kV and above
• Stable accuracy over a long period of time
• Perfect transient performance
• Suitable for line discharging
• Applicable as a low-cost alternative to small power transformer
• Exclusive use of corrosion-resistant materials
• Full range of products available with composite insulator.

Features of gas-insulated transformer
• Explosion-proof design by the compressible insulation medium SF₆ gas and rupture disc
• Excellent seismic performance due to the properties of the composite insulator
• Available for the full voltage range of 72.5 kV up to 800 kV
• Optimum field grading is accomplished by a fine condenser

grading system especially developed for this application
- Wide range ferroresonance-free design without the use of an external damping device (please ask for details)
- Essentially unaffected by external stray magnetic fields
- Stable accuracy over a long period of time
- Suitable for line discharging
- Optimized high-voltage coil ensures identical electric stresses under both transient and steady state conditions
- Exclusive use of corrosion-resistant materials
- Applicable as a low-cost alternative to small power transformer.

Capacitor voltage transformer (oil-immersed)
Coupling capacitors (CC) are utilized to couple high-frequency carrier signals to the power line. A CC supplied with an electromagnetic unit is called a capacitor voltage transformer (CVT) and is used to provide voltage for metering and protection applications (fig. 4.6-6).

Features
- Capable of carrier coupling PLC signals to the network
- Optimized insulation system design utilizing state-of-the-art processing techniques with either mineral oil or synthetic insulating fluids
- Stability of capacitance and accuracy over a long period of time due to superior clamping system design
- Oil expansion by way of hermetically sealed stainless-steel bellows ensures the integrity of the insulation system over time
- Bellows puncture pin provides for release of internal pressure in the event of severe service conditions leading to internal discharges
- Extra-high-strength porcelains provide both superior seismic performance and the ability to mount large line traps directly on the CVT with corresponding savings in installed cost
- Maintenance-free oil-filled cast aluminum basebox
- Superior transient response characteristics
- Internal company routine tests and quality requirements exceed those of international standards with impulse tests and partial discharge test being performed on a routine basis
- Not subject to ferroresonance oscillations with the network or circuit breaker capacitor
- High-capacitance CVTs, when installed in close proximity to EHV circuit breakers, can provide enhanced circuit breaker short line fault/TRV performance.

Electronic voltage measuring system for HVDC
Trench offers special voltage transformers for HVDC systems. These units are primarily used to control the HV valves of the rectifiers or inverse rectifiers. The measuring system consists of an RC voltage divider that provides inputs to a specially designed electronic power amplifier. The high-voltage divider can be supplied either for outdoor operation or for installation into SF6 gas-insulated switchgear (GIS).

The resulting system can accurately transform voltages within a defined burden range with linear frequency response of up to approximately 10 kHz. Thus, the system is ideal for measurement of dynamic and transient phenomena and harmonics associated with HVDC systems.
### Combined instrument transformer

The combined instrument transformer offers the station designer the ability of being able to accommodate the current transformer and the voltage transformer in one free-standing unit. This allows optimum use of substation space while yielding cost savings by elimination of one set of mounting pads and support structures. In addition, installation time is greatly reduced. Combined ITs are available with either oil (fig. 4.6-8) or SF₆ gas dielectric systems (fig. 4.6-10, fig. 4.6-12).

#### Features of oil-immersed combined instrument transformers
- Low weight and minimum oil volume
- Short symmetrically arranged low-reactance, bar-type primary conductor permits higher short-circuit currents and avoids large voltage drop across primary winding
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
- Available for the full voltage range of 72.5 kV up to 300 kV and full current range of 0.5 A up to 5,000 A
- Excellent seismic capability as a consequence of optimized design of flanges, large choice of porcelain strengths and their interconnection and low weight
- Hermetically sealed by stainless-steel metallic bellows and high-quality gaskets
- Only one foundation required in the switchyard as a consequence of combining the voltage and current-sensing functions in one transformer
- Uniformly distributed secondary windings guarantee accurate transformation at both rated and high current
- Essentially unaffected by stray external magnetic fields
- Stable accuracy over a long period of time
- Perfect transient performance
- Suitable for line discharging
- Exclusive use of corrosion-resistant materials
- Full range of products available with composite insulator.

#### Features of gas-insulated combined instrument transformers
- Head-type design with voltage transformer section located on top of the current transformer
- Low weight and compact SF₆ design
- Explosion-proof design by the compressible insulation medium SF₆ gas and rupture disc
- Excellent seismic performance due to the properties of the composite insulator
- The single-section high-voltage coil (not cascaded) of the voltage transformer section enables a product range for combined instrument transformers of up to 800 kV
- Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
- Wide-range ferroresonance-free design without the use of an external damping device
- Low-reactance type primary conductor allows for high short-circuit currents and covers all core standards
- Less foundation space required compared to individual current transformers and voltage transformers
- Suitable for line discharging
- Essentially unaffected by external stray magnetic fields
- Exclusive use of corrosion-resistant materials.

### Instrument transformer for GIS

In addition to the measurement of the voltages and currents, this instrument transformer type for voltage measurement (inductive) has the best discharge capabilities for HV lines (fig. 4.6-13).

---

**Fig. 4.6-11:** 300 kV oil-immersed current transformers

**Fig. 4.6-12:** 800 kV gas-insulated combined instrument transformer

**Fig. 4.6-13:** 145 kV inductive voltage transformer for GIS
Features of inductive type
- Custom-designed instrument transformers for each specific application and extended function designs comply with dimensional restrictions, flange sizes and insulator requirements
- Standard designs for 1-phase and 3-phase units
- Meets all national and international standards in regard to pressure vessel codes
- Prevention of occurrence of stable ferroresonances by integrated ferroresonance suppression
- Shielded against transient overvoltages in accordance with IEC standards. Special additional shielding is available
- Guaranteed SF₆ leakage rate of less than 0.5 % per year
- Equipped with pressure relief disc and deflection device
- All components are designed and tested for mechanical stress to withstand up to at least 20 g
- Accuracy classes in accordance with DIN VDE 0414, IEC 60044, ANSI: IEEE C57.13, AS 1243 (other standards or classes on request)
- Shock indicators warn against inadmissible acceleration during transportation.

RC dividers
Resistive-capacitive voltage dividers, also called resistive-capacitive voltage transformers, are designed for measurement of the voltage in HVDC transmission systems, air-insulated (AIS) (fig. 4.6-7) or gas-insulated (GIS) switchgear (fig. 4.6-14). In AC transmission systems, the transformers are used for the measurement of harmonics and they give an accurate representation of the voltage over a wide frequency band (typically from DC up to 500 kHz).

Features of RC-dividers
- RC divider for voltage measurements
- Conform to microprocessor-based secondary technology
- Ferroresonance-free
- Able to perform voltage test on site
- 1-phase or 3-phase system
- Significant size and weight reduction.
LoPo – the low-power transducers
The low-power current transducers (LPCT) and low-power voltage transducers (LPVT) can be used for a wide range of medium and high-voltage applications in which they replace the conventional measuring transformers for measurement and protection purposes.

Features
- The voltage transducers are based on resistive, capacitive, as well as resistive-capacitive dividers
- The current transducers are based on an iron-core or an air-core design and provide a secondary voltage that represents the primary current
- Standard cables and connectors; twisted pair and double shielded cable
- Connection capability for multiple protection and measuring devices
- Metal-clad housing ensuring operator safety
- Immune to all methods of online switchgear and cable testing
- Current transducers provide a linear transmission up to short-circuit current
- Completely EMC shielded: immune to RFI/EMI.

Advantages
- System conforms to low-power digital microprocessor-based technology for protection and metering
- Simple assembly with compact size and low weight
- No secondary circuit problems; voltage transducers are short-circuit-proof, current transducers can have an open secondary
- Voltage transducers are ferroresonance-free
- Environment-friendly (no oil).

Non conventional instrument transformers
Conventional instrument transformers provide high power output in a proven insulation technology, using mainly inductive technology. Non conventional instrument transformers (NCIT) are current and/or voltage measurement devices that provide a low output power (< 0.5 VA). The NCIT technologies Trench is providing are Low Power Current Transformers with voltage output and RC-dividers, which are both described in previous chapters. They have a wide linearity range and their output signals are suitable to match to modern secondary equipment such as Merging Units.

Merging units convert the output signals of both conventional and non conventional instrument transformers into a digital signal according to the IEC 61850-9-2 protocol. The output is a standardized data stream independent from sensor features. The measurements are distributed with one optical Ethernet connection. The only burden of the instrument transformer is the input impedance of the merging unit. A Trench Merging Unit is under preparation.
4.6.2 Power Voltage Transformers

Power Voltage Transformers for AIS

Power Voltage Transformers (Power VTs) avoid major investments to achieve power supply for remote customers. The Power VTs just have to be connected directly to the high voltage overhead line to ensure customized power supply. A power VT for AIS is shown in fig. 4.6-9.

Features of Power VTs for AIS
- Available for the full voltage range of 72.5 up to 800 kV
- SF₆ or oil insulated power enhanced instrument voltage transformer with proven reliability
- Composite insulator (fibre-glass insulator with silicone sheds)
- Maintenance free
- Single phase unit.

Applications
- Power supply for remote farms and small villages
- Power supply for relay stations for mobile phones
- Auxiliary power supply for substations
- Power supply during substation construction works.

Power Voltage Transformers for GIS

Inductive Voltage Transformer with different active parts becomes a “Power VT”, which then allows for a high voltage test of the primary system without special high voltage test equipment. A Power VT for GIS is shown in fig. 4.6-15.

Features of Power VTs for GIS
- Same dimension as standard VTs and also usable like a standard VT
- No extra space needed for installation of huge high voltage testing facilities
- No SF₆ gas handling at site needed for test preparation
- Reduced transport and packages requirements
- After test the switchgear can be put into operation without mechanical work on the primary circuit (i.e. normally the high voltage test set must be removed)
- Easy support by neutral testing companies (e.g. OMICRON) or testing institutes
- With a “Power VT” the high voltage test becomes like testing a protection relay
- Light weight units allow handling at site without lifting facilities or cranes
- Power supply via standard socket outlet (e.g. 1-phase, 230 V, 16 A)
- Test facilities available with transport cases allowing transport as carry-on luggage during travelling to site or the use of standard parcel services
- Test preparation within minutes e.g. after S/S-extension, re-assembling or extensive service activities
- Low investment in site-based testing facilities
- Possibility for investigation into sporadic effects at PD-test voltage levels.

An overview of the range of Trench instrument transformers appears in table 4.6-1 to table 4.6-7.
## Current Transformers for Gas Insulated Substations (GIS)

<table>
<thead>
<tr>
<th>Type</th>
<th>SAD/SA</th>
<th>LPCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range [kV]</td>
<td>72.5 – 550</td>
<td>72.5 – 550</td>
</tr>
<tr>
<td>Insulation medium</td>
<td>SF₆</td>
<td>–</td>
</tr>
</tbody>
</table>

### Technical data SAD/SA

<table>
<thead>
<tr>
<th>Voltage level [kV]</th>
<th>72.5</th>
<th>123</th>
<th>145</th>
<th>170</th>
<th>245</th>
<th>300</th>
<th>362</th>
<th>420</th>
<th>550</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output current [A]</td>
<td></td>
<td></td>
<td></td>
<td>1 – 5 (LoPo: 3.25 V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Rated short-time thermal current [kA]</td>
<td>31.5</td>
<td>50</td>
<td>63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated duration of short circuit [s]</td>
<td></td>
<td>1 – 3</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rated dynamic current [kA]</td>
<td>78.75</td>
<td>125</td>
<td>160</td>
<td></td>
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<tr>
<td>Rated frequency [Hz]</td>
<td>16 2/3 – 50 – 60</td>
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<tr>
<td>Temperature range [°C]</td>
<td>–35 – +60</td>
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<tr>
<td>Insulation class</td>
<td>E, F</td>
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</tr>
<tr>
<td>Metering accuracy class</td>
<td>0.1 – 0.2 – 0.25 – 0.5 – 0.55 – 1.0</td>
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</tr>
</tbody>
</table>

Values in accordance with IEC; other values like ANSI are available

*Tab 4.6-1: Technical data of Trench current transformers for gas-insulated substations (GIS)*
### Voltage Transformers/RC-Dividers for Gas Insulated Substations (GIS)

<table>
<thead>
<tr>
<th>Type</th>
<th>SUD/SU</th>
<th>RCVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range</td>
<td>72.5 – 800</td>
<td>72.5 – 550</td>
</tr>
<tr>
<td>Insulation medium</td>
<td>SF₆</td>
<td>Oil/SF₆</td>
</tr>
</tbody>
</table>

#### Technical data SUD/SU

<table>
<thead>
<tr>
<th>Voltage level</th>
<th>[kV]</th>
<th>72.5</th>
<th>123</th>
<th>145</th>
<th>170</th>
<th>245</th>
<th>300</th>
<th>362</th>
<th>420</th>
<th>550</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power frequency withstand voltage</td>
<td>[kV]</td>
<td>140</td>
<td>230</td>
<td>275</td>
<td>325</td>
<td>460</td>
<td>460</td>
<td>510</td>
<td>630</td>
<td>680</td>
<td>975</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage</td>
<td>[kV]</td>
<td>325</td>
<td>550</td>
<td>650</td>
<td>750</td>
<td>1,050</td>
<td>1,050</td>
<td>1,175</td>
<td>1,425</td>
<td>1,550</td>
<td>2,100</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage</td>
<td>[kV]</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>850</td>
<td>950</td>
<td>1,050</td>
<td>1,175</td>
<td>1,550</td>
</tr>
<tr>
<td>Output voltage</td>
<td>[V]</td>
<td>110√3 – 200√3 (other values upon request)</td>
<td>(AC &amp; DC RC Divider: 5 – 200V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated voltage factor</td>
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<td>1.2 – 1.5 – 1.9 (other values upon request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated frequency</td>
<td>[Hz]</td>
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<td>–</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Temperature range</td>
<td>[°C]</td>
<td>–35</td>
<td>+40 (other values upon request)</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Insulation class</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metering accuracy class</td>
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<td>0.1 – 0.2 – 0.5 – 1.0 – 3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output burden</td>
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<td>for different classes according to customer specification</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Protection accuracy class</td>
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<td>3P – 6P</td>
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<tr>
<td>Output burden</td>
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<td>for different classes according to customer specification</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Thermal limiting output</td>
<td>2,000</td>
<td>3,000 ¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[¹) valid only for voltage transformers]

Values in accordance with IEC; other values like ANSI are available; ¹) valid only for voltage transformers

---

**Tab 4.6-2: Technical data of Trench voltage transformers for gas-insulated substations (GIS)**

---

Siemens Energy Sector • Power Engineering Guide • Edition 7.0
## Current Transformers for Air Insulated Substations (AIS)

<table>
<thead>
<tr>
<th>Type</th>
<th>SAS</th>
<th>TAG</th>
<th>IOSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range [kV]</td>
<td>72.5 – 800</td>
<td>72.5 – 550</td>
<td>72.5 – 550</td>
</tr>
<tr>
<td>Insulation medium</td>
<td>SF₆</td>
<td>SF₆</td>
<td>Oil</td>
</tr>
<tr>
<td>Composite insulator</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Porcelain insulator</td>
<td>×</td>
<td></td>
<td>×</td>
</tr>
</tbody>
</table>

### Technical data

<table>
<thead>
<tr>
<th>Voltage level [kV]</th>
<th>72.5</th>
<th>123</th>
<th>145</th>
<th>170</th>
<th>245</th>
<th>300</th>
<th>362</th>
<th>420</th>
<th>550</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power frequency withstand voltage [kV]</td>
<td>140</td>
<td>230</td>
<td>275</td>
<td>325</td>
<td>460</td>
<td>460</td>
<td>510</td>
<td>630</td>
<td>680</td>
<td>975</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage [kV]</td>
<td>325</td>
<td>550</td>
<td>650</td>
<td>750</td>
<td>1,050</td>
<td>1,050</td>
<td>1,175</td>
<td>1,425</td>
<td>1,550</td>
<td>2,100</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage [kV]</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>850</td>
<td>950</td>
<td>1,050</td>
<td>1,175</td>
<td>1,550</td>
</tr>
<tr>
<td>Rated normal current up to [A]</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>5,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output current [A]</td>
<td>1 – 2 – 5</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated short-time thermal current [kA]</td>
<td>63 (80 on special request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated duration of short circuit [s]</td>
<td>1 – 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated dynamic current [kA]</td>
<td>160 (200 on special request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated frequency [Hz]</td>
<td>16 ⅔ – 50 – 60</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creepage distance [mm/kV]</td>
<td>25 – 31 (higher upon request)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature range [°C]</td>
<td>–40 – +40 (other values upon request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation class</td>
<td>E (SF₆ insulated devices) – A (oil insulated devices)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metering accuracy class</td>
<td>0.1 – 0.2 – 0.25 – 0.5 – 0.55 – 1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in accordance with IEC; other values like ANSI are available.

*Tab 4.6-3: Technical data of Trench current transformers for air-insulated substations (AIS)*
### Voltage Transformers/RC-Dividers for Air Insulated Substations (AIS)

<table>
<thead>
<tr>
<th>Type</th>
<th>SVS</th>
<th>TVG</th>
<th>VEOT/VEOS</th>
<th>TCVT</th>
<th>AC RCD</th>
<th>DC RCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range [kV]</td>
<td>72.5 – 800</td>
<td>72.5 – 420</td>
<td>72.5 – 550</td>
<td>72.5 – 1200</td>
<td>72.5 – 800</td>
<td>72.5 – 800</td>
</tr>
<tr>
<td>Insulation medium</td>
<td>SF₆</td>
<td>SF₆</td>
<td>Oil</td>
<td>Oil</td>
<td>Oil</td>
<td>Oil/SF₆</td>
</tr>
<tr>
<td>Composite insulator</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Porcelain insulator</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

**Technical data**

<table>
<thead>
<tr>
<th>Voltage level [kV]</th>
<th>72.5</th>
<th>123</th>
<th>145</th>
<th>170</th>
<th>245</th>
<th>300</th>
<th>362</th>
<th>420</th>
<th>550</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power frequency withstand voltage [kV]</td>
<td>140</td>
<td>230</td>
<td>275</td>
<td>325</td>
<td>460</td>
<td>460</td>
<td>510</td>
<td>630</td>
<td>680</td>
<td>975</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage [kV]</td>
<td>325</td>
<td>550</td>
<td>650</td>
<td>750</td>
<td>1,050</td>
<td>1,050</td>
<td>1,175</td>
<td>1,425</td>
<td>1,550</td>
<td>2,100</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage [kV]</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>850</td>
<td>950</td>
<td>1,050</td>
<td>1,175</td>
<td>1,550</td>
</tr>
<tr>
<td>Output voltage [V]</td>
<td>110√3 – 200√3 (other values upon request) (AC &amp; DC RC Divider: 5 – 200V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated voltage factor</td>
<td>1.2 – 1.5 – 1.9 (other values upon request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated frequency [Hz]</td>
<td>16 ⅔ – 50 – 60 (AC &amp; DC RC Divider: 0 – 1 MHz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creepage distance [mm/kV]</td>
<td>25 – 31 (higher upon request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Temperature range [°C]</td>
<td>–40 – +40 (other values upon request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation class</td>
<td>E (SF₆ insulated devices) – A (oil insulated devices)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metering accuracy class</td>
<td>0.1 – 0.2 – 0.5 – 1.0 – 3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output burden (only AC)</td>
<td>for different classes according to customer specification (very low output burden for RC Divider &gt; 100 kΩ)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Protection accuracy class</td>
<td>3P – 6P</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output burden (only AC)</td>
<td>for different classes according to customer specification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal limiting output [VA]</td>
<td>3,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in accordance with IEC; other values like ANSI are available; 1) valid only for voltage transformers

Tab 4.6-4: Technical data of Trench voltage transformers for air-insulated substations (AIS)
## Combined Instrument Transformers for Air Insulated Substations (AIS)

<table>
<thead>
<tr>
<th>Type</th>
<th>SVAS</th>
<th>AVG</th>
<th>IVOKT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range [kV]</td>
<td>72.5 – 800</td>
<td>72.5 – 245</td>
<td>72.5 – 300</td>
</tr>
<tr>
<td>Insulation medium</td>
<td>SF₆</td>
<td>SF₆</td>
<td>Oil</td>
</tr>
<tr>
<td>Composite insulator</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Porcelain insulator</td>
<td>×</td>
<td>×</td>
<td></td>
</tr>
</tbody>
</table>

### Technical data

<table>
<thead>
<tr>
<th>Voltage level [kV]</th>
<th>72.5</th>
<th>123</th>
<th>145</th>
<th>170</th>
<th>245</th>
<th>300</th>
<th>362</th>
<th>420</th>
<th>550</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power frequency withstand voltage [kV]</td>
<td>140</td>
<td>230</td>
<td>275</td>
<td>325</td>
<td>460</td>
<td>460</td>
<td>510</td>
<td>630</td>
<td>680</td>
<td>975</td>
</tr>
<tr>
<td>Rated lightning impulse withstand voltage [kV]</td>
<td>325</td>
<td>550</td>
<td>650</td>
<td>750</td>
<td>1,050</td>
<td>1,050</td>
<td>1,175</td>
<td>1,425</td>
<td>1,550</td>
<td>2,100</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage [kV]</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>850</td>
<td>950</td>
<td>1,050</td>
<td>1,175</td>
<td>1,550</td>
</tr>
<tr>
<td>Rated frequency [Hz]</td>
<td>16 ⅔ – 50 – 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creepage distance [mm/kV]</td>
<td>25 – 31 (higher upon request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature range [°C]</td>
<td>–40 – +40 (other values upon request)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CT ratings

<table>
<thead>
<tr>
<th>Rated normal current up to [A]</th>
<th>5,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output current [A]</td>
<td>1 – 2 – 5</td>
</tr>
<tr>
<td>Rated short-time thermal current [kA]</td>
<td>63 (80 on special request)</td>
</tr>
<tr>
<td>Rated duration of short circuit [s]</td>
<td>1 – 3</td>
</tr>
<tr>
<td>Rated dynamic current [kA]</td>
<td>160 (200 on special request)</td>
</tr>
</tbody>
</table>

### VT ratings

| Output voltage [V] | 110/√3 – 200/√3 (other values upon request) |
| Rated voltage factor | 1.2 – 1.5 – 1.9 (other values upon request) |
| Metering accuracy class | 0.1 – 0.2 – 0.25 – 0.5 – 0.55 – 1.0 |
| Protection accuracy class | 3P – 6P |
| Output burden for different classes according to customer specification |
| Thermal limiting output [VA] | 3000 (other values upon request) |

*Values in accordance with IEC; other values like ANSI are available*

*Tab 4.6-5: Technical data of Trench combined instrument transformers for air-insulated substations (AIS)*
### Power Voltage Transformers for Air Insulated Substations (AIS)

![Transformer Image]

<table>
<thead>
<tr>
<th>Type</th>
<th>PSVS</th>
</tr>
</thead>
</table>

#### Technical data

<table>
<thead>
<tr>
<th>Voltage level [kV]</th>
<th>123</th>
<th>145</th>
<th>170</th>
<th>245</th>
<th>300</th>
<th>362</th>
<th>420</th>
<th>550</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power frequency withstand voltage [kV]</td>
<td>230</td>
<td>275</td>
<td>325</td>
<td>460</td>
<td>460</td>
<td>510</td>
<td>630</td>
<td>680</td>
</tr>
<tr>
<td>Rated lighting impulse withstand voltage [kV]</td>
<td>550</td>
<td>650</td>
<td>750</td>
<td>1,050</td>
<td>1,050</td>
<td>1,175</td>
<td>1,425</td>
<td>1,550</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage [kV]</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>850</td>
<td>950</td>
<td>1,050</td>
<td>1,175</td>
</tr>
<tr>
<td>Output power [kVA]</td>
<td>100</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>75</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage [V]</td>
<td>120 to 400 (values in between according to customer specification)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Rated frequency [Hz]</td>
<td>50 – 60</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Creepage distance [mm/kV]</td>
<td>25 – 31 (higher upon request)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Temperature range [°C]</td>
<td>–25&lt;sup&gt;1)&lt;/sup&gt; – +40</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Insulation class</td>
<td>E</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Metering accuracy class</td>
<td>0.2&lt;sup&gt;2)&lt;/sup&gt; – 0.5&lt;sup&gt;2)&lt;/sup&gt; – 1.0&lt;sup&gt;2)&lt;/sup&gt; – 3.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Protection accuracy class</td>
<td>3P&lt;sup&gt;2)&lt;/sup&gt; – 6P</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Values in accordance with IEC; other values like ANSI are available.<br>1) lower temperature upon request<br>2) not under load condition

**Tab 4.6-6: Technical data of Trench power voltage transformers for air-insulated substations (AIS)**
### Power Voltage Transformers for Gas Insulated Substations (GIS)

<table>
<thead>
<tr>
<th>Type</th>
<th>PSUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage level [kV]</td>
<td>72.5</td>
</tr>
<tr>
<td>Rated power frequency withstand voltage [kV]</td>
<td>140</td>
</tr>
<tr>
<td>Rated lighting impulse withstand voltage [kV]</td>
<td>325</td>
</tr>
<tr>
<td>Rated switching impulse withstand voltage [kV]</td>
<td>–</td>
</tr>
<tr>
<td>Rated frequency [Hz]</td>
<td>–</td>
</tr>
<tr>
<td>Output power [kVA]</td>
<td>depends on customer-specific load cycle</td>
</tr>
<tr>
<td>Output voltage [V]</td>
<td>as required (typically 110/√3)</td>
</tr>
<tr>
<td>Rated voltage factor</td>
<td>1.9 for 8 h</td>
</tr>
<tr>
<td>Temperature range [°C]</td>
<td>–30 – +50</td>
</tr>
<tr>
<td>Insulation class</td>
<td>E</td>
</tr>
<tr>
<td>Metering accuracy class</td>
<td>according to IEC 61869-3</td>
</tr>
<tr>
<td>Protection accuracy class</td>
<td>–</td>
</tr>
</tbody>
</table>

Values in accordance with IEC; other values like ANSI are available

**Tab 4.6-7: Technical data of Trench power voltage transformers for gas-insulated substations (GIS)**

For further information:
Instrument Transformers Portfolio:
http://www.trenchgroup.com/Products-Solutions/Instrument-Transformers
4.7 Coil Products (HV)

Introduction
With 50 years of successful field experience, Trench is the recognized world leader in the design and manufacture of air-core, dry-type, power reactors for all utility and industrial applications. The unique custom design approach, along with fully integrated engineering and manufacturing facilities in North America, Brazil, Europe and China have enabled Trench to become the technical leader for high-voltage inductors worldwide.

A deep commitment to the power industry, along with extensive investment in engineering, manufacturing and test capability, give Trench customers the utmost in high-quality, reliable products that are individually designed for each application. Trench reactor applications have grown from small-distribution class, current-limiting reactors to complex EHV-applied reactors surpassing 300 MVA per coil.

Reactors are manufactured in accordance with the ISO 9001 quality standard. Trench’s highly developed research and development program constantly addresses new technologies and their potential application in reactor products. Trench welcomes challenges for new applications for power reactors.

Design features
Design features of air-core dry-type reactors are:
- Epoxy impregnated, fiberglass-encapsulated construction
- Aluminum construction throughout with all current carrying connections welded
- Highest mechanical and short-circuit strength
- Essentially zero radial-voltage stress, with uniformly graded axial-voltage distribution between terminals
- Low noise levels are maintained throughout the life of the reactor
- Weatherproof construction, with minimum maintenance requirements
- Design service life in excess of 30 years
- Designs available in compliance with ANSI/IEEE, IEC and other major standards.

Construction
A Trench air-core dry-type reactor consists of a number of parallel-connected, individually insulated, aluminum (copper on request) conductors (fig. 4.7-1). These conductors can be small wire or proprietary cables custom-designed and custom-manufactured. The size and type of conductor used in each reactor is dependent on the reactor specification. The various styles and sizes of conductors available ensure optimum performance at the most economical cost.

The windings are mechanically reinforced with epoxy resin-impregnated fiberglass, which after a carefully defined oven cure cycle produces an encapsulated coil. A network of horizontal and vertical fiberglass ties coupled with the encapsulation minimizes vibration in the reactor and achieves the highest available mechanical strength. The windings are terminated at each end to a set of aluminum bars called a spider. This construction results in a very rigid unit capable of withstanding the stresses developed under the most severe short-circuit conditions.

Exceptionally high levels of terminal pull, tensile strength, wind loading and seismic withstand can be accommodated with the reactor. This unique design can be installed in all types of climates and environments and still offer optimum performance.

Trench air-core dry-type reactors are installed in polluted and corrosive areas and supply trouble-free operation. In addition to the standard fixed reactance type of coil, units can be supplied with taps for variable inductance. A number of methods are available to vary inductance for fine-tuning or to provide a range of larger inductance steps.

In addition, Trench utilizes various other designs for reactors, e.g., iron-core and water-cooled.

Series reactors
Reactors are connected in series with the line or feeder. Typical uses are fault-current reduction, load balancing in parallel circuits, limiting inrush currents of capacitor banks, etc.

Current-limiting reactors
Current-limiting reactors reduce the short-circuit current to levels within the rating of the equipment on the load side of the reactor (fig. 4.7-2). Applications range from the simple distribution feeder reactor to large bus-tie and load-balancing reactors on systems rated up to 765 kV/2100 kV BIL.
Capacitor reactors
Capacitor reactors are designed to be installed in series with a shunt-connected capacitor bank to limit inrush currents due to switching, to limit outrush currents due to close-in faults, and to control the resonant frequency of the system due to the addition of the capacitor banks. Reactors can be installed on system voltages through 765 kV/2100 kV BIL. When specifying capacitor reactors, the requested continuous current rating should account for harmonic current content, tolerance on capacitors and allowable system overvoltage.

Buffer reactors for electric arc furnaces
The most effective use of buffer reactors for electric arc furnaces (EAF) is achieved by operating the furnace at low electrode current and long arc length. This requires the use of a series reactor in the supply system of the arc furnace transformer for stabilizing the arc.

Duplex reactors
Duplex reactors are current limiting reactors that consist of two half coils, wound in opposition. These reactors provide a desirable low reactance under normal conditions and a high reactance under fault conditions.

Load-flow control reactors
Load-flow control reactors are series-connected on transmission lines of up to 800 kV. The reactors change the line impedance characteristic such that load flow can be controlled, thus ensuring maximum power transfer over adjacent transmission lines.

Filter reactors
Filter reactors are used in conjunction with capacitor banks to form series tuned harmonic filter circuits, or in conjunction with capacitor banks and resistors to form broadband harmonic filter circuits. When specifying filter reactors, the magnitudes of fundamental and harmonic frequency current should be indicated. If inductance adjustment for fine-tuning is required, the required tapping range and tolerances must be specified. Many filter applications require a Q factor that is much lower than the natural Q of the reactor. This is often achieved by connecting a resistor in the circuit.

An economical alternative is the addition of a de-Q’ing ring structure on a reactor. This can reduce the Q factor of the reactor by as much as one tenth without the necessity of installing additional damping resistors. These rings, mounted on the reactor, are easily coupled to the magnetic field of the reactor. This eliminates the concern of space, connection and reliability of additional components such as resistors.

Shunt reactors
Shunt reactors are used to compensate for capacitive VARs generated by lightly loaded transmission lines or underground cables. They are normally connected to the transformer tertiary winding but can also be directly connected on systems of up to 345 kV.
Thyristor-controlled shunt reactors (TCR) are extensively used in static VAR systems in which reactive VARs are adjusted by thyristor circuits (fig. 4.7-3). Static VAR compensator reactor applications normally include:

- Thyristor-controlled shunt reactors. The compensating power is changed by controlling the current through the reactor by means of the thyristor valves.
- Thyristor-switched reactors (TSR)
- Thyristor-switched capacitor reactors (TSC)
- Filter reactors (FR)
- Step less adjustable shunt reactors with iron core in oil filled design.

**HVDC reactors**

HVDC lines are used for long-distance bulk power transmission as well as back-to-back interconnections between different transmission networks. HVDC reactors normally include smoothing reactors, AC and DC harmonic filter reactors, as well as AC and DC PLC noise filter reactors.

**Smoothing reactors**

Smoothing reactors (fig. 4.7-4) are used to reduce the magnitude of the ripple current in a DC system. They are used in power electronics applications such as variable-speed drives and UPS systems. They are also required on HVDC transmission lines for system voltages of up to 800 kV. Several design and construction techniques are offered by Trench.

**Test lab reactors**

Test lab reactors are installed in high-voltage and high-power test laboratories. Typical applications include current limiting, synthetic testing of circuit breakers, inductive energy storage and artificial lines.

**Neutral earthing reactors**

Neutral earthing reactors limit the line-to-earth fault current to specified levels. Specification should also include unbalanced condition continuous current and short-circuit current duration.

**Arc-suppression coils**

Single-phase neutral earthing (grounding) reactors (arc-suppression coils) are intended to compensate for the capacitive line-to-earth current during a 1-phase earth fault. The arc-suppression coil (ASC) represents the central element of the Trench earth-fault protection system (fig. 4.7-5).

Because the electric system is subject to changes, the inductance of the ASC used for neutral earthing must be variable. The earth-fault detection system developed by Trench utilizes the plunger core coil (moveable-core design). Based on extensive experience in design, construction and application of ASCs, Trench products can meet the most stringent requirements for earth-fault compensating techniques.

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For further information:

Coil Products Portfolio:
http://www.trenchgroup.com/Products-Solutions/Coil-Products

Coil Products Downloads:
http://www.trenchgroup.com/Downloads/Coil-Products
4.8 Bushings

Introduction
HSP Hochspannungsgeräte GmbH – known as HSP – and Trench have a long history and a well-known reputation in manufacturing high-voltage bushings and equipment. Both are world leaders in power engineering and design of specialized electrical products.

As ‘HSP & Trench Bushing Group’ they share their knowledge in the development, design and production of AC and DC bushings up to 1,200 kV. Customers will substantially benefit from their close cooperation in terms of innovation, joint research & development, and common design.

The bushing group provides a wide range of bushing products including bushings for power transformers and HVDC transmission. The portfolio includes epoxy-resin-impregnated bushings up to 1,100 kV, oil-impregnated paper bushings (OIP) up to 1,200 kV, and SF₆-gas bushings up to 1,200 kV. Whatever your bushing requirements, the bushing group has the right bushing for your application.

Their technologies have been successfully in service for more than 60 years now. The bushing group operates globally from their production locations in Troisdorf (Germany), St. Louis (France), Toronto (Canada) and Shenyang (China).

4.8.1 High-Voltage Bushings

A bushing is an electrical engineering component that insulates a high-voltage conductor passing through a metal enclosure or a building. Bushings are needed on:

- Transformers
- Buildings
- Gas-insulated switchgear (GIS)
- Generators
- Other high-voltage equipment.

Typical environmental conditions are:

- Oil-to-air
- Oil-to-gas
- Oil-to-oil
- SF₆-to-air
- Air-to-air.

The internal insulation of a bushing is made of a combination of different insulating materials:

- Oil-impregnated paper (OIP)
- Epoxy-resin-impregnated paper (ERIP)
- SF₆ gas.

The external insulation is made of:

- Epoxy resin for indoor applications
- Porcelain or fiberglass tubes with silicone rubber sheds for outdoor application

Selected state-of-the-art bushing designs are described in the sections that follow.

Transformer bushings: oil-impregnated paper design (OIP)
An oil-impregnated paper transformer bushing is made of the following components (fig. 4.8-1):

1. Terminal
   Terminal (Al or Cu) for connection of overhead lines or busbars and arcing horns. State-of-the-art designs provide maintenance-free termination, and ensure that the connection will not become loose in service.

2. Assembly
   The whole bushing is tightened together by the central tube or conductor.

3. Head
   Al-casted head with oil expansion chamber and oil level indicator. The chamber is hermetically sealed against the atmosphere.
4. Oil filling
State-of-the-art bushings are filled with dried, degassed insulating mineral oil.

5. Insulator
Porcelain insulator made of high-grade electrotechnical porcelain according to IEC 815. The insulator is connected to the mounting flange using Portland cement, and sealed with O-ring gasket. Composite insulators are increasingly demanded and are readily available.

6. Active part
The active part is made of oil-impregnated wide-band paper with conductive layers made of aluminum foil to control the electrical field radially and axially. Depending on the current rating, the paper and foil are wound on either a central tube or a solid conductor.

7. Flange
The mounting flange with integrated test tap made of corrosion free aluminum alloy is machined to ensure an excellent seal between the bushing and the transformer.

8. CT pocket
If current transformers are required on the bushing, the ground sleeve can be extended.

9. Oil-side end
The insulator on the oil side is made of an epoxy resin tube. It is designed to stay installed during the in-tank drying process of the transformer, and can withstand temperatures of up to 130 °C.

10. End shielding
For voltages starting with 52 kV, a special aluminum electrode is cast into the end of the epoxy resin tube. This end shielding controls the electrical field strength in this area to earth.

Transformer bushings: epoxy-resin-impregnated paper design (ERIP)
An epoxy-resin-impregnated paper transformer bushing is made of the following components (fig. 4.8-2).

1. Terminal
Terminal (Al or Cu) for connection of overhead lines or busbars and arcing horns. State-of-the-art designs provide maintenance-free termination, and ensure that the connection will not become loose in service.

2. Dry filling
State-of-the-art bushings are filled with dry-type foam.

3. Insulator
The external insulation consists of a composite insulator with silicone sheds. These are vulcanized on the mechanical support, a high-quality wound insulating tube made of epoxy resins with glass fiber laminate structure. In most cases the flange is part of the insulator.

4. Active part
The active part is made of resin-impregnated paper with conductive layers made of aluminum foil to control the electrical field radially and axially. Depending on the current rating, the paper and foil are wound on either a central tube or a solid conductor.

5. Flange
The mounting flange with integrated test tap made of corrosion free aluminum alloy is machined to ensure an excellent seal between the bushing and the transformer.
6. **Oil-side end (including CT pocket if required)**

The insulator on the oil side is made of an epoxy resin tube. It is designed to stay installed during the in-tank drying process of the transformer, and can withstand temperatures of up to 130 °C.

**Connections**

The modular bushing systems offer a large choice of connecting systems. At the upper end of the bushing head, there is a clamp through which the conductor or the cable bolt is fixed. A releasable cross-pinned fitting at the clamping device prevents it from slipping into the transformer during operation. In addition it serves as locking element. The bolt is sealed through double seals. The clamp is made of stainless steel, and all screws are of non-corrosive steel. The venting of the central tube is located on one side under the edge of the clamp, and can be operated independently of the conductor bolt. In addition to the cable bolt, solid conductor bolts are available, e.g., for higher-current applications. These bolts are wedged against the inner wall of the central tube with insulated spacers. Solid conductor bolts can be provided with a separation point, preferably at the flange or to suit any particular case. The bolts are equipped with a threaded hole at the top, so that a draw wire or a rod can be screwed in and the bolt pulled through the central tube.

**Transformer bushings: high current**

High-current bushings for transformer-to-phase busbar-isolated connections are designed for 24 kV to 36 kV and currents from 7,800 A to 40,000 A. Conductors are in standard aluminum or copper on request. The main insulation is vacuum-impregnated epoxy condenser (fig. 4.8-3).

**Other transformer bushings: oil-to-gas and oil-to-oil**

Oil-to-gas types are intended for the direct connection of power transformers to gas-insulated switchgear; oil-to-oil types are intended for the direct connections within the power transformer (fig. 4.8-4). Both consist of a main insulating body of ERIP (epoxy-resin-impregnated paper). The condenser core is made of special epoxy resin vacuum-impregnated paper incorporating grading foils to ensure uniform voltage distribution. This insulation has proven its reliability in over 40 years of service in various system applications. A high-quality insulation enables a compact design. Furthermore, bushings with this insulation have a low partial discharge level, not only at service voltage but far in excess.
HVDC bushings: transformer and wall
The growing demand for HVDC transmission requires reliable and efficient transformer and wall bushings of up to 800 kV DC (fig. 4.8-6). ERIP solutions are often preferred due to their superior performance in heavily polluted areas, or due to their mechanical strength especially regarding seismic behavior. An example of state-of-the-art solutions is the project Yunnan-Guangdong/China (fig. 4.8-5, fig. 4.8-8), which incorporates wall bushings and transformer bushings up to 800 kV.

Wall bushings
Wall bushings (fig. 4.8-7) are designed for use in high-voltage substations for roof or wall according to their positioning:
- Indoor/indoor bushings for dry indoor conditions
- Outdoor/indoor bushings for use between open air (outer atmosphere) and dry indoor conditions
- Outdoor/outdoor bushings where both ends are in contact with the open air (outer atmosphere)

The main insulating body is capacitive-graded. A number of conductive layers are coaxially located at calculated distances between the central tube and the flange. This leads to a virtual linearization of the axial distribution of voltage on the bushing surface resulting in minimum stress on the surrounding air.

GIS bushings
These bushings are designed for use in GIS substations mainly to connect to overhead lines. Designs are either electrode design up to 245 kV or condenser design above 245 kV (fig. 4.8-9). Composite designs are increasingly demanded, especially for higher voltage ranges and polluted areas.

Generator bushings
Generator bushings (fig. 4.8-10) are designed for leading the current induced in the stator windings through the pressurized hydrogen-gastight, earthed generator housing. Generator bushings are available from 12 kV to 36 kV and current ratings of up to 50,000 A. They are natural, gas or liquid-cooled.

For further information:
www.siemens.com
www.bushing-group.com
sales@hskoeln.de and sales@trench-group.com
4.9 Medium-Voltage Fuses

HV HRC (high-voltage high-rupturing-capacity) fuses are used for short-circuit protection in high-voltage switchgear (frequency range of 50 to 60 Hz). They protect devices and parts of the system such as transformers, motors, capacitors, voltage transformers and cable feeders against the dynamic and thermal effects of high short-circuit currents by breaking them when they arise.

Fuses consist of the fuse-base and the fuse-links. The fuse-links are used for one single breaking of overcurrents and then they must be replaced. In a switch-fuse combination, the thermal striker tripping of the 3GD fuse prevents the thermal destruction of the fuse. The fuses are suitable both for indoor and outdoor switchgear. They are fitted in fuse-bases available as individual 1-phase or 3-phase components, or as built-in components in combination with the corresponding switching device.

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>Reference dimension</th>
<th>Rated current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6 10 16 20 25 31.5 40 50 63 80 100 125 160 200 250 315</td>
</tr>
<tr>
<td>7.2 kV</td>
<td>192 mm</td>
<td>x x x x x x x x x x</td>
</tr>
<tr>
<td></td>
<td>442 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>for motor protection</td>
<td></td>
</tr>
<tr>
<td>12 kV</td>
<td>292 mm</td>
<td>x x x x x x x x x x</td>
</tr>
<tr>
<td></td>
<td>442 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>for motor protection</td>
<td></td>
</tr>
<tr>
<td>24 kV</td>
<td>442 mm</td>
<td>x x x x x x x x x x</td>
</tr>
<tr>
<td>36 kV</td>
<td>537 mm</td>
<td>x x x x x x x x x x</td>
</tr>
</tbody>
</table>

Table 4.9-1: Portfolio of fuses

Fig. 4.9-1: Fuse-link

Fig. 4.9-2: 3-phase fuse-link with fuse monitor

Fig. 4.9-3: Switch-disconnector with fuse-links
4.10 Silicone Long Rod Insulators

4.10.1 3FL Long Rod Insulators

Good reasons for the 3FL
The new Siemens silicone long rod insulators type 3FL combine the highest levels of electrical insulation and mechanical tensile strength with a compact, lightweight design. Thanks to their superior design and minimized weight, 3FL long rod insulators are especially suitable for overhead compact-line applications where low tower design and short line spans are required. Furthermore, they can also be more economically transported and installed.

Design
The 3FL insulator housing is a one-piece HTV¹ silicone rubber housing made by the one-shot injection molding process. The HTV silicone is directly molded onto the core rod by overlapping the triple junction point and part of the metal end fittings. The design ensures a total enclosure of the most sensitive part of a silicone insulator – the junction zone (metal end fitting/FRP rod/silicone housing), where usually the highest electrical field strength is concentrated. This overlapping system eliminates any need of traditional sealing systems while preventing any moisture ingress attacks.

Core
The core rod is a boron-free, corrosion-resistant ECR² glass-fiber-reinforced plastic rod (FRP rod). Due to the extremely high hydrolysis and acid resistance of the FRP rod the risk of so-called brittle fracture is completely eliminated on 3FL insulators.

End fittings
The end fittings, made of hot-dip galvanized forged steel or ductile cast iron, are directly attached to the FRP core rod by a circumferential crimping process. Each crimping process is strongly monitored with a special control system. A complete range of end fittings according to the latest IEC and ANSI standards is available up to 120 kN of SML. The 3FL is 100% exchangeable and compatible with existing insulators and line hardware of all types.

The special design of the end fitting in the junction zone reduces to a minimum the electrical field strength and partial discharge accordingly inside the junction zone as well as on the silicone housing surface by modeling an integrated grading ring. This reliably prevents corrosion of the insulating material and eliminates the risk of subsequent failure of the insulator.

¹ HTV: High-temperature vulcanizing
² ECR glass: Electrical- and corrosion-resistant glass

Fig. 4.10-1: HTV silicone rubber for best pollution performances

Fig. 4.10-2: 3FL long rod insulators can be used either as suspension or tension insulators requirements
3FL – HTV silicone rubber housing for best pollution performances

The excellent pollution layer characteristics of the HTV silicone rubber ensure maximum reliability of the 3FL insulator, even under extreme service conditions. The extremely hydrophobic housing prevents the formation of conductive film on its surface. Even the most severe ambient conditions, such as salt fog in coastal regions or dust-laden air in industrial areas, cannot impair the intrinsic hydrophobicity of the HTV silicone rubber. Surface currents and discharges are ruled out. Neither water nor dirt on the housing surface can cause insulator flashovers – a significant factor in insulator performance.

Quality from Siemens

According to long-established Siemens tradition and making use of the experience of producing high-voltage equipment for more than a century, each production step for the 3FL – beginning with numerous incoming raw material inspections through the assembly of the individual components to routine tests of the finished product – are rigorously monitored and well controlled.

Standards and tests

All 3FL long rod insulators are designed and tested in compliance with the latest standards IEC 61109, IEC 62217, IEC 60815, and IEC 61466-2. All design and type tests have been successfully performed. Each Siemens 3FL insulator that leaves the factory is routinely tested with a corresponding mechanical tensile test load of at least 50 percent of the defined SML load for at least ten seconds.

Accessories

Arc protection devices such as arcing horns and corona rings (also known as grading rings) for field/corona reduction are available as standard solutions. Customer-specific solutions as well as other connection and cable clamps are also available on request.

<table>
<thead>
<tr>
<th>Maximum values</th>
<th>3FL2</th>
<th>3FL4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest voltage for equipment ( U_{\text{m}} )</td>
<td>kV</td>
<td>72.5</td>
</tr>
<tr>
<td>Nominal system voltage ( U_{\text{s}} )</td>
<td>kV</td>
<td>69</td>
</tr>
<tr>
<td>Specified mechanical load (SML)</td>
<td>kN</td>
<td>70</td>
</tr>
<tr>
<td>Minimum unified specific creepage distance</td>
<td>mm / kV( _{\text{m}} )</td>
<td>31</td>
</tr>
</tbody>
</table>

Tab. 4.10-1: Maximum values
Products and Devices

4.10 Silicone Long Rod Insulators

Fig. 4.10-6: 3FL2

Fig. 4.10-7: 3FL2 end fittings

Fig. 4.10-8: 3FL4

Fig. 4.10-9: 3FL4 end fittings
3FL2 long rod insulators for distribution overhead power lines

3FL2 long rod insulators are designed to meet the highest requirements in distribution power systems up to 72 kV. They have high lightning impulse and power frequency withstand voltages and a long creepage class (> 31 mm/kV). 3FL2 insulators are available with mechanical ratings up to SML = 70 kN.

3FL4 long rod insulators for transmission overhead power lines

3FL4 long rod insulators are designed to meet the highest requirements in transmission power systems up to 170 kV. They have a long creepage class (> 31 mm/kV) as well as high lightning impulse and power frequency withstand voltages. 3FL4 insulators are available with mechanical ratings up to SML = 120 kN.

Technical data 3FL2

<table>
<thead>
<tr>
<th>Highest voltage for equipment</th>
<th>Typical nominal system voltages</th>
<th>Rated* lightning impulse withstand voltage (1.2/50 µs, dry)</th>
<th>Rated* power frequency withstand voltage (50 Hz, 1 min, wet)</th>
<th>Flashover distance</th>
<th>Creepage distance</th>
<th>Housing length</th>
<th>Section length** (with ball and socket)</th>
<th>Catalog number</th>
<th>Specified mechanical load</th>
<th>Routine test load</th>
<th>Corona ring diameter</th>
<th>Weight (with ball and socket)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Um kV</td>
<td>Un kV</td>
<td>LIWL min kV</td>
<td>PFWL min kV</td>
<td>S mm</td>
<td>C mm</td>
<td>H mm</td>
<td>L mm</td>
<td></td>
<td>SML kN</td>
<td>RTL kN</td>
<td>D mm</td>
<td>W kg</td>
</tr>
<tr>
<td>12.0</td>
<td>10, 11, 12</td>
<td>95</td>
<td>28</td>
<td>214</td>
<td>178</td>
<td>332</td>
<td>70-009-4xx00-1xx1</td>
<td>70</td>
<td>35</td>
<td>–</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>24.0</td>
<td>15, 20, 22, 24</td>
<td>145</td>
<td>50</td>
<td>304</td>
<td>268</td>
<td>422</td>
<td>70-014-4xx00-1xx1</td>
<td>70</td>
<td>35</td>
<td>–</td>
<td>2.0</td>
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<tr>
<td>36.0</td>
<td>30, 33, 35, 36</td>
<td>170</td>
<td>70</td>
<td>394</td>
<td>358</td>
<td>512</td>
<td>70-017-4xx00-1xx1</td>
<td>70</td>
<td>35</td>
<td>–</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>72.5</td>
<td>60, 66, 69, 72</td>
<td>325</td>
<td>140</td>
<td>664</td>
<td>628</td>
<td>782</td>
<td>70-032-4xx00-1xx1</td>
<td>70</td>
<td>35</td>
<td>–</td>
<td>3.55</td>
<td></td>
</tr>
</tbody>
</table>

* Rated lightning impulse withstand voltage and power frequency withstand voltage in accordance with IEC 60071. The physical value is higher.

** Reference value of the section length of the insulator for version with ball and socket end fittings of size 16 in accordance with IEC 60120. In order to obtain the section length of the insulator implemented with other end fittings, the housing length and connection lengths (see table "End fittings") of both end fittings must be added together. All electrical values refer to an insulator without arcing horns or corona rings.

Tab. 4.10-2: Technical data 3FL2

Technical data 3FL4

<table>
<thead>
<tr>
<th>Highest voltage for equipment</th>
<th>Typical nominal system voltages</th>
<th>Rated* lightning impulse withstand voltage (1.2/50 µs, dry)</th>
<th>Rated* power frequency withstand voltage (50 Hz, 1 min, wet)</th>
<th>Flashover distance</th>
<th>Creepage distance</th>
<th>Housing length</th>
<th>Section length** (with ball and socket)</th>
<th>Catalog number</th>
<th>Specified mechanical load</th>
<th>Routine test load</th>
<th>Corona ring diameter</th>
<th>Weight (with ball and socket)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Um kV</td>
<td>Un kV</td>
<td>LIWL min kV</td>
<td>PFWL min kV</td>
<td>S mm</td>
<td>C mm</td>
<td>H mm</td>
<td>L mm</td>
<td></td>
<td>SML kN</td>
<td>RTL kN</td>
<td>D mm</td>
<td>W kg</td>
</tr>
<tr>
<td>72.5</td>
<td>60, 66, 69, 72</td>
<td>325</td>
<td>140</td>
<td>674</td>
<td>638</td>
<td>846</td>
<td>3FL4-032-4xx00-1xx1</td>
<td>120</td>
<td>60</td>
<td>–</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>123.0</td>
<td>110, 115, 120</td>
<td>550</td>
<td>230</td>
<td>1034</td>
<td>998</td>
<td>1206</td>
<td>3FL4-055-4xx00-1xx1</td>
<td>120</td>
<td>60</td>
<td>–</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>145.0</td>
<td>132, 138</td>
<td>650</td>
<td>275</td>
<td>1214</td>
<td>1178</td>
<td>1386</td>
<td>3FL4-065-4xx00-1xx1</td>
<td>120</td>
<td>60</td>
<td>260</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>170.0</td>
<td>150, 154</td>
<td>750</td>
<td>325</td>
<td>1439</td>
<td>1403</td>
<td>1611</td>
<td>3FL4-075-4xx00-1xx1</td>
<td>120</td>
<td>60</td>
<td>260</td>
<td>7.1</td>
<td></td>
</tr>
</tbody>
</table>

* Rated lightning impulse withstand voltage and power frequency withstand voltage in accordance with IEC 60071. The physical value is higher.

** Reference value of the section length of the insulator for version with ball-and-socket end fittings of size 16 in accordance with IEC 60120. In order to obtain the section length of the insulator implemented with other end fittings, the housing length and connection lengths (see table "End fittings") of both end fittings must be added together. All electrical values refer to an insulator without arcing horns or corona rings.

Tab. 4.10-3: Technical data 3FL4
### Tab. 4.10-4: Product standards

<table>
<thead>
<tr>
<th>Product standards</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61109</td>
<td>Insulators for overhead lines – composite suspension and tension insulators for AC systems with a nominal voltage greater than 1,000 V – definitions, test methods, and acceptance criteria</td>
</tr>
<tr>
<td>IEC 62217</td>
<td>Polymeric insulators for indoor and outdoor use with a nominal voltage greater than 1,000 V – general definitions, test methods, and acceptance criteria</td>
</tr>
<tr>
<td>IEC 60815</td>
<td>Selection and dimensioning of high-voltage insulators intended for use in polluted conditions</td>
</tr>
<tr>
<td>IEC 61466-1</td>
<td>Composite string insulator units for overhead lines with a nominal voltage greater than 1,000 V – Part 1: Standard strength classes and end fittings</td>
</tr>
<tr>
<td>IEC 61466-2</td>
<td>Composite string insulator units for overhead lines with a nominal voltage greater than 1,000 V – Part 2: Dimensional and electrical characteristics</td>
</tr>
<tr>
<td>IEC 60120</td>
<td>Dimensions of ball and socket couplings of string insulator units</td>
</tr>
<tr>
<td>IEC 60471</td>
<td>Dimensions of clevis and tongue couplings of string insulator units</td>
</tr>
</tbody>
</table>

For further information:
- Coil Products Portfolio: [http://www.trenchgroup.com/Products-Solutions/Coil-Products](http://www.trenchgroup.com/Products-Solutions/Coil-Products)
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<th>Section</th>
<th>Page</th>
</tr>
</thead>
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<tr>
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<td>254</td>
</tr>
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<td>256</td>
</tr>
<tr>
<td>5.11 Transformer Lifecycle Management</td>
<td>257</td>
</tr>
</tbody>
</table>
5 Transformers

5.1 Introduction

5.1.1 Overview

Whether in infrastructure systems, industry or households, transformers always play a key role in the reliable transmission and distribution of power. The construction, rated power, voltage level and scope of the application are all key factors that determine the transformer’s design.

Siemens provides the right transformer for every need – from compact distribution transformers to large power transformers with ratings far above 1,000 MVA. The Siemens product range covers all mainstream requirements like UHV DC applications, low noise emission and environmentally friendly products with alternative insulation liquids, also embedded in a complete power system from generation via transmission to distribution networks. The long-term reliability of a transformer begins with its initial high quality. Then transformer lifecycle management measures maintain that quality throughout the transformer’s entire life.

Fig. 5.1-1 and table 5.1-1 are an overview of how various transformers can be used in a network.

Global Footprint
Emerging countries are not just “extended workbenches” for producing goods. First and foremost, they are important future markets. Through its own local production and sales locations, Siemens provides service to customers in the most important global markets. The local presence of Siemens in many countries also ensures that customers have better access to Siemens services and that they benefit from an efficient and effective distribution of Siemens resources as part of a global network. As Siemens factories around the world develop and produce their products, Siemens also encourages them to share their expertise.

Siemens meets the growing global demand for transformers in a variety of ways: by further optimization of value-added steps in the worldwide network, by use of approaches such as vertical integration and by the pursuit of programs for boosting productivity.

For further information: www.siemens.com/energy/transformers
### Fig. 5.1-1: Product range of Siemens transformers

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generator and System Transformers</strong></td>
<td>Above 2.5 MVA up to more than 1,000 MVA, above 30 kV up to 1,500 kV (system and system interconnecting transformers, with separate windings or auto-connected), with on-load tap changers or off-circuit tap changers, of 3-phase or 1-phase design</td>
</tr>
<tr>
<td><strong>Phase Shifters</strong></td>
<td>To control the amount of active power by changing the effective phase displacement</td>
</tr>
<tr>
<td><strong>Reactors</strong></td>
<td>Liquid-immersed shunt and current-limiting reactors up to the highest rated powers Reactors for HVDC transmission systems</td>
</tr>
<tr>
<td><strong>HVDC Transformers</strong></td>
<td>Transformers and smoothing reactors for bulk power transmission systems up to 800 kV DC Transformers for DC coupling of different AC networks</td>
</tr>
<tr>
<td><strong>Cast-Resin Distribution and Power Transformers GEAFOl</strong></td>
<td>100 kVA to more than 40 MVA, highest voltage for equipment up to 36 kV, of 3-phase or 1-phase design, GEAFOl-SL substations</td>
</tr>
<tr>
<td><strong>Liquid-immersed Distribution Transformers</strong></td>
<td>50 to 2,500 kVA, highest voltage for equipment up to 36 kV, with copper or aluminum windings, hermetically sealed or with conservator of 3- or 1-phase design pole mounted transformers and distribution transformers acc. to IEC with amorphous cores</td>
</tr>
<tr>
<td><strong>Special Transformers for Industry</strong></td>
<td>Electric arc furnace transformers Electric arc furnace series reactors DC electric arc furnace transformers Rectifier transformers Converter transformers for large drives</td>
</tr>
<tr>
<td><strong>Traction Transformers</strong></td>
<td>Traction transformers mounted on rolling stock</td>
</tr>
<tr>
<td><strong>Transformer Lifecycle Management</strong></td>
<td>Condition assessment &amp; diagnostics Online monitoring Consulting &amp; expertise Maintenance &amp; lifecycle extension Spare parts &amp; accessories Repair &amp; retrofit Transport, installation &amp; commissioning</td>
</tr>
</tbody>
</table>

*Table 5.1-1: Product range of Siemens transformers*
5.2 Reliability and Project Performance

The quality strategy in the transformer business is based on the three cornerstones of product, people and process quality (fig. 5.2-1). The objective is to achieve the greatest customer satisfaction with cost-efficient processes. This is only possible if all employees are involved in the processes have a profound understanding of the customer needs and specific requirements in the transformer business.

The strategy is implemented in the form of mandatory elements. These elements cover product and service quality, which is visible to customers; personnel quality, which is achieved by training and ongoing education; and process quality in all processes used. Business and process-specific indicators must be used to ensure that each single element is measurable and transparent.

Nine mandatory elements are defined:
- Customer integration
- Embedded quality in processes and projects
- Consequent supplier management
- Business-driven quality planning
- Focused quality reporting
- Qualification of employees on quality issues
- Continuous improvement
- Management commitment
- Control and support role of quality manager

Elements of quality (mandatory elements)

Customer integration
Customer integration depends on the consistent use of:
- Analysis tools for customer requirements and market studies
- Analysis of customer satisfaction
- Professional management of feedback from and to the customer
- Complaint management

Customer requirements need to be precisely defined in a specification. The specification must be continuously updated throughout the definition phase of a transformer project. The actual requirements must also be available to all responsible employees.

Rapid feedback loops – in both directions – are essential in order to increase customer trust and satisfaction.

Siemens resolves customer complaints to the customer’s satisfaction in a timely manner through its complaint management system.

Embedded quality in processes and projects
The quality of the processes used to produce a product has a significant impact on the quality of the product that is actually produced. Process discipline and process stability can be achieved by a high degree of process standardization. All processes should be standardized for all employees based on simple procedures. If this condition is met, it is possible to implement clearly defined work instructions (fig. 5.2-2).

Quality gates are placed at points in the process at which quality-relevant decisions are necessary. The following quality gates are mandatory for the power transformer business.
- Bid approval
- Entry order clarified
- Release of design
- Release of fully assembled transformer
- Evaluation of project

For each quality gate, there is a clear definition of participants, preconditions, results (traffic light) and the escalation process, if necessary. If the result is not acceptable, the process must be stopped until all requirements are fulfilled.

Supplier management
The quality of the product depends not only on the quality of the own processes but also on that of the suppliers. Problems and costs caused by inadequate supplier quality can only be reduced by a systematic supplier management process that includes:
- Selection
- Assessment
- Classification
- Development
- Phasing out of suppliers as well as the support process Supplier Qualification
A further condition for a high level of supplier quality is close cooperation with the suppliers. Joint development of requirements for suppliers and processes leads to continuous improvements in quality. In this context, supplier know-how can also be used to create innovations. This aspect of the relationship with suppliers is becoming more and more important, especially in the transformer business.

**Business-driven quality planning**

Planning quality means analyzing possible future scenarios and anticipated problems and taking preventive steps to solve those problems. It is crucial that both current and future critical business factors are considered in planning. That means that quality is based on business-driven planning and specific objectives, activities and quantitative indicators.

**Focused quality reporting**

Reporting is based on:

- Focused key performance indicators such as non-conformance costs, external failure rate, internal failure rate and on-time delivery
- Concrete quality incidents
- Root cause analysis of quality problems including definition of corrective and preventive measures

For customers, the reliability of transformers is of special importance. ANSI C57.117 has made an attempt to define failures. Based on this definition, statistics on in-service failures and reliability values can be derived. An example for power transformers appears in table 5.2-1.

**Qualification of employees on quality issues**

People are the decisive factor influencing quality. Therefore, all employees involved in the processes must have the skills and abilities appropriate to the quality aspects of the process steps they perform. Any qualification measures that may be necessary must be determined on the basis of a careful analysis of existing deficits.

**Continuous improvement**

Because "there is nothing that cannot be improved", continuous improvement must be an integral part in all processes.

The objective is to continue optimizing each process step. This is also the purpose of improvement teams. Appropriate coaching of these teams should make it possible to reach almost all employees.

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Table 5.2-1: In-service failure statistic

<table>
<thead>
<tr>
<th>E T TR</th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Plant 3</th>
<th>Plant 4</th>
<th>Plant 5</th>
<th>Plant 6</th>
<th>Plant 7*</th>
<th>Plant 8</th>
<th>Plant 9</th>
<th>Plant 10</th>
<th>Plant 11</th>
<th>Plant 12</th>
<th>Plant 13*</th>
<th>Plant 14**</th>
<th>Plant 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>11,278</td>
<td>572</td>
<td>1,704</td>
<td>755</td>
<td>793</td>
<td>774</td>
<td>534</td>
<td>735</td>
<td>1,076</td>
<td>705</td>
<td>649</td>
<td>994</td>
<td>–</td>
<td>1,007</td>
<td>980</td>
</tr>
<tr>
<td>( \eta_{f} )</td>
<td>91</td>
<td>9</td>
<td>7</td>
<td>10</td>
<td>11</td>
<td>1</td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>3</td>
<td>–</td>
<td>13</td>
</tr>
<tr>
<td>FRe (%)</td>
<td>0.18</td>
<td>0.38</td>
<td>0.09</td>
<td>0.26</td>
<td>0.37</td>
<td>0.02</td>
<td>0.55</td>
<td>0.09</td>
<td>0.13</td>
<td>0.05</td>
<td>0.24</td>
<td>0.16</td>
<td>–</td>
<td>0.08</td>
<td>0.27</td>
</tr>
<tr>
<td>MTBF (yrs)</td>
<td>565</td>
<td>262</td>
<td>1068</td>
<td>386</td>
<td>273</td>
<td>4,326</td>
<td>181</td>
<td>1,114</td>
<td>760</td>
<td>2,085</td>
<td>413</td>
<td>612</td>
<td>–</td>
<td>1,26</td>
<td>367</td>
</tr>
</tbody>
</table>

* Plant 7 & 13: new plants; ** Plant 14: 9 years 2001 – 2009

![Fig. 5.2-2: Example of standardized working instruction](image)
Methods like, Kaizen, 5S and methods and tools from Six Sigma e.g. DMAIC circle, FMEA, IPO are helpful in supporting this continuous improvement process (fig. 5.2-3).

**Management commitment**
Every manager in a company also bears responsibility for quality. Thus, each manager’s actions must be characterized by a high level of quality awareness.

The level of commitment shown by all levels of management in the event of quality problems, the establishment of quality demands and the creation of targeted quality controls in day-to-day work together produce a culture in which there is a high level of quality.

**Control and support role of the quality manager**
The role of the quality manager is of fundamental importance for well-running processes. The quality manager combines a supporting role with that of a neutral controller. Quality management must be directly involved in processes and projects. The independence of the quality department and individual quality managers in the processes and projects must be guaranteed and agreed by top management.

**Conclusion**
The quality of a transformer is based on the quality of all processes that are necessary – from project acquisition to project closing. The quality of the processes depends essentially on people. Only well-trained and motivated employees are able to guarantee that a process will be performed with a high degree of quality.

**5.3 Transformer Loss Evaluation**
The sharply increased cost of electrical energy has made it almost mandatory for buyers of electrical machinery to carefully evaluate the inherent losses of these items. For distribution and power transformers, which operate continuously and most frequently in loaded condition, this consideration is especially important. As an example, the added cost of loss-optimized transformers can in most cases be recovered via savings in energy use in less than three years.

Low-loss transformers use more and better materials for their construction and are thus initially more expensive than low-cost transformers. By stipulating loss evaluation figures in the transformer inquiry, the manufacturer receives the necessary incentive to provide a loss-optimized transformer rather than the low-cost model. Detailed loss evaluation methods for transformers have been developed and are described accurately in the literature. These methods take the project-specific evaluation factors of a given customer into account.

A simplified method for a quick evaluation of different quoted transformer losses makes the following assumptions:
- The transformers are operated continuously.
- The transformers operate at partial load, but this partial load is constant.
- Additional cost and inflation factors are not considered.
- Demand charges are based on 100 % load.

The total cost of owning and operating a transformer for one year is thus defined as follows:
- Capital cost \(C_p\), taking into account the purchase price \(C_p\), the interest rate \(p\) and the depreciation period \(n\)
- Cost of no-load loss \(C_{P0}\) based on the no-load loss \(P_0\) and energy cost \(C_e\)
- Cost of load loss \(C_{Pk}\) based on the load loss \(P_k\), the equivalent annual load factor \(a\) and energy cost \(C_e\)
- Cost resulting from demand charges \(C_d\) based on the amount set by the utility and the total kW of connected load (fig. 5.3-1)

The following examples show the difference between a low-cost transformer and a loss-optimized transformer (fig. 5.3-2).

Note that the lowest purchase price is unlike the total cost of ownership.

---

5.3 Transformer Loss Evaluation

**Capital cost**

Taking into account the purchase price \( C_p \), the interest rate \( p \), and the depreciation period \( n \)

\[ C_c = \frac{C_p \cdot r}{100} \quad \text{[amount/year]} \]

- \( C_p \) = purchase price
- \( r = p \cdot q^n / (q^n - 1) \) = depreciation factor
- \( q = p / 100 + 1 \) = interest factor
- \( p \) = interest rate in % p.a
- \( n \) = depreciation period in years

**Cost of no-load loss**

Based on the no-load loss \( P_0 \) and energy cost \( C_e \)

\[ C_{p0} = C_e \cdot 8,760 \text{ h/year} \cdot P_0 \]

- \( C_e \) = energy charges [amount/kWh]
- \( P_0 \) = no-load loss [kW]

**Cost of load loss**

Based on the load loss \( P_k \), the equivalent annual load factor \( a \), and energy cost \( C_e \)

\[ C_{pk} = C_e \cdot 8,760 \text{ h/year} \cdot a^2 \cdot P_k \]

- \( a \) = constant operation load / rated load
- \( P_k \) = copper loss [kW]

**Cost resulting from demand charges**

Based on the no-load loss \( P_0 \) and energy cost \( C_e \)

\[ C_d = C_d (P_0 + P_k) \]

- \( C_d \) = demand charges [amount/(kW · year)]

**Example: Distribution transformer**

- Depreciation period \( n = 20 \) years
- Depreciation factor \( r = 13.39 \)
- Interest rate \( p = 12 \% \text{ p.a.} \)
- Energy charge \( C_e = 0.25 \text{ €/kWh} \)
- Demand charge \( C_d = 350 \text{ €/(kW · year)} \)
- Equivalent annual load factor \( \alpha = 0.8 \)

**A. Low-cost transformer**

- \( P_0 = 19 \text{ kW} \)
- \( P_k = 167 \text{ kW} \)

\[ C_{p0} = 8,760 \text{ h/year} \cdot 0.2 \cdot 19 = \text{ € 33,288/year} \]

\[ C_{pk} = 8,760 \text{ h/year} \cdot 0.64 \cdot 167 = \text{ € 187,254/year} \]

\[ C_d = 350 \cdot (19 + 167) = \text{ € 65,100/year} \]

Total cost of owning and operating this transformer is thus:

\[ \text{€ 355,404/year} \]

**B. Loss-optimized transformer**

- \( P_0 = 16 \text{ kW} \)
- \( P_k = 124 \text{ kW} \)

\[ C_{p0} = 8,760 \text{ h/year} \cdot 0.2 \cdot 16 = \text{ € 28,032/year} \]

\[ C_{pk} = 8,760 \text{ h/year} \cdot 0.64 \cdot 124 = \text{ € 139,039/year} \]

\[ C_d = 350 \cdot (16 + 124) = \text{ € 49,000/year} \]

Total cost of owning and operating this transformer is thus:

\[ \text{€ 294,403/year} \]

The energy saving of the optimized distribution transformer of \( \text{€ 61,001 per year} \) pays for the increased purchase price in less than one year.

Fig. 5.3-1: Calculation of the individual operation cost of a transformer in one year

Fig. 5.3-2: Example for cost saving with optimized distribution transformer
5.4 Power Transformers

5.4.1 Large Power Transformers

In the power range above 250 MVA, generator and network intertie transformers with off-load or on-load tap changers, or a combination of both, are recommended. Depending on the on-site requirements, they can be designed as multiwinding transformers or autotransformers, in 3-phase or 1-phase versions. Even with ratings of more than 1,000 MVA and voltages up to 1,200 kV (800 kV), the feasibility limits have not yet been reached. We manufacture these units according to IEC 60076 as well as other international and national standards (e.g., ANSI/IEEE), (fig. 5.4-1).

Generator step-up (GSU) transformers
GSU units transform the voltage up from the generator voltage level to the transmission voltage level, which may be as high as 1,200 kV system voltage. Such transformers are usually YNd-connected.

In order to make an inquiry regarding a GSU power transformer, the technical data for the items in this section are required.

Step-down transformers
Step-down transformers transform the voltage down from the transmission voltage level to an appropriate distribution voltage level. The power rating of step-down transformers may range up to the power rating of the transmission line.

System interconnecting transformers
System interconnecting transformers connect transmission systems with different voltages together so that active as well as reactive power can be exchanged between the systems.

Main specification data
• Standard
• Installation – indoor/outdoor
• Max. ambient air temperature
• Rated frequency $f$
• Vector group
• Rated power $S$
• Primary rated voltage $U_{HV}$
• Tapping range/taps
• Voltage regulation
• Secondary rated voltage $U_{LV}$
• Impedance $u_k$ at $S$, and $U_r$
• Max. sound power level $L_{WA}$
• Insulation level HV-Ph – $U_{Um/AC/LI}$
• Insulation level HV-N – $U_{Um/AC/LI}$
• Insulation level LV-Ph – $U_{Um/AC/LI}$
• Type of cooling
• HV connection technique
• LV connection technique
• Transportation medium
• Losses

Fig. 5.4-1: Large power transformer
5.4.2 Medium Power Transformers

Medium power transformers with a power range from 30 to 250 MVA and a voltage of over 72.5 kV are used as network and generator step-up transformers (fig. 5.4-2).

Specific items
- Transformer design according to national and international standards (IEC/ANSI) with or without voltage regulation
- 3-phase or 1-phase
- Tank-attached radiators or separate radiator banks

Main specification data
- Number of systems (HV, LV, TV)
- Voltage and MVA rating
- Regulation range and type
- Vector group
- Frequency
- Losses or capitalization
- Impedances
- Type of cooling
- Connection systems (bushing, cable)
- Noise requirements (no-load, load and/or total noise)
- Special insulation fluid
- Application of high temperature/extra small size operation

5.4.3 Small Power Transformers

Small power transformers are distribution transformers from 5 to 30 MVA with a maximum service voltage of 145 kV. They are used as network transformers in distribution networks (fig. 5.4-3).

This type of transformer is normally a 3-phase application and designed according to national and international standards. The low-voltage windings should be designed as foil or layer windings. The high-voltage windings should use layer or disc execution, including transposed conductors. Normally, the cooling type is ONAN (oil-natural, air-natural) or ONAF (oil-natural, air-forced). The tapping can be designed with off-circuit or on-load tap changers (OCTC or OLTC).

Main specification data
- Voltage and MVA rating
- Frequency
- Regulation range and type
- Vector group
- Losses or capitalization
- Impedances
- Noise requirements
- Connection systems (bushing, cable)
- Weight limits
- Dimensions
- Information about the place of installation
- Special insulation fluid
- Application of high temperature/extra small size operation
- Type of cooling
5.5 Reactors

In AC networks, shunt reactors and series reactors are widely used in the system to limit the overvoltage or to limit the short-circuit current. With more high-voltage overhead lines with long transmission distance and increasing network capacity, both types of reactors play an important role in the modern network system.

**Made for every requirements**

Oil filled reactors are manufactured in two versions:
- With an iron core divided by air gaps
- Without an iron core, with a magnetic return circuit

Oil filled reactors offer individual solutions: They satisfy all the specified requirements regarding voltage, rating, type of operation, low-noise and low loss and type of cooling, as well as transportation and installation.

The windings, insulation tank monitoring devices and connection method are practically the same as those found in the construction of transformers.

**Shunt reactors**

For extra-high-voltage (EHV) transmission lines, due to the long distance, the space between the overhead line and the ground naturally forms a capacitor parallel to the transmission line, which causes an increase of voltage along the distance. Depending on the distance, the profile of the line and the power being transmitted, a shunt reactor is necessary either at the line terminals or in the middle. An liquid-immersed shunt reactor is a solution. The advanced design and production technology will ensure the product has low loss and low noise level.

Shunt reactors also can be built as adjustable shunt reactors. This offers the possibility in fine tuning the system voltage and also the reduction of high voltage equipment by substitution of several unregulated reactors by a regulated one.

**Series reactors**

When the network becomes larger, sometimes the short-circuit current on a transmission line will exceed the short-circuit current rating of the equipment. Upgrading of system voltage, upgrading of equipment rating or employing high-impedance transformers are far more expensive than installing liquid-immersed series reactors in the line. The liquid-immersed design can also significantly save space in the substation.

**Specification**

Typically, 3-phase or 1-phase reactors should be considered first. Apart from the insulation level of the reactor, the vector group, overall loss level, noise level and temperature rise should be considered as main data for the shunt reactor.

Although the above data are also necessary for series reactors, the rated current, impedance and thermal/dynamic stability current should also be specified.
5.6 Special Transformers for Industrial Applications

A number of industry applications require specific industrial transformers due to the usage of power (current) as a major resource for production. Electric arc furnaces (EAF), ladle furnaces (LF) and high-current rectifiers need a specific design to supply the necessary power at a low voltage level. These transformer types, as well as transformers with direct connection to a rectifier are called special-purpose or industrial transformers, whose design is tailor-made for high-current solutions for industry applications.

**Electric arc furnace transformers**
EAF and LF transformers are required for many different furnace processes and applications. They are built for steel furnaces, ladle furnaces and ferroalloy furnaces, and are similar to short or submerged arc furnace transformers (fig. 5.6-1).

EAF transformers operate under very severe conditions with regard to frequent overcurrents and overvoltages generated by short-circuit in the furnace and the operation of the HV circuit-breaker. The loading is cyclic. For long-arc steel furnace operation, additional series reactance is normally required to stabilize the arc and optimize the operation of the furnace application process.

**Specific items**
EAF transformers are rigidly designed to withstand repeated short-circuit conditions and high thermal stress, and to be protected against operational overvoltages resulting from the arc processes. The Siemens EAF reactors are built as 3-phase type with an iron core, with or without magnetic return circuits.

**Design options**
- Direct or indirect regulation
- On-load or no-load tap changer (OLTC/NLTC)
- Built-in reactor for long-arc stability
- Secondary bushing arrangements and designs
- Air or water-cooled
- Internal secondary phase closure (internal delta)

**Main specification data**
- Rated power, frequency and rated voltage
- Regulation range and maximum secondary current
- Impedance and vector group
- Type of cooling and temperature of the cooling medium
- Series reactor and regulation range and type (OLTC/NLTC)

**DC electric arc furnace transformers**
Direct-current electric arc furnace (DC EAF) transformers are required for many different furnace processes and applications. They are built for steel furnaces with a Thyristor rectifier. DC EAF transformers operate under very severe conditions, like rectifier transformers in general but using rectifier transformers for furnace operation. The loading is cyclic.
Rectifier transformers
Rectifier transformers are combined with a diode or Thyristor rectifier. The applications range from very large aluminum electrolysis to various medium-size operations. The transformers may have a built-in or a separate voltage regulation unit. Due to a large variety of applications, they can have various designs up to a combination of voltage regulation, rectifier transformers in double-stack configuration, phase-shifting, interphase reactors, transductors and filter-winding (fig. 5.6-2).

Specific items
Thyristor rectifiers require voltage regulation with a no-load tap changer, if any. A diode rectifier will, in comparison, have a longer range and a higher number of small voltage steps than an on-load tap changer. Additionally, an auto-connected regulating transformer can be built in the same tank (depending on transport and site limitations).

Design options
- Thyristor or diode rectifier
- On-load or no-load tap changer (OLTC/NLTC)/filter winding
- Numerous different vector groups and phase shifts possible
- Interphase reactor, transductors
- Secondary bushing arrangements and designs
- Air or water-cooled

Main specification data
- Rated power, frequency and rated voltage
- Regulation range and number of steps
- Impedance and vector group, shift angle
- Type of cooling and temperature of the cooling medium
- Bridge or interphase connection
- Number of pulses of the transformer and system
- Harmonics spectrum or control angle of the rectifier
- Secondary bushing arrangement

Converter transformers
Converter transformers are used for large drive application, static voltage compensation (SVC) and static frequency change (SFC).

Specific items
Converter transformers are mostly built as double-tier, with two secondary windings, allowing a 12-pulse rectifier operation. Such transformers normally have an additional winding as a filter to take out harmonics. Different vector groups and phase shifts are possible.

Main specification data
- Rated power, frequency and rated voltage
- Impedance and vector group, shift angle
- Type of cooling and temperature of the cooling medium
- Number of pulses of the transformer and system
- Harmonics spectrum or control angle of the rectifier
- Type of cooling and temperature of the cooling medium
- Bridge or interphase connection
- Number of pulses of the transformer and system
- Harmonics spectrum or control angle of the rectifier
- Secondary bushing arrangement
- Air or water-cooled

Line Feeder
This kind of transformer realizes the connection between the power network and the power supply for the train. Transformer is operating in specific critical short circuit condition and overload condition in very high frequencies per year, higher reliability is required to secure the train running in safety.

Main specification data
- Rated power, frequency and rated voltage
- Impedance and vector group
- Overload conditions
- Type of cooling and temperature of the cooling medium
- Harmonics spectrum or control angle of the rectifier

Design options
- Direct connection between transmission network and railway overheadcontactline
- Frequency change via DC transformation (e.g. 50 Hz – 16,67 Hz)
- Thyristor or diode rectifier
- On-load or no-load tap changer (OLTC/NLTC)/filter winding
- Secondary bushing arrangements and designs
- Air or water-cooled
5.7 Phase-Shifting Transformers

A phase-shifting transformer is a device for controlling the power flow through specific lines in a complex power transmission network. The basic function of a phase-shifting transformer is to change the effective phase displacement between the input voltage and the output voltage of a transmission line, thus controlling the amount of active power that can flow in the line.

**Guidance on necessary information**

Beside the general information for transformers, the following specific data are of interest (fig. 5.7-1):

- **Rated MVA**
  The apparent power at rated voltage for which the phase-shifting transformer is designed.

- **Rated voltage**
  The phase-to-phase voltage to which operating and performance characteristics are referred to – at no-load.

- **Rated phase angle**
  Phase angle achieved when the phase-shifting transformer is operated under no-load condition, or if stated at full load, at which power factor.

- **Phase shift direction**
  In one or both directions. Changeover from and to under load or no-load condition.

- **Tap positions**
  Minimum and/or maximum number of tap positions.

- **Impedance**
  Rated impedance at rated voltage, rated MVA and zero phase shift connection as well as permissible change in impedance with voltage and phase angle regulation.

- **System short-circuit capability**
  When the system short-circuit level is critical to the design of phase-shifting transformers, the maximum short-circuit fault level shall be specified.

- **BIL**
  Basic impulse level (BIL) of source, load and neutral terminals.

- **Special design tests**
  Besides the standard lightning impulse tests at all terminals, it has to be considered that the lightning impulse might occur simultaneously at the source and the load terminal in case of closed bypass breaker. If such a condition is likely to appear during normal operation, a BIL test with source and load terminals connected might be useful to ensure that the phase-shifting transformer can withstand the stresses of lightning strokes in this situation.

- **Special overload condition**
  The required overload condition and the kind of operation (advance or retard phase angle) should be clearly stated. Especially for the retard phase angle operation, the overload requirements may greatly influence the cost of the phase-shifting transformer.
5.8 HVDC Transformers

HVDC transformers are key components of HVDC stations. HVDC converter and inverter stations terminate long-distance DC transmission lines or DC sea cables. This type of transformer provides the interface between AC grids and high power rectifiers and are used to control the load flow over the DC transmission lines. These actors adapt the AC grid voltage to an adequate level which is suitable for feeding the valve system of DC converter and inverter.

Design options
The design concept of HVDC transformers is mainly influenced by the rated voltage, rated power and transportation requirements like dimensions, weight and mode of transportation. Many large power HVDC converter station are located in rural areas of low infrastructure. Frequently, special geometrical profiles have to be fulfilled in order to move such transformers by railway.

Typically, HVDC transformers are single phase units containing 2 winding limbs. This concept can include either 2 parallel valve windings (two for delta or two for wye system, fig. 5.8-1) or two different valve windings (one for delta and one for wye, fig. 5.8-2). In order to reduce the total transportation height frequently the core assembly includes 2 return limbs. Due to redundancy requirements in HVDC stations 3 phase units are quite uncommon.

The valve windings are exposed to AC and DC dielectric stress and therefore a special insulation assembly is necessary. Furthermore, special lead systems connecting the turrets and windings have to be installed in order to withstand the DC voltage of rectifier. Additionally, the load current contains harmonic components of considerable energy resulting in higher losses and increased noise. Above all, special bushings are necessary for the valve side to access upper and lower winding terminals of each system from outside. Conclusively, two identical bushings are installed for star or delta system.

For approving the proper design and quality of manufacturing special applied DC and DC polarity reversal tests have to be carried out. The test bay has to be equipped with DC test apparatus accordingly and needs to provide adequate geometry to withstand the DC test voltage.

Technical items
In addition to the standard parameters of power transformers, special performance requirements have to be known for the design of HVDC transformers. These parameters are jointly defined by designers of the HVDC station and transformer design engineers in order to reach a cost-effective design for the entire equipment.

Special parameters are:
• Test levels: DC applied, DC polarity reversal and long-time AC defines the insulation assembly of the transformer
• Harmonic spectrum of the load current and phase relation

generate additional losses, which have to compensated by the cooling circuit
• Voltage impedance impacting the dimensions of windings and the total height of the transformer
• DC bias in load and current and transformer-neutral have to be considered for no-load noise and no-load losses
• Derivative of the load current (di/dt) is a key parameter for the on-load tap changer
• Overload requirements have to be considered for cooling circuit and capacity of coolers
• Regulation range and number of steps influence the voltage per turn which is a key design parameter
• Seismic requirements have to be considered for mechanical strength of turrets, outlets and bushings
5.9 Distribution Transformers

5.9.1 Liquid-immersed Distribution Transformers for European/US/Canadian Standard

On the last transformation step from the power station to the consumer, distribution transformers (DT) provide the necessary power for systems and buildings. Accordingly, their operation must be reliable, efficient and, at the same time, silent.

Distribution transformers are used to convert electrical energy of higher voltage, usually up to 36 kV, to a lower voltage, usually 250 up to 435 V, with an identical frequency before and after the transformation. Application of the product is mainly within suburban areas, public supply authorities and industrial customers. Distribution transformers are usually the last item in the chain of electrical energy supply to households and industrial enterprises.

Distribution transformers are fail-safe, economical and have a long life expectancy. These fluid-immersed transformers can be 1-phase or 3-phase. During operation, the windings can be exposed to high electrical stress by external overloads and high mechanical stress by short-circuits. They are made of copper or aluminum. Low-voltage windings are made of strip or flat wire, and the high-voltage windings are manufactured from round wire or flat wire.

Three product classes – standard, special and renewable – are available, as follows:

- **Standard distribution transformers:**
  - Pole mounted (fig. 5.9-1), wound core or stacked core technology distribution transformer ($\leq 2,500$ kVA, $U_m \leq 36$ kV)
  - Wound core or stacked core technology medium distribution transformer ($> 2,500 \leq 6,300$ kVA, $U_m \leq 36$ kV)
  - Large distribution transformer ($> 6.3 – 30.0$ MVA, $U_m \leq 72.5$ kV)
  - Voltage regulator (fig. 5.9-2)

- **Special distribution transformers:**
  - Special application: self-protected DT, regulating DT (OLTC), electronic regulate DT, low-emission DT or others (autotransformer, transformer for converters, double-tier, multiwinding transformer, earthing transformer)
  - Environmental focus: amorphous core DT with significant low no-load losses, DT with special low load-loss design, low-emission DT in regard of noise and/or electromagnetic field emissions, DT with natural or synthetic ester where higher fire-resistance and/or biodegradability is required

- **Renewable distribution transformers:**
  - Used in wind power stations, solar power plants or sea flow/generator power plants
5.9.2 Voltage Regulators

Siemens invented the voltage regulator in 1932 and pioneered its use in the United States. Voltage Regulators are tapped step autotransformers used to ensure that a desired level of voltage is maintained at all times. A voltage regulator comprises a tapped autotransformer and a tap changer. The standard voltage regulator provides ±10% adjustment in thirty-two 0.625% steps. Voltage Regulators with ±15% and ±20% regulation are available for some designs.

Voltage regulators are liquid-immersed and can be 1-phase or 3-phase. They may be self-cooled or forced air-cooled. Available at 50 or 60 Hz and with 55 or 65 °C temperature rise, they can be used in any electrical system to improve voltage quality.

Voltage regulator ratings are based on the percent of regulation (i.e., 10%). For example, a set of three 1-phase 333 kVA regulators would be used with a 10 MVA transformer (e.g., 10 MVA ÷ 0.10/3 = 333 kVA). 1-phase voltage regulators are available in ratings ranging from 2.5 kV to 19.9 kV and from 38.1 kVA to 889 kVA (fig. 5.9-3). 3-phase voltage regulators are available at 13.2 kV or 34.5 kV and from 500 kVA to 4,000 kVA.

Voltage regulators can be partially or completely untanked for inspection and maintenance without disconnecting any internal electrical or mechanical connections. After the unit is untanked, it is possible to operate the voltage regulator mechanism and test the control panel from an external voltage source without any reconnections between the control and the regulator.

**Standard external accessories**
The standard accessories are as follows:
- External metal-oxide varistor (MOV) bypass arrester
- Cover-mounted terminal block with a removable gasketed cover. It allows easy potential transformer reconnections for operation at different voltages
- Oil sampling valve
- Two laser-etched nameplates
- External oil sight gauge that indicates oil level at 25 °C ambient air temperature and oil color
- External position indicator that shows the tap changer position
- Mounting bosses for the addition of lightning arresters to the source (S), load (L) and source-load (SL) bushings. They shall be fully welded around their circumference.

**Accessories and options**

*Remote mounting kit*
Extra-long control cable shall be provided for remote mounting of the control cabinet at the base of the pole.

*Sub-bases*
To raise the voltage regulator to meet safe operating clearances from the ground to the lowest live part.
5.9.3 GEAFOL Cast-Resin Transformers

GEAFOL transformers have been in successful service since 1965. Many licenses have been granted to major manufacturers throughout the world since then. Over 100,000 units have proven themselves in power distribution or converter operation all around the globe.

Advantages and applications
GEAFOL distribution and power transformers in ratings from 100 to approximately 50,000 kVA and lightning impulse (LI) values up to 250 kV are full substitutes for liquid-immersed transformers with comparable electrical and mechanical data. They are designed for indoor installation close to their point of use at the center of the major load consumers. The exclusive use of flame-retardant insulating materials frees these transformers from all restrictions that apply to oil-filled electrical equipment, such as the need for oil collecting pits, fire walls, fire extinguishing equipment. For outdoor use, specially designed sheet metal enclosures are available.

Often these transformers are combined with their primary and secondary switchgear and distribution boards into compact substations that are installed directly at their point of use.

When used as static converter transformers for variable speed drives, they can be installed together with the converters at the drive location. This reduces construction requirements, cable costs, transmission losses and installation costs.

GEAFOL transformers are fully LI-rated. Their noise levels are comparable to oil-filled transformers. Taking into account the indirect cost reductions just mentioned, they are also mostly

---

**Fig. 5.9-4: GEAFOL cast-resin dry-type transformer properties**

<table>
<thead>
<tr>
<th>LV terminals</th>
<th>Three-leg core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal arrangement: Top, rear Special version: Bottom, available on request at extra charge</td>
<td>Made of grain-oriented, low-loss electrolaminations insulated on both sides</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HV terminals</th>
<th>Resilient spacers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable arrangements, for optimal station design. HV tapping links for adjustment to system conditions, reconnectable in de-energized state*</td>
<td>To insulate core and windings from mechanical vibrations, resulting in low noise emissions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature monitoring</th>
<th>HV winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>By PTC or Pt 100 thermistor detectors in the LV winding</td>
<td>Consisting of vacuum-potted single foil-type aluminum coils. See enlarged detail in fig. 5.9-5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paint finish on steel parts</th>
<th>Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thick layer coating, RAL 5009. On request: Two-component varnish (for aggressive environments or high humidity)</td>
<td>Mixture of epoxy resin and quartz powder makes the transformer practically maintenance-free, moisture-proof, tropicalized, flame-resistant and self-extinguishing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ambient class E2</th>
<th>Clamping frame and truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatic category C2 (If the transformer is installed outdoors, degree of protection IP23 must be assured)</td>
<td>Rollers can be swung around for lengthways or sideways travel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fire class F1</th>
<th>* on-load tap changers on request</th>
</tr>
</thead>
</table>
cost-competitive. By virtue of their design, GEAFOL transformers are practically maintenance-free.

Standards and regulations
GEAFOL cast-resin dry-type transformers comply with IEC 60076-11, EN 60076-11 and EN 50541-1.

Characteristic properties (fig. 5.9-4)

HV winding
The high-voltage windings are wound from aluminum foil interleaved with high-grade insulating foils. The assembled and connected individual coils are placed in a heated mold and are potted in a vacuum furnace with a mixture of pure silica (quartz sand) and specially blended epoxy resins. The only connections to the outside are casted brass nuts that are internally bonded to the aluminum winding connections.

The external delta connections are made of insulated copper or aluminum connectors to guarantee an optimal installation design. The resulting high-voltage windings are fire-resistant, moisture-proof and corrosion-proof, and they show excellent aging properties under all operating conditions.

The foil windings combine a simple winding technique with a high degree of electrical safety. The insulation is subjected to less electrical stress than in other types of windings. In a conventional round-wire winding, the interturn voltages can add up to twice the interlayer voltage. In a foil winding, it never exceeds the voltage per turn, because a layer consists of only one winding turn. This results in high AC voltage and impulse voltage withstand capacity.

Aluminum is used because the thermal expansion coefficients of aluminum and cast resin are so similar that thermal stresses resulting from load changes are kept to a minimum (fig. 5.9-5).

LV winding
The standard low-voltage winding with its considerably reduced dielectric stresses is wound from single aluminum sheets with interleaved cast-resin impregnated fiberglass fabric (prepreg).

The assembled coils are then oven-cured to form uniformly bonded solid cylinders that are impervious to moisture. Through the single-sheet winding design, excellent dynamic stability under short-circuit conditions is achieved. Connections are submerged arc-welded to the aluminum sheets and are extended either as aluminum or copper bars to the secondary terminals.

Fire safety
GEAFOL transformers use only flame-retardant and self-extinguishing materials in their construction. No additional substances, such as aluminum oxide trihydrate, which could negatively influence the mechanical stability of the cast-resin molding material, are used. Internal arcing from electrical faults and externally applied flames do not cause the transformers to
burst or burn. After the source of ignition is removed, the transformer is self-extinguishing. This design has been approved by fire officials in many countries for installation in populated buildings and other structures. The environmental safety of the combustion residues has been proven in many tests (fig. 5.9-6).

**Categorization of cast-resin transformers**

Dry-type transformers have to be classified under the categories listed below:

- Environmental category
- Climatic category
- Fire category

These categories have to be shown on the rating plate of each dry-type transformer.

The properties laid down in the standards for ratings within the category relating to environment (humidity), climate and fire behavior have to be demonstrated by means of tests.

These tests are described for the environmental category (code numbers E0, E1 and E2) and for the climatic category (code numbers C1 and C2) in IEC 60076-11. According to this standard, the tests are to be carried out on complete transformers. The tests of fire behavior (fire category code numbers F0 and F1) are limited to tests on a duplicate of a complete transformer that consists of a core leg, a low-voltage winding and a high-voltage winding.

GEAFOL cast-resin transformers meet the requirements of the highest defined protection classes:

- Environmental category E2 (optional for GEAFOL-BASIC)
- Climatic category C2
- Fire category F1

**Insulation class and temperature rise**

The high-voltage winding and the low-voltage winding utilize class F insulating materials with a mean temperature rise of 100 K (standard design).

**Overload capability**

GEAFOL transformers can be overloaded permanently up to 50 % (with a corresponding increase in impedance voltage and load losses) if additional radial cooling fans are installed (dimensions can increase by approximately 100 mm in length and width.) Short-time overloads are uncritical as long as the maximum winding temperatures are not exceeded for extended periods of time (depending on initial load and ambient air temperature).

**Temperature monitoring**

Each GEAFOL transformer is fitted with three temperature sensors installed in the LV winding, and a solid-state tripping device with relay output. The PTC thermistors used for sensing are selected for the applicable maximum hot-spot winding temperature.

Additional sets of sensors can be installed, e.g. for fan control purposes. Alternatively, Pt100 sensors are available. For operating voltages of the LV winding of 3.6 kV and higher, special temperature measuring equipment can be provided.

Auxiliary wiring is run in a protective conduit and terminated in a central LV terminal box (optional). Each wire and terminal is identified, and a wiring diagram is permanently attached to the inside cover of this terminal box.
Installation and enclosures
Indoor installation in electrical operating rooms or in various sheet metal enclosures is the preferred method of installation. The transformers need to be protected only against access to the terminals or the winding surfaces, against direct sunlight and against water. Unless sufficient ventilation is provided by the installation location or the enclosure, forced-air cooling must be specified or provided by others (fig. 5.9-7).

Instead of the standard open terminals, plug-type elbow connectors can be supplied for the high-voltage side with LI ratings up to 170 kV. Primary cables are usually fed to the transformer from trenches below but can also be connected from above (fig. 5.9-8).

Secondary connections can be made by multiple insulated cables, or by connecting bars from either below or above. Secondary terminals are made of aluminum (copper upon request).

A variety of indoor and outdoor enclosures in different protection classes are available for the transformers alone, or for indoor compact substations in conjunction with high-voltage and low-voltage switchgear panels. PEHLA-tested housings are also available (fig. 5.9-9).

Cost-effective recycling
The oldest of the GEAFOL cast-resin transformers that entered production in the mid-1960s are approaching the end of their service life. Much experience has been gathered over the years with the processing of faulty or damaged coils from such transformers. The metal materials and resin used in GEAFOL cast-resin transformers, that is, approximately 95 % of their total mass, can be recycled. The process used is non-polluting. Given the value of secondary raw materials, the procedure is often cost-effective, even with the small amounts currently being processed.

The GEAFOL Basic – a true GEAFOL and more
The GEAFOL Basic is based on more than 45 years of proven GEAFOL technology and quality, but it offers numerous innovations that has allowed Siemens to provide it with several very special characteristics. For example, the GEAFOL Basic distribution transformer with a maximum rated power of 3.15 MVA and a maximum medium voltage of 36 kV is almost ten percent lighter than a comparable model from the proven GEAFOL series. And this "slimming down" also positively affects the dimensions. This could be achieved by a considerably improved heat dissipation because of the new, patented design.

Of course all GEAFOL Basic distribution transformers meet the specifications of IEC 60076-11, EN 60076-11 and EN 50541-1. They meet the highest requirements for safe installation in residential and work environments with Climatic Class C2, Environmental Class E2 (standard model meets E1; E2 is available as option at additional costs) and Fire Classification F1. With fewer horizontal surfaces, less dust is deposited, which leads to a further reduction in the already minimal time and effort needed for maintenance and also increases operational reliability.

Optimum compromise
The GEAFOL Basic distribution transformer represents an optimum compromise between performance, safety and small dimensions. In addition, the high degree of standardization ensures the best possible cost-benefit ratio. Thanks to their compact shape and comprehensive safety certification, GEAFOL Basic distribution transformers can be used in almost every environment.
A new design for your success – the reliable, space-saving GEAFOL Basic

1. Three-limb core
   Made of grain-oriented, low-loss electric sheet steel that is insulated on both sides

2. Low-voltage winding
   Made of aluminum strip; turns are permanently bonded with insulating sheet

3. High-voltage winding
   Made of individual aluminum coils using foil technology and vacuum casting

4. Low-voltage connectors (facing up)
   Integrated into the upper core frame for simple transport

5. Lifting eyes
   Integrated into the upper core frame for simple transport

6. Delta connection tubes with HV terminals

7. Clamping frame and truck
   Convertible rollers for longitudinal and transverse travel (rollers optional)

8. Insulation made of an epoxy resin/quartz powder mixture
   Makes the transformer extensively maintenance-free, moisture-proof and suitable for the tropics, fire-resistant and self-extinguishing

9. High-voltage taps ±2 x 2.5%
   (on the high-voltage connector side) to adapt to the respective network conditions; reconnectable off load

Temperature monitoring
With PTC thermistor detector in limb V of the low-voltage winding (in all three phases upon request)

Painting of steel parts
High-build coating, RAL 5015: two-component coating upon request (for particularly aggressive environments)

Structure made of individual components
For example, windings can be individually assembled and replaced on site
5.9.4 GEAFOL Special Transformers

**GEAFOL cast-resin transformers with oil-free on-load tap changers**
The voltage-regulating cast-resin transformers connected on the load side of the medium-voltage power supply system feed the plant-side distribution transformers. The on-load tap changer controlled transformers used in these medium-voltage systems need to have appropriately high ratings.

Siemens offers suitable transformers in its GEAFOL design (fig. 5.9-10), which has proved successful over many years and is available in ratings of up to 50 MVA. The range of rated voltage extends to 36 kV, and the maximum impulse voltage is 200 kV (250 kV). The main applications of this type of transformer are in modern industrial plants, hospitals, office and apartment blocks and shopping centers.

Linking 1-pole tap changer modules together by means of insulating shafts produces a 3-pole on-load tap changer for regulating the output voltage of 3-phase GEAFOL transformers. In its nine operating positions, this type of tap changer has a rated current of 500 A and a rated voltage of 900 V per step. This allows voltage fluctuations of up to 7,200 V to be kept under control. However, the maximum control range utilizes only 20% of the rated voltage.

**Transformers for static converters**
These are special liquid-immersed or cast-resin power transformers that are designed for the special demands of thyristor converter or diode rectifier operation.

The effects of such conversion equipment on transformers and additional construction requirements are as follows:
- Increased load by harmonic currents
- Balancing of phase currents in multiple winding systems (e.g., 12-pulse systems)
- Overload capability
- Types for 12-pulse systems, if required

Siemens supplies oil-filled converter transformers of all ratings and configurations known today, and dry-type cast-resin converter transformers up to 50 MVA and 250 kV LI (fig. 5.9-11).

To define and quote for such transformers, it is necessary to know considerable details on the converter to be supplied and

---

**Fig. 5.9-10: 16/22-MVA GEAFOL cast-resin transformer with oil-free on-load tap changer**
on the existing harmonics. These transformers are almost exclusively inquired together with the respective drive or rectifier system and are always custom-engineered for the given application.

**Neutral earthing transformers**
When a neutral earthing reactor or earth-fault neutralizer is required in a 3-phase system and no suitable neutral is available, a neutral earthing must be provided by using a neutral earthing transformer.

Neutral earthing transformers are available for continuous operation or short-time operation. The zero impedance is normally low. The standard vector groups are zigzag or wye/delta. Some other vector groups are also possible.

Neutral earthing transformers can be built by Siemens in all common power ratings in liquid-immersed design and in cast-resin design.

**Transformers for Silicon-reactor power feeding**
These special transformers are an important component in plants for producing polycrystalline silicon, which is needed particularly by the solar industry for the manufacture of collectors.

What’s special about these transformers is that they have to provide five or more secondary voltages for the voltage supply of the special thyristor controllers. The load is highly unbalanced and is subject to harmonics that are generated by the converters. Special geafol cast resin transformers with open secondary circuit have been developed for this purpose. The rated power can be up to round about 10 MVA, and the current can exceed an intensity of 5,000 amps depending on the reactor type and operating mode. Depending on the reactor control system two-winding or multi-winding transformers will be used (fig. 5.9-12).

**Fig. 5.9-11: 23-MVA GEAFOL cast resin transformer 10 kV/Dd0Dy11**

**Fig. 5.9-12: 4771 kVA GEAFOL converter transformer with 5 secondary tappings 10/0.33 – 2.4 kV**
5.10 Traction Transformers

Siemens produces transformers for railway applications called traction transformers. These transformers are installed in electric cars such as high-speed trains, electric multiple units (EMUs) and electric locomotives. Their main purpose is transform the overhead contact line voltage, which range mainly from 15 kV up to 25 kV, to voltages suitable for traction converters (between 0.7 kV and 1.5 kV) (fig. 5.10-1).

Siemens develops and produces traction transformers for rolling stock applications of all relevant ratings, voltage levels and customer-specific requirements. All products are optimized with regard to individual customer requirements such as:
- Frequency, rating and voltage
- Required dimensions and weights
- Losses and impedance voltage characteristics
- Operational cycles and frequency response behavior
- Environmental requirements

Characterization

Technically, traction transformers are in general characterized as follows:
- 1-phase transformers
- Ratings up to 10 MVA and above
- Operating frequencies from 16⅔ to 60 Hz
- Voltages: 1.5 kV DC, 3 kV DC, 15 kV, 25 kV, 11.5 kV or other specific solutions
- Weight: < 15 t
- Auxiliary windings and/or heater windings according to customer specification
- Single or multiple system operation
- Under floor, machine room or roof assembly
- Traction windings to be used as line filters
- Integrated absorption circuit reactors
- Various cooling media for all ratings: mineral oil, silicone or ester fluid for highest environmental compatibility

In case of customer request:
- With cooling plant – integrated in one frame together with the transformer or stand-alone solution
- Nomex insulation for highest energy density

Examples

The examples shown in the table are typical applications where traction transformers from Siemens were used (table 5.10-1).

<table>
<thead>
<tr>
<th>High speed train AVE S102 for RENFE Spain</th>
<th>Electric locomotive for ÖBB Austria (1216 Series) for cross-european haulage</th>
<th>World’s most powerful series-production freight locomotive for China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation: Madrid – Barcelona</td>
<td>4 system operation</td>
<td>6 axle machine</td>
</tr>
<tr>
<td>Travel time: 2 h 30 min for 635 km</td>
<td>AC 15 kV; 16⅔ Hz</td>
<td>9,600 kW on 6 axles</td>
</tr>
<tr>
<td>Number of cars: 8</td>
<td>AC 25 kV 50 Hz</td>
<td>hauling of 20,000 t trains</td>
</tr>
<tr>
<td>Power system: 25 kV/50 Hz</td>
<td>DC 3 kV</td>
<td></td>
</tr>
<tr>
<td>Maximum power at wheel: 8,800 kW</td>
<td>DC 1.5 kV</td>
<td></td>
</tr>
<tr>
<td>Max. speed: 350 km/h</td>
<td>Speed: 200 – 230 km/h</td>
<td></td>
</tr>
<tr>
<td>Number of seats: 404</td>
<td>Weight 87 t</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.10-1: Siemens develops and produces traction transformers for rolling stock applications of all relevant ratings and voltage levels
5.11 Transformer Lifecycle Management

Introduction
Power transformers usually perform their work, humming quietly for decades, without any interruption. Operators have thus come to rely on their solid transformer capacity, often performing only minimal maintenance using traditional techniques (fig. 5.11-1).

Today, load requirements, additional environmental constraints and recent corporate sustainability objectives to keep a close eye on the operational value of the equipment, have led Siemens to provide a comprehensive set of solutions to keep the equipment at peak level under any operational circumstances. A new generation of asset managers is interested in the “operational” value, including the replacement cost, instead of the depreciated book-value over decades, which is often close to zero.

Power transformers are long-lasting capital investment goods. Purchasing and replacement require long periods of planning engineering and procurement. Each individual conception is specially adapted to the specific requirements. The corresponding high replacement value, and the important lead time are in the focus.

What is TLM™?
Siemens Transformer Lifecycle Management™ (TLM™) includes highly experienced transformer experts who provide the most effective lifecycle solutions for power transformers of any age and any brand.

Maintaining customers’ power transformers at peak operating level is the prime objective of the Siemens TLM set of solutions. Siemens TLM is based on the expertise available in all Siemens transformer factories, which are well-known for high quality and low failure rates. The TLM scope of services is explained in the following briefly:

Condition Assessment & Diagnostics (fig. 5.11-2)
- Level 1: SITRAM® DIAG ESSENTIAL
- Level 2: SITRAM® DIAG ADVANCED
- Level 3: SITRAM® DIAG HIGH VOLTAGE TESTING

The SITRAM® DIAG program consists of three layers and provides diagnostic modules for individual transformer and for the assessment of complete installed fleets and transformer populations.

SITRAM® DIAG ESSENTIAL (Level 1)
All modules in the diagnosis Level 1 "ESSENTIAL" are to be applied on energized transformers. The most powerful toolbox for this application is the diagnosis of the insulating liquid. Additional stand alone modules are available to be applied when the oil tests and/or the operating personnel gave indication for deficiencies or changes.
- Standard oil test (8 –12 parameters)
- Dissolved Gas in Oil Analysis (DGA)
- Furanic components
- Moisture

Condition Management
High Voltage Testing Performed factory tests on-site
Advanced Integrating apparent diagnostics with intelligent data evaluation
Essential Condition Assessment on energized transformers based on oil diagnostics and additional stand alone modules
Additional stand alone modules

- PD (UHF-, acoustic sensors, corona camera)
- Noise measurement
- Vibration measurement
- Thermograph scans

**SITRAM® DIAG ADVANCED (Level 2)**
The extended modules are applied on de-energized and disconnected transformers. Most measurements repeat the measurements as shown in the manufacturers test report and by comparing the results any differences will be highlighted. Level 2 provide information about the insulation (dielectric) condition as well as the mechanical condition (displacements) of the active part of a transformer.

- Ratio and phase angle
- Winding resistance
- C-tan delta (windings and bushings
- Insulation resistance and
- Polarization Index (PI)
- Impedance
- No load current and losses
- At low voltage
- FDS/PDC
- FRA

Additional all modules of Level 1 apply

**SITRAM® DIAG HIGH VOLTAGE TESTING (Level 3)**
High-Voltage-Tests on-site is usually required following on-site repairs, factory repairs, refurbishment or relocation and also performed to assure the results from the level 1 and level 2 assessments. The SITRAM DIAG mobile test fields provides solutions for all kind of HV testing and loss measurement. Heat runs or long duration tests are feasible depending on size and voltage level of the transformer under test. Level 3 assessment can be combined with all modules out of level 1 and level 2.

- Load losses
- No load losses and currents
- Applied overvoltage tests
- Induced overvoltage tests
- Partial discharge testing
- DC testing
- Heat runs
- Long duration tests

Additional all modules of Level 1 and 2 apply

**Online Monitoring (fig. 5.11-3)**

- SITRAM® GUARDS
- SITRAM® CM
- SITRAM® iCMS

The new Siemens third-generation SITRAM® MONITORING range is providing compatible, modular and customized solutions for individual power transformers (new and retrofit) and solutions for entire transformer fleets.

In general, these systems allow a continuous monitoring of power transformers, which are going far beyond the traditional method of taking offline measurements. The experience demonstrates clearly, that with Online monitoring, an improved efficiency in the early detection of faults can be achieved. So that curative and corrective maintenance actions can be planned and scheduled well in advanced. It is also possible to use spare capacities up to the limits. This is resulting in a higher reliability, efficiency and longer service life of power transformers.

**SITRAM Guard’s:**
Standardized and approved sensor technologies as a single solution for individual transformers.

- GAS Guard (online gas-in-oil analysis)
- PD-Guard (partial discharge monitoring)
- BUSHING Guard (bushing monitoring)
- TAPGUARD® (on-load tap changer monitoring)

**SITRAM Condition Monitor (SITRAM CM):**
The SITRAM Condition Monitor is a modular and customized system, which integrates information from single sensors and SITRAM Guard’s for each transformer individually and is able to provide condition information about all key components. A local data storage module and a communication interface enable the user to access the information remotely.

**SITRAM integrated Condition Monitoring System (SITRAM iCMS):**
This “Knowledge Module” solution is monitoring all transformers in transmission and distribution substations, power generation plants or in large industries to an existing or next generation protection and control system. Furthermore is it able to integrate the recorded data of a complete transformer fleet of a utility to a superordinated system. It is based on the modular hardware architecture of the SITRAM CM.

In addition to the monitoring hardware and software, Siemens TLM transformer experts are available for remote nursing solutions for questionable transformers, analyzing and interpretation of recorded monitoring data.
Consulting Expertise and Training

- Engineering service
- Advice & recommendations
- Educational seminars
- Custom-tailored workshops

The Siemens TLM set of solutions integrates a wide range of services that are designed to considerably extend the life of the operator’s transformers. Siemens’s preferred approach is to integrate all transformers – of any age and any brand – in the plan that is prepared for customers so that they can make the best decision about replacement/extension and any related matters. Siemens TLM also offers a series of standardized customer trainings. These programs are specifically designed to broaden customer awareness of the various concept and design options. Lifecycle management is, of course, an integral part of the training.

Maintenance & Lifecycle Extension

- Preventive & corrective maintenance
- On site active part drying & de-gassing
- Oil regeneration
- Life extension products
- End of life management

We’ll get your transformers back in top form – and without service interruptions. Our TLM™ products for extending service life minimizes the unavoidable, undetectable and ongoing aging process that is taking place inside transformers. This internationally-recognized technologies for life extension are rounded up by a cooling efficiency retrofit solution.

**SITRAM DRY** (fig. 5.11-4)
The SITRAM® DRY is an advanced technology for preventive and continuous online transformer drying. The system removes moisture from the insulation oil through disturbing the moisture equilibrium so that moisture diffuses from the wet insulation paper to the dried insulation oil. This process will removing the moisture in a gentle and smooth way from the solid insulation and will increase the dialectical strength of the insulating oil.

- Continuous online removal of moisture from solid insulation and oil
- Based on a molecular sieve technology
- Easy to install on any transformer in operation
- Temperature and moisture monitoring
- Cartridge replacement and regeneration service
- Cabinet Version (NEMA4)
- New: SITRAM® DRY Smart, mobile solution for distribution transformers very soon available

Experience the functions of SITRAM® DRY in sound and vision: www.siemens.de/energy/sitram-dry-video

**SITRAM REG**
Siemens developed the SITRAM® REG technology to clean contaminated oil and restore its dielectric properties. SITRAM® REG is a modified reclamation process based on the IEC 60422 standard. Oil is circulated continuously through regeneration columns.

- An oil change is not required
- Improves the quality of insulating oil to that of new oil
- Prolongation of the lifetime and increased reliability of old transformers
- Preventive action against the progressive insulation ageing process
- Sustainable improvement in the condition of the insulation
- Suitable for all power transformers
- Economically independent of the current price of new oil
- No service interruptions
- Great and long-lasting cleaning effect

**SITRAM COOL**
SITRAM COOL is an add-on retrofit solution and consists of hardware and software for the automatic, optimized control of transformer cooling system:

- Increase of the total efficiency of the transformer
- Reduction of auxiliary losses
- Reduction of noise level
- Reduction of maintenance
- If required and if applicable –> upgrading

**Spare Parts & Accessories**
The supply of spare parts is another strong point of Siemens TLM. Upon request, Siemens may advise customers on what
accessories will best fit their needs. Examples include Buchholz relays of various sizes, temperature sensors, oil flow alarms and oil level indicators. In order to provide the best solution, Siemens TLM will verify alternative products and strive to make technical improvements using state-of-the-art technologies, particularly important when original spare parts are not longer available.

Spare parts from Siemens TLM™ offers you (fig. 5.11-5):
- Stringent quality assurance standards to ensure that spare parts are manufactured in accordance with the Siemens OEM specifications
- Continuous improvement of technology and materials
- Outage planning and support based on customized spare parts programs
- Spar part service for all transformers in the Siemens family (SIEMENS, TU, VA TECH, Ferranti-Packard, PEEPLES)

Repair & Retrofit
Can we make your old transformer as good as new? We can come very close and usually improve your old transformers with Siemens new state-of-the-art technologies. One highlight of TLM™ is the repair, overhaul, and modernization of your power transformers. Repairs are performed in one of our dedicated repair shops around the world, but are also done on-site when our mobile workshops come to your facility. In addition, we can retrofit or modernize transformers in various ways.

Whether your transformer has failed or you’re planning timely corrective maintenance our TLM™ team of experts is available for short-term repairs.

With its dedicated repair facilities at our technology center in Nuremberg, Germany, and elsewhere around the world, Siemens has created a professional setting to get your transformers back into shape. Even the largest and heaviest transformers in the world can be easily moved, inspected, and repaired.

The repair facilities handle all problems that arise over the lifecycle of a transformer, including installation of new on-load tap changers and tapping switches, increasing performance, as well as completely replacement of windings. In addition, all components can be reconditioned and retrofitted with the latest materials as needed. For everything from design to the latest modern winding techniques to final inspection and testing, the manufacturing processes at our renowned transformer plants are continuously being improved. These improvements support the maintenance and repair of your transformers (fig. 5.11-6).

Transport, Installation & Commissioning
Siemens technical experts and engineers whom work on projects that include installing new transformers or changing the locations of old transformers, have decades of experience. They are expert at disassembly and preparation for transport, storing and handling of delicate components. Assembly is the daily work of these Siemens experts, and Siemens offers its exhaustive experience for complete solutions for customers so that their equipment value remains at its peak for a long time.
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6 Protection, Substation Automation, Power Quality and Measurement

6.1 Introduction

The demands on substation automation solutions are continually growing, which leads to greater complexity and more interfaces. High availability, with all individual components working together smoothly, is one of the most important system operator needs in the area of energy automation.

And that is exactly where Energy Automation products and solutions from Siemens come in. With a comprehensive approach to the entire automation chain, the system operator gets an overview of the entire plant, from planning and start up to operation and maintenance.

Energy Automation products and solutions are based on three main pillars that ensure simple operation:

- Reliable IT security through high-quality applications and seamless network structures
- Limitless communications by means of international standards and flexible expandability
- Efficient engineering for the entire automation chain, from the control center to the field device

Energy Automation from Siemens stands for a simplified workflow, reliable operations, and a significantly lower total cost of ownership. Siemens offers expert solutions that will continue to grow with the market’s demands but still remain manageable. That is how Energy Automation sets a new benchmark with products and solutions which are clearly simpler and more efficient. In the meantime we have delivered more than 200,000 devices with IEC61850 included.

*Energy automation that simply works*

Siemens offers a uniform, universal technology for the entire functional scope of secondary equipment, both in the construction and connection of the devices, and in their operation and communication. This results in uniformity of design, coordinated interfaces, and the same operating principle being established throughout, whether in power system and generator protection, in measurement and recording systems, in substation control or protection or in telecontrol.

The devices are highly compact and immune to interference, and are therefore also suitable for direct installation in switchgear panels.

*Fig. 6.1-1: Siemens energy automation products*
Protection, Substation Automation, Power Quality and Measurement

6.2 Protection Systems

6.2.1 Introduction

Siemens is one of the world’s leading suppliers of protection equipment for power systems. Thousands of Siemens relays ensure first-class performance in transmission and distribution systems on all voltage levels, all over the world, in countries with tropical heat or arctic frost. For many years, Siemens has also significantly influenced the development of protection technology:

- In 1976, the first minicomputer (process computer)-based protection system was commissioned: A total of 10 systems for 110 / 20 kV substations was supplied and is still operating satisfactorily today.
- In 1985, Siemens became the first company to manufacture a range of fully numerical relays with standardized communication interfaces. Siemens now offers a complete range of protection relays for all applications with numerical busbar and machine protection.

Section 6.2.2 gives an overview of the various product lines of the Siemens protection.

Section 6.2.3 offers application hints for typical protection schemes such as:
- Cables and overhead lines
- Transformers
- Motors and generators
- Busbars

To ensure a selective protection system, section 6.2.4 gives hints for coordinated protection setting and selection for instrument transformers. The „Relay Selection Guide“ in section 6.2.5 provides an overview of the relay function mix as a guide for selecting the right protection relay for the corresponding protection application.
6.2 Protection Systems

6.2.2 SIPROTEC and Reyrolle Relay Families

Solutions for today’s and future power supply systems – for more than 100 years

SIPROTEC has established itself on the energy market for decades as a powerful and complete system family of numerical protection relays and bay controllers from Siemens.

SIPROTEC protection relays from Siemens can be consistently used throughout all applications in medium and high voltage. With SIPROTEC, operators have their systems firmly and safely under control, and have the basis to implement cost-efficient solutions for all duties in modern, intelligent and “smart” grids. Users can combine the units of the different SIPROTEC device series at will for solving manifold duties – because SIPROTEC stands for continuity, openness and future-proof design.

As the innovation driver and trendsetter in the field of protection systems for 100 years, Siemens helps system operators to design their grids in an intelligent, ecological, reliable and efficient way, and to operate them economically. As a pioneer, Siemens has decisively influenced the development of numerical protection systems (fig. 6.2-4). The first application went into operation in Würzburg, Germany, in 1977. Consistent integration of protection and control functions for all SIPROTEC devices was the innovation step in the 90ies. After release of the communication standard IEC 61850 in the year 2004, Siemens was the first manufacturer worldwide to put a system with this communication standard into operation.

How can system operators benefit from this experience?
- Proven and complete applications
- Easy integration into your system
- Highest quality of hardware and software
- Excellent operator friendliness of devices and tools
- Easy data exchange between applications
- Extraordinary consistency between product- and systemengineering
- Reduced complexity by easy operation
- Siemens as a reliable, worldwide operating partner

SIPROTEC – a synonym for protection devices

Over 100 years of experience in the field of protection devices and substation automation almost says it all. Yet the highest appreciation must be given to some milestones in the history of this great product. The very first family of SIPROTEC products already had a head start in being ahead of its competitors. Find out how the continuous drive for technological improvements and brilliant minds have kept this success story going and going and going.

Several milestones in the history of SIPROTEC have defined not only the technology of this product family but its fundamental character. With more than one million SIPROTEC units in the field, we are clearly the market leader in Digital Protection Technology.

1902
Schuckert & Co.
(1887):
DC measuring device
based on Georg Hummel’s principle

1925
First overcurrent relay BA1 and delayed action relay RS1

1940
Introduction of new overcurrent relay RA5

1970
Introduction of analog electronic relays

1977
First digital application in Würzburg, Germany

1980s
The digital era for relays begins

1985
Introduction of first numerical relay in combination with control technology SINAUT LSA

1998
Introduction of SIPROTEC 4 family
The products of the long-standing British manufacturer Reyrolle are considered especially powerful and reliable by many markets. With the latest numerical products, Reyrolle – as a part of Siemens shows that the development is being pushed forward, and that new innovations are continuously being developed further for the users’ benefit. In this way, Reyrolle completes the offerings for protection devices, particularly in Great Britain and the Commonwealth countries.
6.2 Protection Systems

SIPROTEC easy
SIPROTEC easy are CT power supplied or auxiliary power supplied, numerical time-overcurrent protection relays, which can be used as line and transformer protection (back-up protection) in electrical power supply systems with single-ended supply. They offer definite time-overcurrent and inverse time-overcurrent protection functions according to IEC and ANSI. The comfortable operation via DIP switch is self-explanatory and simple.

- Two-stage time-overcurrent protection
- Saving the auxiliary power supply by operation via integrated current transformer supply
- Cost-efficient due to the use of instrument transformers with low ratings
- Tripping via pulse output (DC 24 V / 0.1 Ws) or tripping relay output
- Simple, self-explanatory parameterization and operation via DIP switch directly at the device
- Easy installation due to compact assembly on DIN rail.

SIPROTEC Compact (series 600)
The devices of the SIPROTEC Compact series (series 600) are compact, numerical protection devices for application in medium-voltage or industrial power supply systems. The corresponding device types are available for the different applications such as time-overcurrent protection, line differential protection, transient ground-fault relay or busbar protection.

- Space-saving due to compact design
- Reliable process connections by means of solid terminal blocks
- Effective fault evaluation by means of integrated fault recording and SIGRA 4
- Communication interface
- Operable and evaluable via DIGSI 4
- Different device types available for directional and non-directional applications.
Reyrolle – the alternative solution for your distribution grid

Reyrolle has been synonymous with electrical protection devices in the sectors of sub-transmission, distribution and industrial applications for decades. Historically, Reyrolle relays, initially sold mainly in traditional markets, are now sold worldwide as part of the Siemens protection network.

Since its foundation, Reyrolle has been an innovation driver in product development – based on a strong focus on market, customer and technology. Worldwide established brand names such as “Solkor” and “Argus” demonstrate this. But there is more: A wide range of Reyrolle products has determined technological firsts in the market.

The comprehensive range of Reyrolle products provides the total protection requirements of distribution markets – ranging from overcurrent protection via transformer protection and voltage control to a full spectrum of auxiliary and trip relays. The portfolio includes many famous products such as “Argus”, “Duobias”, “Solkor”, “MicroTAPP”, etc.

To serve specific needs in industrial applications, a range of proven products such as “Argus overcurrent”, “Solkor line differential” and “Rho motor protection devices” is offered.

Through successive generations, Reyrolle numerical products have been developed to increase value to system operators. This increase in value is the result of consistent development:

• Ease-of-use as a principle – the products allow flexible, easy operation through high user friendliness.
• One size fits all – the latest generation of numerical products features 1A/5A CT Input, and some models are provided with universal DC supplies.
• Learn once, know all – the new product generation provides a similar look and feel as earlier products. If Reyrolle numerical devices have been previously used, there is a high consistency in both programming and interrogation.
• With Reydisp Evolution, a comprehensive software support toolkit for relay setting, fault interrogation and general system information is provided. It is backward-compatible with all previous Reyrolle numerical devices.
6.2 Protection Systems

SIPROTEC Compact
Perfect protection, smallest space reliable and flexible protection for energy distribution and industrial systems with minimum space requirements. The devices of the SIPROTEC Compact family offer an extensive variety of functions in a compact and thus space-saving 1/6 x 19” housing. The devices can be used as main protection in medium-voltage applications or as back-up protection in high-voltage systems.

SIPROTEC Compact provides suitable devices for many applications in energy distribution, such as the protection of feeders, lines or motors. Moreover, it also performs tasks such as system decoupling, load shedding, load restoration, as well as voltage and frequency protection.

The SIPROTEC Compact series is based on millions of operational experience with SIPROTEC 4 and a further-developed, compact hardware, in which many customer suggestions were integrated. This offers maximum reliability combined with excellent functionality and flexibility.

- Simple installation by means of pluggable current and voltage terminal blocks
- Thresholds adjustable via software (3 stages guarantee a safe and reliable recording of input signals)
- Easy adjustment of secondary current transformer values (1 A/5 A) to primary transformers via DIGSI 4
- Quick operations at the device by means of 9 freely programmable function keys
- Clear overview with six-line display
- Easy service due to buffer battery replaceable at the front side
- Use of standard cables via USB port at the front
- Integration in the communication network by means of two further communication interfaces
- High availability due to integrated redundancy (electrical or visual) for IEC 61850 communication
- Reduction of wiring between devices by means of cross-communication via Ethernet (IEC 61850 GOOSE)
- Time synchronization to the millisecond via Ethernet with SNTP for targeted fault evaluation
- Adjustable to the protection requirements by means of “flexible protection functions”
- Comfortable engineering and evaluation via DIGSI 4.

Fig. 6.2-9: SIPROTEC Compact

Fig. 6.2-10: SIPROTEC Compact – rear view

Fig. 6.2-11: Feeder automation relay 7SC80
SIPROTEC Compact – system features
Field devices in energy distribution systems and in industrial applications must cover the most varying tasks, and yet be adjustable easily and at short notice. These tasks comprise, for example:

- Protection of different operational equipment such as lines, cables, motors and busbars
- Decoupling and disconnecting of parts of the power supply system
- Load shedding and load restoration
- Voltage and frequency protection
- Local or remote control of circuit-breakers
- Acquisition and recording of measured values and events
- Communication with neighboring devices or the control center

Fig. 6.2-12 shows exemplary how the most different tasks can be easily and safely solved with the matching SIPROTEC Compact devices.

Operation
During the development of SIPROTEC Compact, special value was placed not only on a powerful functionality, but also on simple and intuitive operation by the operating personnel. Freely assignable LEDs and a six-line display guarantee an unambiguous and clear indication of the process states.

In conjunction with up to 9 function keys and the control keys for the operational equipment, the operating personnel can react quickly and safely to every situation. This ensures a high operational reliability even under stress situations, thus reducing the training effort considerably.

Fig. 6.2-12: Fields of application in a typical MV system
The Feeder Automation device 7SC80 is designed for decentralized as well as for centralized feeder automation applications. This solution allows various flexible high speed applications like Fault Location, Isolation, and Service Restoration (FLISR). Detect and locate a fault in the feeder, isolate the faulty section and set the healthy portions of the feeder back into service.

**Source transfer**
Detect and isolate a faulty source and set the de-energised sections of the feeder back into service.

**Load Balancing**
Balance the load within a feeder by moving the Normally Open Point.

**Section Isolation**
Isolate a dedicated section of a feeder for maintenance without affecting other sections.

*Set the feeder back to its defined normal/steady state*

Fig. 6.2-13 shows an example of a typical ring main application with overhead lines and 5 sections.

Every section is protected and automated by the 7SC80 Feeder Automation device.

*Fig. 6.2-13: Fields of application with feeder automation controller 7SC80*
Local operation
All operations and information can be executed via an integrated user interface:

- **2 operation LEDs**

- **In an illuminated 6-line LC display, process and device information can be indicated as text in different lists.**

- **4 navigation keys**

- **8 freely programmable LEDs serve for indication of process or device information. The LEDs can be labeled user-specifically. The LED reset key resets the LEDs.**

- **9 freely configurable function keys support the user in performing frequent operations quickly and comfortably.**

- **Numerical operation keys**

- **USB user interface (type B) for modern and fast communication with the operating software DIGSI.**

- **Keys “O” and “I” for direct control of operational equipment.**

- **Battery compartment accessible from outside.**

*Fig. 6.2-14a: with open cover*

*Fig. 6.2-14b: with closed cover and open battery compartment*
6.2 Protection Systems

Construction and hardware

Connection techniques and housing with many advantages
The relay housing is 1/6 of a 19" rack and makes replacement of predecessors model very easy. The height is 244 mm (9.61").

Pluggable current and voltage terminals allow for pre-wiring and simplify the exchange of devices in the case of support. CT shorting is done in the removable current terminal block. It is thus not possible to opencircuit a secondary current transformer.

All binary inputs are independent and the pick-up thresholds are settable using software settings (3 stages). The relay current transformer taps (1 A / 5 A) are new software settings. Up to 9 function keys can be programmed for predefi ned menu entries, switching sequences, etc. The assigned function of the function keys can be shown in the display of the relay.

If a conventional (inductive) set of primary voltage transformers is not available in the feeder, the phase-to-ground voltages can be measured directly through a set of capacitor cones in the medium-voltage switchgear. In this case, the functions directional time-overcurrent protection, ground (ANSI 67N), voltage protection (ANSI 27/59) and frequency protection (ANSI 81O/U) are available. With overcurrent protection 7SJ81 there is also a device for low-power current transformer applications.

* RU = rack unit

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### Tab. 6.2-1: Wiring specifications for process connection

<table>
<thead>
<tr>
<th>Connection</th>
<th>$w_{max} = 9.5 \text{ mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring cable lugs</td>
<td>$d_1 = 5.0 \text{ mm}$</td>
</tr>
<tr>
<td>Wire cross-section</td>
<td>$2.0 – 5.2 \text{ mm}^2 (\text{AWG} 14–10)$</td>
</tr>
</tbody>
</table>

#### Current terminals – ring cable lugs

<table>
<thead>
<tr>
<th>Connection</th>
<th>$w_{max} = 9.5 \text{ mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire cross-section</td>
<td>$2.0 – 5.2 \text{ mm}^2 (\text{AWG} 14–10)$</td>
</tr>
<tr>
<td>Conductor sleeve with plastic sleeve</td>
<td>$L = 10 \text{ mm (0.39 in)}$ or $L = 12 \text{ mm (0.47 in)}$</td>
</tr>
<tr>
<td>Stripping length</td>
<td>$15 \text{ mm (0.59 in)}$</td>
</tr>
<tr>
<td>(when used without conductor sleeve)</td>
<td>Only solid copper wires may be used</td>
</tr>
</tbody>
</table>

#### Current terminals – single conductors

<table>
<thead>
<tr>
<th>Connection</th>
<th>$w_{max} = 9.5 \text{ mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire cross-section</td>
<td>$2.0 – 5.2 \text{ mm}^2 (\text{AWG} 14–10)$</td>
</tr>
<tr>
<td>Conductor sleeve with plastic sleeve</td>
<td>$L = 10 \text{ mm (0.39 in)}$ or $L = 12 \text{ mm (0.47 in)}$</td>
</tr>
<tr>
<td>Stripping length</td>
<td>$12 \text{ mm (0.47 in)}$</td>
</tr>
<tr>
<td>(when used without conductor sleeve)</td>
<td>Only solid copper wires may be used</td>
</tr>
</tbody>
</table>

#### Voltage terminals – single conductors

<table>
<thead>
<tr>
<th>Connection</th>
<th>$w_{max} = 9.5 \text{ mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire cross-section</td>
<td>$0.5 – 2.0 \text{ mm}^2 (\text{AWG} 20–14)$</td>
</tr>
<tr>
<td>Conductor sleeve with plastic sleeve</td>
<td>$L = 10 \text{ mm (0.39 in)}$ or $L = 12 \text{ mm (0.47 in)}$</td>
</tr>
<tr>
<td>Stripping length</td>
<td>$12 \text{ mm (0.47 in)}$</td>
</tr>
<tr>
<td>(when used without conductor sleeve)</td>
<td>Only solid copper wires may be used</td>
</tr>
</tbody>
</table>

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Control and automation functions

Control
In addition to the protection functions, the SIPROTEC Compact units also support all control and monitoring functions that are required for the operation medium-voltage or high-voltage substations. The status of primary equipment or auxiliary devices can be obtained from auxiliary contacts and communicated to the unit via binary inputs. Therefore it is possible to detect and indicate both the OPEN and CLOSED position or a fault or intermediate circuit-breaker or auxiliary contact position.

The switchgear or circuit-breaker can be controlled via:
- Integrated operator panel
- Binary inputs
- Substation control and protection system
- DIGSI 4.

Automation/user-defined logic
With integrated logic, the user can create, through a graphic interface (CFI), specific functions for the automation of a switchgear or a substation. Functions are activated using function keys, a binary input or through the communication interface.

Switching authority
Switching authority is determined by set parameters or through communications to the relay. If a source is set to "LOCAL", only local switching operations are possible. The following sequence for switching authority is available: "LOCAL"; DIGSI PC program, "REMOTE". There is thus no need to have a separate Local/Remote switch wired to the breaker coils and relay. The local/remote selection can be done using a function key on the front of the relay.

Command processing
This relay is designed to be easily integrated into a SCADA or control system. Security features are standard and all the functionality of command processing is offered. This includes the processing of single and double commands with or without feedback, sophisticated monitoring of the control hardware and software, checking of the external process, control actions using functions such as runtime monitoring and automatic command termination after output. Here are some typical applications:
- Single and double commands, using 1, 1 plus 1 common or 2 trip contacts
- User-definable bay interlocks
- Operating sequences combining several switching operations, such as control of circuit-breakers, disconnectors and grounding switches
- Triggering of switching operations, indications or alarms by combination with existing information.

Assignment of feedback to command
The positions of the circuit-breaker or switching devices and transformer taps are acquired through feedback. These indication inputs are logically assigned to the corresponding command outputs. The unit can therefore distinguish whether the indication change is a result of switching operation or whether it is an undesired spontaneous change of state.

Chatter disable
The chatter disable feature evaluates whether, in a set period of time, the number of status changes of indication input exceeds a specified number. If exceeded, the indication input is blocked for a certain period, so that the event list will not record excessive operations.

Indication filtering and delay
Binary indications can be filtered or delayed. Filtering serves to suppress brief changes in potential at the indication input. The indication is passed on only if the indication voltage is still present after a set period of time. In the event of an indication delay, there is a delay for a preset time. The information is passed on only if the indication voltage is still present after this time.

Indication derivation
User-definable indications can be derived from individual or a group of indications. These grouped indications are of great value to the user that need to minimize the number of indications sent to the system or SCADA interface.

Communication
As regards communication, the devices offer high flexibility for the connection to industrial and energy automation standards. The concept of the communication modules running the protocols enables exchangeability and retrofittability. Thus, the devices can also be perfectly adjusted to a changing communication infrastructure in the future, e.g., when Ethernet networks will be increasingly used in the utilities sector in the years to come.

USB interface
There is an USB interface on the front of all devices. All device functions can be set using a PC and DIGSI program. Commissioning tools and fault analysis are built into the DIGSI 4 protection operation program and are used through this interface.

Interfaces
A number of communication modules suitable for various applications can be fitted at the bottom of the housing. The modules can be easily replaced by the user. The interface modules support the following applications:
- System/service interface
  Communication with a central control system takes place through this interface. Radial or ring type station bus topologies can be configured depending on the chosen interface. Furthermore, the units can exchange data through this interface via Ethernet and the IEC 61850 protocol and can also be accessed using DIGSI. Alternatively, up to 2 external temperature detection devices with max. 12 metering sensors can be connected to the system/service interface.
- Ethernet interface
  The Ethernet interface has been designed for quick access to several protection devices via DIGSI. In the case of the motor protection 7SK80, it is possible to connect max. 2 external temperature detection devices with max. 12 metering sensors to the Ethernet interface. As for the line differential protection, the optical interface is located at this interface.
6.2 Protection Systems

System interface protocols (retrofittable):

- **IEC 61850**
  The IEC 61850 protocol based on Ethernet is standardized as worldwide standard for protection and control systems in the utilities sector. Via this protocol it is possible to exchange information also directly between feeder units, so that simple masterless systems for feeder and switchgear interlocking can be set up. Furthermore, the devices can be accessed with DIGSI via the Ethernet bus.

- **IEC 60870-5-103**
  IEC 60870-5-103 is an international standard for the transmission of protection data and fault records. All messages from the unit and also control commands can be transferred by means of published, Siemens-specific extensions to the protocol. Optionally, a redundant IEC 60870-5-103 module is available. This redundant module allows to read and change individual parameters.

- **PROFIBUS-DP protocol**
  PROFIBUS-DP protocol is a widespread protocol in the industrial automation. Through PROFIBUS-DP, SIPROTEC units make their information available to a SIMATIC controller or receive commands from a central SIMATIC controller or PLC. Measured values can also be transferred to a PLC master.

- **MODBUS RTU protocol**
  This simple, serial protocol is mainly used in industry and by power utilities, and is supported by a number of relay manufacturers. SIPROTEC units function as MODBUS slaves, making their information available to a master or receiving information from it. A time-stamped event list is available.

- **DNP 3.0 protocol**
  Power utilities use the serial DNP 3.0 (Distributed Network Protocol) for the station and network control levels. SIPROTEC units function as DNP slaves, supplying their information to a master system or receiving information from it.

System solutions

- **IEC 60870**
  Devices with IEC 60870-5-103 interfaces can be connected to SICAM in parallel via the RS485 bus or radially via optical fiber. Via this interface, the system is open for connection of devices from other manufacturers.

Due to the standardized interfaces, SIPROTEC devices can also be integrated into systems from other manufacturers, or into a SIMATIC system. Electrical RS485 or optical interfaces are available. Optoelectronic converters enable the optimal selection of transmission physics. Thus, cubicle-internal wiring with the RS485 bus, as well as interference-free optical connection to the master can be implemented at low cost.

- **IEC 61850**
  An interoperable system solution is offered for IEC 61850 together with SICAM. Via the 100 Mbit/s Etherbus, the devices are connected electrically or optically to the station PC with SICAM. The interface is standardized, thus enabling the direct connection of devices from other manufacturers to the Ethernet bus.

With IEC 61850, the devices can also be installed in systems of other manufacturers.
SIPROTEC 4 – the proven, reliable and future-proof protection for all applications
SIPROTEC 4 represents a worldwide successful and proven device series with more than 1 million devices in field use.

Due to the homogenous system platform, the unique engineering program DIGSI 4 and the great field experience, the SIPROTEC 4 device family has gained the highest appreciation of users all over the world. Today, SIPROTEC 4 is considered the standard for numerical protection systems in all fields of application.

SIPROTEC 4 provides suitable devices for all applications from power generation and transmission up to distribution and industrial systems.

SIPROTEC 4 is a milestone in protection systems. The SIPROTEC 4 device series implements the integration of protection, control, measuring and automation functions optimally in one device. In many fields of application, all tasks of the secondary systems can be performed with one single device. The open and future-proof concept of SIPROTEC 4 has been ensured for the entire device series with the implementation of IEC 61850.

- Proven protection functions guarantee the safety of the systems operator’s equipment and employees
- Comfortable engineering and evaluation via DIGSI 4
- Simple creation of automation solutions by means of the integrated CFC
- Targeted and easy operation of devices and software thanks to user-friendly design
- Powerful communication components guarantee safe and effective solutions
- Maximum experience worldwide in the use of SIPROTEC 4 and in the implementation of IEC 61850 projects
- Future-proof due to exchangeable communication interfaces and integrated CFC.
To fulfill vital protection redundancy requirements, only those functions that are interdependent and directly associated with each other are integrated into the same unit. For backup protection, one or more additional units should be provided.

All relays can stand fully alone. Thus, the traditional protection principle of separate main and backup protection as well as the external connection to the switchyard remain unchanged.

"One feeder, one relay" concept
Analog protection schemes have been engineered and assembled from individual relays. Interwiring between these relays and scheme testing has been carried out manually in the workshop.

Data sharing now allows for the integration of several protection and protection-related tasks into one single numerical relay. Only a few external devices may be required for completion of the total scheme. This has significantly lowered the costs of engineering, assembly, panel wiring, testing and commissioning. Scheme failure probability has also been lowered.

Engineering has moved from schematic diagrams toward a parameter definition procedure. The powerful user-definable logic of SIPROTEC 4 allows flexible customized design for protection, control and measurement.

Measuring included
For many applications, the accuracy of the protection current transformer is sufficient for operational measuring. The additional measuring current transformer was required to protect the measuring instruments under short-circuit conditions. Due to the low thermal withstand capability of the measuring instruments, they could not be connected to the protection current transformer. Consequently, additional measuring core current transformers and measuring instruments are now only necessary where high accuracy is required, e.g., for revenue metering.

Corrective rather than preventive maintenance
Numerical relays monitor their own hardware and software. Exhaustive self-monitoring and failure diagnostic routines are not restricted to the protection relay itself but are methodically carried through from current transformer circuits to tripping relay coils.

Equipment failures and faults in the current transformer circuits are immediately reported and the protection relay is blocked.

Thus, service personnel are now able to correct the failure upon occurrence, resulting in a significantly upgraded availability of the protection system.

Fig. 6.2-27: Numerical relays offer increased information availability
Adaptive relaying
Numerical relays now offer reliable, convenient and comprehensive matching to changing conditions. Matching may be initiated either by the relay's own intelligence or from other systems via contacts or serial telegrams. Modern numerical relays contain a number of parameter sets that can be pretested during commissioning of the scheme. One set is normally operative. Transfer to the other sets can be controlled via binary inputs or a serial data link (fig. 6.2-28).

There are a number of applications for which multiple setting groups can upgrade the scheme performance, for example:
- For use as a voltage-dependent control of overcurrent-time relay pickup values to overcome alternator fault current decrement to below normal load current when the automatic voltage regulator (AVR) is not in automatic operation
- For maintaining short operation times with lower fault currents, e.g., automatic change of settings if one supply transformer is taken out of service
- For “switch-onto-fault” protection to provide shorter time settings when energizing a circuit after maintenance so that normal settings can be restored automatically after a time delay
- For auto-reclosure programs, that is, instantaneous operation for first trip and delayed operation after unsuccessful reclosure
- For cold load pickup problems where high starting currents may cause relay operation
- For “ring open” or “ring closed” operation.

Implemented functions
SIPROTEC relays are available with a variety of protective functions (please refer to section 6.2.6). The high processing power of modern numerical units allows further integration of non-protective add-on functions.

The question as to whether separate or combined relays should be used for protection and control cannot be unambiguously answered. In transmission-type substations, separation into independent hardware units is still preferred, whereas a trend toward higher function integration can be observed on the distribution level. Here, the use of combined feeder/line relays for protection, monitoring and control is becoming more common (fig. 6.2-29).

Relays with protection functions only and relays with combined protection and control functions are being offered. SIPROTEC 4 relays offer combined protection and control functions. SIPROTEC 4 relays support the “one relay one feeder” principle, and thus contribute to a considerable reduction in space and wiring requirements.

With the well-proven SIPROTEC 4 family, Siemens supports both stand-alone and combined solutions on the basis of a single hardware and software platform. The user can decide within wide limits on the configuration of the control and protection, and the reliability of the protection functions (fig. 6.2-30).

The following solutions are available within one relay family:
- Separate control and protection relays
- Feeder protection and remote control of the line circuit-breaker via the serial communication link
- Combined relays for protection, monitoring and control.
### 6.2 Protection Systems

#### Mechanical design

SIPROTEC 4 relays are available in 1/3 to 1/1 of 19" wide housings with a standard height of 243 mm. Their size is compatible with that of other relay families. Therefore, compatible exchange is always possible (fig. 6.2-31 to fig. 6.2-33).

All wires (cables) are connected at the rear side of the relay with or without ring cable lugs. A special relay version with a detached cable-connected operator panel (fig. 6.2-34) is also available. It allows, for example, the installation of the relay itself in the low-voltage compartment, and of the operator panel separately in the door of the switchgear.

---

#### Terminals: standard relay version with screw-type terminals

**Current terminals**

<table>
<thead>
<tr>
<th>Connection</th>
<th>( W_{\text{max}} = 12 \text{ mm} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring cable lugs</td>
<td>( d_{1} = 5 \text{ mm} )</td>
</tr>
<tr>
<td>Wire size</td>
<td>2.7 – 4 mm² (AWG 13 – 11)</td>
</tr>
<tr>
<td>Direct connection</td>
<td>Solid conductor, flexible lead, connector sleeve</td>
</tr>
<tr>
<td>Wire size</td>
<td>2.7 – 4 mm² (AWG 13 – 11)</td>
</tr>
</tbody>
</table>

**Voltage terminals**

<table>
<thead>
<tr>
<th>Connection</th>
<th>( W_{\text{max}} = 10 \text{ mm} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring cable lugs</td>
<td>( d_{1} = 4 \text{ mm} )</td>
</tr>
<tr>
<td>Wire size</td>
<td>1.0 – 2.6 mm² (AWG 17 – 13)</td>
</tr>
<tr>
<td>Direct connection</td>
<td>Solid conductor, flexible lead, connector sleeve</td>
</tr>
<tr>
<td>Wire size</td>
<td>0.5 – 2.5 mm² (AWG 20 – 13)</td>
</tr>
<tr>
<td>Some relays are alternatively available with plug-in voltage terminals</td>
<td></td>
</tr>
</tbody>
</table>

**Current terminals**

<table>
<thead>
<tr>
<th>Screw type (see standard version)</th>
</tr>
</thead>
</table>

**Voltage terminals**

- 2-pin or 3-pin connectors
- Wire size
  - \( 0.5 – 1.0 \text{ mm}² \)
  - \( 0.75 – 1.5 \text{ mm}² \)
  - \( 1.0 – 2.5 \text{ mm}² \)
6.2 Protection Systems

Fig. 6.2-31: 1/1 of 19” housing

Fig. 6.2-32: 1/2 of 19” housing

Fig. 6.2-33: 1/3 of 19” housing

Fig. 6.2-34: SIPROTEC 4 combined protection, control and monitoring relay with detached operator panel

Fig. 6.2-35: Local operation: All operator actions can be executed and information displayed via an integrated user interface. Two alternatives for this interface are available.

1. On the backlit LCD display, process and device information can be displayed as text.
2. Freely assignable LEDs are used to display process or device information. The LEDs can be labeled according to user requirements. An LED reset key resets the LEDs and can be used for LED testing.
3. Keys for navigation
4. RS232 operator interface (for DIGSI)
5. 4 configurable function keys permit the user to execute frequently used actions simply and fast.
6. Numerical keys

Fig. 6.2-36: Additional features of the interface with graphic display

1. Process and relay information can be displayed on the large illuminated LC display either graphically in the form of a mimic diagram or as text in various lists.
2. The keys mainly used for control of the switchgear are located on the “control axis” directly below the display.
3. Two key-operated switches ensure rapid and reliable changeover between “local” and “remote” control, and between “interlocked” and “non-interlocked” operation.
Apart from the relay-specific protection functions, the SIPROTEC 4 units have a multitude of additional functions that:

- provide the user with information for the evaluation of faults
- facilitate adaptation to customer-specific application
- facilitate monitoring and control of customer installations.

**Operational measured values**
The large scope of measured and limit values permits improved power system management as well as simplified commissioning.

The r.m.s. values are calculated from the acquired current and voltage along with the power factor, frequency, active and reactive power. The following functions are available depending on the relay type:

- Currents $I_{L1}$, $I_{L2}$, $I_{L3}$, $I_N$, $I_{EE}$ (67Ns)
- Voltages $V_{L1}$, $V_{L2}$, $V_{L3}$, $V_{L1-L2}$, $V_{L2-L3}$, $V_{L3-L1}$
- Symmetrical components $I_1$, $I_2$, $I_3$; $V_1$, $V_2$, $V_3$0
- Power Watts, Vars, VA / $P$, $Q$, $S$
- Power factor $p.f.$ (cos $\phi$)
- Frequency
- Energy $\pm$ kWh $\pm$ kVarh, forward and reverse power flow
- Mean as well as minimum and maximum current and voltage values
- Operating hours counter
- Mean operating temperature of overload function
- Limit value monitoring
  Limit values are monitored using programmable logic in the CFC. Commands can be derived from this limit value indication.
- Zero suppression
  In a certain range of very low measured values, the value is set to zero to suppress interference.

**Metered values (some types)**
For internal metering, the unit can calculate energy metered values from the measured current and voltage values. If an external meter with a metering pulse output is available, some SIPROTEC 4 types can obtain and process metering pulses via an indication input.

The metered values can be displayed and passed on to a control center as an accumulation with reset. A distinction is made between forward, reverse, active and reactive energy.

**Operational indications and fault indications with time stamp**
The SIPROTEC 4 units provide extensive data for fault analysis as well as control. All indications listed here are stored, even if the power supply is disconnected.

- Fault event log
  The last eight network faults are stored in the unit. All fault recordings are time-stamped with a resolution of 1 ms.
- Operational indications
  All indications that are not directly associated with a fault (e.g., operating or switching actions) are stored in the status indication buffer. The time resolution is 1 ms (fig. 6.2-37, fig. 6.2-38).
Display editor
A display editor is available to design the display on SIPROTEC 4 units with graphic display. The predefined symbol sets can be expanded to suit the user. The drawing of a single-line diagram is extremely simple. Load monitoring values (analog values) and any texts or symbols can be placed on the display where required.

Four predefined setting groups for adapting relay settings
The settings of the relays can be adapted quickly to suit changing network configurations. The relays include four setting groups that can be predefined during commissioning or even changed remotely via a DIGSI 4 modem link. The setting groups can be activated via binary inputs, via DIGSI 4 (local or remote), via the integrated keypad or via the serial substation control interface.

Fault recording up to five or more seconds
The sampled values for phase currents, earth (ground) currents, line and zero-sequence currents are registered in a fault record. The record can be started using a binary input, on pickup or when a trip command occurs. Up to eight fault records may be stored. For test purposes, it is possible to start fault recording via DIGSI 4. If the storage capacity is exceeded, the oldest fault record in each case is overwritten.

For protection functions with long delay times in generator protection, the r.m.s. value recording is available. Storage of relevant calculated variables (V1, VE, I1, I2, IEE, P, Q, f-fn) takes place at increments of one cycle. The total time is 80 s.

Time synchronization
A battery-backed clock is a standard component and can be synchronized via a synchronization signal (DCF77, IRIG B via satellite receiver), binary input, system interface or SCADA (e.g., SICAM). A date and time is assigned to every indication.

Selectable function keys
Four function keys can be assigned to permit the user to perform frequently recurring actions very quickly and simply.

Typical applications are, for example, to display the list of operating indications or to perform automatic functions such as “switching of circuit-breaker”.

Continuous self-monitoring
The hardware and software are continuously monitored. If abnormal conditions are detected, the unit immediately signals. In this way, a great degree of safety, reliability and availability is achieved.

Reliable battery monitoring
The battery provided is used to back up the clock, the switching statistics, the status and fault indications, and the fault recording in the event of a power supply failure. Its function is checked by the processor at regular intervals. If the capacity of the battery is found to be declining, an alarm is generated. Regular replacement is therefore not necessary.

All setting parameters are stored in the Flash EPROM and are not lost if the power supply or battery fails. The SIPROTEC 4 unit remains fully functional.

Commissioning support
Special attention has been paid to commissioning. All binary inputs and output contacts can be displayed and activated directly. This can significantly simplify the wiring check for the user. Test telegrams to a substation control system can be initiated by the user as well.

CFC: Programming logic
With the help of the CFC (Continuous Function Chart) graphic tool, interlocking schemes and switching sequences can be configured simply via drag and drop of logic symbols; no special knowledge of programming is required. Logical elements, such as AND, OR, flip-flops and timer elements are available. The user can also generate user-defined annunciations and logical combinations of internal or external signals.

Communication interfaces
With respect to communication, particular emphasis has been placed on high levels of flexibility, data integrity and utilization of standards commonly used in energy automation. The design of the communication modules permits interchangeability on the one hand, and on the other hand provides openness for future standards.

Local PC interface
The PC interface accessible from the front of the unit permits quick access to all parameters and fault event data. Of particular advantage is the use of the DIGSI 4 operating program during commissioning.
Retrofitting: Communication modules

It is possible to supply the relays directly with two communication modules for the service and substation control interfaces, or to retrofit the communication modules at a later stage. The modules are mounted on the rear side of the relay. As a standard, the time synchronization interface is always supplied.

The communication modules are available for the entire SIPROTEC 4 relay range. Depending on the relay type, the following protocols are available: IEC 60870-5-103, PROFIBUS DP, MODBUS RTU, DNP 3.0 and Ethernet with IEC 61850. No external protocol converter is required (fig. 6.2-39 to fig. 6.2-43).

With respect to communication, particular emphasis is placed on the requirements in energy automation:
- Every data item is time-stamped at the source, that is, where it originates.
- The communication system automatically handles the transfer of large data blocks (e.g., fault records or parameter data files). The user can apply these features without any additional programming effort.
- For reliable execution of a command, the relevant signal is first acknowledged in the unit involved. When the command has been enabled and executed, a check-back indication is issued. The actual conditions are checked at every command-handling step. Whenever they are not satisfactory, controlled interruption is possible.

The following interfaces can be applied:

1. Service interface (optional)
   Several protection relays can be centrally operated with DIGSI 4, e.g., via a star coupler or RS485 bus. On connection of a modem, remote control is possible. This provides advantages in fault clearance, particularly in unmanned power plants. (Alternatively, the external temperature monitoring box can be connected to this interface.)

2. System interface (optional)
   This is used to carry out communication with a control system and supports, depending on the module connected, a variety of communication protocols and interface designs.

3. Time synchronization interface
   A synchronization signal (DCF 77, IRIG B via satellite receiver) may be connected to this input if no time synchronization is executed on the system interface. This offers a high-precision time tagging.
Safe bus architecture

- Optical-fiber double ring circuit via Ethernet
  The optical-fiber double ring circuit is immune to electromagnetic interference. Upon failure of a section between two units, the communication system continues to operate without interruption. If a unit were to fail, there is no effect on the communication with the rest of the system (fig. 6.2-44).
- RS485 bus
  With this data transmission via copper wires, electromagnetic interference is largely eliminated by the use of twisted-pair conductors. Upon failure of a unit, the remaining system continues to operate without any faults (fig. 6.2-45).
- Star structure
  The relays are connected with a optical-fiber cable with a star structure to the control unit. The failure of one relay / connection does not affect the others (fig. 6.2-46).

Depending on the relay type, the following protocols are available:

- IEC 61850 protocol
  Since 2004, the Ethernet-based IEC 61850 protocol is the worldwide standard for protection and control systems used by power supply corporations. Siemens is the first manufacturer to support this standard. By means of this protocol, information can also be exchanged directly between feeder units so as to set up simple masterless systems for feeder and system interlocking. Access to the units via the Ethernet bus will also be possible with DIGSI.
- IEC 60870-5-103
  IEC 60870-5-103 is an internationally standardized protocol for efficient communication between the protection relays and a substation control system. Specific extensions that are published by Siemens can be used.
- PROFIBUS DP
  For connection to a SIMATIC PLC, the PROFIBUS DP protocol is recommended. With the PROFIBUS DP, the protection relay can be directly connected to a SIMATIC S5/S7. The transferred data are fault data, measured values and control commands.
MODBUS RTU
MODBUS is also a widely utilized communication standard and is used in numerous automation solutions.

DNP 3.0
DNP 3.0 (Distributed Network Protocol, version 3) is a messaging-based communication protocol. The SIPROTEC 4 units are fully Level 1 and Level 2-compliant with DNP 3.0, which is supported by a number of protection unit manufacturers.

Control
In addition to the protection functions, the SIPROTEC 4 units also support all control and monitoring functions required for operating medium-voltage or high-voltage substations. The main application is reliable control of switching and other processes. The status of primary equipment or auxiliary devices can be obtained from auxiliary contacts and communicated to the relay via binary inputs.

Therefore, it is possible to detect and indicate both the OPEN and CLOSED positions or a faulty or intermediate breaker position. The switchgear can be controlled via:
- Integrated operator panel
- Binary inputs
- Substation control system
- DIGSI 4

Automation
With the integrated logic, the user can set specific functions for the automation of the switchgear or substation by means of a graphic interface (CFC). Functions are activated by means of function keys, binary inputs or via the communication interface.

Switching authority
The following hierarchy of switching authority is applicable:
LOCAL, DIGSI 4 PC program, REMOTE. The switching authority is determined according to parameters or by DIGSI 4. If the LOCAL mode is selected, only local switching operations are possible. Every switching operation and change of breaker position is stored in the status indication memory with detailed information and time tag.

Command processing
The SIPROTEC 4 protection relays offer all functions required for command processing, including the processing of single and double commands, with or without feedback, and sophisticated monitoring. Control actions using functions, such as runtime monitoring and automatic command termination after output check of the external process, are also provided by the relays.
Typical applications are:
- Single and double commands using 1, 1 plus 1 common or 2 trip contacts
- User-definable feeder interlocking
- Operating sequences combining several switching operations, such as control of circuit-breakers, disconnectors (isolators) and earthing switches
- Triggering of switching operations, indications or alarms by logical combination of existing information (fig. 6.2-47).
6.2 Protection Systems

SIPROTEC 5 – the new benchmark for protection, automation and monitoring of transmission grids

The SIPROTEC 5 series is based on the long field experience of the SIPROTEC device series, and has been especially designed for the new requirements of modern high-voltage systems. For this purpose, SIPROTEC 5 is equipped with extensive functionalities and device types. With the holistic and consistent engineering tool DIGSI 5, a solution has also been provided for the increasingly complex processes, from the design via the engineering phase up to the test and operation phase.

Thanks to the high modularity of hardware and software, the functionality and hardware of the devices can be tailored to the requested application and adjusted to the continuously changing requirements throughout the entire life cycle.

Besides the reliable and selective protection and the complete automation function, SIPROTEC 5 offers an extensive database for operation and monitoring of modern power supply systems. Synchronphasors (PMU), power quality data and extensive operational equipment data are part of the scope of supply.

- Powerful protection functions guarantee the safety of the system operator’s equipment and employees
- Individually configurable devices save money on initial investment as well as storage of spare parts, maintenance, expansion and adjustment of your equipment
- Clear and easy-to-use of devices and software thanks to user-friendly design
- Increase of reliability and quality of the engineering process
- High reliability due to consequent implementation of safety and security
- Powerful communication components guarantee safe and effective solutions
- Full compatibility between IEC 61850 Editions 1 and 2
- Efficient operating concepts by flexible engineering of IEC 61850 Edition 2
- Comprehensive database for monitoring of modern power grids
- Optimal smart automation platform for transmission grids based on integrated synchronphasor measurement units (PMU) and power quality functions.

Fig. 6.2-48: SIPROTEC 5 – modular hardware

Fig. 6.2-49: SIPROTEC 5 – rear view

Fig. 6.2-50: Application in the high-voltage system
### Innovation highlights

With SIPROTEC 5, we have combined a functionality that has been proven and refined over years with a high-performance and flexible new platform, extended with trendsetting innovations for present and future demands.

### Holistic workflow

The tools for end-to-end engineering from system design to operation will make your work easier throughout the entire process.

The highlight of SIPROTEC 5 is the greater-than-ever emphasis on daily ease of operation. SIPROTEC 5 provides support along all the steps in the engineering workflow, allowing for system view management and configuration down to the details of individual devices, saving time and cost without compromising quality (fig. 6.2-51).

Holistic workflow in SIPROTEC 5 means:
- Integrated, consistent system and device engineering – from the single-line diagram of the unit all the way to device parameterization
- Simple, intuitive graphical linking of primary and secondary equipment
- Easily adaptable library of application templates for the most frequently used applications
- Manufacturer-independent tool for easy system engineering
- Libraries for your own configurations and system parts
- Multiuser concept for parallel engineering
- Open interfaces for seamless integration into your process environment
- A user interface developed and tested jointly with many users
- Integrated tools for testing during engineering, commissioning, and for simulating operational scenarios, e.g., grid disruptions or switching operations.

For system operators, holistic workflow in SIPROTEC 5 means:
An end-to-end tool from system design to operation – even allowing crossing of functional and departmental boundaries – saves time, assures data security and transparency throughout the entire lifecycle of the system.

### Perfectly tailored fit

Individually configurable devices provide you with cost-effective solutions that match your needs precisely throughout the entire lifecycle.

SIPROTEC 5 sets new standards in cost savings and availability with its innovative modular and flexible hardware, software and communication. SIPROTEC 5 provides a perfectly tailored fit for your switchgear and applications unparalleled by any other system.

Perfectly tailored fit with SIPROTEC 5 means:
- Modular system design in hardware, software and communication ensures the perfect fit for your needs
- Functional integration of a wide range of applications, such as protection, control, measurement, power quality or fault recording
- The same expansion and communication modules for all devices in the family
- Innovative terminal technology ensures easy assembly and interchangeability with the highest possible degree of safety
- Identical functions and consistent interfaces throughout the entire system family mean less training requirement and increased safety, e.g., an identical automatic reclosing (AR) for line protection devices 7SD8, 7SA8, 7SL8
- Functions can be individually customized by editing for your specific requirements
- Innovations are made available to all devices at the same time and can easily be retrofitted as needed via libraries.

For system operators, perfectly tailored fit with SIPROTEC 5 means:
Individually configurable devices save money in the initial investment, spare parts storage, maintenance, extending and adapting of systems.

### Smart automation for transmission grids

The extraordinary range of integrated functionalities for all the demands of your smart grid.

Climate change and dwindling fossil fuels are forcing a total re-evaluation of the energy supply industry, from generation to distribution and consumption. This is having fundamental effects on the structure and operation of the power grids.

Smart automation is a major real-time component designed to preserve the stability of these grids and at the same time conserve energy and reduce costs.

SIPROTEC 5 offers the optimum smart automation platform for smart grids.

Smart automation for transmission grids with SIPROTEC 5 means:
- Open, scalable architecture for IT integration and new functions
- The latest standards in the area of communication and Cyber Security
Protection, Substation Automation, Power Quality and Measurement

6.2 Protection Systems

- "Smart functions", e.g., for power system operation, analysis of faults or power quality (power systems monitoring, power control unit, fault location)
- Integrated automation with optimized logic modules based on the IEC 61313-3 standard
- Highly precise acquisition and processing of process values and transmission to other components in the smart grid
- Protection, automation and monitoring in the smart grid.

Functional integration
Due to the modular design of its hardware and software and the powerful engineering tool DIGSI 5, SIPROTEC 5 is ideally suited for protection, automation, measurement and monitoring tasks in the electrical power systems.

The devices are not only pure protection and control equipment, their performance enables them to assure functional integration of desired depth and scope. For example, they can also serve to perform monitoring, phasor measurement, fault recording, a wide range of measurement functions and much more, concurrently, and they have been designed to facilitate future functionality expansion.

SIPROTEC 5 provides an extensive, precise data acquisition and bay level recording for these functions. By combining device functionality with communication flexibility, SIPROTEC 5 has the ability to meet a wide range of today’s applications and specific project specifications as well as the functional expansion capability to adapt to changing needs in the future.

With SIPROTEC 5 it is possible to improve the safety and reliability of the operator’s application. Fig. 6.2-52 shows the possible functional expansion of a SIPROTEC 5 device.

![Fig. 6.2-52: Possible functional expansion of SIPROTEC 5 devices](image)

**Functional integration – Protection**
SIPROTEC 5 provides all the necessary protection functions to address reliability and security of power transmission systems. System configurations with multiple busbars and breaker-and-a-half schemes are both supported. The functions are based on decades of experience in putting systems into operation, including feedback and suggestions from system operators.

The modular, functional structure of SIPROTEC 5 allows exceptional flexibility and enables the creation of a protection functionality that is specific to the conditions of the system while also being capable of further changes in the future.

**Functional integration – Control**
SIPROTEC 5 includes all bay level control and monitoring functions that are required for efficient operation of the substations. The application templates supplied provide the full functionality needed by the system operators. Protection and control functions access the same logical elements.

A new level of quality in control is achieved with the application of communication standard IEC 61850. For example, binary information from the field can be processed and data (e.g., for interlocking across multiple fields) can be transmitted between the devices. Cross communications via GOOSE enables efficient solutions, since here the hardwired circuits are replaced with data telegrams. All devices are provided for up to 4 switching devices (circuit-breakers, disconnectors, earthing switches) in the basic control package. Optionally, additional switching devices and the switching sequence block can be activated (Continuous Function Chart (CFC)).

**Functional integration – Automation**
An integrated graphical automation function enables operators to create logic diagrams clearly and simply. DIGSI 5 supports this with powerful logic modules based on the standard IEC 61131-3.

Example automation applications are:
- Interlocking checks
- Switching sequences (switching sequence function chart (CFC))
- Message derivations from switching actions
- Messages or alarms by linking available information
- Load shedding a feeder (arithmetic function chart (CFC) and switching sequence function chart (CFC))
- Management of decentralized energy feeds
- System transfer depending on the grid status
- Automatic grid separations in the event of grid stability problems.

Of course, SIPROTEC 5 provides a substation automation system such as SICAM PAS with all necessary information, thus ensuring consistent, integrated and efficient solutions for further automation.
**Protection, Substation Automation, Power Quality and Measurement**

### 6.2 Protection Systems

**Functional integration – Monitoring**
SIPROTEC 5 devices can take on a wide variety of monitoring tasks. These are divided into four groups:
- Self monitoring
- Monitoring grid stability
- Monitoring power quality
- Monitoring of equipment (condition monitoring).

**Self monitoring**
SIPROTEC 5 devices are equipped with many self-monitoring procedures. These procedures detect faults internal to the device as well as external faults in the secondary circuits and store them in buffers for recording and reporting. This stored information can then be used to help determine the cause of the self monitoring fault in order to take appropriate corrective actions.

**Grid stability**
Grid monitoring combines all of the monitoring systems that are necessary to assure grid stability during normal grid operation. SIPROTEC 5 provides all necessary functionalities, e.g., fault recorders, continuous recorders, fault locators and phasor measurement units (PMUs) for grid monitoring.

**Power quality**
For this, SIPROTEC 5 provides corresponding power quality recorders. These can be used to detect weak points early so that appropriate corrective measures can be taken.

The large volume of data is archived centrally and analyzed neatly with a SICAM PQS system.

**Equipment**
The monitoring of equipment (condition monitoring) is an important tool in asset management and operational support from which both the environment and the company can benefit.

**Functional integration – Data acquisition and recording**
The recorded and logged field data is comprehensive. It represents the image and history of the field. It is also used by the functions in the SIPROTEC 5 device for monitoring, interbay and substation automation tasks. It therefore provides the basis for these functions now and in the future.

**Functional integration – Communication**
SIPROTEC 5 devices are equipped with high-performance communication interfaces. These are integrated interfaces or interfaces that are extendable with plug-in modules to provide a high level of security and flexibility. There are various communication modules available. At the same time, the module is independent of the protocol used. This can be loaded according to the application. Particular importance was given to the realization of full communication redundancy:
- Multiple redundant communication interfaces
- Redundant, independent protocols with control center possible (e.g. IEC 60870-5-103 and IEC 61850 or double IEC 60870-5-103 or DNP3 and DNP IP)
- Full availability of the communication ring when the switching cell is enabled for servicing operations
- Redundant time synchronization (e.g. IRIG-B and SNTP).

**Fig. 6.2-53: System configuration with application template for one breaker-and-a-half scheme**

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**Diagram Notes:**
- **A** User can configure the assignment with DIGSI 5
- **CB** = Circuit-breaker
- **Busbar**
- **CT**
- **QA**
- **VT**
- **Line**
- **Function group**
- **Function**
- **Stage**
- **Information exchange between FG**
- **Protection-function group Line 1**
- **Trip command**
- **SOBF**
- **Protection-function group QA1**
- **Protection-function group QA2**
- **Application template: DIS overhead line, earthed power systems, 1.5 CB Trip**
6.2 Protection Systems

Functional integration – Cyber Security
A multi-level security concept for the device and DIGSI 5 provides the user with a high level of protection against communication attacks from the outside and conforms to the requirements of the BDEW Whitebook and NERC CIP.

Functional integration – Test
To shorten testing and commissioning times, extensive test and diagnostic functions are available to the user in DIGSI 5. These are combined in the DIGSI 5 Test Suite.

The test spectrum includes, among other tests:
- Hardware and wiring test
- Function and protection-function test
- Simulation of digital signals and analog sequences by integrated test equipment
- De-bugging of function charts
- Circuit-breaker test and AR (automatic reclosing) test function
- Communication testing
- Loop test for communication connections
- Protocol test.

The engineering, including the device test, can therefore be done with one tool.

Application templates
Application templates allow systems operators to fast track their solution. A library of application templates is available that can be tailored to the specific functional scope for typical applications.

Fig. 6.2-54 shows an example of a system configuration with a breaker-and-a-half scheme. The functions in the application template are combined in functional groups (FG). The functional groups (FG) correspond to the primary components (protection object: line; switching device: circuit-breaker), thereby simplifying the direct reference to the actual system. For example, if the switchgear concerned includes 2 circuit-breakers, this is also represented by 2 “circuit-breaker” functional groups – a schematic map of the actual system.

Optimizing the application template for the specific application
The system operator can adapt the application templates to the corresponding application and create his own in-house standards. The required number of protection stages or zones can be increased without difficulty. Additional functions can be loaded into the device directly from an extensive function library. Since the functions conform to a common design structure throughout the SIPROTEC 5 system, protection functions and even entire function groups including parameterization can be copied from one device to another.

Hardware and order configurator
The SIPROTEC 5 hardware building blocks offer a freely configurable device. System operators have the choice:

Either to use a pre-configured device with a quantity structure already tailored to the corresponding application, or to build a device from the extensive SIPROTEC 5 hardware building blocks themselves to exactly fit their application.

The flexible hardware building blocks offer:
- Base modules and expansion modules, each with different I/O modules
- Various on-site operation panels
- A large number of modules for communication, measured value conversion and memory extension

The SIPROTEC 5 hardware building blocks offer:

Durability and robustness
- Tailored hardware extension
- Robust housings
- Excellent EMC shielding in compliance with the most recent standards and IEC 61000-4
- Extended temperature range –25 °C to +70 °C/–13 °F to +158 °F.

Modular principle
- Freely configurable and extendable devices
- Large process data range (up to 24 current and voltage transformers for protection applications and up to 40 for central busbar protection, as well as more than 200 inputs and outputs for recording applications possible)
- Operation panel that is freely selectable for all device types (e.g., large or small display, with or without key switches, detached operation panel)
- Identical wiring of flush-mounting and surface-mounting housings.

Product selection via the order configurator
The order configurator assists in the selection of SIPROTEC 5 products. The order configurator is a Web application that can be used with any browser. The SIPROTEC 5 configurator can be used to configure complete devices or individual components, such as communication modules or extension modules. At the end of the configuration process, the product code and a detailed presentation of the configuration result are provided. It clearly describes the product and also serves as the order number.
6.2 Protection Systems

6.2.3 Operating Programs DIGSI 4, IEC 61850 System Configurator and SIGRA 4

![DIGSI 4 operating program](image)

*Fig. 6.2-55: DIGSI 4 operating program*
DIGSI 4, an operating software for all SIPROTEC protection devices

Description
The PC operating program DIGSI 4 is the user interface to the SIPROTEC devices, regardless of their version. It is designed with a modern, intuitive user interface. With DIGSI 4, SIPROTEC devices are configured and evaluated – it is the tailored program for industrial and energy distribution systems.

Functions
Simple protection setting
From the numerous protection functions it is possible to easily select only those which are really required (see fig. 6.2-56). This increases the clearness of the other menus.

Device setting with primary or secondary values
The settings can be entered and displayed as primary or secondary values. Switching over between primary and secondary values is done with one mouse click in the tool bar (see fig. 6.2-56).

Assignment matrix
The DIGSI 4 matrix shows the user the complete configuration of the device at a glance (fig. 6.2-57). For example, the assignment of the LEDs, the binary inputs and the output relays is displayed in one image. With one click, the assignment can be changed.

CFC: Projecting the logic instead of programming
With the CFC (continuous function chart), it is possible to link and derive information without software knowledge by simply drawing technical processes, interlocks and operating sequences.

Logical elements such as AND, OR, timers, etc., as well as limit value requests of measured values are available (fig. 6.2-58).
Commissioning
Special attention has been paid to commissioning. All binary inputs and outputs can be set and read out in targeted way. Thus, a very simple wiring test is possible. Messages can be sent to the serial interface deliberately for test purposes.

IEC 61850 system configurator
The IEC 61850 system configurator, which is started out of the system manager, is used to determine the IEC 61850 network structure as well as the extent of data exchange between the participants of a IEC 61850 station. To do this, subnets are added in the "network" working area – if required –, available participants are assigned to the subnets, and addressing is defined. The "assignment" working area is used to link data objects between the participants, e.g., the starting indication of the U/inverse-time overcurrent protection I> function of feeder 1, which is transferred to the incoming supply in order to prompt the reverse interlocking of the V/inverse-time overcurrent protection I>> function there (see fig. 6.2-58).
SIGRA 4, powerful analysis of all protection fault records

**Description**

It is of crucial importance after a line fault that the fault is quickly and fully analyzed so that the proper measures can be immediately derived from the evaluation of the cause. As a result, the original line condition can be quickly restored and the downtime reduced to an absolute minimum. It is possible with SIGRA 4 to display records from digital protection units and fault recorders in various views and measure them, as required, depending on the relevant task.

In addition to the usual time-signal display of the measured variables record, it is also designed to display vector diagrams, circle diagrams, bar charts for indicating the harmonics and data tables. From the measured values which have been recorded in the fault records, SIGRA 4 calculates further values, such as: absent quantities in the three-wire system, impedances, outputs, symmetrical components, etc. By means of two measuring cursors, it is possible to evaluate the fault trace simply and conveniently. With SIGRA, however, you can add additional fault records. The signals of another fault record (e.g. from the opposite end of the line) are added to the current signal pattern by means of Drag&Drop. SIGRA 4 offers the possibility to display signals from various fault records in one diagram and fully automatically synchronize these signals to a common time base. In addition to finding out the details of the line fault, the localization of the fault is of special interest.

A precise determination of the fault location will save time that can be used for the on-site inspection of the fault. This aspect is also supported by SIGRA 4 – with its “offline fault localization” feature.

SIGRA 4 can be used for all fault records using the COMTRADE file format.

The functional features and advantages of SIGRA 4 can, however, only be optimally shown on the product itself. For this reason, it is possible to test SIGRA 4 for 30 days with the trial version.

**Functions overview**

- 6 types of diagrams: time signal representation (usual), circle diagram (e.g. for R/X), vector diagram (reading of angles), bar charts (e.g. for visualization of harmonics), table (lists values of several signals at the same instant) and fault locator (shows the location of a fault)
- Calculate additional values such as positive impedances, r.m.s. values, symmetric components, vectors, etc.
- Two measurement cursors, synchronized in each view
- Powerful zoom function
- User-friendly configuration via drag & drop
- Innovative signal configuration in a clearly-structured matrix
- Time-saving user profiles, which can be assigned to individual relay types or series
- Addition of other fault records to the existing fault record
- Synchronization of several fault records to a common time basis
- Easy documentation by copying diagrams to documents of other MS Windows programs
- Offline fault localization

**Hardware requirements**

- Pentium 4 with 1-GHz processor or similar
- 1 GB of RAM (2 GB recommended)
- Graphic display with a resolution of 1024 × 768 (1280 × 1024 recommended)
- 50 MB free storage space on the hard disk
- DVD-ROM drive
- Keyboard and mouse

**Software requirements**

- MS Windows XP Professional
- MS Windows Vista Home Premium, Business and Ultimate
- MS Windows Server 2003 Standard Edition with Service Pack 2 used as a Workstation computer
- MS Windows 7 Professional and Enterprise Ultimate
Functions

Different views of a fault record
In addition to the standard time signal representation, SIGRA 4 also supports the display of circle diagrams (e.g. R/X diagrams), vectors, which enable reading of angles, and bar charts (e.g. for visualization of harmonics). To do this, SIGRA uses the values recorded in the fault record to calculate additional values such as positive impedances, r.m.s. values, symmetric components, vectors, etc.

Measurement of a fault record
Two measurement cursors enable fast and convenient measurement of the fault record. The measured values of the cursor positions and their differences are presented in tables. The cursors operate interactively and across all views, whereby all cursor movement is synchronized in each view: In this manner, the cursor line enables simultaneous “intersection” of a fault occurrence in both a time signal characteristic and circle diagram characteristic. And of course a powerful zoom function ensures that you do not lose track of even the tiniest detail. The views of SIGRA 4 can accommodate any number of diagrams and in each diagram any number of signals.

Operational features
The main aim of the developers of SIGRA 4, who were assisted by ergonomic and design experts, was to produce a system that was simple, intuitive and user-friendly:

• The colours of all the lines have been defined so that they are clear and easily distinguishable. However, the colour, as well as the line style, the scale and other surface features, can be adjusted to suit individual requirements.

• Pop-up menus for each situation offer customized functionality – thus eliminating the need to browse through numerous menu levels (total operational efficiency).

• Configuration of the individual diagrams is simple and intuitive: Object-oriented, measured variables can be simply dragged and dropped from one diagram to another (also diagrams of different types).

• “Snap-to-grid” and “snap-to-object” movement of the cursor lines for easy and accurate placement.

• Redundancy: Most user tasks can be achieved via up to five different operational methods, thus ensuring quick and easy familiarization with the analysis software.

• Utilization of the available screen space is automatically optimized by an intelligent function that, like the “synchronous mouse cursors”, has since been patented.
User friendly tools support you in your daily work:

- Storage of user defined views (e.g. zoom, size), in so-called user profiles and to assign them to individual relay types or series. Then simply select from the toolbar and you can display each fault record quickly and easily as required. No need to waste time scrolling, zooming or resizing and moving windows.
- Additional fault records, e.g. from the other end of a line, can be added to existing records.
- A special function allows several fault records to be synchronized on a mutual time basis, thus considerably improving the quality of fault analysis.
- Fault localization with data from one line end the fault record data (current and voltage measurement) values are imported from the numerical protection unit into SIGRA 4. The fault localizer in SIGRA 4 is then started by the user and the result represented in % or in km of the line length, depending on the parameters assigned.
- Fault localization with data from both line ends. The algorithm of the implemented fault location does not need a zero-phase sequence system. Thus, measuring errors due to earth impedance or interference with the zero current of the parallel line are ruled out. Errors with contact resistance on lines with infeed from both ends are also correctly recorded. The above influences are eliminated due to the import of fault record data from both line ends into SIGRA. For this purpose, the imported data are synchronized in SIGRA and the calculation of the fault location is then started.
- Consequently, fault localization is independent from the zero-phase sequence system and the line infeed conditions and produces precise results to allow as fast an inspection of the fault location as possible.
- So-called marks, which users can insert at various instants as required, enable suitable commentary of the fault record. Each individual diagram can be copied to a document of another MS Windows program via the “clipboard”: Documenting fault records really could not be easier.

Scope of delivery
The software product is quick and easy to install from a CD-ROM. It has a comprehensive “help” system. An user-friendly and practical manual offers easy step-by-step instructions on how to use SIGRA.
6.2.4 Typical Protection Schemes

1. Cables and overhead lines

Radial systems

Notes:
1) Auto-reclosure (ANSI 79) only with overhead lines.
2) Negative sequence overcurrent protection 46 as sensitive backup protection against asymmetrical faults.

General notes:
- The relay at the far end (D) is set with the shortest operating time. Relays further upstream have to be time-graded against the next downstream relay in steps of about 0.3 s.
- Inverse time or definite time can be selected according to the following criteria:
  - Definite time:
    Source impedance is large compared to the line impedance, that is, there is small current variation between near and far end faults.
  - Inverse time:
    Longer lines, where the fault current is much less at the far end of the line than at the local end.
  - Strong or extreme inverse-time:
    Lines where the line impedance is large compared to the source impedance (high difference for close-in and remote faults), or lines where coordination with fuses or reclosers is necessary. Steeper characteristics also provide higher stability on service restoration (cold load pickup and transformer inrush currents).

Ring-main circuit

General notes:
- Operating time of overcurrent relays to be coordinated with downstream fuses of load transformers (preferably with strong inverse-time characteristic with about 0.2 s grading-time delay)
- Thermal overload protection for the cables (option)
- Negative sequence overcurrent protection (46) as sensitive protection against asymmetrical faults (option)
Switch-onto-fault protection
If switched onto a fault, instantaneous tripping can be effected. If the internal control function is used (local, via binary input or via serial interface), the manual closing function is available without any additional wiring. If the control switch is connected to a circuit-breaker bypassing the internal control function, manual detection using a binary input is implemented.

Directional comparison protection (cross-coupling)
Cross-coupling is used for selective protection of sections fed from two sources with instantaneous tripping, that is, without the disadvantage of time coordination. The directional comparison protection is suitable if the distances between the protection stations are not significant and pilot wires are available for signal transmission. In addition to the directional comparison protection, the directional coordinated overcurrent-time protection is used for complete selective backup protection. If operated in a closed-circuit connection, an interruption of the transmission line is detected.

Distribution feeder with reclosers
General notes:
• The feeder relay operating characteristics, delay times and auto-reclosure cycles must be carefully coordinated with downstream reclosers, sectionalizers and fuses. The 50/50N instantaneous zone is normally set to reach out to the first main feeder sectionalizing point. It has to ensure fast clearing of close-in faults and prevent blowing of fuses in this area (“fuse saving”). Fast auto-reclosure is initiated in this case. Further time-delayed tripping and reclosure steps (normally two or three) have to be graded against the recloser.
• The overcurrent relay should automatically switch over to less sensitive characteristics after long breaker interruption times in order to enable overriding of subsequent cold load pickup and transformer inrush currents.
3-pole multishot auto-reclosure (AR, ANSI 79)

Auto-reclosure (AR) enables 3-phase auto-reclosing of a feeder that has previously been disconnected by overcurrent protection.

SIPROTEC 7SJ61 allows up to nine reclosing shots. The first four dead times can be set individually. Reclosing can be blocked or initiated by a binary input or internally. After the first trip in a reclosing sequence, the high-set instantaneous elements ($I_{>>}$, $I_{>}$, $IE_{>>}$) can be blocked. This is used for fuse-saving applications and other similar transient schemes using simple overcurrent relays instead of fuses. The low-set definite-time ($I_{>}$, $IE_{>}$) and the inverse-time ($Ip$, $IEp$) overcurrent elements remain operative during the entire sequence.

Parallel feeder circuit

**General notes:**
- The preferred application of this circuit is in the reliable supply of important consumers without significant infeed from the load side.
- The 67/67N directional overcurrent protection trips instantaneously for faults on the protected line. This saves one time-grading interval for the overcurrent relays at the infeed.
- The 51/51N overcurrent relay functions must be time-graded against the relays located upstream.

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Fig. 6.2-72: 3-pole multishot auto-reclosure (AR, ANSI 79)

Fig. 6.2-73: Parallel feeder circuit
Reverse-power monitoring at double infeed

If a busbar is fed from two parallel infeeds and a fault occurs on one of them, only the faulty infeed should be tripped selectively in order to enable supply to the busbar to continue from the remaining supply. Unidirectional devices that can detect a short-circuit current or energy flow from the busbar toward the incoming feeder should be used. Directional time-overcurrent protection is usually set via the load current. However, it cannot clear weak-current faults. The reverse-power protection can be set much lower than the rated power, thus also detecting the reverse-power flow of weak-current faults with fault currents significantly below the load current.

Synchronization function

Note:
Also available in relays 7SA6, 7SD5, 7SA522, 7VK61.

General notes:
• When two subsystems must be interconnected, the synchronization function monitors whether the subsystems are synchronous and can be connected without risk of losing stability.
• This synchronization function can be applied in conjunction with the auto-reclosure function as well as with the control function CLOSE commands (local/remote).

Fig. 6.2-74: Reverse-power monitoring at double infeed

Fig. 6.2-75: Synchronization function
Cables or short overhead lines with infeed from both ends

Notes:
1) Auto-reclosure only with overhead lines
2) Differential protection options:
   • Type 7SD5 or 7SD610 with direct optical-fiber connection up to about 100 km or via a 64 kbit/s channel (optical-fiber, microwave)
   • Type 7SD52 or 7SD610 with 7XV5662 (CC-CC) with 2 and 3 pilot wires up to about 30 km
   • Type 7SD80 with pilot wire and/or fibre optic protection data interface.

Overhead lines or longer cables with infeed from both ends

Notes:
1) Teleprotection logic (85) for transfer trip or blocking schemes. Signal transmission via pilot wire, power line carrier, digital network or optical fiber (to be provided separately). The teleprotection supplement is only necessary if fast fault clearance on 100 % line length is required, that is, second zone tripping (about 0.3 s delay) cannot be accepted for far end faults. For further application notes on teleprotection schemes, refer to the table on the following page.
2) Directional earth-fault protection 67N with inverse-time delay against high-resistance faults
3) Single or multishot auto-reclosure (79) only with overhead lines.

Subtransmission line

Note:
Connection to open delta winding if available. Relays 7SA6 / 522 and 7SJ62 can, however, also be set to calculate the zero-sequence voltage internally.

General notes:
• Distance teleprotection is proposed as main protection and time-graded directional overcurrent as backup protection.
• The 67N function of 7SA6 / 522 provides additional high-resistance earth-fault protection. It can be used in parallel with the 21 / 21N function.
• Recommended teleprotection schemes: PUTT on medium and long lines with phase shift carrier or other secure communication channel POTT on short lines. BLOCKING with On/Off carrier (all line lengths).
### Table 6.2-2: Application criteria for frequently used teleprotection schemes

<table>
<thead>
<tr>
<th>Preferred application</th>
<th>Signal transmission system</th>
<th>Permissive underreach transfer trip (PUTT)</th>
<th>Permissive overreach transfer trip (POTT)</th>
<th>Blocking</th>
<th>Unblocking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dependable and secure communication channel:</td>
<td>Reliable communication channel (only required during external faults)</td>
<td>Dedicated channel with continuous signal transfer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Power line carrier with frequency shift modulation.</td>
<td>• Power line carrier with amplitude modulation (ON/OFF). The same frequency may be used on all terminals)</td>
<td>• Power line carrier with frequency shift keying. Continuous signal transmission must be permitted.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>HF signal coupled to 2 phases of the protected line, or even better, to a parallel circuit to avoid transmission of the HF signal through the fault location.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Microwave radio, especially digital (PCM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Optical-fiber cables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Characteristic of line</td>
<td>Best suited for longer lines – where the underreach zone provides sufficient resistance coverage</td>
<td>Excellent coverage on short lines in the presence of fault resistance.</td>
<td>All line types – preferred practice in the US</td>
<td>Same as POTT</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Suitable for the protection of multi-terminal lines with intermediate infeed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td></td>
<td>Simple technique</td>
<td>Can be applied without underreaching zone 1 stage (e.g., overcompensated series uncompensated lines)</td>
<td>Same as POTT</td>
<td>Same as POTT but:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No coordination of zones and times with the opposite end required. The combination of different relay types therefore presents no problems</td>
<td>• Can be applied on extremely short lines (impedance less than minimum relay setting)</td>
<td>Same as POTT</td>
<td>• If no signal is received (no block and no uncompensated block) then tripping by the overreach zone is released after 20 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overlapping of the zone 1 reaches must be ensured. On parallel lines, teed feeders and tapped lines, the influence of zero sequence coupling and intermediate infeeds must be carefully considered to make sure a minimum overlapping of the zone 1 reach is always present.</td>
<td>Zone reach and signal timing coordination with the remote end is necessary (current reversal)</td>
<td>Same as POTT</td>
<td>Same as POTT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Not suitable for weak infeed terminals</td>
<td></td>
<td>Same as POTT</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.2-2: Application criteria for frequently used teleprotection schemes
Transmission line with reactor (fig. 6.2-79)

Notes:
1) 51N only applicable with earthed reactor neutral.
2) If phase CTs at the low-voltage reactor side are not available, the high-voltage phase CTs and the CT in the neutral can be connected to a restricted earth-fault protection using one 7VH60 high-impedance relay.

General notes:
- Distance relays are proposed as main 1 and main 2 protection. Duplicated 7SA6 is recommended for series-compensated lines.
- Operating time of the distance relays is in the range of 15 to 25 ms depending on the particular fault condition. These tripping times are valid for faults in the underreaching distance zone (80 to 85% of the line length). Remote end faults must be cleared by the superimposed teleprotection scheme. Its overall operating time depends on the signal transmission time of the channel, typically 15 to 20 ms for frequency shift audio-tone PLC or microwave channels, and lower than 10 ms for ON/OFF PLC or digital PCM signaling via optical fibers.

Teleprotection schemes based on distance relays therefore have operating times on the order of 25 to 30 ms with digital PCM coded communication. With state-of-the-art two-cycle circuit-breakers, fault clearing times well below 100 ms (4 to 5 cycles) can normally be achieved.
- Dissimilar carrier schemes are recommended for main 1 and main 2 protection, for example, PUTT, and POTT or Blocking/Unblocking.
- Both 7SA522 and 7SA6 provide selective 1-pole and/or 3-pole tripping and auto-reclosure. The earth-current directional comparison protection (67N) of the 7SA6 relay uses phase selectors based on symmetrical components. Thus, 1-pole auto-reclosure can also be executed with high-resistance faults. The 67N function of the 7SA522 relay can also be used as time-delayed directional overcurrent backup.
- The 67N functions are provided as high-impedance fault protection. 67N is often used with an additional channel as a separate carrier scheme. Use of a common channel with distance protection is only possible if the mode is compatible (e.g., POTT with directional comparison). The 67N may be blocked when function 21/21N picks up. Alternatively, it can be used as time-delayed backup protection.

Fig. 6.2-79: Transmission line with reactor
Transmission line or cable
(with wide-band communication)

General notes:
- Digital PCM-coded communication (with \( n \times 64 \text{ kbit/s} \) channels) between line ends is becoming more and more frequently available, either directly by optical or microwave point-to-point links, or via a general-purpose digital communication network.

In both cases, the relay-type current differential protection 7SD52/61 can be applied. It provides absolute phase and zone selectivity by phase-segregated measurement, and is not affected by power swing or parallel line zero-sequence coupling effects. It is, furthermore, a current-only protection that does not need a VT connection. For this reason, the adverse effects of CVT transients are not applicable.

This makes it particularly suitable for double and multi-circuit lines where complex fault situations can occur. The 7SD5/61 can be applied to lines up to about 120 km in direct relay-to-relay connections via dedicated optical fiber cores (see also application 10), and also to much longer distances of up to about 120 km by using separate PCM devices for optical fiber or microwave transmission. The 7SD5/61 then uses only a small part (64-512 64 kbit/s) of the total transmission capacity (on the order of Mbits/s).

- The 7SDS2/61 protection relays can be combined with the distance relay 7SA52 or 7SA6 to form a redundant protection system with dissimilar measuring principles complementing each other (fig. 6.2-80). This provides the highest degree of availability. Also, separate signal transmission ways should be used for main 1 and main 2 line protection, e.g., optical fiber or microwave, and power line carrier (PLC).

The current comparison protection has a typical operating time of 15 ms for faults on 100 % line length, including signaling time.

General notes for fig. 6.2-81:
- SIPROTEC 7SDS offers fully redundant differential and distance relays accommodated in one single bay control unit, and provides both high-speed operation of relays and excellent fault coverage, even under complicated conditions. Precise distance-to-fault location avoids time-consuming line patrolling, and reduces the downtime of the line to a minimum.

- The high-speed distance relay operates fully independently from the differential relay. Backup zones provide remote backup for upstream and downstream lines and other power system components.

![Fig. 6.2-80: Redundant transmission line protection](image1)

![Fig. 6.2-81: Transmission line protection with redundant algorithm in one device](image2)
Transmission line, one-breaker-and-a-half terminal

Notes:
1) When the line is switched off and the line line disconnector (isolator) is open, high through-fault currents in the diameter may cause maloperation of the distance relay due to unequal CT errors (saturation).

Normal practice is therefore to block the distance protection (21/21N) and the directional earth-fault protection (67N) under this condition via an auxiliary contact of the line line disconnector (isolator). A standby overcurrent function (50/51N, 51/51N) is released instead to protect the remaining stub between the breakers ("stub" protection).

2) Overvoltage protection only with 7SA6/52.

General notes:
- The protection functions of one diameter of a breaker-and-a-half arrangement are shown.
- The currents of two CTs have each to be summed up to get the relevant line currents as input for main 1 and 2 line protection. The location of the CTs on both sides of the circuit-breakers is typical for substations with dead-tank circuit-breakers. Livetank circuit-breakers may have CTs only on one side to reduce cost. A fault between circuit-breakers and CT (end fault) may then still be fed from one side even when the circuit-breaker has opened. Consequently, final fault clearing by cascaded tripping has to be accepted in this case.

The 7VK61 relay provides the necessary end fault protection function and trips the circuit-breakers of the remaining infeeding circuits.

Fig. 6.2-82: Transmission line, one-breaker-and-a-half terminal, using 3 breaker management relays 7VK61
General notes for fig. 6.2-82 and fig. 6.2-83:

- For the selection of the main 1 and main 2 line protection schemes, the comments of application examples fig. 6.2-77 and fig. 6.2-78 apply.
- Auto-reclosure (79) and synchrocheck function (25) are each assigned directly to the circuit-breakers and controlled by main 1 and 2 line protection in parallel. In the event of a line fault, both adjacent circuit-breakers have to be tripped by the line protection. The sequence of auto-reclosure of both circuit-breakers or, alternatively, the auto-reclosure of only one circuit-breaker and the manual closure of the other circuit-breaker, may be made selectable by a control switch.
- A coordinated scheme of control circuits is necessary to ensure selective tripping interlocking and reclosing of the two circuit-breakers of one line (or transformer feeder).
- The voltages for synchrocheck have to be selected according to the circuit-breaker and disconnecter (isolator) position by a voltage replica circuit.

General notes for fig. 6.2-83:
- In this optimized application, the 7VK61 is only used for the center breaker. In the line feeders, functions 25, 79 and BF are also performed by transmission line protection 7SA522 or 7SA6.

Fig. 6.2-83: Transmission line, breaker-and-a-half terminal, using 1 breaker management relay 7VK61
2. Transformers

Small transformer infeed

**General notes:**
- Earth faults on the secondary side are detected by current relay 51N. However, it has to be time-graded against downstream feeder protection relays.
- The restricted earth-fault relay 87N can optionally be applied to achieve fast clearance of earth faults in the transformer secondary winding.
- Relay 7VH60 is of the high-impedance type and requires class × CTs with equal transformation ratios.
- Primary circuit-breaker and relay may be replaced by fuses.

Large or important transformer infeed

**General note:**
- Relay 7UT612 provides numerical ratio and vector group adaptation. Matching transformers as used with traditional relays are therefore no longer applicable.

**Notes:**
1) If an independent high-impedance-type earth-fault function is required, the 7VH60 earth-fault relay can be used instead of the 87N inside the 7UT612. However, class × CT cores would also be necessary in this case (see small transformer protection).
2) 51 and 51N may be provided in a separate 7SJ60 if required.
Dual infeed with single transformer

General notes:
- Line CTs are to be connected to separate stabilizing inputs of the differential relay 87T in order to ensure stability in the event of line through-fault currents.
- Relay 7UT613 provides numerical ratio and vector group adaptation. Matching transformers, as used with traditional relays, are therefore no longer applicable.

Parallel incoming transformer feeders

Note:
The directional functions 67 and 67N do not apply for cases where the transformers are equipped with the transformer differential relays 87T.

Parallel incoming transformer feeders with bus tie

General notes:
- Overcurrent relay 51, 51N each connected as a partial differential scheme. This provides simple and fast busbar protection and saves one time-grading step.
Three-winding transformer

Notes:
1) The zero-sequence current must be blocked before entering the differential relay with a delta winding in the CT connection on the transformer side with earthed starpoint. This is to avoid false operation during external earth faults (numerical relays provide this function by calculation). About 30% sensitivity, however, is then lost in the event of internal faults. Optionally, the zero-sequence current can be regained by introducing the winding neutral current in the differential relay (87T). Relay type 7UT613 provides two current inputs for this purpose. By using this feature, the earth-fault sensitivity can be upgraded again to its original value. Restricted earth-fault protection (87T) is optional. It provides backup protection for earth faults and increased earth-fault sensitivity (about 10% IN, compared to about 20 to 30% IN of the transformer differential relay). Separate class × CT-cores with equal transformation ratios are also required for this protection.
2) High impedance and overcurrent in one 7SJ61.

General notes:
• In this example, the transformer feeds two different distribution systems with cogeneration. Restraining differential relay inputs are therefore provided at each transformer side.
• If both distribution systems only consume load and no through-feed is possible from one MV system to the other, parallel connection of the CTs of the two MV transformer windings is admissible, which allows the use of a two-winding differential relay (7UT612).

Autotransformer

Notes:
1) 87N high-impedance protection requires special class × current transformer cores with equal transformation ratios.
2) The 7SJ60 relay can alternatively be connected in series with the 7UT613 relay to save this CT core.

General note:
• Two different protection schemes are provided: 87T is chosen as the low-impedance three-winding version (7UT613). 87N is a 1-phase high-impedance relay (7VH60) connected as restricted earth-fault protection. (In this example, it is assumed that the phase ends of the transformer winding are not accessible on the neutral side, that is, there exists a CT only in the neutral earthing connection.)
Large autotransformer bank

General notes:
- The transformer bank is connected in a breaker-and-a-half arrangement.
- Duplicated differential protection is proposed:
  - Main 1: Low-impedance differential protection 87TL (7UT613) connected to the transformer bushing CTs.
  - Main 2: High-impedance differential overall protection 87TL (7VH60). Separate class × cores and equal CT ratios are required for this type of protection.
- Backup protection is provided by distance protection relay (7SA52 and 7SA6), each “looking” with an instantaneous first zone about 80% into the transformer and with a time-delayed zone beyond the transformer.
- The tertiary winding is assumed to feed a small station supply system with isolated neutral.

3. Motors

Small and medium-sized motors < about 1 MW
a) With effective or low-resistance earthed infeed ($I_E \geq I_N \text{Motor}$)

General note:
- Applicable to low-voltage motors and high-voltage motors with low-resistance earthed infeed ($I_E \geq I_N \text{Motor}$)

b) With high-resistance earthed infeed ($I_E \leq I_N \text{Motor}$)

Notes:
1) Core-balance CT.
2) Sensitive directional earth-fault protection (67N) only applicable with infeed from isolated or Petersen coil earthed system (for dimensioning of the sensitive directional earth-fault protection, see also application circuit no. 30)
3) The 7SJ602 relay can be applied for isolated and compensated systems.
Large HV motors > about 1 MW

Notes:
1) Core-balance CT.
2) Sensitive directional earth-fault protection (67N) only applicable with infeed from isolated or Petersen coil earthed system.
3) This function is only needed for motors where the startup time is longer than the safe stall time $t_E$. According to IEC 60079-7, the $t_E$ time is the time needed to heat up AC windings, when carrying the starting current $I_A$, from the temperature reached in rated service and at maximum ambient air temperature to the limiting temperature. A separate speed switch is used to supervise actual starting of the motor. The motor circuit-breaker is tripped if the motor does not reach speed in the preset time. The speed switch is part of the motor supply itself.
4) Pt100, Ni100, Ni120
5) 49T only available with external temperature monitoring device (7HV5662)

Cold load pickup

By means of a binary input that can be wired from a manual close contact, it is possible to switch the overcurrent pickup settings to less sensitive settings for a programmable amount of time. After the set time has expired, the pickup settings automatically return to their original setting. This can compensate for initial inrush when energizing a circuit without compromising the sensitivity of the overcurrent elements during steady-state conditions.
4. Generators

Generators < 500 kW (fig. 6.2-96 and fig. 6.2-97)

Note:
If a core-balance CT is provided for sensitive earth-fault protection, relay 7SJ602 with separate earth-current input can be used.

Generators, typically 1–3 MW
(fig. 6.2-98)

Note:
Two VTs in V connection are also sufficient.

Generators > 1–3 MW
(fig. 6.2-99)

Notes:
1) Functions 81 and 59 are required only where prime mover can assume excess speed and the voltage regulator may permit rise of output voltage above upper limit.
2) Differential relaying options:
   – Low-impedance differential protection 87.
   – Restricted earth-fault protection with low-resistance earthed neutral (fig. 6.2-98).
Generators > 5 – 10 MW feeding into a system with isolated neutral
(fig. 6.2-100)

**General notes:**
- The setting range of the directional earth-fault protection (67N) in the 7UM6 relay is 2 – 1,000 mA. Depending on the current transformer accuracy, a certain minimum setting is required to avoid false operation on load or transient currents.
- In practice, efforts are generally made to protect about 90 % of the machine winding, measured from the machine terminals. The full earth current for a terminal fault must then be ten times the setting value, which corresponds to the fault current of a fault at 10 % distance from the machine neutral.

For the most sensitive setting of 2 mA, we therefore need 20 mA secondary earth current, corresponding to \((60/1) \times 20 = 1.2\) A primary.

If sufficient capacitive earth current is not available, an earthing transformer with resistive zero-sequence load can be installed as earth-current source at the station busbar. The smallest standard earthing transformer TGAG 3541 has a 20 s short-time rating of input connected to: \(S_E = 27\) kVA

In a 5 kV system, it would deliver:

\[
I_{G_{20s}} = \frac{\sqrt{3} \cdot S_E}{U_N} = \frac{\sqrt{3} \cdot 27,000\ \text{VA}}{5,000\ \text{V}} = 9.4\ \text{A}
\]

corresponding to a relay input current of \(9.4\ \text{A} \times 1/60 = 156\) mA. This would provide a 90 % protection range with a setting of about 15 mA, allowing the use of 4 parallel connected core-balance CTs. The resistance at the 500 V open-delta winding of the earthing transformer would then have to be designed for

\[
R_B = \frac{U_N^2}{S_E} = 500 \cdot \frac{U_N^2}{27,000\ \text{VA}} = 9.26\ \Omega \ (27\ kW, 20\ s)
\]

For a 5 MVA machine and 600/5 A CTs with special calibration for minimum residual false current, we would get a secondary current of \(I_{G_{SEC}} = 9.4\ \text{A} / (600/5) = 78\) mA.

With a relay setting of 12 mA, the protection range would in this case be \(100 \left(1 - \frac{12}{78}\right) = 85\%\).
Notes (fig. 6.2-100):
1) The standard core-balance CT 7XR96 has a transformation ratio of 60/1 A.
2) Instead of an open-delta winding at the terminal VT, a 1-phase VT at the machine neutral could be used as zero-sequence polarizing voltage.
3) The earthing transformer is designed for a short-time rating of 20 s. To prevent overloading, the load resistor is automatically switched off by a time-delayed zero-sequence voltage relay (59N + 62) and a contactor (52).
4) During the startup time of the generator with the open circuit-breaker, the earthing source is not available. To ensure earth-fault protection during this time interval, an auxiliary contact of the circuit-breaker can be used to change over the directional earth-fault relay function (67N) to a zero-sequence voltage detection function via binary input.

Generators > 50 – 100 MW in generator transformer unit connection (fig. 6.2-101)

Notes:
1) 100 % stator earth-fault protection based on 20 Hz voltage injection
2) Sensitive rotor earth-fault protection based on 1–3 Hz voltage injection
3) Non-electrical signals can be incoupled in the protection via binary inputs (BI)
4) Only used functions shown; further integrated functions available in each relay type.

Fig. 6.2-101: Protections for generators > 50 MW

<table>
<thead>
<tr>
<th>Relay type</th>
<th>Functions</th>
<th>Number of relays required</th>
</tr>
</thead>
<tbody>
<tr>
<td>7UM62</td>
<td>21, 24, 32, 40, 46, 49</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>51GN, 59GN</td>
<td></td>
</tr>
<tr>
<td>7UM61 or 7UM62</td>
<td>51, 51N optionally</td>
<td>1</td>
</tr>
<tr>
<td>7UT612</td>
<td>57, 51N</td>
<td>optionally</td>
</tr>
<tr>
<td>7UT613</td>
<td>57</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 6.2-102: Assignment for functions to relay type
Synchronization of a generator

Fig. 6.2-103 shows a typical connection for synchronizing a generator. Paralleling device 7VE6 acquires the line and generator voltage, and calculates the differential voltage, frequency and phase angle. If these values are within a permitted range, a CLOSE command is issued after a specified circuit-breaker make time. If these variables are out of range, the paralleling device automatically sends a command to the voltage and speed controller. For example, if the frequency is outside the range, an actuation command is sent to the speed controller. If the voltage is outside the range, the voltage controller is activated.

Fig. 6.2-103: Synchronization of a generator

5. Busbars

Busbar protection by overcurrent relays with reverse interlocking

General note:
- Applicable to distribution busbars without substantial (< 0.25 × Iₙ) backfeed from the outgoing feeders.

Fig. 6.2-104: Busbar protection by O/C relays with reverse interlocking
High-impedance busbar protection

General notes:
- Normally used with single busbar, and one-breaker-and-a-half schemes.
- Requires separate class X current transformer cores. All CTs must have the same transformation ratio.

Note:
A varistor is normally applied across the relay input terminals to limit the voltage to a value safely below the insulation voltage of the secondary circuits.

Low-impedance busbar protection 7SS60

General notes:
- Normally used with single busbar, one-breaker-and-a-half, and double busbar schemes, different transformation ratios can be adapted by matching transformers.
- Unlimited number of feeders.
- Feeder protection can be connected to the same CT core.

Distributed busbar protection 7SS52

General notes:
- Suitable for all types of busbar schemes.
- Preferably used for multiple busbar schemes where a disconnector (isolator) replica is necessary.
- The numerical busbar protection 7SS52 provides additional breaker failure protection.
- Different CT transformation ratios can be adapted numerically.
- The protection system and the disconnector (isolator) replica are continuously self-monitored by the 7SS52.
- Feeder protection can be connected to the same CT core.
6. Power systems

Load shedding
In unstable power systems (e.g., isolated systems, emergency power supply in hospitals), it may be necessary to isolate selected loads from the power system to prevent overload of the overall system. The overcurrent-time protection functions are effective only in the case of a short-circuit. Overloading of the generator can be measured as a frequency or voltage drop.

(Protection functions 27 and 81 available in 7RW600, 7SJ6 and 7SJ8.)

Load shedding with rate-of-frequency-change protection
The rate-of-frequency-change protection calculates, from the measured frequency, the gradient or frequency change $\frac{df}{dt}$. It is thus possible to detect and record any major active power loss in the power system, to disconnect certain consumers accordingly and to restore the system to stability. Unlike frequency protection, rate-of-frequency-change protection reacts before the frequency threshold is undershot. To ensure effective protection settings, it is recommended to consider requirements throughout the power system as a whole. The rate-of-frequency-change protection function can also be used for the purposes of system decoupling.

Rate-of-frequency-change protection can also be enabled by an underfrequency state.

Trip circuit supervision (ANSI 74TC)
One or two binary inputs can be used for the trip circuit supervision.

---

Fig. 6.2-108: Load shedding

Fig. 6.2-109: Load shedding with rate-of-frequency-change protection

Fig. 6.2-110: Trip circuit supervision (ANSI 74TC)
Disconnecting facility with flexible protection function

General note:
The SIPROTEC protection relay 7SJ64 disconnects the switchgear from the utility power system if the generator feeds energy back into the power system (protection function $P_{\text{reverse}}$). This functionality is achieved by using flexible protection. Disconnection also takes place in the event of frequency or voltage fluctuations in the utility power system (protection functions $f<, f>, U<, U>, I_{\text{dir}}>l 81, 27, 59, 67, 67N$).

Notes:
1) The transformer is protected by differential protection and inverse or definite-time overcurrent protection functions for the phase currents. In the event of a fault, the circuit-breaker CB1 on the utility side is tripped by a remote link. Circuit-breaker CB2 is also tripped.
2) Overcurrent-time protection functions protect feeders 1 and 2 against short-circuits and overload caused by the connected loads. Both the phase currents and the zero currents of the feeders can be protected by inverse and definite-time overcurrent stages. The circuit-breakers CB4 and CB5 are tripped in the event of a fault.

Fig. 6.2-111: Example of a switchgear with autonomous generator supply
6.2 Protection Systems

6.2.5 Protection Coordination

Typical applications and functions
Relay operating characteristics and their settings must be carefully coordinated in order to achieve selectivity. The aim is basically to switch off only the faulty component and to leave the rest of the power system in service in order to minimize supply interruptions and to ensure stability.

Sensitivity
Protection should be as sensitive as possible in order to detect faults at the lowest possible current level. At the same time, however, it should remain stable under all permissible load, overload and through-fault conditions. For more information: http://www.siemens.com/systemplanning. The Siemens engineering programs SINCAL and SIGRADE are especially designed for selective protection grading of protection relay systems. They provide short-circuit calculations, international standard characteristics of relays, fuses and circuit-breakers for easy protection grading with respect to motor starting, inrush phenomena, and equipment damage curves.

Phase-fault overcurrent relays
The pickup values of phase overcurrent relays are normally set 30% above the maximum load current, provided that sufficient short-circuit current is available. This practice is recommended particularly for mechanical relays with reset ratios of 0.8 to 0.85. Numerical relays have high reset ratios near 0.95 and allow, therefore, about a 10% lower setting. Feeders with high transformer and/or motor load require special consideration.

Transformer feeders
The energizing of transformers causes inrush currents that may last for seconds, depending on their size (fig. 6.2-112). Selection of the pickup current and assigned time delay have to be coordinated so that the inrush current decreases below the relay overcurrent reset value before the set operating time has elapsed. The inrush current typically contains only about a 50% fundamental frequency component. Numerical relays that filter out harmonics and the DC component of the inrush current can therefore be set to be more sensitive. The inrush current peak values of fig. 6.2-112 will be reduced to more than one half in this case. Some digital relay types have an inrush detection function that may block the trip of the overcurrent protection resulting from inrush currents.

Ground-fault protection relays
Earth-current relays enable a much more sensitive setting, because load currents do not have to be considered (except 4-wire circuits with 1-phase load). In solidly and low-resistance earthed systems, a setting of 10 to 20% rated load current can generally be applied. High-resistance earthing requires a much more sensitive setting, on the order of some amperes primary. The earth-fault current of motors and generators, for example, should be limited to values below 10 A in order to avoid iron burning. In this case, residual-current relays in the start point connection of CTs cannot be used; in particular, with rated CT primary currents higher than 200 A. The pickup value of the zero-sequence relay would be on the order of the error currents of the CTs. A special core-balance CT is therefore used as the earth-current sensor. The core-balance CT 7XR96 is designed for a ratio of 60/1 A. The detection of 6 A primary would then require a relay pickup setting of 0.1 A secondary. An even more sensitive setting is applied in isolated or Petersen coil earthed systems where very low earth currents occur with 1-phase-to-earth faults. Settings of 20 mA and lower may then be required depending on the minimum earth-fault current. Sensitive directional earth-fault relays (integrated into the relays 7SJ62, 63, 64, 7SJ80, 7SK80, 7SA6) allow settings as low as 5 mA.
Motor feeders
The energization of motors causes a starting current of initially 5 to 6 times the rated current (locked rotor current).

A typical time-current curve for an induction motor is shown in fig. 6.2-113.

In the first 100 ms, a fast-decaying asymmetrical inrush current also appears. With conventional relays, it was common practice to set the instantaneous overcurrent stage of the short-circuit protection 20 to 30 % above the locked rotor current with a short-time delay of 50 to 100 ms to override the asymmetrical inrush period.

Numerical relays are able to filter out the asymmetrical current component very rapidly so that the setting of an additional time delay is no longer applicable.

The overload protection characteristic should follow the thermal motor characteristic as closely as possible. The adaptation is made by setting the pickup value and the thermal time constant, using the data supplied by the motor manufacturer. Furthermore, the locked-rotor protection timer has to be set according to the characteristic motor value.

Time grading of overcurrent relays (51)
The selectivity of overcurrent protection is based on time grading of the relay operating characteristics. The relay closer to the infeed (upstream relay) is time-delayed against the relay further away from the infeed (downstream relay). The calculation of necessary grading times is shown in fig. 6.2-113 by an example for definite-time overcurrent relays.

The overshoot times take into account the fact that the measuring relay continues to operate due to its inertia, even if when the fault current is interrupted. This may be high for mechanical relays (about 0.1 s) and negligible for numerical relays (20 ms).

Inverse-time relays (51)
For the time grading of inverse-time relays, in principle the same rules apply as for the definite-time relays. The time grading is first calculated for the maximum fault level and then checked for lower current levels (fig. 6.2-114).

If the same characteristic is used for all relays, or if when the upstream relay has a steeper characteristic (e.g., very much over normal inverse), then selectivity is automatically fulfilled at lower currents.

Differential relay (87)
Transformer differential relays are normally set to pickup values between 20 and 30 % of the rated current. The higher value has to be chosen when the transformer is fitted with a tap changer.

Restricted earth-fault relays and high-resistance motor/generator differential relays are, as a rule, set to about 10 % of the rated current.

Instantaneous overcurrent protection (50)
This is typically applied on the final supply load or on any protection relay with sufficient circuit impedance between itself and the next downstream protection relay. The setting at transformers, for example, must be chosen about 20 to 30 % higher than the maximum through-fault current. The relay must remain stable during energization of the transformer.
**Calculation example**

The feeder configuration of fig. 6.2-116 and the associated load and short-circuit currents are given. Numerical overcurrent relays 7SJ60 with normal inverse-time characteristics are applied.

The relay operating times, depending on the current, can be derived from the diagram or calculated with the formula given in fig. 6.2-117.

The \( I_p / I_N \) settings shown in fig. 6.2-116 have been chosen to get pickup values safely above maximum load current.

This current setting should be lowest for the relay farthest downstream. The relays further upstream should each have equal or higher current settings.

The time multiplier settings can now be calculated as follows:

**Station C:**
- For coordination with the fuses, we consider the fault in location F1.
- The short-circuit current \( I_{sec. \, max} \) related to 13.8 kV is 523 A. This results in 7.47 for \( I / I_p \) at the overcurrent relay in location C.
- This current setting should be lowest for the relay farthest downstream. The relays further upstream should each have equal or higher current settings.

This setting was selected for the overcurrent relay to get a safe grading time over the fuse on the transformer low-voltage side. Safety margin for the setting values for the relay at station C are therefore:
- Pickup current: \( I_p / I_N = 0.7 \)
- Time multiplier: \( T_p = 0.05 \)

**Station B:**

The relay in B has a primary protection function for line B-C and a backup function for the relay in C. The maximum through-fault current of 1.395 A becomes effective for a fault in location F2.

For the relay in C, an operating time of 0.11 s (\( I / I_p = 19.93 \)) is obtained.

It is assumed that no special requirements for short operating times exist and therefore an average time grading interval of 0.3 s can be chosen. The operating time of the relay in B can then be calculated.

- \( t_B = 0.11 + 0.3 = 0.41 \) s
- Value of \( I_p / I_N = 1.395 \) A
- With the operating time 0.41 s and \( I_p / I_N = 6.34 \), \( T_p = 0.11 \) can be derived from fig. 6.2-117.
The setting values for the relay at station B are:

- Pickup current: $I_p / I_N = 1.1$
- Time multiplier $T_p = 0.11$

Given these settings, the operating time of the relay in B for a close fault in F3 can also be checked: The short-circuit current increases to 2,690 A in this case (fig. 6.2-116). The corresponding $I / I_p$ value is 12.23.

- With this value and the set value of $T_p = 0.11$, an operating time of 0.3 s is obtained again (fig. 6.2-117).

**Station A:**
- Adding the time grading interval of 0.3 s, the desired operating time is $t_A = 0.3 + 0.3 = 0.6$ s.

Following the same procedure as for the relay in station B, the following values are obtained for the relay in station A:

- Pickup current: $I_p / I_N = 1.0$
- Time multiplier $T_p = 0.17$
- For the close-in fault at location F4, an operating time of 0.48 s is obtained.

The normal way

To prove the selectivity over the whole range of possible short-circuit currents, it is normal practice to draw the set of operating curves in a common diagram with double log scales. These diagrams can be calculated manually and drawn point-by-point or constructed by using templates.

Today, computer programs are also available for this purpose. Fig. 6.2-118 shows the relay coordination diagram for the selected example, as calculated by the Siemens program SIGRADE (Siemens Grading Program).

Note:
To simplify calculations, only inverse-time characteristics have been used for this example. About 0.1 s shorter operating times could have been reached for high-current faults by additionally applying the instantaneous zones $I>>$ of the 7SJ60 relays.

**Coordination of overcurrent relays with fuses and low-voltage trip devices**

The procedure is similar to the above-described grading of overcurrent relays. A time interval of between 0.1 and 0.2 s is usually sufficient for a safe time coordination.

Strong and extremely inverse characteristics are often more suitable than normal inverse characteristics in this case. Fig. 6.2-119 shows typical examples.

Simple distribution substations use a power fuse on the secondary side of the supply transformers (fig. 6.2-119a).

In this case, the operating characteristic of the overcurrent relay at the infeed has to be coordinated with the fuse curve.

---

**Fig. 6.2-117: Normal inverse-time characteristic of the 7SJ60 relay**
6.2 Protection Systems

Coordination of distance relays

The distance relay setting must take into account the limited relay accuracy, including transient overreach (5 %, according to IEC 60255-6), the CT error (1 % for class 5P and 3 % for class 10P) and a security margin of about 5 %. Furthermore, the line parameters are often only calculated, not measured. This is a further source of errors. A setting of 80 to 85 % is therefore common practice; 80 % is used for mechanical relays, while 85 % can be used for the more accurate numerical relays.

Where measured line or cable impedances are available, the protected zone setting may be extended to 90 %. The second and third zones have to keep a safety margin of about 15 to 20 % to the corresponding zones of the following lines. The shortest following line always has to be considered (fig. 6.2-120).

As a general rule, the second zone should at least reach 20 % over the next station to ensure backup for busbar faults, and the third zone should cover the longest following line as backup for the line protection.
Grading of zone times
The first zone normally operates undelayed. For the grading of the time delays of the second and third zones, the same rules as for overcurrent relays apply (fig. 6.2-115, page 308). For the quadrilateral characteristics (relays 7SA6 and 7SA5), only the reactance values (X values) have to be considered for the protected zone setting. The setting of the R values should cover the line resistance and possible arc or fault resistances. The arc resistance can be roughly estimated as follows:

\[
R_{\text{Arc}} = \frac{2.5 \cdot I_{\text{arc}}}{I_{\text{SCC Min}}} \quad [\Omega]
\]

\[
I_{\text{arc}} = \text{Arc length in mm}
\]

\[
I_{\text{SCC Min}} = \text{Minimum short-circuit current in kA}
\]

- Typical settings of the ratio R/X are:
  - Short lines and cables (≤ 10 km): R/X = 2 to 6
  - Medium line lengths < 25 km: R/X = 2
  - Longer lines 25 to 50 km: R/X = 1

Shortest feeder protectable by distance relays
The shortest feeder that can be protected by underreaching distance zones without the need for signaling links depends on the shortest settable relay reactance.

\[
X_{\text{Prim Min}} = X_{\text{Relay Min}} \frac{V_{\text{ratio}}}{C_{\text{ratio}}}
\]

\[
I_{\text{min}} = \frac{X_{\text{Prim Min}}}{X_{\text{Line}}}
\]

The shortest setting of the numerical Siemens relays is 0.05 Ω for 1 A relays, corresponding to 0.01 Ω for 5 A relays. This allows distance protection of distribution cables down to the range of some 500 meters.

Breaker failure protection setting
Most numerical relays in this guide provide breaker failure (BF) protection as an integral function. The initiation of the BF protection by the internal protection functions then takes place via software logic. However, the BF protection function may also be initiated externally via binary inputs by an alternate protection. In this case, the operating time of intermediate relays (BFI time) may have to be considered. Finally, the tripping of the infeeding breakers requires auxiliary relays, which add a small time delay (BFI) to the overall fault clearing time. This is particularly the case with one-breaker-and-a-half or ring bus arrangements where a separate breaker failure relay (7SV600 or 7VK61) is used per breaker (fig. 6.2-82, fig. 6.2-83).

The decisive criterion of BF protection time coordination is the reset time of the current detector (50BF), which must not be exceeded under any condition during normal current interruption. The reset times specified in the Siemens numerical relay manuals are valid for the worst-case condition: interruption of a fully offset short-circuit current and low current pickup setting (0.1 to 0.2 times rated CT current).
Protection, Substation Automation, Power Quality and Measurement

6.2 Protection Systems

High-impedance differential protection – verification of design

The following design data must be established:

CT data
The prerequisite for a high-impedance scheme is that all CTs used for that scheme must have the same ratio. They should also be of low leakage flux design according to Class PX of IEC 60044-1 (former Class X of BS 3938) or TPS of IEC 60044-6, when used for high-impedance busbar protection schemes. When used for restricted earth-fault differential protection of, e.g., a transformer winding especially in solidly earthed systems, CTs of Class 5P according to IEC 60044-1 can be used as well. In each case the excitation characteristic and the secondary winding resistance are to be provided by the manufacturer. The knee-point voltage of the CT must be at least twice the relay pickup voltage to ensure operation on internal faults.

Relay
The relay can be either:
A) a dedicated design high-impedance relay, e.g., designed as a sensitive current relay 7VH60 or 7SG12 (DAD-N) with external series resistor \( R_{stab} \). If the series resistor is integrated into the relay, the setting values may be directly applied in volts, as with the relay 7VH60 (6 to 60V or 24 to 240 V); or
B) a numerical overcurrent protection relay with sensitive current input, like 7SJ6 or 7SR1 (Argus-C). To the input of the relay a series stabilizing resistor \( R_{stab} \) will be then connected as a rule in order to obtain enough stabilization for the high-impedance scheme. Typically, a non-linear resistor \( V \) (varistor) will be also connected to protect the relay, as well as wiring against overvoltages.

Sensitivity of the scheme
For the relay to operate in the event of an internal fault, the primary current must reach a minimum value to supply the relay pickup current \( I_{set} \), the varistor leakage current \( I_{var} \) and the magnetizing currents of all parallel-connected CTs at the set pickup voltage. A low relay voltage setting and CTs with low magnetizing current therefore increase the protection sensitivity.

Stability during external faults
This check is made by assuming an external fault with maximum through-fault current and full saturation of the CT in the faulty feeder. The saturated CT is then substituted with its secondary winding resistance \( R_{CT} \), and the appearing relay voltage \( V_R \) corresponds to the voltage drop of the infeeding currents (through-fault current) across \( R_{CT} \) and \( R_{lead} \). The current (voltage) at the relay must, under this condition, stay reliably below the relay pickup value.

In practice, the wiring resistances \( R_{lead} \) may not be equal. In this case, the worst condition with the highest relay voltage (corresponding to the highest through-fault current) must be sought by considering all possible external feeder faults.

Setting
The setting is always a trade-off between sensitivity and stability. A higher voltage setting leads not only to enhanced...
through-fault stability but also to higher CT magnetizing and varistor leakage currents, resulting consequently in a higher primary pickup current.

A higher voltage setting also requires a higher knee-point voltage of the CTs and therefore greater size of the CTs. A sensitivity of 10 to 20 % of \( I_f \) (rated current) is typical for restricted earth-fault protection. With busbar protection, a pickup value \( \geq I_f \) is normally applied. In systems with neutral earthing via impedance, the fault setting shall be revised against the minimum earth-fault conditions.

**Non-linear resistor (varistor)**

Voltage limitation by a varistor is needed if peak voltages near or above the insulation voltage (2 kV ... 3 kV) are expected. A limited \( U_{rms} = 1,500 \) V is then recommended. This can be checked for the maximum internal fault current by applying the formula shown for \( U_{max,relay} \). A restricted earth-fault protection may sometimes not require a varistor, but a busbar protection in general does. However, it is considered a good practice to equip with a varistor all high impedance protection installations. The electrical characteristic of a varistor can be expressed as \( U = C \beta \) where \( C \) and \( \beta \) are the varistor constants.

Moreover, \( R_{stab} \) must have a short-time rating large enough to withstand the fault current levels before the fault is cleared. The time duration of 0.5 seconds can be typically considered \( (P_{stab,0.5s}) \) to take into account longer fault clearance times of back-up protection. The r.m.s. voltage developed across the stabilizing resistor is decisive for the thermal stress of the stabilizing resistor. It is calculated according to formula:

\[
U_{rms,relay} = 1.3 \cdot \left[ U_{set, relay} \times R_{stab} \times I_{set, I_{set, max,int}} \right] = 1.3 \cdot \sqrt[4]{400^3 \cdot 1,000 \cdot 50} = 1738.7 \text{ V}
\]

The resulting short-time rating \( P_{stab,0.5s} \) equals to:

\[
P_{stab,0.5s} = \frac{U_{rms,relay}^2}{R_{stab}} = \frac{1,739^2}{1,000} = 3023 \text{ W}
\]

**Check whether the voltage limitation by a varistor is required**

The relay should normally be applied with an external varistor which should be connected across the relay and stabilizing resistor input terminals. The varistor limits the voltage across the terminals under maximum internal fault conditions. The theoretical voltage which may occur at the terminals can be determined according to following equation:

\[
U_{k, max, int} = I_{k,max,int} \frac{I_{p, des}}{I_{p, des}} (R_{CT} + R_{lead}) = 40,000 \frac{1}{800} (0.05 + 1,000) = 50,003 \text{ V}
\]

with \( I_{k,max,int} \) taken as the rated short-circuit current of the switchgear = 40 kA.

The resulting maximum peak voltage across the panel terminals (i.e., tie with relay and \( R_{stab} \) connected in series):

\[
\hat{U}_{max,relay} = 2 \sqrt[4]{2 \cdot U_{rms,relay} (U_{k, max, int})} = 2 \sqrt[4]{2 \cdot 400(50003 - 400)} = 12600 \text{ V}
\]

Since \( U_{max,relay} > 1.5 \) kV, the varistor is necessary.

Exemplarily, a METROSIL of type 600A/S1/Spec.1088 can be used (\( \beta = 0.25, C = 900 \)).

This Metrosil leakage current at voltage setting \( U_{set} =130 \text{ V} \) equals to

\[
I_{rms} = 0.52 \left( \frac{U_{set, rms, \beta}}{C} \right)^{\frac{3}{2}} = 0.91 \text{ mA}
\]

and can be neglected by the calculations, since its influence on the proposed fault setting is negligible.

**CT requirements for protection relays**

**Instrument transformers**

Instrument transformers must comply with the applicable IEC recommendations IEC 60044 and 60186 (PT), ANSI/IEEE C57.13 or other comparable standards.

**Voltage transformers (VT)**

Voltage transformers (VT) in single-pole design for all primary voltages have typical single or dual secondary windings of 100, 110 or 115 V / √3, with output ratings between 10 and 50 VA suitable from most applications with digital metering and protection equipment, and accuracies of 0.1 % to 6 % to suit the particular application. Primary BIL values are selected to match those of the associated switchgear.

**Current transformers**

Current transformers (CT) are usually of the single-ratio type with wound or bar-type primaries of adequate thermal rating. Single, double or triple secondary windings of 1 or 5 A are standard. A 1A rating should, however, be preferred, particularly in HV and EHV substations, to reduce the burden of the connected lines. Output power (rated burden in VA), accuracy and...
saturation characteristics (rated symmetrical short-circuit current limiting factor) of the cores and secondary windings must meet the requirements of the particular application. The CT classification code of IEC is used in the following:

- Measuring cores
  These are normally specified with 0.2 % or 0.5 % accuracy (class 0.2 or class 0.5), and an rated symmetrical short-circuit current limiting factor FS of 5 or 10.
- Protection cores
  The required output power (rated burden) should be higher than the actually connected burden. Typical values are 2.5, 5 or 10 VA. Higher values are normally not necessary when only electronic meters and recorders are connected.

A typical specification could be: 0.5 FS 10, 5 VA.

- Protection cores
  For the size of the protection core depends mainly on the maximum short-circuit current and the total burden (internal CT burden, plus burden of connected lines, plus relay burden). Furthermore, a transient dimensioning factor has to be considered to cover the influence of the DC component in the short-circuit current.

The requirements for protective current transformers for transient performance are specified in IEC 60044-6. In many practical cases, iron-core CTs cannot be designed to avoid saturation under all circumstances because of cost and space reasons, particularly with metal-enclosed switchgear.

**CT dimensioning formulae**

\[
K_{ssc}^* = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R_{b\text{K'ssc}} \left(\text{effective}\right)}
\]

with \( K_{ssc}^* \geq K_{td} \cdot \frac{I_{sec \text{ max}}}{I_{pn}} \) (required)

The Siemens relays are therefore designed to tolerate CT saturation to a large extent. The numerical relays proposed in this guide are particularly stable in this case due to their integrated saturation detection function. The effective symmetrical short-circuit current factor \( K_{ssc}^* \) can be calculated as shown in the table above. The rated transient dimensioning factor \( K_{td} \) depends on the type of relay and the primary DC time constant. For relays with a required saturation-free time from \( \leq 0.4 \) cycle, the primary (DC) time constant TP has little influence.

**CT design according to BS 3938/IEC 60044-1 (2000)**

IEC Class P can be approximately transferred into the IEC Class PX (BS Class X) standard definition by following formula:

\[
U_k = \frac{(R_b + R_{relay}) \cdot I_n \cdot K_{ssc}}{1.3}
\]

Example:

IEC 60044: 600/1, 5P10, 15 VA, \( R_{ct} = 4 \) Ω

IEC PX or BS: \( U_k = \frac{(15 + 4) \cdot 1 \cdot 10}{1.3} = 146 \) V

\( R_{nl} = 4 \) Ω

For CT design according to ANSI/IEEE C 57.13 please refer to page 331

The CT requirements mentioned in table 6.2-3 are simplified in order to allow fast CT calculations on the safe side. More accurate dimensioning can be done by more intensive calculation with Siemens's CTDIM (www.siemens.com/ctdim) program. Results of CTDIM are released by the relay manufacturer.

**Adaption factor for 7UT6, 7UM62 relays in fig 6.2-122 (limited resolution of measurement)**

\[
F_{adap} = \frac{I_{pn} \cdot I_{Nrelay}}{I_{sn} \cdot I_{Nrelay}} \cdot \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO} \cdot S_{nmax}}{I_{sn}} \text{ Request: } b \leq 8
\]

7SD52, 53, 610, when transformer inside protected zone

\[
\frac{I_{n-prf,CT_{max}}}{I_{n-prf,CT_{min}}} \cdot \frac{1}{\text{Transformer ratio}^*} \leq 8
\]

* If transformer in protection zone, else 1

\( I_{n-prf,CT-Transf-Site} \leq I_{n-prf,CT-Transf-Site} \) AND

\( I_{n-prf,CT-Transf-Site} \geq I_{n-prf,CT-Transf-Site} \) with

\( I_{nO} = \text{Rated current of the protected object} \)

\( U_{nO} = \text{Rated voltage of the protected object} \)

\( I_{Nrelay} = \text{Rated current of the relay} \)

\( S_{nmax} = \text{Maximum load of the protected object} \)

(for transformers: winding with max. load)
### 6.2 Protection Systems

**Overcurrent-time and motor protection**


**Fig. 6.2-125:** Example 1 – CT verification for 7UM62, 7UT6, 7SD52 (7SD53, 7SD610)

#### Table 6.2-3: CT requirements

<table>
<thead>
<tr>
<th>Relay type</th>
<th>Transient dimensioning factor $K_{td}$</th>
<th>Min. required sym. short-circuit current factor $K'^{ss}$</th>
<th>Min. required knee-point voltage $U_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overcurrent-time and motor protection 7SJ511, 512, 531 7SJ45, 46, 60 7SJ61, 62, 63, 64 7SJ80, 7SK80</td>
<td>–</td>
<td>$K'^{ss} \geq \frac{I_{High \ set \ point}}{I_{pn}}$ at least: 20</td>
<td>$U_{k} \geq \frac{I_{High \ set \ point}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'<em>{b}) \cdot I</em>{sn}$ at least: $\frac{20}{1.3}$ $(R_{ct} + R'<em>{b}) \cdot I</em>{sn}$</td>
</tr>
<tr>
<td>Line differential protection (pilot wire) 7SD600</td>
<td>–</td>
<td>$K'^{ss} \geq \frac{I_{sec \ max \ (ext. \ fault)}}{I_{pn}}$ and: $\frac{3}{4} (K'^{ss} \cdot I_{pn})<em>{end1} \leq 4 \frac{3}{4} (K'^{ss} \cdot I</em>{pn})_{end2} \leq 3$</td>
<td>$U_{k} \geq \frac{I_{sec \ max \ (ext. \ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'<em>{b}) \cdot I</em>{sn}$ and: $\frac{3}{4} (U_{k}/(R_{ct} + R'<em>{b}) \cdot I</em>{sn}/I_{pn})<em>{end1} \leq 4 \frac{3}{4} (U</em>{k}/(R_{ct} + R'<em>{b}) \cdot I</em>{sn}/I_{pn})_{end2} \leq 3$</td>
</tr>
<tr>
<td>Line differential protection (without distance function) 7SD52x, 53x, 610 (50/60 Hz)</td>
<td>Transformer 1.2</td>
<td>Busbar / Line 1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Transformer / generator differential protection 7UT612, 7UT612 V4.0 7UT613, 633, 635, 7UT612 V4.6 7UTM62</td>
<td>Transformer 4 7UT612 4 4 5 3 5 – 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Busbar / Line / Gen. / Motor 4 5 5 5 4 5 5 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$K'^{ss} \geq \frac{I_{sec \ max \ (ext. \ fault)}}{I_{pn}}$ and (only for 7SS): $I_{sec \ max \ (ext. \ fault)} \leq 100 \frac{I_{pn}}{I_{pn}}$ (measuring range)</td>
<td>$U_{k} \geq \frac{K_{td}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'<em>{b}) \cdot I</em>{sn}$ and (only for 7SS): $I_{sec \ max \ (ext. \ fault)} \leq 100 \frac{I_{pn}}{I_{pn}}$ (measuring range)</td>
<td></td>
</tr>
<tr>
<td>Busbar protection 7SS52, 7SS60</td>
<td>for stabilizing factors k ≥ 0.5 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance protection 7SA522, 7SA6, 7SD5xx (with distance function)</td>
<td>primary DC time constant $T_{p}$ [ms] ≤ 30 ≤ 50 ≤ 100 ≤ 200</td>
<td>$K_{td} (a) \geq \frac{I_{sec \ max \ (close \ – \ in \ fault)}}{I_{pn}}$ and: $I_{sec \ max \ (zone 1 \ – \ end \ fault)} \leq 100 \frac{I_{pn}}{I_{pn}}$ (measuring range)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$K_{td} (a) \geq \frac{I_{sec \ max \ (close \ – \ in \ fault)}}{I_{pn}}$ and: $\frac{3}{4} (U_{k}/(R_{ct} + R'<em>{b}) \cdot I</em>{sn}/I_{pn})<em>{end1} \leq 4 \frac{3}{4} (U</em>{k}/(R_{ct} + R'<em>{b}) \cdot I</em>{sn}/I_{pn})_{end2} \leq 3$</td>
<td>$U_{k} \geq \frac{K_{td} (a) \cdot I_{sec \ max \ (close \ – \ in \ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'<em>{b}) \cdot I</em>{sn}$ and: $\frac{3}{4} (U_{k}/(R_{ct} + R'<em>{b}) \cdot I</em>{sn}/I_{pn})<em>{end1} \leq 4 \frac{3}{4} (U</em>{k}/(R_{ct} + R'<em>{b}) \cdot I</em>{sn}/I_{pn})_{end2} \leq 3$</td>
<td></td>
</tr>
<tr>
<td>Transformer / generator / differential protection 7UT612, 7UT612 V4.0 7UT613, 633, 635, 7UT612 V4.6 7UTM62</td>
<td>Transformer 4 7UT612 4 4 5 3 5 – 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$K_{td} (a) \geq \frac{I_{sec \ max \ (close \ – \ in \ fault)}}{I_{pn}}$ and: $I_{sec \ max \ (zone 1 \ – \ end \ fault)} \leq 100 \frac{I_{pn}}{I_{pn}}$ (measuring range)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformer / generator / differential protection 7UT612, 7UT612 V4.0 7UT613, 633, 635, 7UT612 V4.6 7UTM62</td>
<td>Transformer 4 7UT612 4 4 5 3 5 – 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$K_{td} (a) \geq \frac{I_{sec \ max \ (close \ – \ in \ fault)}}{I_{pn}}$ and: $I_{sec \ max \ (zone 1 \ – \ end \ fault)} \leq 100 \frac{I_{pn}}{I_{pn}}$ (measuring range)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6.2-3: CT requirements**

---

CB arrangement inside power plant is not shown

$x_{d} = \text{Generator direct axis subtransient reactance in p.u.}$

$u_{k} = \text{Transformer impedance voltage HV side – LV side in %}$

$R_{ct} = \text{Assumed with 0.1 \Omega, (power consumption for above relays is below 0.1 VA)}$

1) Current from side 3 is due to $u_{k\ 2\ 3}$ and $x_{d}$ of G2 in most cases negligible

---

Fig. 6.2-125: Example 1 – CT verification for 7UM62, 7UT6, 7SD52 (7SD53, 7SD610)
### Table 6.2-4: Example 1 (continued) – verification of the numerical differential protection

<table>
<thead>
<tr>
<th></th>
<th>-T (G S2), 7UM62</th>
<th>-T (T LV1), 7UT633</th>
<th>-T (T HV), 7UT633</th>
<th>-T (L end 1), 7SD52</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{acc max (ext. fault)}}$</td>
<td>$\frac{c \cdot S_{\text{max}}}{\sqrt{3} \cdot U_{\text{N}} \cdot x_d}$</td>
<td>$\frac{S_{\text{max}}}{\sqrt{3} \cdot U_{\text{N}} \cdot u_k}$</td>
<td>$\frac{S_{\text{max}}}{\sqrt{3} \cdot U_{\text{N}} \cdot u_k}$</td>
<td>$I_{\text{acc max (ext. fault)}} = 17 \text{ kA (given)}$</td>
</tr>
<tr>
<td></td>
<td>$1.1 \cdot 120,000 \text{ kVA \cdot 0.16} = 34,516 \text{ A}$</td>
<td>$120,000 \text{ kVA \cdot 0.14} = 35,860 \text{ A}$</td>
<td>$240,000 \text{ kVA \cdot 0.14} = 7,498 \text{ A}$</td>
<td></td>
</tr>
<tr>
<td>$K_{id}$</td>
<td>5 (from table 6.2-3)</td>
<td>3 (from table 6.2-3)</td>
<td>3 (from table 6.2-3)</td>
<td>1.2 (from table 6.2-3)</td>
</tr>
<tr>
<td>$K_{acc} \geq K_{id} \cdot \frac{I_{\text{acc max (ext. fault)}}}{I_{pn}}$</td>
<td>$5 \cdot \frac{31,378 \text{ A}}{6,000 \text{ A}} = 28.8$</td>
<td>$3 \cdot \frac{35,860 \text{ A}}{6,000 \text{ A}} = 17.9$</td>
<td>$3 \cdot \frac{7,498 \text{ A}}{1,200 \text{ A}} = 18.7$</td>
<td></td>
</tr>
<tr>
<td>$R_{b}$</td>
<td>$\frac{S_{n}}{P_{sn}} = 20 \text{ VA} \cdot 1 \text{ A}^2 = 20 \Omega$</td>
<td>$\frac{S_{n}}{P_{sn}} = 20 \text{ VA} \cdot 1 \text{ A}^2 = 20 \Omega$</td>
<td>$\frac{S_{n}}{P_{sn}} = 50 \text{ VA} \cdot (5 \text{ A})^2 = 2 \Omega$</td>
<td></td>
</tr>
<tr>
<td>$R'<em>{b} = R</em>{\text{lead}} + R_{\text{relay}}$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
</tr>
<tr>
<td>$R_b$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
<td>$2 \cdot \frac{p \cdot l}{\Omega} + 0.1 \Omega$</td>
</tr>
<tr>
<td>$K'<em>{acc} = K</em>{acc} \cdot \frac{R_{ct} + R_{b}'}{R_{ct} + R_{b}}$</td>
<td>$20 \cdot \frac{18 \Omega + 20 \Omega}{18 \Omega + 0.625 \Omega} = 40.8$</td>
<td>$20 \cdot \frac{18 \Omega + 20 \Omega}{18 \Omega + 0.450 \Omega} = 41.2$</td>
<td>$20 \cdot \frac{0.96 \Omega + 2 \Omega}{0.96 \Omega + 0.975 \Omega} = 30.6$</td>
<td>$20 \cdot \frac{0.96 \Omega + 2 \Omega}{0.96 \Omega + 0.975 \Omega} = 30.6$</td>
</tr>
<tr>
<td>$K'<em>{acc} \text{ required} = 28.8, K'</em>{acc} \text{ effective} = 40.8$</td>
<td>$18.7 &lt; 41.2$</td>
<td>$18.7 &lt; 30.6$</td>
<td>$18.7 &lt; 30.6$</td>
<td>$18.7 &lt; 30.6$</td>
</tr>
<tr>
<td>CT dimensioning is ok</td>
<td>CT dimensioning is ok</td>
<td>CT dimensioning is ok</td>
<td>CT dimensioning is ok</td>
<td>CT dimensioning is ok</td>
</tr>
<tr>
<td>$F_{\text{Adap}} = \frac{2 \cdot \sqrt{3} \cdot U_{\text{N}} \cdot I_{\text{NrelayFAdap}}}{S_{\text{max}}} \cdot \frac{I_{\text{sn}}}{I_{pn}}$</td>
<td>$6,000 \text{ A} \cdot \sqrt{3} \cdot 13.8 \text{ kV} \cdot 1 \text{ A} \cdot \frac{1}{120,000 \text{ kVA}} \cdot \frac{1}{1 \text{ A}}$</td>
<td>$6,000 \text{ A} \cdot \sqrt{3} \cdot 13.8 \text{ kV} \cdot 1 \text{ A} \cdot \frac{1}{240,000 \text{ kVA}} \cdot \frac{1}{1 \text{ A}}$</td>
<td>$1,200 \text{ A} \cdot \sqrt{3} \cdot 132 \text{ kV} \cdot 5 \text{ A} \cdot \frac{1}{240,000 \text{ kVA}} \cdot \frac{1}{5 \text{ A}}$</td>
<td>$1,200 \text{ A} \cdot \sqrt{3} \cdot 132 \text{ kV} \cdot 5 \text{ A} \cdot \frac{1}{240,000 \text{ kVA}} \cdot \frac{1}{5 \text{ A}}$</td>
</tr>
<tr>
<td>$= 1.195$</td>
<td>$= 0.598$</td>
<td>$= 1.143$</td>
<td>$= 1.143$</td>
<td>$= 1.143$</td>
</tr>
<tr>
<td>$1/8 \leq 1.195 \leq 8 \rightarrow \text{ ok!}$</td>
<td>$1/8 \leq 0.598 \leq 8 \rightarrow \text{ ok!}$</td>
<td>$1/8 \leq 1.143 \leq 8 \rightarrow \text{ ok!}$</td>
<td>$1/8 \leq 1.143 \leq 8 \rightarrow \text{ ok!}$</td>
<td>$1/8 \leq 1.143 \leq 8 \rightarrow \text{ ok!}$</td>
</tr>
</tbody>
</table>
Example 2: Stability verification of the numerical busbar protection relay 7SS52

Analog static relays in general have burdens below about 1 VA. Mechanical relays, however, have a much higher burden, up to the order of 10 VA. This has to be considered when older relays are connected to the same CT circuit.

In any case, the relevant relay manuals should always be consulted for the actual burden values.

Burden of the connection leads
The resistance of the current loop from the CT to the relay has to be considered:

\[ R_{\text{lead}} = \frac{2 \cdot \rho \cdot l}{A} \]

\( l \) = Single conductor length from the CT to the relay in m

\( \rho \) = Specific resistance: \( 0.0175 \ \Omega \cdot \text{mm}^2 \text{m}^{-1} \) (copper wires) at 20 °C/68 °F

\( A \) = Conductor cross-section in mm²

CT design according to ANSI/IEEE C 57.13

Class C of this standard defines the CT by its secondary terminal voltage at 20 times rated current, for which the ratio error shall not exceed 10 %. Standard classes are C100, C200, C400 and C800 for 5 A rated secondary current.

This terminal voltage can be approximately calculated from the IEC data as follows:

\[ U_{s.t.\max} = 20 \cdot 5 \text{A} \cdot R_b \cdot \frac{K_{sec}}{20} \]

with

\[ R_b = \frac{P_b}{I_{\text{nom}}^2} \]

and \( I_{\text{nom}} = 5 \text{A} \), the result is

\[ U_{s.t.\max} = \frac{P_b \cdot K_{sec}}{5\text{A}} \]

Example: IEC 600/5, SP20, 25 VA,

ANSI C57.13: \( U_{s.t.\max} = \frac{(25 \text{VA} \cdot 20)}{5 \text{A}} = 100 \text{V, acc. to class C100} \)

For further information:
www.siemens.com/protection

Intermediate CTs are normally no longer necessary, because the ratio adaptation for busbar protection 7SS52 and transformer protection is numerically performed in the relay.
## 6.2.6 Relay Selection Guide

<table>
<thead>
<tr>
<th>ANSI</th>
<th>Function</th>
<th>Abbr.</th>
<th>Device series</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>7SA522</td>
</tr>
<tr>
<td>1</td>
<td>Protection functions for 3-pole tripping</td>
<td>3-pole</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Locked rotor protection</td>
<td>1&gt; + V&lt;</td>
<td>-</td>
</tr>
<tr>
<td>21</td>
<td>Distance protection</td>
<td>Z&lt;</td>
<td>-</td>
</tr>
<tr>
<td>FL</td>
<td>Fault locator</td>
<td>FL</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>Overexcitation protection</td>
<td>VI/f</td>
<td>-</td>
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<td>25</td>
<td>Synchrocheck, synchronizing function</td>
<td>Sync</td>
<td>-</td>
</tr>
<tr>
<td>27</td>
<td>Undervoltage protection</td>
<td>V&lt;</td>
<td>-</td>
</tr>
<tr>
<td>27TN/59TN</td>
<td>Stator ground fault 3rd harmonics</td>
<td>V0&lt;, &gt; (3rd harm.)</td>
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<td>32</td>
<td>Directional power supervision</td>
<td>P&gt;, P&lt;</td>
<td>-</td>
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<td>37</td>
<td>Undercurrent, underpower</td>
<td>I&lt;, P&lt;</td>
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<td>Temperature supervision</td>
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<td>Underexcitation protection</td>
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<td>Unbalanced-load protection</td>
<td>I2&gt;</td>
<td>-</td>
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<tr>
<td>47</td>
<td>Phase-sequence-voltage supervision</td>
<td>LA, LB, LC</td>
<td>-</td>
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<tr>
<td>48</td>
<td>Start-time supervision</td>
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- = basic  
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- = not available  
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2) via CFC

*More functions next page*
6.2 Protection Systems

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(Further devices on page 324)

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### Protection, Substation Automation, Power Quality and Measurement

#### 6.2 Protection Systems

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- = basic  
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2) via CFC

Further functions next page
### 6.2 Protection Systems

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### Protection Systems

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#### Line differential protection

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<tr>
<td>Reyrolle</td>
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</table>

### Further functions

- Measured values
- Switching-statistic counters
- Logic editor
- Inrush-current detection
- External trip initiation
- Control
- Fault recording of analog and binary signals

#### Extended fault recording

- Fast-scan recorder
- Slow-scan recorder
- Continuous recorder
- Power quality recorder (class S)
- GOOSE recorder
- Sequence-of-events recorder
- Extended trigger functions
- Monitoring and supervision
- Protection interface, serial
- No. Setting groups

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### Notes

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### 6.2 Protection Systems

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### 6.2 Protection Systems

#### Protection, Substation Automation, Power Quality and Measurement

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- = basic  ● = optional (additional price)  – = not available  1) in preparation  2) via CFC

*More functions next page*
### Protection Systems

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1) = basic  
2) = optional (additional price)  
3) = not available  
4) 1) in preparation  
5) 2) via CFC
### 6.2 Protection Systems

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- = basic  
0 = optional (additional price)  
- = not available

Footnotes:
1) in preparation  
2) via CFC

Further functions next page
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- = basic  ● = optional (additional price)  – = not available

1) in preparation  2) via CFC
### 6.2 Protection Systems

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- = basic  
• = optional (additional price)  
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1) in preparation  
2) via CFC
6.3 Substation Automation

6.3.1 Introduction

In the past, the operation and monitoring of energy automation and substation equipment was expensive, as it required staff on site. Modern station automation solutions enable the remote monitoring and control of all assets based on a consistent communication platform that integrates all elements from bay level all the way to the control center. Siemens substation automation products can be precisely customized to meet user requirements for utilities, as well as for industrial plants and bulk consumers. A variety of services from analysis to the operation of an entire system round out Siemens’s range of supply, and ensure complete asset monitoring. By acquiring and transmitting all relevant data and information, substation automation and telecontrol technologies from Siemens are the key to stable grid operation. New applications, such as online monitoring, can easily be integrated in existing IT architectures. This is how Siemens enables provident asset management, and makes it possible to have all equipment optimally automated throughout its entire life cycle.

6.3.2 Overview and Solutions

During the last years, the influences on the business of the power supply companies have changed a lot. The approach to power grid operation has changed from a static quasi-stable interpretation to a dynamic operational management of the electric power grid. Enhanced requirements regarding the economy of lifetime for all assets in the grid are gaining importance.

As a result, the significance of automation systems has increased a lot, and the requirements for control, protection and remote control have undergone severe changes of paradigm:

- Flexible and tailor-made solutions for manifold applications
- Secure and reliable operation management
- Cost-effective investment and economic operation
- Efficient project management
- Long-term concepts, future-proof and open for new requirements

Siemens energy automation solutions offer an answer to all current issues of today’s utilities. Based on a versatile product portfolio and many years of experience, Siemens plans and delivers solutions for all voltage levels and all kinds of substations (fig. 6.3-1).

Siemens energy automation solutions are available both for refurbishment and new turnkey substations, and can be used in classic centralized or distributed concepts. All automation functions can be performed where they are needed.

Flexible and tailor-made solutions for manifold applications
Siemens energy automation solutions offer a variety of standardized default configurations and functions for many typical tasks. Whereas these defaults facilitate the use of the flexible products, they are open for more sophisticated and tailor-made applications. Acquisition of all kinds of data, calculation and automation functions, as well as versatile communication can be combined in a very flexible way to form specific solutions, and fit into the existing surrounding system environment.

The classical interface to the primary equipment is centralized with many parallel cables sorted by a marshalling rack. In such an environment, central protection panels and centralized RTUs are standard. Data interfaces can make use of high density I/O – elements in the rack, or of intelligent terminal modules, which are even available with DC 220 V for digital inputs and direct CT / VT interfaces.

Fig. 6.3-1: Siemens energy automation products
Even in such configurations, the user can benefit from full automation and communication capabilities. This means that classical RTU solution, interfaces to other IEDs are included, and HMIs for station operation and supervision can be added as an option. Also, the protection relays are connected to the RTU, so that data from the relays are available both at the station operation terminal and in the control centers.

All members of the SICAM AK, TM, BC, EMIC and MIC family can be equipped with different combinations of communication, both serial and Ethernet (TCP/IP). Different protocols are available, mainly IEC standards, e.g., IEC 60870-5-101/103/104 IEC 61850, IEC 62056-21, but also a lot of other well-known protocols from different vendors.

Fig. 6.3-2 shows an example of refurbishment and centralized data acquisition in an MV substation. The interface to the primary equipment is connected via a marshalling rack, but can use any peripheral voltage (DC 24–220 V). The electronic terminal blocks are designed to substitute conventional terminal blocks, thereby realizing a very economic design. Existing protection relays can be connected either by IEC 60870-5-103 or by the more enhanced IEC 61850.

In new substations, the amount of cabling can be reduced by decentralizing the automation system. Both protection relays and bay controllers are situated as near as possible to the primary switchgear. Typically they are located in relay houses (EHV) or in control cabinets directly beneath HV GIS feeders. The rugged design with maximum EMC provides high security and availability.

For station control, two different products are available: SICAM PAS is a software-oriented product based on standard industrial hardware, whereas SICAM AK, TM, BC, EMIC and MIC represents the modular hardware-oriented design which bridges the gap between remote terminal units (RTUs) and substation automation (SA) (fig. 6.3-3).
The flexible Siemens solutions are available for every kind of substation:
- For different voltage levels, from ring main unit to transmission substation
- For new substations or refurbishment
- For gas-insulated or air-insulated switchgear
- For indoor or outdoor design
- For manned or unmanned substations

Communication is the backbone of every automation system. Therefore, Siemens solutions are designed to collect the data from the high-voltage equipment and present them to the different users: the right information for the right users at the right place and time with the required quality and security.

Here are some default examples for typical configurations. They are like elements which can be combined according to the respective requirements. The products, which are the bricks of the configurations, are an integral part of the harmonized system behavior, and support according to the principle of single-point data input. This means that multiple data input is avoided. Even if different engineering tools are necessary for certain configurations, these tools exchange their data for more efficient engineering.

Example of a small medium-voltage substation: Typically it consists of 4 to 16 MV feeders and is unmanned. In most cases, combined bay control and protection devices are located directly in the low-voltage compartments of the switchgear panels.

A station operation terminal is usually not required, because such substations are normally remote-controlled, and in case of local service/maintenance they are easy to control at the front side of the switchgear panels (fig. 6.3-4).

Example of a distribution substation in industry supply: In principle they are similar to the configuration above, but they are often connected to a control center via local area network (LAN). A distinctive feature is the interface to low-voltage distribution boards and sometimes even to the industrial auto-
Protection, Substation Automation, Power Quality and Measurement

6.3 Substation Automation

A subtransmission substation requires even more complexity: 2 or 3 voltage levels have to be equipped; a station operation terminal is usually required; more communication interfaces to external locations, separated control and protection devices on HV level, powerful LAN based on IEC 61850, and remote maintenance access are typical features of such applications (fig. 6.3-6).

In transmission substations, typically two to four voltage levels are to be automated. According to the high importance of such substations, availability is of the highest priority. Therefore, redundancy at substation level is generally required, both for station control units and station operation. Multiple operator stations are often required, multiple communication links to different control centers or neighboring substations are standard. Although most standard applications are IEC protocols, specific protocols also have to be offered for interfacing existing third-party devices. Complex automation functions support the operation and maintenance of such substations, such as voltage regulation by controlling on-load tap changers, synchrocheck, automatic command sequences, etc. (fig. 6.3-7).

The devices are as flexible as the configurations: Bay controllers, protection relays, station control units, station operation units and RTUs can be configured from small to very large. The well-known products of the SICAM and SIPROTEC series are a well proven base for the Siemens solutions.

**Secure and reliable operation**

Siemens solutions provide human machine interfaces (HMI) for every control level and support the operators with reliable information and secure, easy-to-use control features.

At feeder level:
- Conventional panels with pushbuttons and instruments for refurbishment
- Electronic front panels combined with bay control units (default)
6.3 Substation Automation

- Access points for remote terminals connected to the station operation units
- Portable touch panels with wireless access in defined areas
- Single or redundant HMI
- Distributed server/client architectures with multiple and/or remote terminals
- Interface to office automation

At substation level:

- Interlocking
- Feeder or remote blocking (option)
- Command sequences (option)
- Automatic recloser (option)
- Automatic switchover (option)
- etc.

Automation functions support operation:

- All images and pictures of the HMIs are designed according to ergonomic requirements, so as to give the operators clear information that is easy to use. Control commands are only accepted if access rights are met, the local/remote switches are in the right position and the multi-step command sequence is actively handled. Care is taken that only commands which are intended and explicitly given are processed and sent to the switchgear.

All images and pictures of the HMI are organized hierarchically and, for easy access, they guide the user to the required information and to fast alarm recognition. In addition, alarm and event logs, measurement curves, fault records, archives and flexible reports support the analysis of any situation in the power grid (fig. 6.3-8).

For security reasons only specially authorized personnel is granted access to operation and engineering tools. Flexible access rights are defined for operators, design engineers and service personnel, and differentiate between engineering access and operation rights.

Security of data transmission is catered for by secure protocols and secure network design. Especially, easy remote access to substations creates the need for such complex measures. The experienced Siemens engineers provide all the necessary knowledge for network security concepts.

Cost-effective investment and economic operation

The customized solutions from Siemens cater for effective investment. Tailor-made configurations and functions make sure that only required items are offered. The efficient tools cater for fast and easy engineering and support all project phases of an automation system, from collection of the substation data to deployment of all needed functions, and finally to reporting and archiving. The long lifetime of the involved future-proof products extend the time period between investments into automation systems.

Siemens solutions ensure low cost of ownership, thus taking into account all costs during lifetime. The automation systems are maintenance free and easy to expand at a later date. Last but not least, the powerful services for remote maintenance (diagnosis, settings, updates, test, etc.) provide a very economic way to keep any substation up-to-date and running.

Simple handling of the solutions is provided by:

- Same look and feel of all HMI on different levels.
- Vertical and horizontal interoperability of the involved products.
- Plug and play for spare parts by simple exchange of flash cards.

Reduction of engineering effort by

- Seamless data management, only single data input for whole project.
- Easy up and downloads, even remote.
- Integrated test tools.

Reduction of service expenses during lifetime by

- Integrated self-supervision in all components
- Powerful diagnosis in clear text
- Remote access for diagnosis, settings, test, expansions, etc.
Reduction of complexity by seamless communication
• Worldwide standard IEC 61850 promoted by Siemens
• Integrated IT security concepts
• Latest technology integrated

Efficient and state-of-the-art projects
The solutions for energy automation are part of the extensive programme, “Siemens One”. This means that energy automation solutions are integrated in different applications of the vast activity and expertise of Siemens:
• Power grids in transmission and distribution
• Complete building automation
• Solutions for pipelines and infrastructure
• Turnkey railway systems

They all make use of the energy automation solutions and the associated transfer of expertise for efficient project and order execution. Our worldwide engineering centers are always close to the system operators (fig. 6.3-9).

Long-term stability and trendsetting features for new requirements
With Siemens energy automation systems every user benefits from more than 70 years of experience in remote control and substation automation. The energy automation systems are designed for a long lifetime. Innovation is based on existing products, and compatibility of different product generations is part of the Siemens development philosophy.

The extensive use of available IEC standards strongly supports long-term stability and expandability. Examples are communication protocols like IEC 61850 in the substation, IEC 61970 for control centers, and IEC 60870-5 for remote communication. They form the strong backbone for the seamless solutions in energy automation. Additionally, the systems are tested in rugged environmental conditions and certified according to applicable IEC standards.

Investments in our solutions are secured by the “evergreen concept”, which defines migration methods when a new generation of products is introduced to the markets, e.g., the migration solution for SICAM LSA 678 from the early 90ies: By substituting the station control device with today’s SICAM PAS, it is possible to retain the installed feeder devices and import the existing...
database with the settings into the new tool SICAM PAS UI. This method reduces the refurbishment work significantly and adds new features to the system: In the next years the substation can be expanded with new feeder devices through the use of IEC 61850, even though some parts of the system might already be older than 15 years (fig. 6.3-10).

Our solutions are not only compatible with older devices, they are also very innovative. The Frost&Sullivan Technology Leadership Award 2006 was presented to Siemens for pioneering in the development of an innovative technology, the IEC 61850.

With Siemens energy automation solutions, every user is on the safe side: The combination of long-term experience and the newest innovation supplies safety for many years to come.

### 6.3.3 SICAM PAS

SICAM PAS (Power Automation System) meets all the demands placed on a distributed substation control system – both now and in the future. Amongst many other standardized communication protocols, SICAM PAS particularly supports the IEC 61850 standard for communication between substations and IEDs. SICAM PAS is an open system and – in addition to standardized data transfer processes – it features user interfaces for the integration of system-specific tasks and offers multiple automation options. SICAM PAS can thus be easily included in existing systems and used for system integration, too. With modern diagnostics, it optimally supports commissioning and maintenance. SICAM PAS is clearly structured and reliable, thanks to its open, fully documented and tested system (fig. 6.3-11).

**System overview, application and functionality of SICAM PAS**

- SICAM PAS is an energy automation solution; its system architecture makes it scalable.
- SICAM PAS is suitable for operating a substation not only from one single station level computer, but also in combination with further SICAM PAS or other station control units. Communication in this network is based on a powerful Ethernet LAN.
- With its features and its modular expandability, SICAM PAS covers a broad range of applications and supports distributed system configurations. A distributed SICAM PAS system operates simultaneously on several computers.
- SICAM PAS can use existing hardware components and communication standards as well as their connections.
- SICAM PAS controls and registers the process data for all devices of a substation, within the scope of the data transfer protocols supported.
- SICAM PAS is a communication gateway. This is why only one single data connection to a higher-level system control center is required.
- SICAM PAS enables integration of a fully graphical process visualization system directly in the substation.
- SICAM PAS simplifies installation and parameterization of new devices, thanks to its intuitive user interface.
- SICAM PAS is notable for its online parameter setting features, particularly when the system has to be expanded. There are no generation times; loading into a target system is not required at all or only required if configuration is performed on a separate engineering PC.
- SICAM PAS features integrated testing and diagnostic functions.
- Its user-friendliness, its operator control logic, its orientation to the Windows world and its open structure ideally suit users’ requirements.
- SICAM PAS is developed in accordance with selected security standards and meets modern demands placed on safe communication.

**Fig. 6.3-11:** Typical SICAM PAS configuration; IEDs are connected to the station unit with IEC 61850 and various other protocols (IEC 60870-5-103, DNPv3.00, etc.). The station unit communicates with the higher-level system control center by means of IEC 60870-5-101 and/or 104.
System architecture
SICAM PAS works on industrial-standard hardware with the Microsoft Windows operating systems. The advantages of this platform are low hardware and software costs, ease of operation, scalability, flexibility and constantly available support. With the powerful real-time data distribution system, applications can be allocated among several computers, thus boosting performance, connectivity and availability.

A database system stores and organizes the data basis (e.g. configuration data, administrative status data, etc.). The device master function for communication with Intelligent Electronic Devices (IEDs) supports a large number of well-established protocols.

The SICAM PAS data normalization function allows conversions such as measured-value filtering, threshold value calculation and linear characteristics.

SICAM SCC is used for process visualization. Specifically designed for energy applications, it assists the operating personnel in optimizing the operations management. It provides a quick introduction to the subject matter and a clearly arranged display of the system’s operating states. SICAM SCC is based on SIMATIC WinCC, one of the leading process visualization processes that is used in industrial automation worldwide.

To facilitate incident analysis, the fault recordings from protection relays are retrieved and archived automatically during operation. This is particularly supported for the standard protocols IEC 61850 and IEC 60870-5-103, but also for PROFIBUS FMS (SIPROTEC 4) and SINAUT LSAS ILSA. Furthermore, SIMEAS R fault recorders can also be connected to the system, and their detailed fault recordings can be retrieved and archived as well.

To manage the fault recording archive, the program SICAM PQ Analyzer with its program part Incident Explorer is used. Fault recordings are visualized and evaluated with the program Comtrade View as standard. Alternatively, SIGRA 4 with its additional functions can also be used.

Communication

**Device interfaces and communication protocols**

In a substation configured and operated with SICAM PAS, various types of protection relays, IEDs, bay control units, measured-value recorders and telecontrol units from a wide range of manufacturers can be used. SICAM PAS offers a large number of commercially available communication protocols for recording data from various devices and through differing communication channels. Subsequent expansion is easy.

**Protocols**

SICAM PAS supports the following communication protocols (optionally available):

- Control center connection IEC 60870-5-101, IEC 60870-5-104, DNP V3.00, MODBUS, TG 8979, CDT
- Open data exchange OPC server, OPC XML DA server, OPC client
- IED and substation connection IEC 61850, IEC 60870-5-101, IEC 60870-5-103, IEC 60870-5-104, DNP V3.00, PROFIBUS FMS (SIPROTEC 4), PROFIBUS DP, MODBUS, SINAUT LSA-ILSA
### 6.3 Substation Automation

**Available protocols:**

These communication protocols and device drivers can be obtained as optional additions to the standard scope of SICAM PAS.

- **IEC 61850 (Client):**
  IEC 61850 is the communication standard for interconnecting the devices at the feeder and station control levels on the basis of Ethernet. IEC 61850 supports the direct exchange of data between IEDs, thus enabling switching interlocks across feeders independently of the station control unit, for example.

- **IEC 60870-5-103 (Master):**
  Protection relays, IEDs, bay control units, measured value recorders and transformer controllers from many manufacturers support the IEC 60870-5-103 protocol and can therefore be connected directly to SICAM PAS.

- **IEC 60870-5-101 (Master):**
  The IEC 60870-5-101 protocol is generally used to connect telecontrol units. The “balanced” and “unbalanced” traffic modes are supported.

- **Automatic dialing** is also supported for the connection of substations with this protocol. SICAM PAS can establish the dial-up connection to the substation either cyclically or as required (e.g., for command output). By contrast, the substation can also establish a connection cyclically or in event-triggered mode.

- **IEC 60870-5-104 (Master):**
  Furthermore, connection of substations is also supported by the TCP/IP-based IEC 60870-5-104 protocol.

- **DNP V3.0 (Master) – Level 3:**
  Apart from the IEC protocols -101 and -104, DNP 3.0 is another standardized telecontrol protocol used by many IEDs and RTUs and applied worldwide. The units can be connected both serially and with TCP/IP (DNPi). TCP/IP-based communication can operate with an asymmetrical encryption procedure, thus meeting security requirements.

- **PROFIBUS DP (Master):**
  PROFIBUS DP is a highly powerful field bus protocol. For example, it is used for industrial automation and for automating the supply of electricity and gas. PROFIBUS DP serves to interface multifunctional measuring instruments such as SICAM P (I, V, P, Q, p.f. (cosφ)) or, for example, to connect ET200 components for gathering messages and for simple commands. Messages, for example, can be derived from the signaling contacts of fuse switch-disconnectors.

- **MODBUS (Master):**
  Besides PROFIBUS DP, the MODBUS protocol is also well-known in industrial applications. SICAM PAS allows to connect IEDs and RTUs with this protocol, both via serial and TCP/IP-based connections.

- **PROFIBUS FMS (SIPROTEC 4):**
  Most SIPROTEC 4 bay controllers and protection relays can be connected to the SICAM PAS station unit via PROFIBUS FMS.

- **SINAUT LSA ILSA (Master):**
  Communication via the SINAUT LSA ILSA protocol is a special advantage of SICAM PAS. Existing LSA central units can be replaced without changing the configuration on bay level.

**System control center connections, distributed process connection and process visualization:**

- **SICAM PAS** operates on the basis of Microsoft Windows operating systems. This means that the extensive support which Windows offers for modern communication protocols is also available with SICAM PAS.

- **SICAM PAS** was conceived for easy and fast integration of conventional protocols. Please contact Siemens in case of questions about integration of user-specific protocols.

- **For the purpose of linking up to higher-level system control centers, the standardized telecontrol protocols** IEC 60870-5-101, IEC 60870-5-104 and DNP V3.0 (Level 3) serially and over IP (DNPi), as well as MODBUS (serially and over IP), TG 8979 (serially) and CDT (serially) are supported. Security or “safe communication” are gaining more and more importance. Asymmetric encryption enables tap-proof communication connection to higher-level control centers with IEC 60870-5-104 and DNP V3.0 via TCP/IP. For DNP V3.0, authentication can be used as an additional security mechanism.

- **Distributed process connection** in the substation is possible thanks to the SICAM PAS Device Interface Processor (DIP).

- **SICAM PAS** can also be set up on computers networked with TCP/IP. Here, one computer performs the task of the so-called “full server”. Up to six other computers can be used as DIPs. With this architecture, the system can be adapted to the topological situation and its performance also boosted.

- **SICAM PAS** allows use of the SICAM SCC process visualization system for central process control and monitoring. For industrial applications, it is easy to configure an interface to process visualization systems via OPC (object linking and embedding for process control).

- **SICAM PAS** can be configured as an OPC server or as an OPC client. The SICAM PAS process variables – available with the OPC server – can be read and written with OPC clients working either on the same device or on one networked by TCP/IP. This mechanism enables, for example, communication with another process visualization system. The OPC server is included in the basic system. Optionally, this server functionality is also available as OPC XML DA for communication with clients based on other operating systems as well as beyond firewall limits. The OPC client can read and write data from other OPC servers. A typical application could be the connection of SIMATIC programmable controllers. The OPC client is available as an optional package.

- **SICAM Diamond** can be used to monitor the system interfaces, to indicate switching device states and up-to-date measured values, and also for further diagnostic purposes. Apart from these configuration-free diagnostic views, SICAM Diamond also supports message logging in event and alarm lists as well as process visualization in single-line diagrams, and can thus be used as a simple human-machine interface. Messages and measured values can be archived in files (monthly). On the one hand, SICAM Diamond consists of the Diamond Server, which is directly connected with SICAM PAS and prepares the data for access with a Web browser, and on the other hand, the SICAM Diamond Client as operator interface in the context of the Microsoft Internet Explorer. Except for the Microsoft Internet Explorer, no additional software has to be installed on.
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the Web clients. SICAM Diamond allows access to archive files and fault recordings through the World Wide Web. The archive files can be saved on the Web client for evaluation, e.g. with Microsoft Excel. Fault recordings can be visualized directly in the Internet Explorer.

**Further station control aspects**
During, e.g., maintenance work or for other operational reasons, information exchange with the control centers or the substation itself can be blocked with the telecontrol blocking and bay blocking functions. The telecontrol blocking function can also be configured for specific channels so as to prevent the transfer of information to one particular control center during operation, while transfer continues with other control centers. The bay blocking and telecontrol blocking functions act in both the signaling and the command directions. Channel-specific switching authority also makes it possible to distinguish between local control (SICAM SCC) and remote control for the switching direction, but also between control center connections. For these three functions, information-specific exceptions can be declared additionally, so that, e.g., certain messages are transmitted despite an activated block, or special commands are processed and issued despite of a defined switching authority. While a 1-out-of-n check is normally effective in IEDs, i.e. only one command is accepted and issued at the same time, an m-out-of-n check is supported on the side of the substation control system with SICAM PAS. This helps to define how many commands can be processed at the same time for all IEDs. Circuit-breakers can be controlled in synchronized/unsynchronized mode.

**Automation tasks**
can be configured in SICAM PAS with the CFC (Continuous Function Chart), which conforms to IEC 61131. In this editor, tasks are configured graphically by wiring function blocks. SICAM PAS comes with an extensive library of CFC function blocks, developed and system-tested specially for energy automation.

Applications range from generation of simple group indications through switching interlocks to complex operating sequences. Creation of operating sequences is supported by the SFC Editor (Sequential Function Chart).

In this context, additionally pre-configured and system-tested applications such as frequency-based load shedding, transformer monitoring and SF6 gas monitoring can be optionally licensed. Besides special functional components and CFCs, the scope of supply also covers operating images for SICAM SCC.

**Redundancy**
SICAM PAS features comprehensive redundancy functions to boost the availability of the station automation system:
- The substation control unit can be used in a duplicate configuration ("system redundancy")
- The communication to IEDs and RTUs can be redundant ("interface redundancy")
- Subordinate units can be duplicated (redundancy at the bay control level)
- Subunits that are only designed for communication with one master (e.g., with only one serial interface) can be supported.
The individual applications (communication protocols) operate independently of each other in a hot/standby connection, i.e. a changeover, e.g., of the IEC 61850 client from one station control unit to the other due to a disturbance has no effects on the communication connection to the control center, which remains on the first station control unit without interruption. Apart from a higher stability in unaffected communication connections, the redundancy changeover of affected components takes place within a very short time (depending on application and configuration, between 250 ms and max. 3 sec). Adjustments during operation such as bay/telecontrol blocking, switching authority, but also marking commands to the SoftPLC for operational control of the automation functions, are kept synchronous in both station control units during redundancy operation. The current adjustments are also valid after a redundancy changeover. SICAM SCC communicates simultaneously with both redundant station control units.

**Process visualization with SICAM SCC**

In the operation of a substation, SICAM PAS is used for configuration purposes and as a powerful data concentrator. SICAM SCC serves as the process visualization system. Several independent SICAM SCC servers can be connected to one SICAM PAS. Connection of redundant servers is also possible. SICAM SCC supports the connection of several SICAM PAS systems. In the signal lists, the original time stamps are logged in ms resolution as they occur in the devices. With every signal, a series of additional data is also presented to provide information about causes (spontaneous, command), event sources (close range, local, remote), etc. Besides process signals, command signals are also logged. IndustrialX controls are used to control and monitor switchgear. These switching-device objects support four different forms of presentation (IEC, DIN, SINAUT LSA, SICAM) for circuit-breakers and disconnectors. It is also possible to create bitmaps (defined for a specific project) to represent switching devices, and to link them to the objects. For informative visualization, not only nominal and spontaneous flashing are supported, but also the display of various device and communication states (e.g., up-to-date/not up-to-date, feeder and telecontrol blocking, etc.). Measured values and switching device states that are not continuously updated due to, e.g., device or communication failure or feeder blocking, may be updated directly via the operation panel with SICAM SCC.

**Scope of information**

The amount of information to be processed by SICAM PAS is essentially determined by the following factors:

- Computer network concept (multiple-computer network or single-station system)
- Performance data of the hardware used
- Performance data of the network
- Size of the database (RDBMS)
- Rate of change of values

With a distributed PAS system using a full server and up to 6 DIPs, a maximum of 350 IEDs and 20,000 data points can be supported.

**Fig. 6.3-16: Process visualization with SICAM SCC**
In conjunction with the SICAM PAS station unit, the switching devices can be controlled either directly or with “select before operate”. When visualizing the process by single-line diagrams, topological coloring can be used. The WinCC add-on SIMATIC Web navigator can be used for control and monitoring via the Internet. SICAM Valpro can be used to evaluate measured and metered values. It not only allows a graphical and a tabular display of archived values, but also enables subsequent evaluation functions such as minimum, maximum and averages values (on an hourly or daily basis). For protection devices connected with the protocols IEC 61850, IEC 60870-5-103 as well as PROFIBUS FMS (SIPROTEC 4) or SINAUT LSA ILSA, fault recordings can be retrieved and archived automatically. SICAM PQ Analyzer with its component Incident Explorer is used for management and evaluation of the fault recordings.

SICAM SCC V7.0 SP1 can also be used as a process visualization system for:
- SICAM AK, TM, BC, EMIC and MIC
- IEC 61850 devices (for example, SIPROTEC 4)

**SICAM SCC for SICAM AK, TM, BC, EMIC and MIC**
For communication with SICAM AK, TM, BC, EMIC and MIC, the protocol IEC 60870-5-104 or IEC 61850 can be used. Both SICAM TOOLBOX II V5.0 and SICAM SCC V7.0 SP1 support exchange of configuration data.

**SICAM SCC for devices with communication standard IEC 61850**
Devices communicating via IEC 61850 can be connected directly to SICAM SCC. For this usage, SCL files (SCD, ICD, CID) are imported. The files are created, for example, with the DIGSI 4 system configurator.

**SICAM SCC for SICAM PAS, SICAM AK, TM, BC, EMIC and MIC and IEC 61850 devices**
With SICAM SCC V7.0 SP1, a common control and monitoring system for the systems SICAM PAS, SICAM AK, TM, BC, EMIC and MIC and for IEC 61850 devices can be realized.

SICAM SCC is based on SIMATIC WinCC, which has advanced to become both the industrial standard and the market leader in Europe. It features:
- Multilingual capability
- All operation and monitoring functions on board. These include not only the graphics system for plant displays and the signaling and archiving system for alarms and measured values, but also a reporting and logging system. Further advantages are integrated user administration, along with the granting and checking of access rights for configuration and runtime operations.
- Easy and efficient configuration
  - Configuration is assisted by dialogs, wizards and extensive libraries.
- Consistently scalable, even via the Web
  - In conformity with requirements, the bandwidth ranges from small single-user stations up to client/server solutions with user stations on the Web as well as support of the server redundancy.
- WinCC/Redundancy – increases system availability by redundant WinCC stations or servers monitoring each other mutually, ensuring the operability of the system and enabling complete data acquisition.
- Open standards for easy integration
  - Using any external tools, archived data can be accessed through a series of open interfaces (such as SQL and ODBC) for further editing.
  - Manufacturer-independent communication with lower-level controllers (or with applications such as MS Excel) is supported with OPC (OLE for Process Control).
- Visual Basic for Applications (VBA), VBScript or ANSI-C create an ideal scope for project-specific solutions.
- Expandable with options and add-ons such as
  - WinCC/Dat@Monitor serves to display and evaluate current process states and historical data on office PCs, using standard tools such as the Microsoft Internet Explorer or Microsoft Excel
  - WinCC/Web Navigator is an option with SIMATIC WinCC for controlling and monitoring systems over the Internet, a company Intranet or a LAN
  - WINCC/Connectivity Pack
  - Alarm management system ACC
  - With the aid of the alarm management system ACC, messages from the WinCC signaling system can be forwarded automatically to radio call receivers.
Overview of the operator control philosophy and user interface
The SICAM PAS user interface is based on customary Windows technology, which allows to navigate in the familiar Windows environment both when configuring the system and during ongoing operation. The system distinguishes between configuration and operation of a substation. In SICAM PAS, these two tasks are firmly separated by two independent programs.

The SICAM PAS UI – configuration program (fig. 6.3-17) is used to create and edit a project-specific configuration. To enhance clarity, four views are distinguished:

- Configuration
- Mapping
- System topology
- Device templates

A common feature of all views is that they have an Explorer window that shows the system configuration in a clearly arranged tree structure. As in the Windows Explorer, it is possible to open individual levels of this tree structure to work in them. Meanwhile, other levels can be closed to improve clarity. Depending on the current navigation level and the chosen component, in the context menu (right mouse button) SICAM PAS offers precisely those program functions that are currently appropriate.

Operation takes place through the necessary steps in the data window on the right. Here, parameters can be set, information selected and assignments defined to form a user-specific, process-oriented system topology. The user interface is uncomplicated and structured according to the task definition, so as to enable intuitive working and to simplify changes. The user interface assists the editing process by displaying parameter descriptions and messages when incorrect parameters are entered. In the tabular views for

![Fig. 6.3-17: SICAM PAS UI – Configuration](image-url)
information assignment and allocation to the system topology, configuration is made easy by extensive sorting and filtering mechanisms, multiple choices and Drag & Drop.

To ensure data consistency and to avoid redundant data input, SICAM PAS UI provides extensive import and export functions for the exchange of configuration data, e.g., with the bay control level and with process visualization. To create new PAS projects and change the structure of existing PAS projects, a configuration license is required for using “SICAM PAS UI – Configuration”. For reading access to the parameterizing data as well as parameter changes, the program can also be used on a runtime license basis. In SICAM PAS, everything is on board. Apart from the actual runtime environment, the “SICAM PAS UI – Configuration” program is always installed on the station computer. Thus, the project database and the configuration program always match, and adjustments and expansions are also possible after many years – regardless of separate engineering computers.

Fig. 6.3-18: SICAM PAS UI – Operation

Fig. 6.3-19: SICAM PAS Value Viewer
6.3.4 SICAM Station Unit

Hardware components of the SICAM station unit
The industrial standard SICAM station unit represents the robust, embedded hardware platform for the SICAM PAS software product. It is based on the 19” rack technology. The SICAM Station Unit (fig. 6.3-21) consists of the following hardware components:

- Optional extensions must be ordered separately
- Power supply modules as ordered
- Power supply control unit
- 2 USB interfaces (V2.0) on the rear panel (for dongle and memory stick)
- Three different CPU modules
  - Single core CPU – the classic version
    Recommended for use with older versions of SICAM PAS (e.g., V5.11) and standard substation automation configurations
  - Dual core CPU RAID – optimized for power quality
    Recommended for use in power quality applications
  - Dual core CPU – best performance for SICAM PAS
- SDRAM, DDR2, 4 GB
- 2 flash cards, 4 GB each
- Graphic feature: 2048 pixels × 1536 pixels, 16.7 million colors
- VGA interface for monitor

Fig. 6.3-21: SICAM station unit: industrial hardware for high reliability

- 4 USB interfaces (V2.0) e.g., for keyboard/mouse
- 2 RJ45 interfaces for LAN (10/100/1000BaseT Gigabit Ethernet)
- 2 COM interfaces
- Connection unit with connections for power supply and ON/OFF switch
### SICAM station unit

SICAM PAS station unit V2 based on industrial mobile processor 19" rack system, fanless operation, without moving components.  
4 external USB, 2 internal USB, 2 x Gbit Ethernet RJ45, 1 serial port, status LEDs.  
Redundant power supplies, switchover without reboot.  
Monitored by SNMP, HW Watchdog, Temperature/voltage monitoring, live contact  
Windows XP Embedded service pack 2  
SICAM PAS software must be ordered separately.

#### Power supply

- **Primary power supply**
  - DC 24 – 60 V
  - AC/DC 110 – 230 V

- **Secondary power supply**
  - without
  - DC 24 – 60 V
  - AC/DC 110 – 230 V no secondary power supply

#### CPU type

- **CPU module with single core CPU**
  - Celeron® M #40, 1.86GHz, 2 x 4GB CF, 2GB RAM, image SU V2 20, backup DVD

- **CPU module with dual core CPU**
  - Core Duo T2500, 2GHz, 2 x 4GB CF, 2GB RAM, image SU V2 20, backup DVD
  - Core Duo T2550, 1.86GHz, 2 x 4GB CF, 4GB RAM, Image SU V2 20,
  - Backup DVD, incl. RAID controller and RAID system level 1 incl. 2x100GByte hard disks

- **CPU module with dual core CPU with RAID System**
  - Intel Core 2 Duo E7200 1.6GHz, 2 x 4GB CF, 4GB RAM, Image SU V2 20,
  - Backup DVD, incl. RAID controller and RAID system level 1 incl. 2x100GByte hard disks

#### I/O boards

- None
- One digital I/O module (32 binary contacts)
- Two digital I/O modules (64 binary contacts)

#### PCI adapter

- Without PCI-adapter
- With PCI-adapter

#### Com port expander

- Without com port expander
- 8 Ports, incl. octopus cable

#### Guarantee extension

- Standard 2 year guarantee
- Guarantee for third year

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**Fig. 6.3-22: Overview of available packages for the station unit**

Optional extensions:
- External USB-DVD drive for image DVD
- External USB hard disk for backup
- USB memory stick
- PCI adapter for up to 4 PCI cards
- COM-port extension cards
- PROFIBUS card
- GPS/DCF 77 time signal receiver manufactured by Hopf
- Up to 64 binary I/O-contacts
6.3.5 Configuration Examples

Configuration for medium to large applications
If the substation comprises 30 to 150 bay control units, SICAM PAS and SICAM SCC must run on separate PCs. The example below illustrates the connection of the bay control units to a SICAM station unit (fig. 6.3-23).

Configuration for large to extra-large applications
In large to extra-large applications with up to 350 bay devices, SICAM PAS is implemented as a distributed system equipped with a full server and up to 6 DIPs. SICAM SCC is installed on a separate PC (fig. 6.3-24).

Several SICAM PAS full servers connected to a human-machine interface (HMI)
The example illustrates a SICAM SCC human-machine interface (HMI) with 2 SICAM station units to which bay devices are connected. This configuration makes sense in cases where no spatially distributed human-machine interface and no failsafe SICAM SCC are required (fig. 6.3-25).

Redundant human-machine interface (HMI)
The connection of several full servers to a redundant SICAM SCC human-machine interface represents another configuration option. This configuration enhances the system’s operational reliability (fig. 6.3-26).
Distributed system with full server and DIP
The example shows a distributed SICAM PAS system. It consists of a full server and DIP, and communicates with a control center via TCP/IP. Bay control units and substations are connected to a distributed system via Ethernet and serial interfaces (fig. 6.3-27).

Redundant connection of bay control units and substations
SICAM PAS supports the redundant connection of bay control units and substations. The example illustrates the following configuration:

- Redundant full servers
- Redundant SICAM SCCs implemented in server/client architecture
- Connection of bay control units to 2 SICAM PAS stations

Bay control units with 2 interfaces are required for the redundant connection of bay control units. Alternatively, bay control units equipped with one interface can be connected redundantly via a splitter (fig. 6.3-28).

Fig. 6.3-27: Example of a distributed SICAM PAS system with full server and DIPs

Fig. 6.3-28: SICAM PAS station bus configuration with redundant connection of the feeder devices and the redundant SICAM SCC station controller
6.3.6 SICAM AK, TM, BC, EMIC and MIC

Versatile functionality and high flexibility are fundamental for a modern remote control system. SICAM AK, TM, BC, EMIC and MIC adds comprehensive options for communication, automation and process interfaces. The different components of SICAM AK, TM, BC, EMIC and MIC offer optimal scalability regarding the number of interfaces and signals. Nevertheless these components are all based on the same system architecture, the same technology, and are handled with the same engineering tool (SICAM TOOLBOX II).

- **SICAM AK** is the large automation component for a flexible mix of communication, automation and I/O. It offers optimal support as master controller or RTU, gateway or front-end, with local or distributed I/O. Versatile redundancy concepts are another asset of these components.

- **SICAM TM** is the solution for compact applications. This component offers up to 4 communication interfaces plus automation function and process interface per distributed terminal modules. All modules are easily mounted to standard DIN rails. The terminal modules can be distributed up to 200 m with fiber-optic cables.

- **SICAM BC** is the ruggedized component for highest EMC and direct process interface up to DC 220 V. High switching capacity and direct interface for measurement transformers, plus expandability with TM modules provide flexible application in centralized and distributed configurations. Up to 3 communication interfaces and automation functions are integrated.

- **SICAM MIC** is a small RTU and offers either a serial interface according to IEC 60870-5-101 or an Ethernet interface with IEC 60870-5-104. Up to 8 terminal modules for I/O can be connected. A simplified automation function and a Web server for easy engineering are integrated.

- **SICAM EMIC**, the new smart automation system. Thanks to its node functionality with 3 interfaces, SICAM EMIC has many different potential applications. It can be used as an ordinary telecontrol substation with any kind of communication to a control center. If SICAM EMIC doesn’t offer adequate signal scope, it can be connected additional. Freely programmable application programs for local control functions complete the all-round versatility of the SICAM EMIC.

All components of the ACP family are using the same communication modules, and therefore they can use all available protocols. In addition to standards like IEC 60870-5-101/103/104 and IEC 61850 (client and/or server), also DNP 3.0 and Modbus are available in addition to a lot of legacy and third-party protocols for connecting third-party devices.

Another joint feature of all components is the integrated flash memory card, where all parameters and firmwares are stored. A simple exchange of a component is now possible, just by changing the memory card.

The SICAM TOOLBOX II offers all functions for an integrated, seamless engineering of complete projects, and works with all components of SICAM AK, TM, BC, EMIC and MIC. It supports all phases of an RTU or station automation project. Data exchange with DIGSI and PAS UI means a single entry point for data engineering avoiding multiple manual data inputs for a mixed configuration.

With SICAM AK, TM, BC, EMIC and MIC there is always enough performance at hand: The modular multiprocessor concept grows with every enhancement of the system. The distributed architecture and the principle of “evolutionary development” cater for a future proof system with long lifetime expectation and high security of investment. SICAM AK, TM, BC, EMIC and MIC carries the experience of more than 30 years of remote control and automation; many references are proving the flexible ways of application.

**Automation component SICAM AK**

*Longevity through continuity and innovation*

SICAM AK features high functionality and flexibility through the implementation of innovative and reliable technologies, on the stable basis of a reliable product platform.
For this, the system concept ACP (Automation, Control and Protection) creates the technological preconditions. Balanced functionality permits the flexible combination of automation, telecontrol and communication tasks. Complemented with the scalable performance and various redundancy configurations, an optimal adaptation to the respective requirements of the process is achieved (fig. 6.3-29).

SICAM AK is thus perfectly suitable for automation with integrated telecontrol technology as:
- Telecontrol substation or central device
- Automation unit with autonomous functional groups
- Data node, station control device, front-end or gateway
- With local or remote peripherals
- For rear panel installation or 19 inch assembly

**SICAM AK – the forward-looking product**

Versatile communication:
- Up to 66 serial interfaces according to IEC 60870-5-101/103
- LAN/WAN communication according to IEC 60870-5-104
- LAN communication according to IEC 61850
- Various third-party protocols possible

Easy engineering with SICAM TOOLBOX II:
- Object-oriented data model
- Creation of open-loop and closed-loop control application programs according to IEC 61131-3
- All engineering tasks can also be carried out remotely

Plug and play for spare parts:
- Storage of parameters and firmware on a flash card
- Spare part exchange does not require additional loading with SICAM TOOLBOX II

Open system architecture:
- Modular, open and technology-independent system structure
- System-consistent further development and therefore an innovative and future-proof product

**Scalable redundancy:**
- Component redundancy
- Doubling of processing/communication elements

The intelligent terminal – SICAM TM, EMIC and MIC:
- Direct connection of actuators and sensors with wire cross-sections up to 2.5 mm²
- Can be located remotely up to 200 m
- Binary input/output also for DC 110/220 V
- Assembly on 35 mm DIN rail

**Versatile communication capability**

With SICAM AK, a variety of media can be utilized for local and remote communication. (wire connections, FO, radio, dial-up traffic, GSM, GPRS, WAN, LAN, field bus etc.)

Through the simple installation of serial interface modules, in total up to 66 communication interfaces are possible in one SICAM AK, whereby a different individual protocol can be used for each interface.

For standard communication protocols according to IEC 60870-5-101/103/104 and IEC 61850 are implemented.

Besides the standard protocols there are also a variety of third-party protocols available (DNP 3.0, Modbus etc.).

**Simple process interfacing**

In addition to the central acquisition and output of process signals within an SICAM AK mounting rack, it is possible to use SICAM TM, EMIC and MIC peripheral elements (fig. 6.3-30).

An essential feature of the SICAM TM, EMIC and MIC peripheral elements is the efficient and simple interfacing possibility of the process signals. This takes place on so-called I/O modules, which are distinguished through a robust casing, a secure contact as well as solid electronics. The I/O modules are lined up in rows. The contact takes place during the process of latching together,
without any further manipulation. Thereby each module remains individually exchangeable.

A clearly arranged connection front with LEDs for the status display ensures clarity locally. The structure of the terminals enables a direct sensor/actuator wiring without using intermediate terminal blocks with wire cross-sections up to 2.5 mm². Modules for binary inputs and outputs up to DC 220 V open further saving potentials at the interface level.

Depending on the requirements, the I/O modules can be fitted with either an electrical bus or an optical bus, through which the peripheral signals can be acquired as close as possible to the point of origin. In this way, broad cabling can be reduced to a minimum.

**Easy engineering**

An essential aspect in the overall economical consideration are the costs that occur for the creation, maintenance and service. For this, the reliable SICAM TOOLBOX II is used.

- **Object orientation:**
  The object orientation makes it possible to also utilize the same characteristics of same-type primary-technology units and operational equipment (e.g., disconnectors, circuit-breakers, feeders etc.) for the configuration. The close coupling with the design tool ensures the consistent, uniform documentation of the entire plant through to circuit diagram. Through this, considerable rationalization results with engineering.

- **Open-loop and closed-loop control according to IEC 61131-3:**
  Open-loop and closed-loop control application programs are created by means of CAEx plus according to IEC 61131-3, a standard that is generally accepted and recognized in the market. As a result, the training periods are reduced considerably.

- **All engineering tasks can also be carried out remotely:**
  All engineering tasks, from the system diagnostic through to the online test, can also be performed remotely with the SICAM TOOLBOX II. For this, a separate communication link between SICAM TOOLBOX II and SICAM AK is not necessary: Every available communication interface can be used. Using further automation units of SICAM TM, AK or BC, the SICAM TOOLBOX II can be remotely positioned over an arbitrary number of hierarchies.

The access to the engineering data is fundamentally protected by a password.

**Plug and play for spare parts**

All data of an automation unit – such as firmware and parameters – are stored non-volatile centrally on an exchangeable flash card. With a restart of the automation unit, and also with a restart of individual modules, all necessary data are automatically transferred from the flash card to all CPUs and modules. Consequently, with the exchange of modules, new loading is no longer required, since new modules obtain all data from the memory card. With the replacement of spare parts, plug and play becomes a reality: No special tool is required, even loading is no longer necessary.

Thereby, work during a service operation is reduced to a minimum.

**Open system architecture**

The basis for this automation concept is a modular, open and consequently technology-independent system architecture for processing, communication and peripherals (multi-processor system, firmware).

Standardized interfaces between the individual elements again permit, even with further developments, the latest state of technology to be implemented, without having to modify the existing elements. In this way, a longevity of the product and consequently investment security and continuity can be ensured (fig. 6.3-31).

Every board and every module on which a firmware can run, forms, together with the function-determining firmware, one system element.

The adaptation to the specific requirements of the application is achieved through the individual configuration and through the loading of standard firmware and parameters. Within their defined limits, the parameters thereby not only influence the behavior of the firmware functions, but also that of the hardware functions. With that, for all module types, all mechanical parameter settings are omitted, such as e.g., the changing of jumpers or loads, thus enabling not only the online change, but also a consistent documentation of the set parameters by the SICAM TOOLBOX II as well as a simplified storage.

**System overview**

**Mechanics**

Fig. 6.2-32 and fig. 6.2-33 show two types of basic mounting racks: module CM-2832 with 9 slots and module CM-2835 with 17 slots.

Module CM-2833 (not pictured here) is the expansion mounting rack for up to 16 peripheral elements outside the basic mounting rack.

With the mechanics, value has been placed on flexibility and easy handling. Consequently, the mounting rack is available for rear panel installation or for 19" (swing) frame installation.

Almost all necessary external connectors (e.g., communication, peripherals, external periphery bus) can be connected with the help of standard cables or prefabricated cables without any additional tools (fig. 6.3-34, fig. 6.3-35, fig. 6.3-36).
“Protected” area = Internal communication

“Open” area = Adaption to the current technical and economic demands

Decoupled from individual technology and functionally standardized

Autonomous unit for expansions and renewals

– Interfaces (process, communication)
– Functions and concepts
– Technology

Fig. 6.3-31: Open system architecture

Fig. 6.3-32: CM-2832 – SICAM AK mounting rack with 9 slots

Fig. 6.3-33: CM-2835 – SICAM AK mounting rack with 17 slots
6.3 Substation Automation

Fig. 6.3-34: Connection technique for peripheral signals

Fig. 6.3-35: RJ45 connection technique for communication
System architecture
The system architecture is shown in fig. 6.3-37.

Configuration
SICAM AK is structured from the following elements:
- Master control element
- Processing and communication element
- Protocol element(s) (*)
- Peripheral element(s) (*)
- Mounting rack with one to four power supplies

Peripheral elements can also be installed outside of the basic mounting rack.

Configuration
The configuration of an automation unit Ax 1703 peripheral bus is shown in fig. 6.3-38, next page.

Configuration
- 1 master control element
  - Forms the independent Ax 1703 peripheral bus AXPE-C0, on which up to 16 peripheral elements can be installed
- Up to 16 processing and communication elements
  - Each processing and communication element forms an independent Ax 1703 peripheral bus AXPE-Cn (n = 1...16), on which up to 16 peripheral elements can be installed
  - Up to 272 peripheral elements
- Up to 66 protocol elements (interfaces with individual communication protocol)
  - Up to 2 protocol elements on the master control unit
  - Up to 4 protocol elements for each processing and communication element
Ax 1703 peripheral bus
The Ax PE-Cn buses (n = 1...16) are available on connectors, in order to be able to connect peripheral elements outside the basic mounting rack. One of the buses can be selected, in order to also supply those peripheral elements in the basic mounting rack.

Peripheral elements outside the basic mounting rack
Peripheral elements may be
• installed in the basic mounting rack (as shown above), and / or
• installed in an expansion mounting rack and connected electrically, and / or
• installed at remote locations and connected electrically or optically.

System elements
A system element is a functional unit and consists of hardware and firmware. The firmware gives the hardware the necessary functionality.

Master control element
The master control element (fig. 6.3-39) forms the heart of the automation unit.

Functions of the master control element:
• Communication with installed peripheral elements via the serial Ax 1703 peripheral bus
• Open / closed-loop control function with a freely programmable user program according to IEC 61131-3, e.g., in function diagram technology
• Communication with other automation units via protocol elements installable on the master control element (up to 2 interfaces)
• Central coordinating element for all system services and all internal and overlapping concepts, such as e.g.,
  – Data flow control
  – Monitoring functions
  – Diagnostic
  – Time management and time synchronization via minute pulse, serial time signal (DCF77 / GPS-receiver), serial communication link, NTP – Server over LAN / WAN
  – Local SICAM TOOLBOX II connection
  – Storage of parameters and firmware on a flash card

Fig. 6.3-38: Configuration of an automation unit SICAM AK
Fig. 6.3-39: Master control element
6.3 Substation Automation

Processing and communication element
Functions of the processing and communication elements (fig. 6.3-40):

- Communication with installed peripheral elements via the serial Ax 1703 peripheral bus
- Open/closed-loop control function with a freely programmable user program according to IEC 61131-3, e.g., in function diagram technology
- Communication with other automation units via protocol elements installable on the processing and communication element (up to 4 interfaces)

Peripheral element
Peripheral elements, as shown in fig. 6.3-41, are used for acquisition or output of process information and perform process-oriented adaptation, monitoring and processing of the process signals at each point where the signals enter or leave an automation unit. Processing is performed to some degree by

- hardware (e.g., filter, ADC, DAC) and by
- firmware (e.g., smoothing of measured values, time tagging)

![Fig. 6.3-40: Processing and communication element](image-url)

![Fig. 6.3-41: Peripheral elements](image-url)
The peripheral elements deliver over the Ax 1703 peripheral bus
- periodical information,
- messages with process information, and
- messages with system information (e.g., diagnostic information)

and receive
- messages with process information,
- periodical information, and
- messages with system information (e.g., parameters)

**Protocol element**

A protocol element (fig. 6.3-42) is used for the exchange of data – and thereby for the transmission of messages – over a communication interface to other automation units or devices of third-party manufacturers, e.g., control systems.

The hardware of a protocol element is a communication interface which – dependent on system and interface – can be available in different ways:
- Integrated on a basic system element
- On a serial interface module (SIM), which is installed – directly or cascaded (SIM on SIM) – on the basic system element

On every interface provided by the SIM, a communication protocol available for the interface can be loaded with the SICAM TOOLBOX II.

### System elements in SICAM AK

#### Master control element

- **Module**
  - CP-2010 / CPC25
- **Designation**
  - System functions, processing and communication

#### Processing and Communication Element

- **Module**
  - CP-2017 / PCCX25
- **Designation**
  - Processing and communication

### Peripheral elements SICAM AK

- **Module**
  - DI-2100 / BISI25
  - Binary signal input (8 x 8, DC 24 – 60 V)
- **Designation**
  - Binary signal input

- **Module**
  - DI-2110 / BISI26
  - Binary signal input (8 x 8, DC 24 – 60 V)
- **Designation**
  - Binary signal input

- **Module**
  - DI-2111 / BISI26
  - Binary signal input (8 x 8, DC 110 / 220 V)
- **Designation**
  - Binary signal input

- **Module**
  - DO-2201 / BISO25
  - Binary output (Transistor, 40 x 1, DC 24 – 60 V)
- **Designation**
  - Binary output

- **Module**
  - AI-2300 / PASI25
  - Analog input/output (16 x ±20 mA + 4 x 2 opt. exps.)
- **Designation**
  - Analog input/output

- **Module**
  - AI-2302 / PASI25
  - Analog input/output (16 x ±6 mA + 4 x 2 opt. exps.)
- **Designation**
  - Analog input/output

- **Module**
  - DO-2210 / PCCO2X
  - Checked command output (64 x DC 24 – 60 V)
- **Designation**
  - Checked command output

- **Module**
  - DO-2211 / PCCO2X
  - Checked command output (64 x DC 60 – 125 V)
- **Designation**
  - Checked command output

- **Module**
  - MX-2400 / USIO2X
  - Signal input/output (DC 24 – 60 V, ±20 mA, opt. exp.)
- **Designation**
  - Signal input/output

### Supported peripheral elements SICAM TM

- **Module**
  - PE-6410 / USIO66
  - Peripheral controller (Ax-PE bus el)
- **Designation**
  - Peripheral controller (Ax-PE bus el)

- **Module**
  - PE-6411 / USIO66
  - Peripheral controller (1x Ax-PE bus opt)
- **Designation**
  - Peripheral controller (1x Ax-PE bus opt)

### Power supply

The mounting racks CM-2832, CM-2835 and CM-2833 are to be equipped with 80W power supplies of the following types:

- **Designation**
  - PS-5620
  - Power supply (DC 24 – 60 V)

- **Designation**
  - PS-5622
  - Power supply (DC 110 – 220 V, AC 230 V)
Function packages

Telecontrol
The function package “Telecontrol” includes the following functions:
- Process input and output on peripheral elements
- Communication with other automation units
- Protocol elements
- Automatic data flow routing
- Data storage
- Priority control
- Redundant communication routes
- Communication within the automation unit
- Protocol element control and return information

Automation
The function package “Automation” includes the following functions:
- Process input and output on peripheral elements
- Telecontrol functions
  - Treatment for commands according to IEC 60870-5-101 / 104
  - Change monitoring and generation of messages with time tag
- Open/Closed-loop control function

System services
“System Services” is a function package providing general functions and basic services in an automation unit, which are required by other function packages:
- Communication with the engineering system
- Data flow control
- Addressing
- Time management
- General interrogation
- Self-test
- Failure
- Diagnostic and signaling
- Autonomy

System concept SICAM TM
SICAM TM is designed especially for easy installation and powerful application. Due to consequent development it fits optimally both for automation and telecontrol systems (fig. 6.3-43).

An essential feature of SICAM TM is its efficient and simple way of interfacing to the process signals. This is accomplished by so-called I/O modules boasting a robust housing, reliable contacting, and sound electronics. The I/O modules are arranged side-by-side. Contact between them is established as soon as they engage with one another, without requiring any further manual intervention. Even so, it is still possible to replace every
single module separately.

A clearly structured connection front featuring status indicator LEDs makes sure that things at the site remain clear and transparent. The structure of the terminals permits direct sensor/actuator wiring without requiring the use of intermediate terminals.

The I/O modules may, depending on the requirements, be equipped with either an electrical or an optical bus, whereby the peripheral signals can be acquired very close to their point of origin. Consequently, wide cabling can be reduced to a minimum.

SICAM TM is highlighted by the following future-oriented features:
- Modular, open and technology-independent system structure
- Direct periphery coupling without intermediate terminals
- Software parameter setting (hardware and software)
- Online parameter modification
- LED’s for process and operating conditions
- Simplified connection handling by “intelligent terminals”
- 35 mm international standard profile rails
- Secured internal communication over all bus systems
- Little training needed
- Data storage via multi media card (plug and play for spares)
- Periodical processing and creation of automation functions carried out with the tool CAEx.plus
- Spontaneous processing supports the processing- and communication-orientated telecontrol functions and includes:
  - Parameterizable telecontrol functions
  - Time management and time synchronization via minute pulse, serial time signal (DCF77 / GPS-receiver), serial communication link, NTP server via LAN / WAN
  - Communication via the mountable protocol elements
  - Engineering by means of SICAM TOOLBOX II
  - Storage of parameters and firmware on a flash card

Functions of the master control element:
- Communication with peripheral elements via the serial Ax 1703 peripheral bus
- Open/closed-loop control functions with a user program created freely according to IEC 61131-3, e.g., in function diagram technology
- Parameterizable telecontrol functions
- Periodical processing and creation of automation functions (periodical communication with the periphery)
- Engineering by means of SICAM TOOLBOX II
- Storage of parameters and firmware on a flash card

The master control element provides the open-/closed-loop functions and/or the parameterizable telecontrol function, as well as the node function for the communication via serial interfaces and LAN/WAN. Therefore, it also serves as a centrally coordinating element for all system functions and all internal and integral concepts.

This architecture ensures
- Deterministic behavior of the open/closed-loop control function with guaranteed reaction times,
- Autonomous behavior (e.g., in the case of communication failure), and
- Integration of the telecontrol functionality (spontaneous processing and spontaneous communication) as well as the open/closed-loop control functions (periodical processing and periodical communication with the periphery) into one common automation device.

To connect peripheral elements to the master control element, a bus interface module must be arranged side by side with the master control element.
For this purpose,
• the master control element has a 9-pin D-SUB socket on its right side, and the
• bus interface module has a 9-pin D-SUB connector on its left side.

Up to 2 bus interface modules can be attached to one master control element.

Up to 14 peripheral elements can be connected to a master control element.

**Peripherals**
A peripheral element is constituted of
• 1 power supply module,
• 1 peripheral control module, and
• up to 8 I/O modules (fig. 6.3-45)

The respective data sheets document how many I/O modules may actually be used per peripheral element and in what order they can be used.

A key feature of SICAM™ is that it provides for the efficient and simple connection of the process signals. This is done at the I/O modules standing out for a robust housing, reliable contacting, and sound electronics.

The I/O modules are added side by side to the peripheral control module. Contact is established as soon as they engage with one another, without requiring any further manual intervention. Even so, every single I/O module can still be exchanged separately and mounted on a DIN rail. It may be installed horizontally or vertically.

Removable terminals (I/O connectors) are used for the simple handling of modules when they are to be mounted or exchanged. Since the terminals carry the wiring, no connections need to be disconnected when devices are exchanged.

To interface peripheral elements to the master control element, a bus interface module must be fitted on the side of the master control element. Using simple, standardized USB cables, the peripheral control modules are connected to the bus interface module, thereby reducing the assembly effort required for their connection to a minimum.

The Ax 1703 peripheral bus permits the secured, serial, in-system communication between the master control element and the peripheral elements. Serial communication also renders it possible to detach individual or all peripheral elements via optical links up to 200 m from the master, with full system functionality remaining intact.

**Functions of the peripheral control module:**
• Secured data exchange with the master control element
• Secured data exchange with the connected I/O modules via the TM bus (Terminal Module Bus)
• Monitoring of the connected I/O modules
• Preprocessing of the input and output signals

**Functions of the I/O modules:**
• Acquisition and output of binary and analog process signals,
• Secured data exchange with the peripheral control element via the TM bus

The communication between the I/O modules and the peripheral control module takes place via the TM bus according to the master/slave method, with the I/O modules being the slaves.

By arranging the various modules side by side, contact will be established automatically throughout the TM bus so that no additional wiring is required.

**Communication**
The communication function is used for the exchange of data – and thus for the transmission of messages – via protocol elements to other automation units or control systems.

The hardware for the protocol elements is serial interface modules (SIMs), which can be mounted on the master control element. On one master control element, up to 2 SIMs can be mounted.

A serial interface module features:
• Two serial communication interfaces, or
• one LAN communication interface (Ethernet) plus optional serial interface, or
• one Profibus interface (DP master)

Since a communication interface corresponds to one protocol element, a total of up to 4 protocol elements can be used for each SICAM™. This way, a multitude of communication options is available.
### Product overview

#### Master control unit

<table>
<thead>
<tr>
<th>Module</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP-6014 / CPCX65</td>
<td>Processing and communication</td>
</tr>
</tbody>
</table>

#### Bus interface module

<table>
<thead>
<tr>
<th>Module</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM-0843</td>
<td>Ax-bus interface, electrical</td>
</tr>
<tr>
<td>CM-0842</td>
<td>Ax-bus interface, optical fiber</td>
</tr>
</tbody>
</table>

#### Peripherals

<table>
<thead>
<tr>
<th>Module</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS-6630</td>
<td>Power supply module (DC 24-60 V (EMC+))</td>
</tr>
<tr>
<td>PS-6632</td>
<td>Power supply module (DC 110/220 V (EMC+))</td>
</tr>
<tr>
<td>PE-6410/USIO66</td>
<td>Periphery interfacing for Ax electrical peripherals bus</td>
</tr>
<tr>
<td>PE-6411/USIO66</td>
<td>Periphery interfacing for Ax peripherals bus 2 x optical</td>
</tr>
<tr>
<td>PE-6412/USIO66</td>
<td>In combination with SICAM AK in redundancy configurations</td>
</tr>
<tr>
<td>DI-6100</td>
<td>Binary input (2 × 8, DC 24-60 V)</td>
</tr>
<tr>
<td>DI-6101</td>
<td>Binary input (2 × 8, DC 110/220 V)</td>
</tr>
<tr>
<td>DO-6200</td>
<td>Binary output transistor (2 × 8, DC 24-60 V)</td>
</tr>
<tr>
<td>DO-6212</td>
<td>Binary output relays (8 × DC 24-220 V/AC 230 V)</td>
</tr>
<tr>
<td>DO-6220</td>
<td>Command output basic module (4 × DC 24 – 110 V)</td>
</tr>
<tr>
<td>DO-6221</td>
<td>Command output basic module measure (4 × DC 24 – 110 V)</td>
</tr>
<tr>
<td>DO-6230</td>
<td>Command output relais module (16 × DC 24 – 110 V)</td>
</tr>
<tr>
<td>AI-6300</td>
<td>Analog input (2 × 2 ± 20 mA / ± 10 mA / ± 10 V)</td>
</tr>
<tr>
<td>AI-6307</td>
<td>Analog input (2 × 2 ± 5 mA)</td>
</tr>
<tr>
<td>AI-6310</td>
<td>Analog input (2 × 2 Pt100/Ni100)</td>
</tr>
<tr>
<td>AO-6380</td>
<td>Analog output (4 × 20 mA / ± 10 mA / ± 10 V)</td>
</tr>
</tbody>
</table>

**Compact RTU SICAM MIC**

SICAM MIC, as a part of SICAM AK, TM, BC, EMIC and MIC, is designed for application of compact telecontrol systems.

Installation takes place on a 35 mm rail. It must be considered that the modules are mounted horizontally or vertically on a vertically standing rack.

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**Fig. 6.3-46: SICAM MIC system architecture**

**Fig. 6.3-47: SICAM MIC configuration – multi-point traffic**

The sequence of modules from left to right or from top to bottom is prescribed as follows:

- Power supply module
- Master control module
- Up to 8 I/O modules in arbitrary order (fig. 6.3-46)

The power supply and TM bus are electrically connected during the process of latching together, wherein each module can be individually replaced.
Protection, Substation Automation, Power Quality and Measurement

6.3 Substation Automation

The master control modules are:
- CP-6020 master control module (V.28 / 8 modules)
- CP-6040 master control module (ET10TX/V.28 /8 modules)

Configuration
The following figures show the configurations of multi-point traffic (fig. 6.3-47), of dial-up traffic (fig. 6.3-48), of multimaster dial-up traffic (fig. 6.3-49), of LAN/WAN (fig. 6.3-50) and of GPRS (fig. 6.3-51).

Bay control units
The Bay Control Unit (BCU) is the linking member between the station control level and the primary system, and is integrated in the feeder-related local control cubicle.

It is therefore designed for rough electric and thermal ambient conditions and is based on the SICAM BC bay controller.

The bay control unit acquires all feeder-relevant process data and time tags them at a resolution of 1 ms. All feeder related functions are executed autonomous in the bay control unit:
- Interlocking
- Synchrocheck
- Automatic voltage regulation by control of transformer onload tap changer (option)
- Closed-loop control for arc suppression coils (option)
- Operation cycle counter
- Calculation of r.m.s. values of currents and voltages, active and reactive power

Local control panel for feeder operation
The bay control unit comes in two mechanical sizes (fig. 6.3-53): SICAM BC is designed for compact feeders (typical in distribution); SICAM BC is the modular version for larger amounts of I/O (typical in transmission).

Both versions are based on the same system architecture and use the same modules. They are ruggedised for use as near as possible to the primary equipment featuring the highest EMC and a broad temperature range, and the I/O-modules are designed for direct interfacing of all signals from the process without any interposing level (e.g., interposing relays, measuring transducers, etc.). This means a peripheral voltage of up to DC 220 V or direct interfacing of transformers with 1 A to 6 A or AC 110/220 V.

Architecture of SICAM BC
A SICAM BC forms an automation unit of the SICAM system family and consists of the following elements:
6.3 Substation Automation

- Master control element (control) (*)
- Processing element (protection) (*)
- Protocol element(s) (*)
- Peripheral element(s) (*)
- Operation and display panel
- Mounting rack with one or two power supplies

The mounting rack is available in two sizes:
- The compact SICAM BC can host up to 2 peripheral elements
- The modular SICAM BC can host up to 15 peripheral elements.

**Seamless communication**

SICAM BC offers a complete solution based on IEC standards (IEC 60870-5-101 / 103 / 104 and IEC 61850).

A serial interface is included in the control master CPU based on IEC 60870-5-103 SLAVE via fiber-optic for communication with upper levels. Local communication to the maintenance notebook for the engineering tool is done via a 9-terminal connector on the front side of the device. In addition, a SIP (Serial Interface Processor) with two serial interfaces or a NIP (Network Interface Processor) with one Ethernet interface, or a combined SIP+NIP with one serial and one Ethernet interface can be equipped for enhanced communication capability.

*Parts that are marked with (*) are system elements*

![Fig. 6.3-50: SICAM MIC configuration – LAN/WAN](image1)

![Fig. 6.3-51: SICAM MIC configuration – GPRS](image2)
Plug and play for spare parts by flash card
Parameters and firmware are stored directly on flash card. That means that no tool for device exchange is necessary. This facilities the maintenance and service tasks. Additionally the flash card can be written by the engineering tool.

General features
• Power supply is available in DC 110–220 V / AC 230 V (80 W) or DC 24–60 V (80 W) and a second power supply can be added for redundancy
• The signal acquisition has a 1 ms resolution of real-time stamping.

As shown in the picture, the bay control units are designed for rough electric and thermal environments.

The operating temperature ranges from –25 °C to + 70 °C / –13 to + 158 °F. Installation in outdoor cabinets is intended.

Bay control unit HMI
In order to make it easier for the system operator’s staff to perform operation and maintenance tasks from the local bay control cubicle, the SICAM BC bay control unit can be operated through a display panel (fig. 6.3-52).

The local operation panel is designed as a dedicated solution to show all necessary information about the status of a feeder in a clear and simple way, and to support easy and secure local operation directly at the feeder. It is designed for use in the door of local bay control cubicles at all voltage levels of a substation. Therefore it complies with highest EMC and a wide temperature range.

It provides an interface to be used with the SICAM BC, and can be combined both with the compact and the modular version of the bay controller. It can be directly attached to the SICAM BC, or be used separated with only two connecting cables (up to 3 m). The integrated and divided frame allows for either surface mounting, without the need for a big cut-out in the door, or for flush mounting. Operation and display have been arranged in accordance with ergonomic principles, and are compatible with similar sequences on the station operation terminal. The display shows the status of the dynamic single-line diagram of the feeder, plus selected measurement information. By changing to other images, the operator gets information about all accessible measurements, statistical data, important alarms, etc. Additional LEDs indicate important status and alarms beside the display, so that any unusual condition can be recognized immediately. The associated description is provided with a slide-in strip, so that image and status are shown simultaneously. Two key locks give access to the operation mode: one for local / remote / test, and the other one for interlocked / non-interlocked operation. Command initiation is done securely in multiple steps. In this way, inadvertent input is definitely avoided.

Temperature range: –25 °C to + 70 °C / –13 to + 158 °F. The display has a limited readability below –10 °C / 14 °F. External dimensions (H × W × D) are 280 mm × 220 mm × 37 mm / 11.0236 × 8.6614 × 1.45669 inch.
6.3.7 SICAM EMIC – a Member of the Proven SICAM Family

With growing pressure on costs in virtually all processes, there is an increasing need to also automate smaller stations to make better and more reliable use of existing equipment. Modern, high-performance automation systems allow the integration of smaller stations to provide universal and reliable management of complex processes. But smaller stations are also being equipped with greater functionality because of the increased demand for more information.

From straightforward monitoring activities to control functions and the integration of additional equipment, modern systems need to offer a wide range of functionality.

Flexible use of SICAM EMIC

As the logical consequence of these demands, SICAM EMIC (Terminal Module SICAM enhanced microcontrol) represents the expansion of the proven product SICAM MIC. SICAM EMIC is a low-cost, flexible and modular telecontrol station, and is part of the proven SICAM AK, TM, BC, EMIC and MIC automation family. The hardware consists of a master control element and various I/O modules, and is designed for DIN rail mounting. The proven I/O modules can be used and fitted on all products in the SICAM AK, TM, BC, EMIC and MIC family.

The master control element is used for interfacing and supplying the I/O modules and provides three communication interfaces (1 × Ethernet and 2 × serial) to meet a wide range of requirements. Complete flexibility is ensured here as well, because different communication protocols can be allocated freely. The option of automation functions rounds out the range of functionality of the SICAM EMIC.

Integrated Web server for simple engineering

Keeping the engineering process as simple as possible was a top priority with the SICAM EMIC – the master control element has an integrated Web server for configuration, diagnostics and testing, so that no special tools or additional licenses are needed. The tool is already integrated in SICAM EMIC and is operated with a standard Web browser. Engineering, diagnostics and testing of the SICAM EMIC can also be carried out with the proven SICAM TOOLBOX II, the integrated engineering tool for the entire SICAM AK, TM, BC, EMIC and MIC family. SICAM EMIC puts everything on one card and receives the parameterizing data via a flash card. Consequently, the correct parameters are always available locally and there is no need to load data from a PC. This makes exchanging devices during servicing a straightforward Plug & Play operation, and it is very simple to transfer configuration data to the replacement device with the flash card. For this reason, and because of the comprehensive remote diagnostics options, downtimes can be reduced to a minimum.

Thanks to its node functionality, SICAM EMIC has many different potential applications. SICAM EMIC can be used as an ordinary telecontrol substation with any kind of communication to a control center. If SICAM EMIC doesn’t offer adequate signal scope, additional SICAM EMIC systems can be connected. Freely programmable application programs for local control functions complete the all-round versatility of the SICAM EMIC.

Highly flexible options for communication to the control center

• Multi-point traffic
  – External data transmission equipment—can be connected via the V.28 interface for multi-point traffic transmission.

• Dial-up traffic
  – A wide range of connection-oriented transmission media (analog, ISDN, GSM, TETRA) are supported as standard for dial-up traffic as well.

• LAN/WAN
  – IEC 60870-5-104/DNP3 communication based on Ethernet TCP/IP is used for communication via LAN/WAN networks.

SICAM EMIC – the system in detail

Functions of the master control element:
• Central processing functions
• Storing of the parameters and the firmware on a flash card
• Interfacing and supplying of the I/O modules
• 3 communication interfaces, with different individual communication protocols (IEC 60870-5-101, 103, 104, Modbus, DNP 3.0, other protocols on request)

Fig. 6.3-54: SICAM EMIC – the new member of the proven SICAM AK, TM, BC, EMIC and MIC family
6.3 Substation Automation

Fig. 6.3-55: Practical applications of SICAM EMIC

Fig. 6.3-56: Architecture of SICAM EMIC

For further information:
www.siemens.com/sicam
6.4 Power Quality and Measurements

6.4.1 Introduction

Power quality

Supply quality
Quality is generally recognized as an important aspect of any electricity supply service. Customers care about high quality just as much as low prices. Price and quality are complementary. Together, they define the value that customers derive from the electrical supply service.

The quality of the electricity supply provided to final customers results from a range of quality factors, for which different sectors of the electricity industry are responsible. Quality of service in the electrical supply has a number of different dimensions, which can be grouped under three general headings: commercial relationships between a supplier and a user, continuity of supply, and voltage quality.

To avoid the high cost of equipment failures, all customers must make sure that they obtain an electricity supply of satisfactory quality, and that their electrical equipment is capable of functioning as required even when small disturbances occur. In practice, the voltage can never be perfect.

Electrical supply is one of the most essential basic services supporting an industrial society. Electricity consumers require this basic service:
• To be available all the time (i.e. a high level of reliability)
• To enable all consumers’ electrical equipment to work safely and satisfactorily (i.e. a high level of power quality).

Voltage quality
Voltage quality, also termed power quality (PQ), covers a variety of characteristics in a power system. Chief among these is the quality of the voltage waveform. There are several technical standards defining voltage quality criteria, but ultimately quality is determined by the ability of customers’ equipment to perform properly. The relevant technical phenomena are: variations in frequency, fluctuations in voltage magnitude, short-duration voltage variations (dips, swells, and short interruptions), long-duration voltage variations (overvoltages or undervoltages), transients (temporarily transient overvoltages), waveform distortion, etc. In many countries voltage quality is regulated to some extent, often using industry-wide accepted standards or practices to provide indicative levels of performance.

Everybody is now aware of the effects of poor power quality but few really have it under control. The levels of power quality disturbances need to be monitored weekly, sometimes even daily.

Fig. 6.4-1: Power quality monitoring provides value to everyone – to the local utility, to the consumer, to the local economy and to the environment
daily, in order to trigger appropriate remedial measures before severe consequences occur.

The power utility therefore has an interest in monitoring the power quality, showing that it is acting correctly and improving its know-how about the system. This ensures customer satisfaction by providing electricity with quality and reliability.

The availability and quality of power is of even greater concern to distribution companies. The liberalization of the electricity market has put them in the uncomfortable position of being affected by other players’ actions. This situation has been stabilizing and power quality is becoming a top priority issue in the restructuring process. With increasing customer awareness of energy efficiency, it is clear that the quality of supply will be receiving much attention.

Most power quality problems directly concern the end user, or are experienced at this level. End users have to measure the power quality and invest in local mitigation facilities. However, consumers often turn to the utility company, instead, and exert pressure to obtain the required supply quality.

The EN 50160 power quality standard describes the main characteristics of the voltage at the customer’s supply terminals in public low, medium, and, in the near future, high-voltage systems, under normal operating conditions.

Who is responsible?
An interesting problem arises when the market fails to offer products that meet the customer’s power quality needs. If a customer cannot find equipment that is designed to tolerate momentary power interruptions, the customer may, for example, pressure the power supplier and the regulator to increase the power quality of the overall distribution system. It may be in the supplier’s interest to help the customer address the power quality and reliability problem locally.

The electrical supply system can be considered a sort of open-access resource: In practice, almost everybody is connected to it and can “freely” feed into it. This freedom is now limited by standards, and/or agreements. In European countries, the EN 50160 European standard is generally used as a basis for the supply quality, often also termed the voltage or power quality. There is currently no standard for the current quality at the point of common coupling (PCC), but only for equipment. The interaction between the voltage and current makes it hard to draw a line between the customer as “receiving” and the network company as “supplying” a certain level of power quality. The voltage quality (for which the network is often considered responsible) and the current quality (for which the customer is often considered responsible) affect each other in mutual interaction.

Fig. 6.4-2: Utility and industries, both are responsible for voltage quality
### Table 6.4-1: Main problems with power quality

<table>
<thead>
<tr>
<th>Problem</th>
<th>Description</th>
<th>Cause</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency distortions:</strong></td>
<td>A frequency variation involves variation in frequency above or below the normally stable utility frequency of 50 or 60 Hz</td>
<td>• Start-up or shutdown of very large item of consumer equipment, e.g. motor&lt;br&gt;• Loading and unloading of generator or small co-generation sites&lt;br&gt;• Unstable frequency power sources</td>
<td>• Misoperation, data loss, system crashes and damage to equipment and motor&lt;br&gt;• For certain kinds of motor load, such as in textile mills, tight control of frequency is essential</td>
</tr>
<tr>
<td><strong>Supply interruption:</strong></td>
<td>Planned or accidental total loss of power in a specific area&lt;br&gt;Temporary interruptions lasting from a half second to 3 seconds&lt;br&gt;Temporary interruptions lasting from 3 seconds to 1 minute&lt;br&gt;Long-term interruptions lasting longer than 1 minute</td>
<td>• Switching operations attempting to isolate an electrical problem and maintain power to your area&lt;br&gt;• Accidents, acts of nature, etc.&lt;br&gt;• Fuses, actions by a protection function, e.g. automatic recloser cycle</td>
<td>• Sensible processes and system shutdown or damages&lt;br&gt;• Loss of computer/controller memory&lt;br&gt;• Production losses or damage</td>
</tr>
<tr>
<td><strong>Voltage dip/sag or swell:</strong></td>
<td>Any short-term (half cycle to 3 seconds) decrease (sag) or increase (swell) in voltage</td>
<td>• Start-up or shutdown of very large item of consumer equipment, e.g. motor&lt;br&gt;• Short circuits (faults)&lt;br&gt;• Underdimensioned electrical circuit&lt;br&gt;• Utility equipment failure or utility switching</td>
<td>• Memory loss, data errors, dim or bright lights, shrinking display screens, equipment shutdown&lt;br&gt;• Motors stalling or stopping and decreased motor life</td>
</tr>
<tr>
<td><strong>Supply voltage variations:</strong></td>
<td>Variation in the voltage level above or below the nominal voltage under normal operating conditions</td>
<td>• The line voltage amplitude may change due to normal changing load situations</td>
<td>• Equipment shutdown by tripping due to undervoltage or even overheating and/or damage to equipment due to overvoltage&lt;br&gt;• Reduced efficiency or life of electrical equipment</td>
</tr>
<tr>
<td><strong>Flicker:</strong></td>
<td>Impression of unsteadiness of visual sensation induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time</td>
<td>• Intermittent loads&lt;br&gt;• Motor starting&lt;br&gt;• Arc furnaces&lt;br&gt;• Welding plants</td>
<td>• Changes in the luminance of lamps can result in the visual phenomenon called flicker on people, disturbing concentration, causing headaches, etc.</td>
</tr>
<tr>
<td><strong>Transient:</strong></td>
<td>A transient is a sudden change in voltage up to several thousand volts. It may be of the impulsive or oscillatory type (also termed impulse, surge, or spike)&lt;br&gt;<strong>Notch:</strong> This is a disturbance of opposite polarity from the waveform</td>
<td>• Utility switching operations, starting and stopping heavy equipment, elevators, welding equipment static discharges, and lightning</td>
<td>• Processing errors&lt;br&gt;• Data loss&lt;br&gt;• Lock-up of sensitive equipment&lt;br&gt;• Burned circuit boards</td>
</tr>
<tr>
<td><strong>Noise:</strong></td>
<td>This is an unwanted electrical signal of high frequency from other equipment&lt;br&gt;<strong>Harmonic:</strong> Distortion is alteration of the pure sine wave due to non-linear loads on the power supply</td>
<td>• Noise is caused by electromagnetic interference from appliances, e.g. microwave, radio and TV broadcasts, arc welding, heaters, laser printers, thermostats, loose wiring, or improper grounding&lt;br&gt;• Harmonic distortion is caused by non-linear loads</td>
<td>• Noise interferes with sensitive electronic equipment&lt;br&gt;• It can cause processing errors and data loss&lt;br&gt;• Harmonic distortion causes motors, transformers, and wiring to overheat&lt;br&gt;• Improper operation of breakers, relays, or fuses</td>
</tr>
</tbody>
</table>
Table 6.4-2: Power quality applications

<table>
<thead>
<tr>
<th>PQ application</th>
<th>Description</th>
<th>Hardware</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regulatory power quality:</strong></td>
<td>Regulative PQ analysis approaches the comparison of the quality of voltage or power with recognized standards (e.g. EN 50160) or with the quality defined in power supply contracts. Periodically produce compliance reports.</td>
<td>Power Quality Recorders (mainly Class A)</td>
<td>Voltage quality parameters (at least) at selected system interfaces and customer supply points (e.g. EN 50160) for: Power system performance Planning levels (i.e. internal objectives) Specific customer contracts</td>
</tr>
<tr>
<td><strong>Explanatory power quality:</strong></td>
<td>Explanatory PQ analysis to provide an understanding of what is going on in particular cases, such as fault analysis, to support the wider aspects of system stability. It is a process that aims to document selected, observed power quality and maximize the level of understanding, possibly including knowledge of the cause and consequences and possible mitigation of power quality problems.</td>
<td>PQ recorders Class A, S or B and fault recorder / PMU</td>
<td>$V+I_{rms}$, waveforms, status of binaries, power swing, MV transformers, busbars and loads</td>
</tr>
</tbody>
</table>

Power quality recording steps

Fig. 6.4-3: Power quality recording in five steps

Standards
The purpose of power quality indexes and measurement objectives is to characterize power system disturbance levels. Such indexes may be defined as “voltage characteristics” and may be stipulated in a Grid Code that applies to electrical system interfaces. Power quality Grid Codes make use of existing standards or guidelines defining voltage and current indexes to be applied to interfaces in low, medium, or high-voltage systems, for example, EN 50160. This standard defines and describes the main characteristics of the voltage at the system operator’s supply terminals in public LV and MV power distribution systems. Indexes for HV-EHV will also be described in the new edition of EN 50160. Since electrical systems among regions and countries are different, there are also many other regional or national recommendations, mainly described in Grid Codes, defining specific or adapted limit values.

These local standards are normally the result of practical voltage quality measurement campaigns or the system experience, which are mostly acquired through a permanent and deep electrical system behavior know-how. Measuring according to EN 50160 is, however, only part of the power quality measurement process. Another important standard for power quality measurement is IEC 61000-4-30, which defines the measurement methodology.
6.4 Power Quality and Measurements

Fig. 6.4-4: Overview of international and national standards for power quality

Fig. 6.4-5: Illustration of a voltage dip and a short supply interruption, classified according to EN 50160; \( V_N \) – nominal voltage of the supply system (r.m.s.), \( V_A \) – amplitude of the supply voltage, \( V_{(r.m.s.)} \) – the actual r.m.s. value of the supply voltage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Supply voltage characteristics according to EN 50160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power frequency</td>
<td>LV, MV: mean value of fundamental measured over 10 s ± 1 % (49.5 – 50.5 Hz) for 99.5 % of week – 6 %/4 % (47 – 52 Hz) for 100 % of week</td>
</tr>
<tr>
<td>Voltage magnitude variations</td>
<td>LV, MV: ± 10 % for 95 % of week, mean 10 minutes r.m.s. values (fig. 6.4-5)</td>
</tr>
<tr>
<td>Rapid voltage changes</td>
<td>LV: 5 % normal 10 % infrequently ( P_{11} ) ≤ 1 for 95 % of week MV: 4 % normal 6 % infrequently ( P_{11} ) ≤ 1 for 95 % of week</td>
</tr>
<tr>
<td>Supply voltage dips</td>
<td>Majority: duration &lt; 1 s, depth &lt; 60 %. Locally limited dips caused by load switching on LV: 10 – 50 %, MV: 10 – 15 %</td>
</tr>
<tr>
<td>Short interruptions of supply voltage</td>
<td>LV, MV: (up to 3 minutes) few tens – few hundreds/year duration 70 % of them &lt; 1 s</td>
</tr>
<tr>
<td>Long interruption of supply voltage</td>
<td>LV, MV: (longer than 3 minutes) ≤ 10 – 50/year</td>
</tr>
<tr>
<td>Temporary, power frequency overvoltages</td>
<td>LV: &lt; 1.5 kV r.m.s. MV: 1.7 ( V_c ) (solid or impedance earth) 2.0 ( V_c ) (unearthed or resonant earth)</td>
</tr>
<tr>
<td>Transient overvoltages</td>
<td>LV: generally &lt; 6 kV, occasionally higher; rise time: μs to ms MV: not specified</td>
</tr>
<tr>
<td>Supply voltage unbalance</td>
<td>LV, MV: up to 2 % for 95 % of week, mean 10 minutes r.m.s. values, up to 3 % in some locations</td>
</tr>
<tr>
<td>Harmonic voltage/THD</td>
<td>Harmonics LV, MV THD: 8</td>
</tr>
<tr>
<td>Interharmonic voltage</td>
<td>LV, MV: under consideration</td>
</tr>
</tbody>
</table>

Table 6.4-3: Requirements according to EN 50160

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Odd harmonics Not multiples of 3</th>
<th>Even harmonics Multiples of 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order h</td>
<td>Relative voltage (%)</td>
<td>Order h</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>3.5</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.4-4: Values of individual harmonic voltages at the supply terminals for orders up to 25, given in percent of \( V_N \)

From IEC 61000-4-30 also accuracy classes, Class A “higher accuracy” and Class S “lower accuracy” are derived. In other words, in a simple way, if the EN 50160 defines “what” to measure, the IEC 61000-4-30 defines “how” to measure it. The end result of a measurement process is expected to be fully automated, standard compliant documentation of all measurements.

Calculation of r.m.s. values after every half period is the touchstone of an IEC 61000-4-30 Class A measurement device. To define the range of normal voltage states, a hysteresis range is specified for event detection. SICAM Q80 meets the precision requirements for a Class A measurement device according to the IEC 61000-4-30 standard.
IEC 61000-4-30, Ed. 2, 2008-10:
Power Quality Measurement Methods: This standard defines the methods for measurement and interpretation of results for power quality parameters in AC supply systems.

IEC 61000-4-15:1997 + A1:2003:
Flickermeter, Functional and Design Specifications: This section of IEC 61000 provides a functional and design specification for flicker measuring apparatus intended to indicate the correct flicker perception level for all practical voltage fluctuation waveforms.

IEC 61000-4-7, Ed. 2, 2002-08:
General Guide on Harmonics and Interharmonics: This is a general guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

Definition of a measuring point and power quality measurement objectives
Power quality measurements address the aspect of power performance by describing the quality of every individual interface in an electrical system and in the networks of its various customers. Identifying, defining, profiling the power quality measurement points are essential tasks in defining a power quality project. However, the electrical system is dynamic by nature, so optimizing the measuring points is a routine that is developed by day-to-day learning. This may not help predict changes, but will permit a more effective response to them.

Identification of measuring points
Measurement points may be located and defined as shown in table 6.4-5.

Measuring power quality requires not only an effective choice of measuring points but also defined objectives for the PQ analysis at the measuring points.

We generally classify “power quality” monitoring as a mixture of data gathering technologies classified by their purpose or application.

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurement points</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transmission feeder (line or transformer)</td>
<td>Possibly busbar</td>
</tr>
<tr>
<td>2</td>
<td>Generation station/distributed generation</td>
<td>Busbar, transformer or generator connection</td>
</tr>
<tr>
<td>3</td>
<td>Subtransmission, line supply</td>
<td>Busbar (e.g. where the busbar is owned and operated by the transmission company)</td>
</tr>
<tr>
<td>4</td>
<td>Subtransmission feeder (line or transformer)</td>
<td>Remote line terminals (e.g. where the lines are owned and operated by the transmission company)</td>
</tr>
<tr>
<td>5</td>
<td>Distribution, line supply</td>
<td>Transformer secondary side or cable to neighbor’s substation</td>
</tr>
<tr>
<td>6</td>
<td>Distribution feeder (line or transformer)</td>
<td>Step-down transformers</td>
</tr>
<tr>
<td>7</td>
<td>Distribution load</td>
<td>Step-down transformers, (e.g. where the transformers are owned by the distribution company)</td>
</tr>
<tr>
<td>8</td>
<td>LV supply</td>
<td>Transformer of the distribution company</td>
</tr>
<tr>
<td>9</td>
<td>LV load</td>
<td>Load or transformer at the customer</td>
</tr>
</tbody>
</table>

Table 6.4-5: Measurement points and system location
6.4.2 SICAM P Power Meter

SICAM P is a power meter for panel mounting with graphic display and background illumination, or for standard rail mounting, used for acquiring and/or displaying measured values in electrical power supply systems. More than 100 values can be measured, including r.m.s. values of voltages (phase-to-phase and/or phase-to-ground), currents, active, reactive and apparent power and energy, power factor, phase angle, harmonics of currents and voltages, total harmonic distortion per phase plus frequency and symmetry factor, energy output, as well as external signals and states.

SICAM P is available with mounting dimension of 96 mm x 96 mm and can be ordered with or without display.

The SICAM P comes standard with two binary outputs, which can be configured for energy counters, limit violations or status signals. By ordering, SICAM P can be fitted with 1 additional analog input or output modules.

The unit is also able to trigger on settable limits. This function can be programmed for sampled or r.m.s. values. SICAM P generates a list of minimum, average and maximum values for currents, voltages, power, energy, etc. Independent settings for currents, voltages, active and reactive power, power factor, etc. are also possible. In case of a violation of these limits, the unit generates alarms. Up to 6 alarm groups can be defined using AND/OR for logical combinations. The alarms can be used to increase counter values, to trigger the oscilloscope function, to generate binary output pulses, etc.

**Function overview**

- Measurement of voltage, current, active & reactive power, frequency, active and reactive energy, power factor, symmetry factor, voltage and current harmonics up to the 21st, total harmonic distortion
- Single-phase, three-phase balanced or unbalanced connection, four-wire connection
- Communications: PROFIBUS-DP, MODBUS RTU / ASCII or IEC 60870-5-103, MODBUS RTU/ASCII (only SICAM P50 Series) communication protocol
- Simple parameterization via front key or RS485 communication port using SICAM P PAR software

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**Fig. 6.4-7: SICAM P – power meter**

**Fig. 6.4-8: Input/outputs for P50 Series**
• Graphic display with background illumination with up to 20 programmable screens
• Real-time clock: Measured values and states will be recorded with time stamps
• 1 MB memory management: The allocation of the nonvolatile measurement memory is programmable
• Recording and display of limit value violations and log entries.
• Battery: Recordings like limit value violations or energy counter values stay safely in the memory up to 3 months in case of a blackout.

Applications
Power monitoring systems with SICAM P, a permanently installed system, enables continuous logging of energy related data and provides information on operational characteristics of electrical systems. SICAM P helps identify sources of energy consumption and time of peak consumption. This knowledge allows to allocate and reduce energy costs.

The major application area is power monitoring and recording at MV and LV level. The major information types are measured values, alarms and status information.

SICAM PS0/PS5
Input and output modules
SICAM PS0/PS5 can be equipped with additional analog or digital input or output modules. SICAM PS0/PS5 comes with 1 slot where the module may be installed. For different application areas, 5 different modules are available.

Application
The input modules can be used for acquisition, display and further processing of external signals with a measurement range of 0–20 mA D.C.

Measured values can be shown together with their units on the display. Transmission of the current status of a measured signal to a central master station via PROFIBUS-DP V1, MODBUS RTU/ASCII or IEC 60870-5-103 is also possible.

In addition, mean values of all external analog channels as well as states of digital channels can be recorded and saved into the memory.

All recorded quantities and binary state information can be “read out” and evaluated with the configuration software SICAM P Manager.

Output modules can be used for conversion of any electrical quantity (current, voltage, etc.) into a 0–20/4–20 mA D.C. output signal, generation of impulses for metering, indication of limit value violations, as well as for switching operations.

Module assignment
The assignment of the different analog/digital modules can only be done in the course of an order of a SICAM P. A change or a retrofit of modules of an existing SICAM P is not possible.
6.4.3 SICAM T – Electrical Measurement Transducer

The SICAM T is an digital measurement transducer that allows the measuring of electrical quantities in electrical networks in a single unit. In industries, power plants and substations, transducers are especially used for measurand (e.g. current, voltage, power, phase angle, energy or frequency) assignment into further processing through analog outputs or communication interface for precise control, notification or visualization tasks.

**Device type**
- Top-hat rail mounted device
- Plastic case 96 mm × 96 mm × 100 mm /
  3.7795 × 3.7795 × 3.9370 inch (W × H × D)
- Degree of protection IP20.

**Input and output circuits**
- 4 inputs for alternating voltage measurements
- 3 inputs for alternating current measurements up to 10 A continuous
- 4 optional DC analog outputs freely configurable:
  - Direct currents: 0 mA to 20 mA, 4 mA to 20 mA and –20 mA to 20 mA
  - Direct voltages: 0 V to 10 V and –10 V to 10 V
- individually programmable binary outputs.

**Signalization LEDs**
- Automatically monitor the functions of the hardware, software and firmware components.

**Communication**
- Ethernet: IEC 61850 or MODBUS TCP communication protocol
- Optional serial RS485 interface that enables the device to communicate via the MODBUS RTU or the IEC 60870-5-103 communication protocol.

**Measurands**
The following measurands can be recorded or calculated from the measured quantities:
- TRMS (True RMS) for alternating voltage and current
- Active, reactive and apparent power
- Active, reactive and apparent energy
- Power frequency
- Phase angle
- Power factor and active power factor
- Voltage and current unbalance
  - Mean value of the 3 phase voltages: $V_{avg}$
  - Mean value of the 3 phase currents: $I_{avg}$

**Time synchronization**
For a common time basis when communicating with peripheral devices and time stamping of the process data.
- External time synchronization via Ethernet NTP
- External time synchronization via field bus using the MODBUS RTU or the IEC 60870-5-103 communication protocol
- Internal time synchronization via RTC (if external time synchronization is not available).

**Response time for analog and binary outputs**
The faster response time of the analog and binary output is a very important feature of SICAM T that enables a reliable reaction of the controlling applications. The response time of the device is 120 ms at 50 Hz and 100 ms at 60 Hz.

**Applications**
- Conversion and integration of measurands into substation automation, protection or SCADA process via RTU and/or via protocols IEC 61850 (for KG9662 variant), MODBUS TCP, IEC 60870-5-103 for further control and/or monitoring tasks
- Monitoring of lower voltage levels and heavy load control, e.g. air conditioning and motors
- Depending on the device type, the input circuits for voltage measurement are either designed as voltage dividers or they are galvanically isolated. Devices with galvanic isolation can be used without voltage transformers in the power systems IT, TT and TN. Devices with a voltage divider can also be used in these power systems; for IT power systems, however, an upstream voltage transformer is required.
6.4 Power Quality and Measurements

Main features
- Design: compact and robust for flexible application in industrial and utility environments
- Connections in 1-phase systems, in 3-wire and 4-wire systems
- Applications: flexible for power utilities, industrial and commercial sectors applications
- Measurements: up to 60 measured or calculated values available
- Temperature range: -25 °C to +55 °C (−13 to 131 °F)
- High accuracy: typically 0.1 % for voltage and current at rated input IEC 60688, and 0.2 % acc. to IEC 62053-21
- High EMC immunity: according to standards EN 61000-6-2 and EN 61000-6-4 for the EMC directives, and with the standard EN 61010-1 for the low-voltage directive
- UL Certification: This product is UL-certified to Standard UL 61010-1.

SICAM T applications
Local monitoring or control purposes through assignment of up to 60 available electrical parameters to analog outputs, notifications through binary outputs or integration into SCADA/monitoring systems through communication interface, e.g. serial or Ethernet (fig. 6.4-13).

Highlights
- Flexible current measurement range (up to $2 \times I_n$)
- 4 fast analog outputs (reaction approx. 120 ms at 50 Hz and 100 ms at 60 Hz) for reliable control
- 2 individually binary outputs for fast switching, indications (e.g. limit violation) and operation status monitoring
- 4 LEDs for local status visualization
- Ethernet communications via IEC 61850 and Modbus TCP and serial interface via MODBUS RTU or IEC 60870-5-103
- Internal battery for real time clock and saving of energy counter values in case of a power outage
- User-friendly operation through Web server (no extra software for parameterization needed, no converters and extra cables)
- Real time clock (RTC), field bus synchronization or network synchronization possible via NTP.

Graphical user interface

Parameterization and monitoring software
The device is configured from a connected PC or notebook only. The user interface SICAM T GUI (GUI = Graphical User Interface) is implemented in the device, meaning that for the whole operation and parameterization of the device no additional software is required. It is possible to navigate through the Microsoft Internet Explorer using the icons on the toolbar.

Device status, so as communication, parameterization, log files, value view and maintenance can be easily processed through SICAM T GUI interface (fig. 6.4-14).
6.4 Power Quality and Measurements

6.4.4 Monitoring and Analysis of Voltage Quality with SICAM Q80

Power quality is a complex issue. The voltage quality is affected by all parties connected in the power system: power utilities of transmission and distribution, power producers and consumers. Inadequate power quality has an adverse effect on the dependability of loads in the power supply system, and can have serious consequences. SICAM Q80 is a compact and powerful recorder designed for utilities and industries to continuously monitor the power quality for regulatory purposes (e.g., evaluation against the standards) as well as event-based recordings for explanatory purposes (e.g., wave shape recording), from the generation plant to the last customer in the electrical supply chain.

With SICAM Q80, the quality of the power supply system can be continuously monitored. This can be based on the quality criteria defined in the European electricity supply system quality standard EN 50160 or other assessment criteria. Moreover, data that are above or below the defined threshold values are stored and can thus be used for a meaningful overall analysis. It provides information that allows to see the whole electrical healthy of the power system!

Field of application of SICAM Q80
- Regulatory power quality application: measurement, comparison and profiling of power quality parameters at the individual electrical system interfaces: e.g., generation, transmission, subtransmission and distribution systems.
- Explanatory power quality application: disturbance recording (e.g., waveform capture) support to understand the causes and consequences of power quality problems.

Benefits
- Customer satisfaction: Companies with a suitable power quality monitoring system are proven to be more reliable suppliers and users of energy.
- Asset protection: Early identification of disturbances and active response to them. Comprehensive information for enhancing the visibility and control of assets at the edge of the grid.
- In case of negotiations or disputes, power quality monitoring provides evidences to align interests and to support agreements between parts.
- Quality of supply is in the interests of power utilities, regulators, consumers and the environment.

Function overview
Measurement of continuous phenomena and disturbances according to the necessary accuracy requirements, as stipulated in IEC 61000-4-15, IEC 61000-4-7 and IEC 61000-4-30 (Class A).

Recording and evaluation
- Voltage frequency: frequency deviation
- Slow voltage variation: detection and monitoring of supply interruption
- Rapid voltage variations: voltage dips, voltage swells, rapid voltage changes and voltage fluctuations (flicker)
- Power line signaling superimposed on the supply voltage
- Voltage waveshape: harmonics (up to the 50th harmonic) and up to 10 interharmonics
- Flexible value limit and event definition
- Fault recording triggered by waveform and binary values
- Comparison and reporting of power quality profile according to EN 50160 or local standards.
### Features
- Suitable for monitoring single-phase, 3- and 4-wire power systems (up to 1,000 V<sub>rms</sub>)
- 4 voltage, 4 current, or 8 voltage measuring channels
- Standard: 4 binary inputs, 4 binary outputs
- Sampling rate 10 kHz for network analysis
- Measurement accuracy 0.1 % of the range
- High local storage capability: removable compact flash (standard delivery 2 GB)
- Enhanced data compression process (power quality data)
- Automatic data transfer
- Automatic comparison and reporting of the power quality profile according to EN 50160 or your local standards
- Automatic notification in case of a fault or violations by e-mail, SMS, and fax
- Export functions
- Ethernet and modem communication interfaces for parameterization, remote monitoring and polling
- GPS/DCF-77/IRIG-B and NTP for synchronization
- Network trigger system
- Simple operation, compact and robust design.

**Fig. 6.4-16: Model configuration for a PQ monitoring system**
6.4 Power Quality and Measurements

6.4.5 SIPROTEC 7KE85 – Digital Fault Recorder with integrated Power Quality (PQ)* Measurement and Phasor Measurement Unit (PMU)

Application
- Stand-alone stationary recorder for extra-high, high and medium-voltage systems
- Component of secondary equipment of power plants and substations or industrial plants

Function overview
- Integration to SIPROTEC 5 family
  - Consistent HW concept
  - Variety of extension modules
  - DIGSI as configuration tool
  - Choice of functionality via functional points
- Disturbance recorder class S for applications in substations at MV/HV/EHV level and in power plants
  - 1 x FastScan recorder
  - 2 x SlowScan recorder
  - 5 x Continuous recorder
- Power quality recorder class S according to EN50160 for analysis and recording/archiving of power quality problems of all power applications
- Event recorder for binary signals for observation of the status of various primary components like circuit-breakers, disconnectors, etc.
- PMU according to IEEE C37.118.
- Communication with IEC 61850
- Sampling frequencies programmable between 1kHz and 16KHz
- Time synchronization via IRIG B/DCF77/SNTP
- Internal mass storage:
  - 12 GByte ring buffer
  - Health monitoring / Lossless data compression
- Flexible routing
  - Any assignment of a measured value to each recorder
  - Free combination of measuring groups for power calculation
- Recorded quality bits
  - Quality statement for each recorded value + monitoring of channel quality in SIGRA or SIC AM PQ Analyzer
  - Recording of and triggering on GOOSE values
- Creating of flexible trigger conditions with CFC (Continuous Function Chart)
- Auxiliary functions for simple tests and commissioning
- Test recorder for commissioning and system test

Fig. 6.4-17: Generator and motor protection device 7KE85

Fig. 6.4-18: Expansion module

Fig. 6.4-19: Rear view of a basic module

*In preparation
Application as Phasor Measurement Unit

With the digital fault recorder 7KE85, the function “Phasor Measurement Unit” (PMU) is available like in the past.

Fig. 6.4-20 shows the principle. A measurement of current and voltage with regard to amplitude and phase is performed with PMUs on selected substations of the transmission system. Due to the high-precision time stamps assigned to these phasor quantities by the PMU, these measured values can be displayed together at a central analysis point. This provides a good overview of the condition of the system stability, and enables the display of dynamic processes, e.g., power swings.

If the option “Phasor Measurement Unit” is selected, the devices determine current and voltage phasors, mark them with high-precision time stamps, and send them to a phasor data concentrator together with other measured values (frequency, rate of frequency change) via the communication protocol IEEE C37.118, see fig. 6.4-21.

By means of the synchrophasors and a suitable analysis program (e.g., SIGUARD PDP) it is possible to determine power swings automatically and to trigger alarms, which are sent, for example, to the network control center.
When the PMU function is used, a "PMU" function is created in the device, see fig. 6.4-22. This function group calculates the phasors and analog values, sets the time stamps, and sends the data to the selected Ethernet interface with the protocol IEEE C37.118. They can be received, stored and processed by one or more clients. Up to three client IP addresses can be allocated in the device.

**Information for project planning with 7KE85**

The secondary components of high or medium-voltage systems can either be accommodated in a central relay room or in the feeder-related low-voltage compartments of switchgear panels. For this reason, the 7KE85 system has been designed in such a way as to allow both centralized or decentralized installation.

The 7KE85 can be delivered in different widths, depending on the selected IO combinations. For example the small version is favorable if measurands of only one feeder are to be considered (8 analog and 8 binary signals). This often applies to high-voltage plants where each feeder is provided with an extra relay kiosk for the secondary equipment. In all other cases the extension with more analogue and binary signals via IOs is more economical. The modular structure with a variety of interface and communication modules provides a maximum of flexibility.

**Typical applications of 7KE85**

- Monitoring the power feed
  Monitoring the infeed from a high-voltage network via 2 transformers on two busbars of the medium-voltage network. This application is relevant for the infeeds of municipal utilities companies and medium to large industrial enterprises (fig. 6.4-24).
- Monitoring the infeed (fig. 6.4-24)

**Fault monitoring and power quality in power distribution networks**

Power supply companies with distribution networks are not only suppliers but also consumers, particularly of renewable energy. Therefore, it is important to monitor power quality both at the transfer points of critical industrial enterprises and at the power supply points of the suppliers (fig. 6.4-25).

**Monitoring power quality in an industrial enterprise**

All industrial enterprises with sensitive productions need to document the power quality at the transfer point, and thus document any claims for damages against the suppliers. For internal control, it is important to monitor individual breakouts with regard to cost-center accounting and specific quality features (fig. 6.4-26).
6.4 Power Quality and Measurements

Solution 1:

Evaluated with:
SICAM PQS
PQ Analyzer

Solution 2:

Evaluated with:
SICAM PQS
PQ Analyzer

Fig. 6.4-23: Monitoring the power feed

Fig. 6.4-24: Monitoring the infeed

Solution:

220 kV

110 kV

20 kV

Industrial enterprise
Municipal utilities companies
Wind energy

Evaluated with:
SICAM PQS
PQ Analyzer

Fig. 6.4-25: Monitoring the quality in power distribution systems

Solution:

20 kV

400 V

Welding shop
Press shop
Paint shop

Evaluated with:
SICAM PQS
PQ Analyzer

Fig. 6.4-26: Monitoring the power quality in an industrial enterprise
SICAM PQS fault record and power quality analysis software

The SICAM PQS software package is suitable for use in personal computers provided with the operating systems MS Windows 7. It is used for remote transmission IEC61850, evaluation and archiving of the data received from 7KE85, digital protection devices as well as from SICAM Q80 power quality recorders. The program is used to setup the system configuration and to parameterize the 7KE85 and SICAM Q80 units installed in the field. It enables fully-automated data transmission of all recorded data (fault records, events, mean values) from the acquisition units to one or more networked SICAM PQS evaluation stations; the received data can then be immediately displayed and evaluated and benchmarked according to quality standards so called Grid Codes (fig. 6.4-27).

SICAM PQS offers a variety of applications and evaluation tools enabling the operator to carry out detailed fault record analysis by using time diagrams with curve profiles, vector diagrams etc. The individual diagrams can, of course, be adjusted to individual requirements with the help of variable scaling and zoom functions. The different quantities measured can be immediately calculated by marking a specific point in a diagram with the cursor (impedance, reactance, active and reactive power, harmonics, peak value, r.m.s. value, symmetry, etc.).

Additionally automatic distance to fault calculation and report generation will be executed after an event was recognized in the power supply system.

The power quality analysis is based on the applicable standards EN 50160 and IEC 61000 or on any user-defined Grid Code, and uses an effective reporting tool that provides automatic information about any deviations from the defined limit value.

The data transmission is preferably effected via WAN (Wide Area Network) or telephone network. Depending on the power system which has to be monitored the SICAM PQS system can be aligned accordingly. The modular structure of SICAM PQS permits the use of individual functional packages perfectly matched the requirements. Furthermore the SICAM PQS can also easily expand to create a station control system for combined applications. The program fully supports server/client system architecture.

Highlights

- Vendor-neutral integration of fault recorders, protection devices and power quality equipment via standard protocols or COMTRADE/PQDIF import
- Quick overview of system quality through the chronological display of the PQ index
- Seamless documentation of power system quality
- Automatic notification in case of violation of thresholds of a predefined Grid Code.
- Automatic and precise fault location with parallel line compensation
- Structured, consistent and permanent data documentation and archiving
- Automatic generation of cyclic power quality report

Fig. 6.4-27: SICAM PQS – One System for all Power Quality Data
SICAM PQS functional packages

Incident explorer
Incident explorer is the central navigation interface of SICAM PQS. It acts as a cockpit for the user and delivers a structured overview of events throughout the whole system. It visualizes the contents of the entire power quality archive with fault records, fault locating reports, post-disturbance review reports, power quality reports, and the ability for manual fault location and manual import of comtrade files. The comtrade viewer, which is part of the scope of delivery, makes it possible to analyze the fault (fig. 6.4-28).

PQ inspector
The PQ inspector is a supplementary module that shows at a glance the power quality condition of the entire network for a selected period. This allows for quick identification of the origin and type of violation. Another feature of PQ inspector is the option of generating power quality reports through step-by-step user prompting and on the basis (fig. 6.4-29).

PQ explorer
PQ explorer makes detailed analyses possible based on comparing the measured power quality data directly with the Grid Codes. This comparison and the large number of different diagrams available for displaying power quality data make it possible to understand the nature and extent of a power quality violation very quickly and to initiate adequate (fig. 6.4-30).
6.4 Power Quality and Measurements

**Report browser**

Reports are created automatically at weekly, monthly, and annual intervals and in the event of a violation of the Grid Code. The report browser shows an overview of these automatically generated reports in selected time ranges and the assessment of the results. The individual reports can be opened directly in the report browser (fig. 6.4-31).

**Fault location with parallel line compensation**

Single- or two-sided fault location allows precise pinpointing of the fault, and this can be refined even more through the inclusion of parallel line compensation. The report generated for each fault location computation contains all the important data required. Fast, reliable localization of the fault allows more efficient coordination of personnel deployment and thus helps minimize downtimes (fig. 6.4-32).
Monitoring of fault records and PQ reports via Web Tool

**SICAM Diamond**

Simple access via web to the PQ Archive with SICAM Diamond. It is possible to monitor the Fault records, PQ violation reports (the result of a validation of the PQ data against a assigned Grid Code), fault location reports, scheduled reports (the automatic cyclically generated user-defined PQ reports).

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![Diagram](image)

**Fig. 6.4-33:** SICAM PQS V7.01 / SICAM Diamond V4.0 HF1 goes Web via SICAM Diamond
6.4 Power Quality and Measurements

6.4.6 SIGUARD PDP – Phasor Data Processor

SIGUARD PDP – Reliable System Operation with Wide Area Monitoring

The load on electricity supply systems has increased continuously over the past few years. There are many reasons for this:

- Increased cross-border power trading in Europe, for example, is placing new demands on the tie lines between control areas.
- For example, power transmission on tie lines in the European grid increased almost 6-fold from 1975 to 2008 (source: Statistical Yearbook of the ENTSO-E 2008)
- Increased input of wind power and the planned shutdown of existing power plants will extend the transmission distances between generation and consumers.
- Severe weather and storms can put important lines out of operation, for a short time exposing the remaining grid to increased load quickly.

This means that the power system is increasingly operated closer to its stability limit and new load flows arise that are unfamiliar to network control center operators.

This is where SIGUARD PDP (Phasor Data Processor) comes in. This system for network monitoring using synchrophasors helps with fast appraisal of the current system situation. Power swings and transients are indicated without delay to help the control center personnel find the causes and take countermeasures.

Highlights

- Phasor data processor per IEEE C37.118 standard
- 2 selectable monitoring modes:
  - Online mode
  - Offline mode (analysis of past events)
- Vector view or time chart view can be selected for all phasors
- Calculation and display of the power system status curve
- System monitoring, incl. communication links and PMU status
- Geographic overview (based on Google Earth)
- Basis for fast reporting after faults
- Flexible analysis with formula editor for calculations based on measured values
- Limit values that can be changed online
- Runs under Windows XP and Windows 7, as a pure PDC (without user interface) also under Windows Server 2008.

Applications

- Analysis of the power flows in the system
  SIGUARD PDP can display a clear and up-to-date image of the current power flows in the system with just a few measured values from widely distributed phasor measurement units (PMU). This requires no knowledge of the network topology. The power flows are shown by means of phase angle differences.

![Voltage vector of two measurement points in the network](image)

- Power Swing Recognition
  All measured values from PMUs can be displayed and monitored with easy-to-configure phasor diagrams and time charts. Any power swings that occur are quickly and reliably detected. The zone being monitored can be flexibly adjusted to the current situation in terms of time, geography, and content.
  Using the function ”Power Swing Recognition” (available as from Version V2.1), an incipient power swing is detected and the appropriate damping determined. Detection of a power swing and, if applicable, its insufficient or non-existent damping is signaled (alarm list).
Monitoring of the load on transmission corridors
The voltage-stability curve is especially suitable for displaying the instantaneous load on a transmission corridor. The currently measured operating point is shown on the work curve of the line (voltage as a function of the transmitted power). In this way, the remaining reserve can be shown at any time. This requires PMUs at both ends of the line.

Island state detection
This function automatically indicates if parts of the network become detached from the rest of the network. For this purpose, frequency differences and rates of frequency changes can be automatically monitored. If islands are detected, warnings and event messages are output.

Retrospective event analysis
SIGUARD PDP is ideal for analyzing critical events in the network. After switchover to offline mode, the entire archive can be systematically analyzed and the events played back as often as necessary. This makes dynamic events transparent, and reports can be quickly and precisely compiled. Simply copy the informative diagrams from SIGUARD PDP into your reports.

Alarming on limit value violation with an alarm list and color change in the geographic network overview map
This allows you to locate the position and cause of the disturbance quickly. This function is also available for analyzing the archive.

Display of the power system status as a characteristic value for the stability of the power system
Due to the constant availability of the power system status curve in the upper part of the screen, the operator is constantly informed about trends in system dynamics and any remaining reserves. This curve shows a weighted average of the distances of all measured values, to their limit values.

For further information:
www.siemens.com/powerquality

For further information to chapter 6:
www.siemens.com/protection
www.siemens.com/sicam
www.siemens.com/powerquality
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7 Energy Management

7.1 Principles of Energy Management

Maintaining a reliable supply of electrical power to consumers is a highly complex process as most of this power cannot be stored and the individual components of this process, forming what is called a power system, can be spread over a wide geographical area. The purpose of power system management, also referred to as Energy Management, is to monitor, control and optimize this process in real-time. The basic functionality of power system control is found in the Supervisory Control and Data Acquisition (SCADA) function that collects and records values and statuses acquired from the power system elements via remote telemetry to enable control center operators to supervise and control the power system. Other decision support functions complement this function to provide power system management for a secure and optimal process (fig. 7.1-1).

7.1.1 The Role of the Network Control System in Power System Management

History
The control and information technology used for the management of a power system has its origins in the automation of power plants. The primary objective was then to improve operational reliability (fig. 7.1-2).

With the increasing number of power plants and their interconnection via the grid, primary frequency control, also referred to as generator droop control, was no longer sufficient. To improve on power delivery quality, coordination, including secondary frequency control, of power generation and, later, external interchange became unavoidable and was promptly implemented in control centers.

Before the introduction of the transistor in 1947, the vast majority of protection and control devices used in power system control were of electromechanical design. In the early days, information was transmitted by means of relays and pulse...
As computers became more efficient in the 1970s, the switchgear in transmission networks was also gradually monitored and automated with the aid of power system control technology. In response to the growing demand for network control systems, a number of companies began developing standardized systems for these applications. The systems of that period can be called the first generation of network control systems.

Because of the inadequate graphics capability of computer terminals at that time, the master computers were used mainly for remote monitoring of unmanned stations or for performing calculations to support operations. The network state was displayed visually on large switch panels or mosaic walls that were also used to control the switchgear. Only as the performance of graphical displays improved were Operation management functions gradually transferred to VDU-based Workstations.

As computing power continued to increase in the mid-1970s, it also became possible to use computers for optimization processes. With the aid of optimization programs run initially as batch Jobs and later online as well, it was possible, for instance, to determine the most economical use of hydroelectric and thermal power plants. These programs also provided a method of economically assessing the exchange of energy, a basic requirement for energy trading later on. Increasing computer power was, however, also harnessed to further develop man-machine communication towards greater user friendliness.

In the mid-1980s, power system control, which had until then been restricted to transmission networks, was increasingly used in the distribution network area as well. Apart from pure network supervision, additional functions such as work or material administration were integrated into control systems during the ongoing automation of the distribution network.

**Functions of a network control system**

With the aid of network control systems, network operators can obtain information from the network, usually in real time, which they can then use as the basis for optimizing supervision and control of the power supply system (fig. 7.1-3).

The information transmitted by the station automation systems via telecontrol must be collected and processed at a central point. This function is performed by network control systems that are installed at central locations, which are also known as system control centers or control rooms.
A distinction is made between Transmission Management Systems (TMS) and Distribution Management Systems (DMS) depending on the type of network being managed (transmission or distribution). Prior to deregulation, Energy Management Systems (EMS) were commonly used for the integrated management of generation and transmission. After deregulation, the unbundling of these two functions led to the creation of Generation Management Systems (GMS) for the independent management of the generating units.

All types of network control systems use the so-called SCADA system platform. Other applications may also use this platform. The most important application components of a network control system and their application areas.

Spectrum Power™ offers you a comprehensive range of functions for requirements in energy generation, network operations management and communications, including:

- Supervisory Control and Data Acquisition (SCADA).
- Data input and data modeling:
  - Data modeling compliant with IEC 61970 using the Common Information Model (CIM)
  - Powerful graphics editor
  - Parallel multi-station engineering with job management and undo functions
  - Powerful online data activation
- Extensive communications options with communication protocols
- Maintenance and outage management:
  - Fault report handling
  - Planning and monitoring
  - Fault correction
- Functions for managing transmission networks:
  - State estimation
  - Load flow calculation or short circuit calculation
  - Contingency Analysis
- Functions for managing distribution networks:
  - Fault isolation and restoration of power
  - Load flow calculation
  - Short circuit calculation
  - Expert system
- Functions for energy data management
  - Schedule management
  - Forecasting
  - Archiving
  - Reporting
- Functions for demand side management
  - Load management for electricity and gas
  - Water supply management
- Functions for electric power producers
  - Automatic generation control with load frequency control
  - Scheduling applications

Real-time processing
SCADA applications are basic functions of the network control system and provide a means of supervising and controlling the power supply system. For this purpose, all information transmitted from the network is collected, preprocessed and visually displayed in order to keep the operator constantly informed about the current operating state of the power supply system. The operator can also store additional information in the system or enter corrections for incorrectly reported information or information reported by phone into the system in order to complete the current operational network display (fig. 7.1-4).

The main objective of preprocessing is to relieve the operator of routine work and to supply the operator with essential information. The most important preprocessing steps to mention are limit value monitoring and alarm processing. These are absolutely essential, especially in the case of a fault incident, in order to enable the operator to identify the cause of the fault quickly and precisely and to take suitable countermeasures. The supply state of the network elements is shown in color (topological network coloring) in the process images used for network monitoring in order to provide better visualization of the current network state. As a result, the operator can see at a glance which network sections are supplied and can identify any interruption in the supply at that particular moment.

Another important function performed by the SCADA applications is the so-called operational logbook, in which the process history is shown chronologically in plain text. Entries in the operational logbook can be triggered by events in the power supply system as well as by operator actions.

Switching measures in the power supply system, such as disconnecting and earthing a cable so that maintenance can be carried out without danger, generally require a sequence of individual commands. Because disconnection processes of this type have to be checked for plausibility in advance, a switching sequence management system in a control system can assist the operator in drawing up and testing the required switching sequences. During this process, the switching actions carried out in a simulation environment are recorded and can then be carried out partly or fully automatically after positive testing and in the real-time environment.

![Fig. 7.1-4: Example for a network diagram of a power grid](image-url)
Process data and control center communication
Process data from operational equipment is transferred and recorded directly from the process. There is often also an exchange of process data with other control centers. This exchange of information also has the purpose of enabling processes in the directly adjacent section of the network to be included in the network supervision and control process.

Today, the standardized IEC 870-5-101 and 104 protocols are increasingly used alongside old proprietary transmission protocols for transferring information from the local network. The OPC (OLE for Process Control) standard also offers a method of process communication and a means of communicating with the world of automation. The Inter-Control Center Communication Protocol (ICCP), also known as TASE2, has now become the established form of data exchange between control centers and is compliant with IEC standard 870-6.

Archiving
Another basic function of a control system is the processing of archive data. Archive data processing is responsible for cyclical collection, storage and aggregation. The archive allows different functions for data collection that group together and further process the data received from the real-time database. The resulting values are stored in turn in the archive. However, archives often also provide additional functions such as generating a sliding average or determining maximum and minimum values in order to process the real-time values before they are stored (fig. 7.1-5).

The calculation functions of an archive usually also comprise functions for implementing recurring calculations for time-dependent data. For example, the four fundamental operations can be used on measurement values. These calculations can be carried out at several levels, with the calculations at the lowest level being completed before the calculations at the next higher level are started. A typical application is the totaling of power generation in its entirety and per power plant type, or the balancing of energy consumption according to regions under different customer groups.

Load forecasting
In order to ensure a reliable power supply, a forecast of energy consumption (load) over time is required. Forecasting methods working on the basis of a regression approach, Kalman filtering or neural networks are used for medium-term planning in the range of up to one year (load planning). For the short term, i.e. in the range of up to one week, pattern-based approach is typically used with options to adjust for actual load values, for actual weather data, etc.

Power generation planning
A power producer company has typically a portfolio of different power plants available for generating electrical power. Power generation planning is made whilst economically optimizing the generation of the power needed according to the load forecast, market price forecast and contracts, taking into account the characteristics of the different power plants in the portfolio (fuel costs, start-up and shutdown times and costs, and rate of power change) to produce a generation timetable for all power generating units. These timetables are then used as target for power generation control (fig. 7.1-6). Note that to meet its load the power producer may opt to buy additional energy

- from a 3rd party within the same power system in which case purchase contracts will be integrated to this optimization process, and/or
- from a 3rd party outside the same power system in which case interconnection exchanges will be integrated to this optimization process.

Accordingly purchase and interchange schedules will then be integrated to these timetables.

Power generation control and frequency regulation
The advantage that electric power has of being universally usable is offset by the disadvantage that it is difficult to store. For this reason, the generation of electrical power must take place simultaneously with consumption. The frequency is used as the means of measuring whether generation and consump-
tion are balanced. As long as generation and consumption are in equilibrium, the network frequency corresponds to the rated frequency. If consumption exceeds the power generation, the difference is covered from the kinetic energy of the rotating generator or turbine masses. This drawing of energy, however, causes a reduction in the rotational speed and hence a drop in the frequency. In the reverse situation, in other words, in over-generation, the difference is converted into kinetic energy, and the speed of rotation increases and so too does the frequency.

Because the system frequency is equal at all points in the system, it can be easily used as the input quantity for controlling the frequency of power systems. New setpoint values for the individual generators are determined there from the measured frequency deviation on the basis of technical and economic factors, and transmitted to the decentralized generator control systems by means of telecontrol. If a power supply system is linked to adjacent power systems, the frequency as well as the power exchange with the adjoining systems must be monitored and controlled. This power exchange is taking place over a number of interconnections for which the flow is telemetered.

A PI-type controller, based on a so-called Area Control Error (ACE) updated, typically, every 2–10 seconds, is used to identify the net generation adjustment required to maintain the frequency at or very near its nominal value. Contractual power exchanges can also be accounted for by the same controller such that deviations from the interchange schedules are minimized. Accordingly, individual generation unit adjustments will be calculated and sent as correction signals to the generating units participating to this regulation. This assignment process will also account for the committed (economic or market) schedules of the generating units and the reserve requirements. The set of applications supporting this process is referred to as Automatic Generation Control (AGC).

Transmission network management applications
A transmission network is characterized by a meshed structure, being mesh-operated and having a number of interconnections with one or more external networks. Most, if not all, of its substations are automated. Typically most, if not all, of its switchgear statuses, busbar voltages and line flows are telemetered. The transmission network includes typically an extra high voltage (EHV) part and a high voltage (HV) part. The latter is sometimes referred to as the sub-transmission network. Typically, these measurements are in such a number that they provide more information than it is necessary to solve a power flow. However, these measurements include errors due to the accuracy of their measurement equipment and are even sometimes outright wrong due to faulty measurement equipment and/or telecommunication. A least square approach for optimal estimation combined with a statistical analysis for bad measurement is applied to this problem to determine most accurately the state of the network. This function is commonly referred to as State Estimation. The estimation of the network state supplies the operator with a complete load flow solution for supervising the network, including those sections of the network for which no measurement values are available.

The network state estimation is generally followed by a limit value monitoring process that compares the result of the estimation with the operating limits of the individual operational equipment in order to inform the operator about overloads or other limit violations in a timely fashion. The load flow solution of the network state estimation is then used by other network functions such as contingency analysis, short-circuit analysis or optimal power flow.

The contingency analysis carries out a, typically very large, number of “What if?” studies in which the failure of one or more items of operational equipment is simulated. The results of these load flow calculations are then compared against the operational equipment limits in order to assess the network security resulting from an operational equipment failure. Typically a transmission network must remain secure against any single equipment failure (n-1 criterion) and against selected double and other multiple equipment failures which will be all simulated by this contingency analysis application. In the case of security violations other application tools can then be used to identify preventive or corrective solutions for such cases with violations.

The short-circuit analysis simulates different types, e.g. phase-to-ground, of short-circuits at selected node points, typically busbars, of the network to calculate the resulting fault current and fault current contributions from neighboring branches and generating units. The results are then compared to the short-circuit ratings of these near-the-fault equipments, i.e. breaker, branch and/or generating unit, for possible violations. The operator is informed about any limit violations so that suitable remedial action can be taken in a timely fashion.

The optimal power flow attempts to determine the settings of control equipments, e.g. the tap of a transformer, to operate optimally the power system according to some selected criterion and subject to operating constraints such as equipment limits:

- Network loss minimization – network losses are directly related to the amount of reactive power flow and, therefore, to the voltage profile throughout the network. The optimal power flow will minimize the transmission losses by determining the optimal settings of all voltage controls available, i.e. generators, transformers, capacitors, etc.
- Generation cost minimization – The optimal power flow will minimize the total cost of generation by determining the optimal dispatch of each generating units. Today this criterion is applied mostly in pre-deregulation or centralized markets. Variations of this criterion, e.g. involving deviations from market set points, are also solved by optimal power flow in fully deregulated energy markets.
- Network security – In the presence of equipment limit violations the optimal power flow will determine corrective actions in terms of voltage control settings and/or real power control settings to minimize equipment limit violations, i.e. the settings to restore the network to a secure state. Similarly, the optimal power flow can also be used in normal operating conditions to increase the security of the network by increasing operational margins to limits, i.e. by enforcing tighter equipment limits. As increased security margin can be
operationally very expensive it is typically applied only to a few selected critical equipments.

The network calculation functions just described can also be used to study network conditions different from actual conditions. This study mode is used, for example, for checking a planned switching operation.

**Distribution network management applications**

A distribution network is characterized by a mostly radial and lightly meshed structure that is operated mostly radial. The distribution network typically includes a medium voltage (MV) part and a low voltage (LV) part and is interconnected to the transmission network at HV/MV substations. Depending upon countries few to all of the HV/MV substations are today automated. Under the Smart Grid pressure automation of the MV/LV substations is now accelerating in Europe whilst automation of the MV feeders is now accelerating as well in the US. For these reasons telemetry, e.g. that of power flows, is relatively limited but rapidly increasing (fig. 7.1-7).

Perhaps the most important application in distribution network is the outage management that is responsible for the management of all planned and unplanned outages, the latter part being also referred to as Fault Management. Outage Management integrates information from SCADA (events), metering (events), and customers (trouble calls) to infer one or more concurrent network outages. With the additional help of crews and support from analysis tools, operators are then able to promptly locate faults, isolate faults and restore service. Outage Management will also provide calculation of performance indices that are typically required by the regulator to assess the performance of the utility towards its customers. Outage Management with the support from analysis tools provides also for the coordination of planned outages with the normal operation of the network to ensure safety of the crews and continuity of service to the customers.

Other applications in distribution network belong to one of 2 domains: outage analysis or network analysis. Outage analysis includes typically a fault location application destined at providing the operator with the (visual and descriptive) location of the fault from real-time events using, for example, fault indicators and distance relays, and a fault isolation/service restoration application destined at providing the operator with a switching sequence for isolating the fault and restoring service to customers. As the latter may encounter problems meeting all network security constraints and/or restoring service to all customers one or more switching sequences may be provided to the operator.

Distribution network analysis applications are in many ways similar to those for transmission network but with a different emphasis due to the specific size, structure and mode of operation of the distribution network. One resulting requirement is the need to support balanced, unbalanced and/or unsymmetrical operation of the network. Due to the limited amount of available measurements and their quality a distribution load flow with load scaling has been typically used to determine the state of the network. However, as measurement availability increases, this approach is being progressively replaced by a state-estimation-like approach, e.g. load flow in combination with a least square approach to optimally scale loads to the measurements, to determine the state of the network. This latter function is

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**Fig. 7.1-7: Schematic workflow in a distribution management system**
7.1 Principles of Energy Management

referred to as Distribution State Estimation. The solution will then be checked against equipment limits for any violations. This application provides the operator with a complete state of the network including security risks beyond that available from SCADA. This application’s solution is also used by the other network applications to perform further analysis.

For example, optimal power flow will be used to optimize the operation of the network, either towards minimizing network losses by adjusting voltage controls such as capacitors and transformer taps or towards minimizing network overloads by reconfiguring the network. A short circuit application, similar to that used in transmission, is also used in distribution to identify security risks against short circuits in different parts of the network. A security analysis application is also appearing in distribution to validate restoration procedures in parts of the network that are under abnormal conditions, the applicability of pre- and post-planned-outage procedures ahead of schedule, etc. As the distribution network is often in constant state of change, a relay coordination application is becoming more and more common to validate or suggest adjustments to relay settings under abnormal network configurations.

**Load shedding**

To insure system stability and maximum service availability during periods of very high demand concurrent to generation shortage and/or large disturbances utilities have, sometimes, no other alternative but to disconnect some loads. This process is typically referred to as load shedding. It is normally used as a last resort solution after all other alternatives (generation reserve, etc.) have been exhausted. This process is supported by an application called Load Shedding (LS).

Typically load shedding will be implemented via direct SCADA commands, Load Shedding Controllers (LSC) and/or under-frequency/voltage relays. In the last two implementations configurations/settings may be downloaded from the control center. Note that these two implementations are the fastest (< 100 ms) but required careful coordination (e.g. 2003 US blackout). The following typical load shedding activations are possible:

- **Manual load shedding**
- **Rotating load shedding** (generation shortage for extended time)
- **Equipment overload load shedding** (delay/avoid tripping of equipment)
- **Balancing load shedding** (import target deviation, islanding)
- **Under-frequency/voltage load shedding** (system stability/voltage collapse).

As conditions return to normal, the load shedding application will also provide support for load restoration, i.e. the manual or automatic re-connection of shed loads.

**Load management**

As demand has increased much faster than production and network capacity peak demand has become more and more difficult and costly to meet. Considering also that the network is under-used in other periods (e.g. at night) various incentive programs reducing or shifting consumption have been created that would allow the utility to manage some of that peak load should the need arise.

In this context of balancing demand with production, load serving entities, including distribution utilities, must ensure that energy balancing is met whilst still respecting their energy purchase contracts. This process includes the forecasting of the customer loads, the optimal scheduling (typical cycles of 15, 30 or 60 minutes) of their dispatchable means to meet the forecasted demand and the energy purchase constraints, the monitoring of this plan’s execution in real-time (typical cycles are 30, 60 or 120 seconds), and, when necessary, the implementation of corrective actions including load control. The first two steps are implemented using similar tools to those already described earlier albeit with adaptations, that is load forecasting and energy resource optimization. The last two steps will monitor all resources and control those resources available to control towards meeting energy purchase schedules over contractual (tariff) time periods and towards balancing energy as demand fluctuates outside the forecast. The load control that may be required must, of course, account for slow, fast and time-constrained load response.

In the near future, this process will integrate Demand Response, a concept identifying dynamically the loads to be available for such control.

**Training simulator**

The growing complexity of existing power systems places increasing demands on operation personnel (fig. 7.1-8). Efficient training simulators are therefore required for carrying out the necessary comprehensive hands-on training. The following areas can be covered with training simulators:

- **Familiarization of operation personnel with the control system and the existing network**
- **Training of experienced personnel to changes in network, operating procedures, tools, etc.**
- **Training of personnel to daily work as well as to emergency conditions (e.g. blackouts)**
- **Simulation and analysis of operational incidents (post-mortem or anticipated) towards improving on existing operating procedures**
- **Testing of possible network expansions and analysis of alternatives, testing of new tools and analysis of results, etc.**
For the training of personnel, training simulators must reflect accurately the power system behavior and provide to the operator the very same tools, including visualization, as those used in the control center for an effective training. The training simulator includes 4 essential components (fig. 7.1-9):

- A training management component
- A power system simulation component
- A telemetry simulation component
- A copy of the management system (EMS, TMS, DMS or GMS).

The power system simulation component is responsible for the accurate simulation of the dynamic behavior of the managed system, i.e. that of all its field equipments (generating units, network and loads). The telemetry simulation component feeds into the management system copy the simulated field data as they would normally come from field equipments into the control center.

The training simulator provides to the trainee an environment identical to that used in operation and to the instructor an environment that allows him to create training scenarios, influence (with or without knowledge of trainee) the training session, etc.

**Operator Training Simulator (OTS)**

OTS is based on 4 key components (fig. 7.1-9):

- A training management component
- A power system simulation component
- A telemetry simulation component
- A copy of the control system (e.g. EMS).

The training management component provides tools for creating training sessions, executing training sessions and reviewing trainee performance. It provides tools to

- initialize the training session, e.g. from real-time or a saved case
- define the system load profile
- create event sequences, e.g. a breaker opening, a telemetry failure, etc., that can be either time triggered, event triggered or command triggered
- create training scenarios, i.e. a number of event sequences, to be activated during the training.

It also provides start/stop and pause/resume functions for the execution of the training session. During the training session it is possible for the trainer to create new events and/or modify the running scenario.

The power system simulation component provides a realistic simulation of the power system behavior to support training from normal operation to emergency operation including islanding conditions and blackout restoration. The simulation is based on a long-term dynamic modeling of the power system including:

- Load modeling with voltage & frequency dependency
- Generation modeling with governor, turbine/boiler and generator models
- Frequency modeling
- Voltage regulator modeling

- Protection relay modeling
- External company LFC modeling.

The telemetry simulation component provides the simulation of the data communication between the power system and the control system. It transfers as simulated field telemetry the results of the power system simulation to the control system copy. And it processes all commands issued by SCADA (operator), LFC, etc. and transfers them to the power system simulation. This simulated telemetry can be modified via the scenario builder by the trainer to reflect measurement errors, telemetry or RTU failures, etc.

This operator training simulator provides a dedicated environment for the trainee (operator) and one for the instructor that allows the instructor to influence the process in order to force responses from the trainees. The trainee interface is identical with that of the control system so that, for the trainee, there is no difference in functionality and usability between training and real operation.

**Multi-Utility**

Some distribution utilities will manage the distribution of multiple commodities, e.g. electricity, district heating, gas and/or water. Whilst the distribution process, for example with load management, is commodity specific, inter-dependencies will be created either by the procurement process or the production model.

It is not unusual to find in distribution cogeneration power plants, also referred to as combined heat and power (CHP) power plants, providing electrical power and district heating. Management of these 2 highly integrated commodities will require adapted tools accounting for the high inter-dependencies existing between the production and the demand of these 2 commodities.
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7.1.2 Network Control Centers in a Deregulated Energy Market

As a result of the movement towards deregulation and liberalization of the energy business, the electricity industry has undergone dramatic changes since the beginning of the 1990s. This process has been marked by the following characteristics:

- Competition wherever possible – electrical energy is traded as a commodity. This initially affects power generation, but other services can also be offered on a competitive basis.
- Commercial Separation of the natural network monopolies from the competitive elements. This impacts numerous areas, such as planning, operation and maintenance of formerly integrated systems.
- Access to the networks by third parties. This is an essential precondition for open trading in electrical energy via the natural network monopoly.
- Regulation of the network monopolies by a public agency. Because the network is the basis for competition in the electrical energy market, considerable importance is attached to reliable, economical and neutral network operation. In order to ensure such operation, a new regulatory element must be introduced at the same time that other sections of the electricity business are deregulated.

Restructuring models

In a deregulated environment of the type just described, the power companies that traditionally had a vertically integrated structure start to split into companies responsible for power generation (GENeration COMPanies), transmission (TRANsmission COMPanies), distribution (DISTribution COMPanies) and energy service (Load Serving Entites – Service Provider COMPanies). This restructuring opened the door to many new market players (fig. 7.1-10), such as electricity traders and brokers who purchase energy from GenCos, independent power producers (IPPs) or other sources and resell it.

The technically critical part of deregulation concerns the operation of the overall system. Because there is no longer integrated operation of generation, transmission, distribution and energy service in one business unit, a dedicated organization must take over the responsibility for observing specific electrical energy quality standards such as frequency control, the voltage level and provision of adequate generation and transmission reserves for emergencies. When implemented independently of all other energy business activities this organization is referred to as an Independent System Operator (ISO), e.g. in North America, and when integrated with a TransCo it is referred to as a Transmission System Operator (TSO), e.g. in Western Europe. An ISO is typically managing the energy market over a grid that encompasses multiple TransCos whilst a TSO is typically managing the energy market over the grid under its own TransCo’s responsibility. ISOs are also referred to as Regional Transmission Operators (RTOs).

The ISO/TSO does not have its own generation capability. Therefore it must purchase regulating energy (active and reactive power) from the power producers. Whilst many energy contracts are established as bilateral contracts some of the energy can also be bought/sold in an open energy market facilitated by one or more energy exchanges, e.g. the European Energy Exchange (EEX) in Germany. This market model is typically referred to as a spot energy market and is most common in TSO-structured energy markets for better market transparency and liquidity. Energy markets are often structured along time lines such as day-ahead, intra-day, etc. energy markets and types such as balancing, reserve, etc. energy markets. The proportion of energy traded on the spot market compared with what is fixed by bilateral agreements can vary from one country to another.

New requirements for network control centers

Energy markets models vary significantly from region to region and typically take many years to reach relative maturity, i.e. stable market rules. There is, therefore, a strong requirement for high flexibility/customization in the proposed market solutions (fig. 7.1-11).

The ISO/TSO whilst responsible for rules that have been enforced for decades are now facing a much more complex process using market mechanisms to acquire the information and means enabling them to enforce these rules; information and means that are now owned and controlled by the many competing market participants. And the ISO/TSO, as it gets access to the data necessary to fulfill his role and responsibilities from the market participants, will need to enforce absolute confidentiality since these data reflects often market participants positioning, i.e. market competitive data.

Similarly, network planning necessary to support a properly functioning energy market, i.e. one operating without congestion, has become a real challenge between the ISO/TSO, TransCos and these same market participants.
Last but not least, energy markets require transparency and auditing. Many services that used to be bundled must now be all separately identified and accounted for, detailed market compliance monitoring must be performed, and extensive archiving of it all must be possible.

Communication
As extensive communication between the control center and the various market participants such as power producers, distribution companies, energy exchanges and traders will increase greatly. Whilst some communication media have been already in use in the control center, the use of open media such as internet will expand significantly. And the many new market interactions such as network access/capacity requests, ancillary market requests, etc. will require new solutions using this new communication infrastructure. The OASIS system (Open Access Same-Time Information system) for reserving transmission capacity in the United States is an example of an existing system of this kind.

Fundamental changes to the properties of network control systems
Many of the ISO/TSO functions will no longer be self-serving but instead will be to serve the market participants towards open and fair access to the network. Whilst many functions will remain the same as those prior to unbundling, many of the tools needed by the ISO/TSO for executing them will rest with the market participants. The ISO/TSO will therefore need to buy the use of these tools from the market participants whilst building its own revenue through network access fees. Many new functions will also be required to support an open and fair access to the network to all market participants particularly when to manage network congestion (e.g. locational marginal pricing), transfer capacity limitation (e.g. cross-border capacity auctioning), etc.

To guarantee open and fair access to the network and equal treatment between all market participants, many of these functions will be using market mechanisms. This implies that many of the solutions developed for these functions will be financially-driven whilst still addressing the same physical problems and therefore will require a lot more integration with back office functions such as, for example, settlement.

Network calculations
The basic functions, such as state estimator, load flow calculation, short-circuit calculation and contingency analysis, will not normally be influenced by the restructuring. However an application such as optimal power flow considering availability/controllability of generation resources will be affected by the restructuring of the energy business. The total cost optimization of generation is no longer the responsibility of the ISO/TSO but that of each market participants. But the use of generation (MW and Volt/VAr) whether for security violation relief or network loss reduction, still responsibilities of the ISO/TSO, will require the application to account for the cost of using (variable cost) that...
resource within the terms agreed in a separate market based process. The cost of availability (fixed costs) is already included in this market based process.

Power generation planning
Power generation planning is no longer the responsibility of the ISO/TSO and therefore no longer considered within the control center. However its results must be communicated by the market participants to the ISO/TSO for it to assume its network operation and security responsibilities.

This process (fig. 7.1-12 and fig. 7.1-13) is quite elaborate and varies from market to market (e.g. with/without exchange, single/multiple buyer, etc.) but with some constants with respect to the part under the ISO/RTO responsibility. The ISO/TSO basic process consists in collecting all market participants’ positions, i.e. their production plans, and validating it against network security whilst satisfying load forecasts and planned outage schedules. In the case network security is not satisfied market signals are returned to the market participants for a new production plan and this until network security is satisfied. In parallel or concurrently the ISO/TSO will also request from the market participants bids to provide power for ancillary services, e.g. regulating power. These bids will be finalized upon a market clearing at the market clearing price. Of course, these bids will be integrated to the load serving energy schedules in the above mentioned network security validation process. These market mechanisms will be, typically, performed at least one day ahead (day-ahead market), and one hour ahead (real-time market) of real-time operation. This process will then be completed on the next day by market settlement to address the actual energy served.

Power generation control
The full set of generation control applications still apply with, however, some adjustments. Indeed target generation timetable is now defined by the market participants (see process description above). And the availability and limits of regulating power and reserve power are now defined by the process where the ISO/TSO acquires access to and use of these resources from the market participants (see process description above). The production cost monitoring application is still sometimes used with adjustment to account only for the regulating costs.

Fig. 7.1-12: Fundamentals
Fig. 7.1-13: ISO/TSO Overview
7.1.3 Common Information Model

In order to survive in the deregulated energy market, power companies today face the urgent task of optimizing their core processes (fig. 7.1-14). This is the only way that they can survive in this competitive environment. One vital step here is to combine the large number of autonomous IT systems into a homogeneous IT landscape. However, conventional network control systems could only be integrated with considerable effort because they did not use a uniform data model standard. Network control systems with a standardized source data based on the Common Information Model (CIM), in accordance with IEC 61970, and its extensions IEC 61968 (DMS) and IEC 62325 (energy market), offer the best basis for IT integration.

CIM – key to interoperability and openness

The Common Information Model (CIM) defines a common language and data modeling with the object of simplifying the exchange of information between the participating systems and applications via direct interfaces (fig. 7.1-15). The CIM was adopted by IEC TC 57 and fast-tracked for international standardization. In the United States, CIM is already stipulated by the North American Reliability Council (NERC) for the exchange of data between electricity supply companies. The standardized CIM data model offers a very large number of advantages for power suppliers and manufacturers:

- Simple data exchange
- Standardized CIM data remains stable, and data model expansions are simple to implement
- As a result, simpler, faster and less risky upgrading of energy management systems, and if necessary, also migration to systems of other manufacturers
- The CIM application program interface creates an open application interface. The aim is to use this to interconnect the application packages of all kinds of different suppliers per “Plug and Play” to create an EMS.

CIM forms the basis for the definition of important standard interfaces to other IT systems. Siemens is an active member of the standardization bodies and the working group in IEC TC 57, playing a leading role in the further development and international standardization of IEC 61970 and the Common Information Model. Working group WG14 (IEC 61968 Standards) in the TC57 is responsible for standardization of interfaces between systems, especially for the power distribution area.

Standardization in the outstation area is defined in IEC 61850. With the extension of document 61850 for communication to the control center, there are overlaps in the object model between 61970 and 61850. In order to accelerate harmonization between documents 61970 and 61850, TC57 has set up a working group (ad hoc WG07).

The primary future challenge is to extend the standard beyond the control center. Once the standard is extended, it will allow full data management and data exchange between the transmission, distribution, planning, and generation areas of the enterprise. Especially urgent at the present time is to move the standard into the newest areas of smart grid, Advanced Metering Infrastructure (AMI), and Home Area Network (HAN).

CIM data model and packages

The CIM data model describes the electrical network, the connected electrical components, the additional elements and the data needed for network operation as well as the relations between these elements. The Unified Modeling Language (UML), a standardized, object-oriented method that is supported by various software tools, is used as the descriptive language. CIM is used primarily to define a common language for exchanging information via direct interfaces or an integration bus and for accessing data from various sources.

The CIM model is subdivided into packages such as basic elements, topology, generation, load model, measurement values and protection. The sole purpose of these packages is to make the model more transparent. Relations between specific types of...
7.1 Principles of Energy Management

objects being modeled may extend beyond the boundaries of packages.

Topology model

The electrically conductive connections between the elements are defined via terminals and nodes (connectivity nodes). Every conductive element has one or more terminals. A terminal connects the element, such as a generator, or one side of, for example, a circuit-breaker, to a node. A node can hold any number of terminals and provides an impedance-free connection linking all elements connected to it. A topology processor can determine the current network topology via these relations and with the current states of the circuit-breakers. This topology model can also be used to describe gas, water, district heating and other networks for tasks such as modeling interconnected control centers.

Measurement value model

The dynamic states of an electric network are displayed in the form of measurement values. Measurement values can contain numerical values, such as active/reactive power, current and voltage, or discrete states such as a 1-switch position. Measurement values always belong to a measurement. A measurement always measures a single physical quantity or a state of the relevant object. It is either allocated directly to the object or to a terminal of the object if it is significant at which end of the object the measurement is made, such as a measurement at the beginning of a high-voltage line. A measurement contains one or more measurement values, e.g., the value transmitted by SCADA, or the value determined by the state estimator or by the voltage/reactive power optimizer. Whether the current value comes from the expected source or is a substitute value can also be indicated if, for example, the connection to the process is interrupted (fig. 7.1-16).

Interoperability tests and model data exchange

Since September 2001, North American Electric Reliability Corporation (NERC) has prescribed the CIM/RDF/XML formal for the exchange of electrical network data between network security coordinators. With funding from the Electric Power Research Institute (EPRI), leading manufacturers of complete EMSs or partial components (ABB, Alstom, CIM-Logic, Langdale, PsyCor, Siemens and Cisco) have started planning interoperability tests and developing the tools necessary for this. CIM XML interoperability tests began in December 2000 and take place annually today. Interoperability (IOP) testing proves that products from different participants can exchange information and provide the interfacing requirements based on the use of the IEC standards that have been developed to date. An additional feature and objective of this and future IOP tests is to verify and validate that changes made to the IEC standards have been implemented and do not prevent or impede data exchange or interaction between the participants. The verification of annual IEC specification updates is an integral part of the IOP testing process. The IOP test report gets published afterwards and fully documents all the results as well as the issues discovered during testing.

The principle of the test can be seen in fig. 7.1-17. Participant A imports the test data using the tool, modifies the data and exports it for further use by participant B. Participant B imports the data, processes it and amends it and exports it for participant C, and so on. Some participants provide a model that is used during the IOP testing (for example: Areva 60 Bus Model, GE WAPA 262 Bus Model, SNC-Lavalin 60 Bus Model, and Siemens 100 Bus Model). Typically full and incremental model are exchanged and validated between the participants. Power flow solution tests are intended to verify the correct exchange of power system model files including generation and load through the execution of power flow applications. In addition specific tests focused on implementing the latest annual IEC standard contents are performed specifically.

Fig. 7.1-16: Measurement value model

Fig. 7.1-17: Principle of the interoperability test
7.1.4 IT Integration and Service-Oriented Architecture

In order to survive in the deregulated energy market, power companies today face the urgent task of optimizing their core processes. This is the only way that they can survive in this competitive environment. The aim is to make the system architecture modular and component-based so that a flexible configuration and IT integration can be implemented in a cost-efficient manner. The crucial step here is to combine the large number of autonomous IT systems into one homogeneous IT landscape. However, conventional network control systems could only be integrated with considerable effort because they did not use any integration standard as none did exist. Network control systems designed with a Service Oriented Architecture (SOA) offer the best basis for IT integration.

Open systems through the use of standards and de facto standards
A modern network control system provides the basis for integration of an energy management system in the existing system landscape of the utility through the use of standards and de facto standards.
- IEC 61970 Common Information Model (CIM) defines the standard for data models in electrical networks. It supports the import and export of formats such as XDF and RDF, which are based on the XML standard
- Web-based user interface, webtechnology
- Standardized PC hardware instead of proprietary hardware
- Client/server configuration based on Standard LANs and protocols (TCP/IP)
- Open interfaces (OBCD, OLE, OPC, etc.)
- RDBMS basis with open interfaces
- Nationally and internationally standardized transmission protocols (IEC 60870-5, IEC 60870-6)

Service-oriented architecture
A modern network control system provides a service-oriented architecture with standardized process, interface and communication specifications based on standards IEC 61968 and IEC 61970. They form the basis for integrating the network control system in the enterprise service environment of the utility.

The services of a control system comprise:
- Data services with which, for example, the databases of the core applications can be accessed, e.g., readout of the operational equipment affected by a fault incident in the power supply system
- Functional logic services, e.g., for starting a computing program for calculating the load flow in the power supply system
- Business logic services that coordinate the business logic for specific energy management work processes of the participating systems, e.g., fault management in the network control system within the customer information system at the utility.

The network control system is one of many systems in the IT network of the utility that interacts with other systems and that offers and uses services such as:
- Services forming part of the offered scope of functions of the network control system
- Services that are used by the network control system and are provided by other systems and applications

Fig. 7.1-18 shows a typical example of the incorporation of the network control system in the enterprise service environment of the utility. Further planning with respect to the required work processes and integration in the heterogeneous system landscape of the utility are based on this incorporation.
Fig. 7.1-18: Spectrum Power SOA (Service-Oriented Architecture): Integration of the network control system in the enterprise Service environment of the utility
Integration into IT networks
A modern network control system acting as an energy management system fits harmoniously into the IT networks and the existing IT landscape of the utility (fig. 7.1-19). The network control system is one of many systems in the IT network of the utility that interacts with other systems. The following are some of the points defined for the IT integration process: Access to the system by intranet users, e.g., from the back office:

- Configuration for the DMZ (Demilitarized Zone) Integration of the corporate network, such as for e-mail notification
- Protected area for the application and SCADA Servers
- TCP/IP-based communication to substations or to adjoining control centers
- Configuration of switches/routers
- Password protection and requirements.

Fig. 7.1-20 shows an example of the integration of the network control system in the IT network of the utility. It forms the basis for further planning with respect to the tasks required during IT integration in the heterogeneous system landscapes of the utility.

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![Image of integration diagram](image-url)
7.2 Energy Management

Products and Solutions

7.2.1 Spectrum Power Control Systems

Siemens has supplied more than 1,600 computer-based control systems for power systems worldwide. The result of these many years of experience is the development of the product family Spectrum Power™ – control systems for electric power systems as well as for gas, water and district heating networks (fig. 7.2-1).

A Spectrum Power control system is divided into various Subsystems. On the basis of a minimum configuration for operation, it is possible to add subsystems to meet the other requirements in terms of additional functions, structure and size of the system. With its modular structure, the system can be expanded with little effort, even subsequently. Modules can be replaced or new modules can be added to implement the required modifications. On the basis of the standard system, open programming interfaces permit individual adaptations and subsequent expansions for new or existing customer-specific components. In a basic configuration, a Spectrum Power control system encompasses the following components, which are described in greater detail in the remainder of this section:

- **Basic services**
  To ensure that the basic functions are provided, such as real-time database services, data exchange and coordination of computers (e.g. redundancy) involved in the control center
- **User interface**
  For providing user-friendly, powerful and graphically oriented interfaces to the operator
- **Information Model Management**
  For data entry and data maintenance of network data, single-line diagrams and data exchange with other IT systems
- **Communication front end**
  For interfacing the field remote terminal units (RTU) to the process
- **ICCP and ELCOM**
  For Inter-communication between Control Centers based on Standard-protocols (ICCP) and de facto standard protocols (ELCOM).
- **SCADA applications**
  For implementing the functions required for system operation, i.e. system monitoring and controlling.

In addition to these components, the following Subsystems, which are described in greater detail in the remainder of this section, are available for expanding the functionality. They are used and configured to match the tasks and size of the control systems:

- **Multi-site operation of control centers**
  For the flexible and dynamic system management (modeling and operation) in multi-site configuration
- **Historical Information System**
  For the archiving and subsequent reconstruction of the process data

- **Forecasting applications**
  For the long-, medium- and short-term forecasting of system loads
- **Power scheduling applications**
  For optimal resource planning, including commitment and planned dispatch, of the power generating units
- **Power control applications**
  For the monitoring and control, i.e. real-time dispatching, of the power generating units participating to frequency regulation
- **Transmission network applications**
  For fast and comprehensive analysis and optimization of the transmission network operation
- **Outage management applications**
  For efficient management of planned and unplanned outages in the distribution networks
- **Distribution network applications**
  For fast and comprehensive analysis and optimization of the distribution network operation

Fig. 7.2-1: Spectrum Power control system
Expert system applications
For supporting the operator in critical and complex tasks in the field of distribution network faults

Training simulator
For training the operator to all range of network behaviors with the tools and user interface as used in operation.

SCADA applications
The SCADA applications group together all Spectrum Power functions that are the minimum required to operate a network control center. SCADA contains all functions for signaling, measuring, controlling and monitoring (fig. 7.2-2).

The basic data processing uses preprocessed data of the communication front end for further processing. Value changes are monitored, and data are distributed to other subsystems and written to the operational database. Moreover, calculations, logic operations and special processing functions for special data types (e.g., metered values) are performed.

Spectrum Power control systems use a mature network control concept that reduces the execution time and increases operational reliability. Network control can be performed for any elements of the energy distribution network from any operator station that is set up to perform that task. Individual switching operations and switching sequences can be implemented. Online adaptations of interlock conditions and safety features permit network expansion without interrupting operation (using a preliminary test in study mode). Complex switching operations such as busbar changeover and line switching permit reduced switching times and therefore fast execution of the switching operations. To ensure operational reliability, the network control concept of Spectrum Power contains various additional safety features such as checking the various interlock conditions, network reliability monitoring of planned switching operations, and monitoring of network changes during switching operations.

Spectrum Power control systems allow the user to freely position temporary network modifications such as temporary jumpers, earth connections and isolating points online or to remove them without having to resort to source data management. Temporary network modifications become active in the topology immediately (interlocking, path tracing, etc.). They remain active in topology until they are removed again. The set temporary network modifications can be parameterized.

Switching procedure management provides the control room personnel of a dispatch center with powerful tools for creating, checking and executing switching operations in the network (in the process and study mode). Up to 1,000 switching procedures can be managed; each switching procedure can contain up to 100 actions.

Acoustic alarms and blinking display elements on the screen inform the user about alarms and deviations from the normal state of the power supply system. Logs are used to record alarms and indications. Several logs can be kept. Each log can be assigned to a certain output unit. By using fault data acquisition, the dispatch center personnel and system engineers can analyze the states prevailing in the power supply system before and after a fault. Snapshots, trend data and state changes are stored in this analysis.

Interactive topological path tracing allows the operator to determine paths between electrically connected equipment in the distribution network. The network coloring function controls the color display of equipment depending on various properties of individual items of equipment. Partial networks, network groups (e.g., voltage levels) and operating states of equipment (e.g., dead, earthed, undefined) can be highlighted in different colors.

The report generator is an easy-to-use tool for simple and fast creation, management and output of reports. An SQL interface permits direct access to the database of the system. The layout can be configured individually by the operator using the graphic editor (in the formal world view). The user can define variables for dynamic values that are updated automatically when a report is created. Moreover, data views (tables and station diagrams) can be linked in, and their dynamic elements are updated automatically.

Basic system services
The Spectrum Power contains various basic functions (services and systems) that govern the fundamental functions required to operate a network management system. Based on the operating systems and relational databases, these functions are used to organize data management, data exchange and communication between the modules installed on distributed computers.

The multi-computer system is a subsystem that manages communication between distributed computers and various services for hardware and software redundancy, multi-computer coordination and system state monitoring. Bidirectional communication between individual programs of the system is possible. The following functions are implemented:
7.2 Energy Management Products and Solutions

- Management of the operating contexts
- Process Operation (normal state of the system)
- Study context (to perform “What if?” studies)
- Test context (system test after data or program modifications)
- Training (context for training Simulator)
- Management of computer states
- Redundancy
- Monitoring
- Error detection and automatic recovery
- Data consistency
- Start-up coordination and switchover
- Updating and synchronization of date and time

The high-speed data bus is a communication system that organizes the link between the user programs and the basic system via standardized interfaces. This communication is provided between individual program modules within a computer. Communication between several computers is conducted via the local area network (via TCP/IP). The high-speed data bus is also used as the link between the modules and the database. Further features are:

- Integrated time processing
- Support of redundant LANs
- Support of the test and Simulation mode
- Performance of immediate program activation after delay or cyclically

The database system of Spectrum Power consists of an operational database for real-time operation (process and application data) and a relational database that is used by the Information Model Management. Features of the database system are:

- Standard model for all process and application data
- Incremental data changes
- Import and export of data

**Information Model Management**

The Spectrum Power Information Model Management (IMM) is the data modeling, data maintenance and data exchange tool specifically designed to cost effectively and efficiently manage the power system model data for the EMS/DMS applications, SCADA, communication to RTUs, ICCP and other enterprise information (fig. 7.2-3). It provides a single, central location to manage all power-system-related data.

**Fig. 7.2-3:** The Spectrum PowerCC Information Model Management provides the functionality to enter and maintain all power-system-related data
input and maintain all power system-related data and is fully compliant with the international Standard for a Common Information Model (CIM), IEC 61970. The IMM embraces widely accepted industry standard technology such as a commercial Relational Database Management System (RDBMS) and Extensible Markup Language (XML).

The task of IMM within the power control system is to manage the input of the data of the electric power system into the database, both during commissioning of the system and afterwards for subsequent modifications and extensions of the network (new substations, changes to the network, etc.).

Input and validation of the data is performed in the source database, so that current online data and online system operations remain unaffected. Once entered, prepared and checked, the modified set of data can then be activated in the operational database at a time convenient to the operator. Activation means the takeover of modified data from the source database to the operational database, without interruption of system operation and without losing any manually entered data. Data activation is coordinated automatically with all other subsystems, servers or activities of a Spectrum Power control system.

After activation, newly entered data (e.g., status information, analog values, station feeders, entire stations) can immediately be called up and displayed by the operator.

Modifications that are recognized later as erroneous can be corrected by an UNDO function, because all modifications carried out in the database are automatically recorded in a built-in database change log. Several levels of security-checking functions provide an audit trail for all data changes in the database and guarantee data consistency throughout the entire system.

An integral part of the user interface is the graphics editor. This editor is used to build and maintain the graphic displays used in the system.

All single-line displays of the Spectrum Power control systems are world-maps. A worldmap is a two-dimensional (2D) graphical representation of a part of the real world. Each point in a worldmap is defined by a pair of unique X, Y coordinates (world coordinates). A worldmap is divided into a set of planes. Each plane covers the complete 2D area including the whole range of the unique world coordinates. The first plane is visible over the entire worldmap magnification range. Any other plane is visible within a certain magnification range only, and contains different graphic representations of the technological (real) objects (e.g., plane 2 shows the substation state, plane 3 shows the summary state of the main feeders, plane 4 shows the single-switching states and so on). Planes can overlap magnification ranges of other planes.

IMM provides standardized interfaces for import and export of source data (fig. 7.2-4). Network data and facility data, as well as graphic data, can be imported or exported via these interfaces. The ability to import large or small amounts of data is supported for the purpose of major or minor system updates and the initial loading of the database (bulk loading). The following functions are provided:

- Single point for all data changes. Avoids the necessity of redundant data maintenance within multiple systems and locations
- Manual data entry or by incremental or bulk data import
- Workflow oriented views on existing, modified or new data
- Multiple and simultaneous data entry sessions of different users on different Spectrum Power user interface consoles
- CIM-compliant data model allows easy incorporation of future information types
- Lifecycle management for planned data modifications
- Data structure version management and automatic data model archiving facilities provides a history of changes as well as an outlook to the planned model at a certain time in the future to reflect the evolutionary nature of models
- Automatic change detection
- Automatic and on request data validation provides information consistency and secures the integrity of the model
- Activation of data modifications without impact on Spectrum Power runtime system
- Automatic Spectrum Power system wide dissemination of data modifications
- Role-based security features and audit records
- Instance-level access rights provide clear responsibilities within the whole data model
- Display (worldmap) editing and automatic generation of displays based on the topology of the network models
- Report generation
- Hierarchical Model Management supports data maintenance and exchange of modified data in a system of hierarchically arranged control centers in an automated way to prevent model inconsistencies between or within organizations
User interface
The user interface of the Spectrum Power control system provides powerful functions to ensure an overview at all times and to permit fast and easy switching between views across all worldmaps. The user interface allows the user to operate the networks and power plant efficiently and permits the administrator to maintain the database and system parameters. The system uses static and dynamic display elements to display the network structure and network state. The user interface provides means for guiding the operator to the workflows, e.g., by checking the plausibility of switching actions after each operating step. Multi-screen operation using drag and drop supports the operator in having a good overview of the power system and in accessing the required equipment in a fast and comfortable manner (fig. 7.2-5).

Spectrum Power map portal is the flexible platform for presenting geospatial control center data to corporate users. It is the link between Spectrum Power control systems and Google Maps and provides:
- A Web-Server for embedding Google Maps into corporate web sites
- An optional database system for joining information from different resources, like
  - Spectrum Power
  - Outage Management Systems
  - Archiving Systems
  - Workforce Management Systems
  - ...
- Interfaces for
  - Invoking Google Maps displays from Spectrum Power on-line diagrams and cartographic displays

Fig. 7.2-5: Typical control room environment

Fig. 7.2-6: Sample visualization of outages

- All outages at a glance
- Easy access to outage details
- See what others do (roadwork, construction ...)
- Crew position
- Information about lightings
- Address search

Fig. 7.2-7: Samples for network displays of electrical, gas and water networks
Communication front end

The remote terminal interface of Spectrum Power is the Communication Front End (CFE). It is part of the control center system and communicates with the other Subsystems of a Spectrum Power control system via the local area network (LAN). CFE has direct access to the Remote Terminal Units (RTU) of various manufacturers. The control center system is connected to the substations or power stations through these RTUs, which transmit process data of the power supply system. The data is preprocessed by the CFE, which exchanges data with the RTU, preprocesses data in real time and monitors and controls the system, including redundant components.

CFE supports different connections of remote terminal units as point-to-point, multiple point-to-point and multi-point. The transmission can be spontaneous, cyclic, periodic or scanned. The process interface is able to process several protocols such as IEC 870-5-101 or the metered value protocol IEC 870-5-102. Substation equipment (RTUs, submasters) having a TCP/IP Interface according to the standard IEC 60870-5-104 may be connected via a WAN link directly to the CFE-LAN. Both dual channel connections and multi-channel connections are possible (fig. 7.2-8).

The following data are implemented in the process data preprocessing:
- Detection of state changes with image maintenance (old/new comparison of Status messages; forwarding only on change)
- Intermediate position suppression (parameterizable monitoring time)
- Plausibility check of all numeric values (error message on invalid data or limit violations)
- Threshold value monitoring of analog values (passed on only if a parameterized threshold value is exceeded)
- Measured value smoothing (parameterizable filtering function)
- Resultant value formation from raw values using specific characteristics
- Renewal check of cyclically transmitted values
- Information type conversion for raised/cleared indication and transient indications
- Time processing and time synchronization. The CFE server regularly receives the absolute time. The substations are synchronized via time signal transmitters or by protocol specific synchronization telegrams. All information is kept internally with a resolution of 1 ms.
- Monitoring of remote terminal units, communication connections and system components

Communication between Control Centers
with ICCP and ELCOM

The necessity of process data exchange between control centers, often from different vendors, is increasing worldwide. Examples are hierarchical control centers, the interconnection of networks, energy exchange between suppliers or the use of external billing systems.

Defacto standard protocols for communication between control centers have been established, e.g., ELCOM-90 or ICCP. The ICCP protocol was defined as an international standard (IEC 870-6 TASE.2) and is now widely accepted and used all over the world.

The Inter-Control Center Communication Protocol (ICCP) is designed to allow data exchange over wide area networks (WANs) between a utility control center and other control centers. Examples of other control centers include neighboring utilities, power pools, regional control centers and non-utility generators. Exchanged data may include cyclic data, real-time data and supervisory control commands such as measured values and operator messages.

Fig. 7.2-8: Sample hardware-configuration of a power control system
Data exchange occurs between a SCADA/EMS server of one control center and the server of another control center. The ICCP server is responsible for access control when a client requests data. One ICCP Server may interact with several clients.

Access control of data elements between control centers is implemented through bilateral agreements. A bilateral agreement is a document negotiated by two control centers that includes the elements (that is, data and control elements) that each is willing to transmit to the other.

The ICCP data link supports a redundant configuration utilizing dual communication servers in active and standby mode. A redundant configuration supports two physically separate paths between the Spectrum Power control systems and the remote system to provide backup in the event that the primary data path becomes unavailable.

**Historical Information System**

Storage of process data and processing of historical data is an important basis for various power control system functions (fig. 7.2-9 and fig. 7.2-10):

- Historical data allows trending and general data analysis
- Forecast applications (for example load forecast) need a consistent set of historical data as input
- Historical data allows post mortem analysis for example in case of disturbances
- Reports and audit trails are generated from historical data
- Historical data is used to restore past scenarios as input for studies (for example power flow studies)
- Historical data is also an important input to asset management (for example monitoring of equipment maintenance cycles).

Analog values, accumulator values and calculated values (for example state estimator results) can be stored in the Historical Information System as well as status information and messages (for example alarms).

The data to be archived is collected from SCADA and applications (for example state estimator). The data can be collected either spontaneously or at a configurable cycle. Based on the stored data, the Historical Information System provides aggregations (minimum, maximum, average, integral, sum) and calculations. Missing or incorrect data can be entered or updated manually.

The online part of the Historical Information System provides the historical data for immediate access. The retention period for this online part is configurable (typically 1 to 3 years). Historical data that exceeds this retention period can be stored to and reloaded from the so called long term archive.

**Multi-site operation of control centers**

With the multi-site operation subsystem in Spectrum Power, the operator is provided with a powerful tool for optimizing operation management. It is possible to transfer network management partially or wholly from one control center to another. Emergency concepts can thus be designed and implemented effectively. Such a capability provides for greater reliability of the system (emergency strategies) and makes a considerable contribution to cost reduction. The multi-site control centers can be configured from two or more control centers and permit a very flexible and dynamic system. In the event of failures, each system continues to work autonomously. After recovery of the communication link, the data is automatically updated.
Energy Accounting

Energy Accounting (EA) provides the capability to collect, edit and store generation, interchange and other energy values on a periodic basis. These energy values are processed from accumulator data collected from the field and monitored by SCADA. EA also performs various aggregate calculations such as the inadvertent energy, calculations of energy values over multiple time periods (e.g. hourly, weekly, monthly, yearly), etc. for reporting and billing purposes. EA provides extensive editing support such as keeping track of original value, changed value, time of change, author of change, etc. for auditing purpose.

Load Shedding

The load shedding application automatically performs load rejection or disconnection of parts of the network in the event of certain faults and emergencies in order to maintain system stability. It analyzes the state of the network, detects significant events, defines the load to be shed and prepares the required switching actions. The emergency strategies can be configured individually. Depending on the customer requirements, a configuration can be selected from a simple manual solution to a fully automatic system for dealing with faults and emergencies.

The following strategies are possible:
- Manual load shedding
- Rotating load shedding (generation shortage for extended time)
- Equipment overload load shedding (delay/avoid tripping of equipment)
- Balancing load shedding (import target deviation, islanding)
- Under-frequency load shedding (system stability).

Power control applications

The aim of the Power Applications (PA) is to support frequency control, i.e. the power system stability (equilibrium between generation and demand), whilst maintaining an optimum generation dispatch and scheduled interchanges across the power system interconnections. The power applications support single area control, multiple autonomous area controls and hierarchical area control configurations. To enable this real-time process the power applications provide several functions:

Load Frequency Control (LFC)

LFC provides control mechanisms that maintain equilibrium between generation and demand in real-time. At the hart of LFC is a PI-controller that, combining actual generation, interchange and frequency, calculates the deviation from equilibrium, referred to as the area control error (ACE), and sends accordingly correction signals to the (single, groups of, virtual, etc.) generating units participating to this regulation process to maintain or restore equilibrium. The corrections will be calculated to meet numerous generation unit operating constraints (base/target point, operating and response limits, etc.). LFC will also implement the necessary corrections to satisfy performance criteria defined, typically, by a regulatory body such as NERC in the US or UCTE in Europe (fig. 7.2-11).

In parallel a performance monitoring function will collect all data related to the performance of such an automatic control according to the pre-specified criteria and store this information for reporting as required by the regulatory body.

Production Cost Monitoring (PCM)

The PCM function calculates, typically, the cost of production for monitoring, e.g. deviations from optimum cost, from planned cost, etc. and for recording purpose. In the case of an ISO/TSO the function may be configured to include the regulating cost.

Reserve Monitoring (RM)

RM calculates reserve contributions to reserve from generation and interchanges and compares them to the requirements. The requirements are typically defined by a regulatory body to guarantee continued security of operation following the loss of a generating unit or an interconnection. These requirements are divided in 2 or 3 categories, e.g. spinning, secondary and tertiary reserves, characterized by the response time window in which such reserves can be activated. Reserve can include many types of generation and interchange capabilities. For example, peakers would be included in secondary reserve and load shedding would be included in tertiary reserve.

Economic Dispatch (ED)

ED optimally dispatches generation to meet the net interchange, system load and network losses whilst respecting generation operating limits. Depending on the operating business, i.e. GMS, EMS or ISO/TSO, ED objective will vary from optimizing production and/or regulating costs to optimizing profits. ED will also operate different dispatch modes, each including a different generation set, e.g. online units under AGC control and in economic mode, online units under automatic control and online units under plant control, etc.

Forecasting applications

Forecasting applications are used for predicting the system (i.e. area and customer group) load, water inflow (hydro) and wind as the basis for generation and interchange planning/scheduling. These applications are also used in support of operation as
real-time conditions changes. The load forecast applications further described below supports, besides electricity, also commodities such as water and gas; supports multiple concurrent users and a working forecast environment to allow for review and tuning/adjustments before load forecast is made current for real-time use; and provides for adjustments (e.g. scaling) and tracking mode (i.e. the next few hours of the active forecast are (automatically or on manual request) adjusted based on the observed deviations between the actual measurement and forecast during the last few hours).

**Medium-/Long-Term Load Forecast (MTLF/LTFL)**
MTLF is used to forecast the load over a period of 1 week up to 2 years whilst LTFL is used to forecast the load over a period of 1 year up to 5 years. The methods used in both applications are processing historical data with multiple regression analysis (one method is based on the ARIMA model).

**Short-Term Load Forecast (STLF)**
STLF is used to forecast the load over a period of few days up to 14 days in 30-60 minutes increments. The load forecast supports several prediction algorithms (e.g. Similar Day, Pattern Matching, and Regression Analysis) that can be used separately or in user configurable combination and provides the operator with tools to edit the forecast.

**Very Short-Term Load Forecast (VSTLF)**
VSTLF is used to forecast the load over a 1-2 hour period in short, e.g. 5 minutes, time increments. The method used by VSTLF is based on a neural network algorithm and its use divided in two phases: the training phase and the forecast phase. Training is executed automatically periodically or on request.

**Short-Term Inflow Forecast (STIF)**
STIF calculates future inflows into a hydrological system. On the basis of this data, the planning function (e.g., hydro scheduling) can calculate the schedule for hydro plant units.

**Power Scheduling Applications**
The aim of Scheduling Applications (SA) is to optimize the use of individual power plants (thermal, hydro) and external power transactions in such a way that either the total operating cost is minimized or the total profit on energy sales is maximized after taking all maintenance and operational constraints into account.

The scheduling applications use a sophisticated combination of Mixed Integer Linear Programming and successive Linear Programming. Special techniques are applied to consider non-linear effects and speed up the solution process (fig. 7.2-12).

The scheduling applications include: **Resource Scheduler (RO)** Resource Scheduler optimizes either the medium-term generation plan including energy transactions for minimum cost or the medium-term electricity delivery contracts including energy trades for maximum profit subject to optimal use of energy resources (fuels, water, emission, etc.), to maintenance constraints, to emission rights, etc.

![Fig. 7.2-12: Generation management and planning](image-url)
RO determines therefore the optimal generation schedules, the amount of traded energy in bilateral, forward and spot markets, and the corresponding consumption of resources (fuels, emission, etc.).

Generation Scheduler (GS)

Generation Scheduler optimizes the short-term (thermal and hydro) unit commitment & generation plan including energy transactions for minimum cost subject to maintenance, forecasted load, reserve requirement, energy resources (fuels, water, emission, etc.) and emission constraints.

Results (e.g. reservoir levels, accumulated fuel consumption, etc.) from the Resource Scheduler at the end of the short-term planning horizon are used as targets by the Generation Scheduler application.

Unit commitment, hydro scheduling and hydro-thermal coordination are integral part of this application.

Trade Scheduler (TS)

Trade Scheduler is similar to the Generation Scheduler application except for optimizing the short-term traded energy on the spot market for maximum profit.

Results are also similar but for the energy volumes to be bid on the spot market.

Transmission Network Applications

The Transmission Network Applications (TNA) suite provides tools for the advanced monitoring, security assessment and operational improvement of the operation of an electrical transmission network. They are used:

- to provide a fast and comprehensible assessment of the current state of the network and improve monitoring beyond SCADA
- to assess the security against faults & outages
- to provide preventive/corrective measures against planned/ existing events
- to optimize operation against costs & losses

These applications considerably increase operational reliability and efficiency in network management. TNA responds automatically to the many different operational (secure, unsecure, emergency) conditions to provide the appropriate support to the operator. The application suite will execute, in real-time, periodically, on events and on operator request as a configurable sequence (fig. 7.2-13). Among many other features, TNA also supports study mode allowing concurrent users to execute different studies including preparing corrective strategies, preparing next day operating plan, analyzing post-mortem operational events, etc.

Network Model Update (NMU)

The Network Model Update integrates all external and internal information, construct the network topology, and update accordingly the network data required to create the operating conditions to be evaluated by the State Estimator or the Power Flow, i.e.:

- Gathering data from SCADA and other external sources such as AGC, Load Forecast and Outage Scheduler (user options in study)
- Performing topological analysis including identification of electrical island(s), energized/de-energized equipment(s), etc.
- Scheduling accordingly all network loads, generations, regulation settings and limits.

In study mode the retrieval of data is user configurable and offers additional retrieval options typically not applicable in real-time.

State Estimator (SE)

The purpose of this function is to provide a reliable and complete network solution from the real-time measurements, pseudo-measurements (e.g. non-telemetered loads) from model update (MU) and operator entries. The state estimator will identify the observable parts of the network where real-time measurements are redundant. Using this redundancy, the state estimator will identify “bad” measurements, remove them from the valid set of measurements, and then solve for the complete network combining, for the portion of the network that is unobservable, isolated measurements and load, generation and bus voltage scheduled by the MU function. The state estimator will also alarm the operator of any operational limit violations. It will also enable other applications to develop reliable solutions to specific aspects of network operation (e.g. remedial actions against operational limit violations). The state estimator features:

- Orthogonal transformation algorithm
- Measurement consistency check
- Chi-Square test w/ Normalized Residual or Measurement Compensation approach
- Single-pass solution
- Enforcement of equipment limits in the unobservable parts of the network.
Although the state estimator’s essential task is to process real-time data, the State Estimator can optionally also be executed in study mode for, for example, post-mortem analysis.

**Network Parameter Adaptation (NPA)**

The Network Parameter Adaptation (NPA) maintains a time-dependent database of adapted network data used by the network model update to schedule net interchanges, bus loads, regulated voltages, and statuses of time-dependent breakers. NPA adapts these network data in real-time via exponential smoothing using the state estimator results. Then,

- In real time execution, the parameters are used by the model update function to schedule loads and regulated bus voltages to be used by State Estimator as pseudo measurements at unobservable buses.
- In study, the parameters are used by the model update function to schedule loads and regulated bus voltages for the user-specified study day-type and hour. The results are then used by the Power Flow.

**Dispatcher Power Flow (DPF)**

DPF is used to evaluate the network state under various operating conditions in the present or the future such as, for example, tomorrow’s work plan. It is used exclusively in study and typically in conjunction with other applications such as Security Analysis and Optimal Power Flow.

DPF solves either – user selectable – using the Fast Decoupled or Newton-Raphson algorithm. DPF supports, among many standard features,

- Continuous (e.g. Generator) and discrete controllers (LTCs, Capacitors, etc.);
- DC injections and branches (iterative process between DC and AC power flows);
- Area Interchange control, single/distributed slack, MVAR/MW generator curves, etc.

DPF offers plenty of user selectable options for full flexibility of analysis.

**Optimal Power Flow (OPF)**

The OPF is used to improve the system operation under normal (secure) as well as abnormal (unsecure) conditions by recommending control adjustments to achieve either of the following optimization objectives:

- **SECURITY**: active & reactive security optimization
- **COST**: active cost & reactive security optimization
- **LOSS**: loss minimization
- **FULL**: COST optimization & LOSS optimization

OPF solves the LOSS minimization using Newton optimization and the other optimizations using Linear Programming. OPF supports, among many standard features,

- Constraint & Control priorities
- Constraint relaxation (e.g. long-to-medium & medium-to-short limits)
- Load shedding

OPF offers also plenty of user selectable options for full flexibility in identifying remedial measures to operational violations and/or in optimizing secure operational conditions. Depending on the optimization objectives, the OPF applications can be defined as a reactive power optimization or as an active power optimization.

OPF as described here is used only in study whilst two customized versions described below are provided for real-time use.

**Voltage Scheduler (VS)**

VS is a real-time application version of the OPF. It determines the optimal use of VAR resources and the optimal voltage profile that should be maintained in order either to minimize operational voltage violations or to minimize the network losses. For that purpose, optimal settings of reactive power controls are determined and displayed for implementation.

When the objective is to alleviate voltage violations, minimum shifting of controls from specified setpoints (least-squares shift) is implemented. For that purpose, VS minimizes an objective function consisting of the sum of the quadratic "cost" curves for all control variables. Each such "cost" curve penalizes its related control variable for a shift away from the target value. Weighting of the "cost" curves is performed by a factor specified for each control variable.

**Remedial Dispatch (RD)**

RD is a real-time application version of the OPF. It determines the optimal use of MW resources and the optimal loading profile that should be maintained in order either to minimize operational overloads or to minimize the operating costs. For that purpose, optimal settings of active power controls are determined and displayed for open- or closed-loop implementation. Note that the set of overload constraints can be automatically extended to include branch loading constraints corresponding to critically loaded branches (user specified critical loading factor).

Similarly to VS, when the objective is to alleviate overloads, minimum shifting of controls from specified setpoints (least-squares shift) is implemented. For that purpose, RD minimizes an objective function consisting of the sum of the quadratic "cost" curves for all control variables. These "costs" are constructed and handled as described for VS.

Basically, RD provides optimal dispatch similarly to conventional economic dispatch (ED). Compared to ED, however, it is extended to also take into account network loading constraints. This is particularly useful in usually highly loaded systems as well as during exceptional load situations, e.g., due to outages of generating units or transmission lines.

**Security Analysis (SA)**

The purpose of this function is to determine the security of the power system under a very large number of contingencies (e.g. n-1 criteria). Contingency evaluation in large meshed transmission networks is an exhaustive task because a lot of contingencies (single outages and multiple outages) have to be studied in
order to get a reliable result. On the other hand, usually only very few of the possible contingencies are actually critical, and therefore a lot of computation effort could be wasted. To overcome this difficulty, a two-step approach is used. The two sub-functions of SA are as follows:

- Contingency Screening (CS) provides a ranking of contingencies from the contingency list according to the expected resulting limit violations. For that purpose, a fast power flow calculation (user definable number of iterations) is performed.
- Contingency Analysis (CA) checks contingencies from the ranked list produced by the CS sub-function. For each of those contingencies, a complete AC power flow is performed.

Security analysis supports, among many features,

- user specified contingency and monitored equipment lists
- Single and multiple contingencies
- automatic simulation of contingencies corresponding to the real-time violations
- conditional contingencies
- load transfer and Generator reallocation
- modeling of regulating controllers (LTC, ...)
- contingency screening bypass

Security Analysis Look-Ahead (SL)

Provides the very same function as SA but merges, to the base case, outages from Outage Scheduler that are scheduled within a configurable time window from real-time. SL provides the operator with the security impact from these scheduled outages on real-time operation (which may differ from the conditions used to validate the scheduling of the outage). In case the scheduled outage put real-time operation at risk, the operator can decide whether to cancel the outage, reschedule the outage and/or take preventive measures to allow the scheduled outage to take place as scheduled.

Network Sensitivity (NS)

The purpose of this function is to support calculation and management of loss penalty factors for use by Power Applications (PA) and Scheduling Applications (SA). Penalty factors are used for taking network transmission losses into consideration when dispatching generation whilst minimizing total cost. This NS function is executed automatically as part of the real-time network application sequence. It calculates, for the current network state, the sensitivity of system losses to changes in unit generation and interchanges with neighboring companies. It, then, maintains, using exponential smoothing, a database of such loss sensitivities for a number of system load ranges and net interchange ranges. In real-time mode, NS operates from the network solution produced by the state estimator function, and in study mode from that produced by the dispatcher power flow function.

Fault Calculation (FC)

The purpose of this function is to calculate the fault current and fault current contributions from branches and generating units near the faulted bus are also calculated and may be compared against their respective fault ratings. FC includes, among many features, the effects of mutually coupled lines, the modeling of fault and fault-to-ground impedance and the combination of a fault with a single branch outage.

Operator Training Simulator (OTS)

OTS is based on 4 key components (fig. 7.1-9, section 7.1.1):

- Training management function
- Power system simulation
- Telecontrol model
- Power Control System (copy).

The training management component provides tools for creating training sessions, executing training sessions and reviewing trainee performance. It provides tools to

- initialize the training session, e.g. from real-time or a saved case;
- define the system load profile;
- create event sequences, e.g. a breaker opening, a telemetry failure, etc., that can be either time triggered, event triggered or command triggered;
- create training scenarios, i.e. a number of event sequences, to be activated during the training.

It also provides start/stop and pause/resume functions for the execution of the training session. During the training session it is possible for the trainer to create new events and/or modify the running scenario.

The power system simulation component provides a realistic simulation of the power system behavior to support training from normal operation to emergency operation including islanding conditions and blackout restoration. The simulation is based on a long-term dynamic modeling of the power system including:

- load modeling with voltage & frequency dependency;
- generation modeling with governor, turbine/boiler and generator models;
- frequency modeling;
- voltage regulator modeling;
- protection relay modeling;
- external company LFC modeling.

The telemetry simulation component provides the simulation of the data communication between the power system and the control system. It transfers as simulated field telemetry the results of the power system simulation to the control system copy. And it processes all commands issued by SCADA (operator), LFC, etc. and transfers them to the power system simulation. This simulated telemetry can be modified via the scenario builder by the trainer to reflect measurement errors, telemetry or RTU failures, etc.

This operator training simulator provides a dedicated environment for the trainee (operator) and one for the instructor that
allows the instructor to influence the process in order to force responses from the trainees. The trainee interface is identical with that of the control system so that, for the trainee, there is no difference in functionality and usability between training and real operation.

**Distribution management applications**
In distribution networks, the telemetry is relatively limited; the fault rate is high as well as the frequency of changes in the network. To meet these requirements, Spectrum Power provides powerful functions with which the operator can operate the distribution network effectively and efficiently.

**Fault Management**
Fault Management is a set of applications used for locating system incidents and providing fault (or planned outage) isolation and service restoration in distribution networks.

The main Fault Management functionality consists of:
- Fault location
  Locating the faulty section or area of the network as closely as possible
- Fault isolation
  Isolating the planned outage or the faulty section or area of the network
- Service restoration
  Restoring power to de-energized non-faulty areas of the network
- Fault isolation and immediate restoration
  Isolating faulty areas and immediately restoring power to de-energized areas of the non-faulty or isolated network
- Restore to normal or pre-fault state
  Restoring selected number of switches to their normal state or pre-fault state

Fault location, as a part of the Fault Management application, helps to locate permanent faults. Outage faults (for example, short circuits) as well as non-outage faults (for example earth faults) are considered. Fault location is performed by using remotely controlled and manually updated information (communicated by the field crews) from, for example, protection devices and fault indicators. Fault Management localizes the faulty section as closely as possible, based on available real-time data from SCADA and/or field crews.

The isolation function is performed to determine a set of switching operations to isolate an area of the network.

It can be initiated by the location of the faulty segment or area, or by selecting sections directly on the user interface. The purpose is to isolate sections or areas of the network specified by the isolation request to minimize the outage effect on the network.

Service restoration provides a possible choice of switching procedures to restore service. For each switching procedure suggested by the restoration tool, performance indices are calculated based on the network conditions.

The user can select the way of ranking of suggested switching procedures according to one or more performance indices and select the best one for service restoration.

Fault Management switching procedures are typically transferred to a Switching Procedure Management (SPM) application for further processing, that is, edit, review and implementation.

Fault isolation and service restoration can also be used for sections isolation due to maintenance work.

**Outage Management (OM)**
is a collection of functions, tools and procedures that an operator/dispatcher uses to manage the detection, location, isolation, correction and restoration of faults that occur in the power supply system. OMS is also used to facilitate the preparation and resolution of outages that are planned for the network. These processes are used to expedite the execution of the tasks associated with the handling of outages that affect the network and provide support to operators at all stages of the outage life cycle, starting from events such as the reception of a trouble call or a SCADA indication of an outage and extending until power is restored to all customers. This process is used to solve the outage regardless of whether the outage is at the level of a single distribution transformer providing power to one or a few energy consumers, or at the level of a primary substation providing power to many energy consumers. All operations, authorizations and comments that occur in these processes are documented and collected in outage records. This information is made available to external sites for further statistical analysis and processing. QMS provides the automatic processing of an outage record used to monitor changes in the network and has an internal interface to the crew management or switching procedure management. OMS also provides an interface to the external trouble call systems and an SQL interface (fig. 7.2-14).

**Switching Procedure Management (SPM)**
allows the operator to create, edit, select, sort, print, execute and store switching procedures. Entries in a switching procedure can be created manually by recording the operator’s actions in a...
Simulation mode, by modifying an existing procedure or by recording the operator’s actions in real-time mode or automatically by applications such as FISR and the OMS system. The switching procedure management capabilities can be used to prepare, study and execute clearance operations. It can also be used to execute switching operations to alleviate fault conditions and to restore power following a fault, as well as to optimize the network operation. SPM provides management capabilities via summary displays and easy-to-use menus.

Crew Management (CM)
This system provides convenient access to the information necessary to track, contact and assign work schedules (outage records) to the field crews of a Utility. The information consists of data such as crew name, work assignments and locations.

Trouble Call Management (TCM)
This system provides convenient access to the information necessary to track, contact and assign work schedules (outage records) to the field crews of a utility. The information consists of data such as crew name, work assignments and locations.

Distribution network applications
The distribution system network applications (DNA) provide fast and comprehensive analysis and optimization of the current distribution network state (fig. 7.2-15). The Distribution System Power Flow (DSPF) calculates voltages (magnitudes and angles) for all nodes (busbars), active/reactive powers for slack buses, and reactive power/voltage angles for nodes with PV generators. All other electrical result values are calculated from the node voltages and branch impedances/admittances after DSPF is solved. The most important result values are flows (powers kW/kVARs and currents A) through lines and transformers, and active and reactive power losses that allow to detect potential limit violations.

DSPF is used to calculate the network statuses under different load conditions and configurations:
• Calculate the actual state of the distribution networks using real-time measurements and the current topology
• Calculate the state of the distribution network in the near future (look-ahead) with actual topology but load values of the given time
• Study the state of the distribution network in the near future with different topology (i.e. according to planned maintenance) and the load values of the given time

Distribution System State Estimator (DSSE) provides a solution for monitoring the actual operating state of the network and to provide a complete network solution for further analysis, for example, optimization of voltage profile.

DSSE provides the statistical estimates of the most probable active and reactive power values of the loads using existing measured values, switching positions, and initial active and reactive power consumption of the power system loads.

The initial active and reactive power values of the loads are provided by static load curves or load schedules (generated based on load curves and measured values/meter readings). Further DSSE estimates the real-time network operating state using measured values.

DSPF and DSSE can handle both symmetrical balanced as well as unsymmetrical unbalanced distribution systems.

Fig. 7.2-15: A typical workflow in managing the distribution grid
The results of DSPF/DSSE are presented on network diagrams and in tabular displays.

**Short Circuit Calculation (SCC)**

This application helps operators to detect possible problems regarding short circuits, to check capability of circuit breakers and to check if earth fault currents are within the limits. Based on the results and warnings of SCC, the user can initiate or reject changes of the network topology.

SCC solves symmetric or asymmetric faults in symmetrical balanced as well as in unsymmetrical unbalanced distribution networks. The SCC function is used to determine:

- The maximum shortcircuit current that determines the rating of electrical equipment (normally a circuit-breaker for real-time SCC)
- The minimum shortcircuit current that can be a basis for the protection sensitivity checking or fuses selection
- Fault current calculation at selected locations

The following fault types are supported, and each of them may contain fault impedance and/or earthing impedance, depending on user requirements:

- 3-phase faults without earth (ground) connection
- 3-phases faults with earth (ground) connection
- 2-phase faults without earth (ground) connection
- 2-phases faults with earth (ground) connection
- 1-phase to earth (ground), with or without earthed neutral point

SCC can be started on demand to calculate a single fault and can run in screening mode. In screening mode, SCC checks breaking capability, protection sensitivity and earth fault current for a selectable area or the entire distribution network.

The results of SCC are presented on network diagrams and in tabular displays.

**Voltage/Var Control (VVC)**

calculates the optimal settings of the voltage controller of LTCs, voltage regulators and capacitor states, optimizing the operations according to the different objectives. The following objectives are supported by the application:

- Minimize distribution system power loss
- Minimize power demand (reduce load while respecting given voltage tolerance)
- Maximize generated reactive power in distribution network (provide reactive power support for transmission/distribution bus)
- Maximize revenue (the difference between energy sales and energy prime cost)
- Keep the system within constraints

System operational constraints such as line loading and consumer voltage limits are automatically accounted for in terms of penalties. VVC supports three modes of operation:

- **Online mode**
  The purpose of this mode is to provide an optimal solution that conforms to the desired objective function.
- **"What if?" VVC studies online**
  The purpose of this mode is to provide an optimal solution that reflects the current Status of the distribution network with the actual topology but with different loading values.
- **Study VVC**
  The purpose of this mode is to allow the user to execute short-term operational studies, with different topology and different loading values.

The output of VVC application includes the switching procedure for implementing the solution and the values of the objective functions before and after optimization. In online mode, VVC supports both open-loop (VVC proposes switching actions) as well as closed-loop (VVC actually initiates switching commands to implement the solution). Results such as flows, currents, voltages and losses are displayed on network diagrams and tabular displays.

**Optimal Feeder Reconfiguration (OFR)**

The objective of this application is to enhance the reliability of distribution system service, power quality and distribution system efficiency by reconfiguring the primary distribution feeders. OFR performs a multi-level reconfiguration to meet one of the following objectives:

- Optimally unload an overload segment (removal of constraint violations)
- Load balancing among supply substation transformers
- Minimization of feeder losses
- Combination of the latter two objectives (load balancing and loss minimization), where each objective is included in the total sum with a user-specified or default weighting factor

System operational constraints such as line loading and consumer voltage limits are automatically accounted for in terms of penalties. OFR supports two modes of operation: In online mode, the application uses the existing real-time measurements and the current topology. In the study mode, the operator can simulate short-term operational studies with different topology and measurements. The output of OFR application includes the switching procedure for reconfiguration and the values of the objective functions before and after reconfiguration.

**Optimal Capacitor Placement (OCP)**

The objective of this application is to optimize the placement of capacitors – optimal positions (busbars), optimal regulator positions and optimal sizes of capacitor banks are considered.

OCP can optimize the placement of mobile capacitors for planned and unplanned outages as well as fixed capacitors. When determining the busbars on which capacitor banks should be placed, the sizing of capacitor banks and the positions of capacitor bank regulators, OCP considers minimization of active power losses as well as power factor limits and voltage limits. OCP runs on user request.
The results of OCP are displayed in network diagrams and tabular displays.

**Distribution Security Analysis (DSA)**
The objective of this application is to see the influence of faults (unplanned outages) as well as planned outages on the security of the distribution network.

**DSA assesses**
- N-1 security in all meshed parts of the distribution network
- Security of simplified restoration procedures based on the current reserve
- Security of reconfiguration scenarios (back-feed, coupling of substations, etc.)
- Security of pre-defined restoration procedures
- Security of scheduled switching procedures

**Expert system applications**
The Spectrum Power expert system supports the operator in solving critical and complex tasks in the field of network operation and disturbance analysis (fig. 7.2-16). Spectrum Power expert system applications provide two functions, an intelligent alarm processor (IAP) and an expert system for Advanced Network Operation (ANOP).

The IAP provides information about the fault location in case of a network disturbance. It is based upon a hierarchical, multi-level problem-solving architecture that combines model-based and heuristic techniques, and works with an object-oriented data structure. Within the diagnosis, the IAP determines the location and the type of disturbances in electrical networks, e.g., fault within a transformer. The model used by the IAP corresponds to the model of the protection system. This provides the additional advantage of monitoring the correct operation of the protection system. The diagnosis results are displayed in the XPS report list.

**Advanced Network Operation (ANOP)**
This system supports the following network operations of the operator:
- Automatically triggered operations for:
  - Automatic fault isolation and restoration
  - Automatic removal of overload
- Manually triggered operations for:
  - Manual fault isolation and restoration (trigger fault)
  - Planned outage (take out of Service)
  - Load relax
  - Resupply (energizing)

The algorithm of ANOP manages all types of distribution networks – for cities or provinces, small networks or large networks – with radial configurations and also with looped configurations. It can be used in telemetered networks as well as in non-telemetered networks. The algorithm is fully generic, considers the actual network status (topology, values, tagging), and provides an authentic and extensive solution for the given task, taking into account all electrical and operational requirements. The algorithm develops the best strategy for the given situation and considers all necessary steps to reach a solution that fulfills the task in a secure, complete and efficient way.

With the help of the built-in power flow, each step is checked; tagged equipment is respected. The proposed solution changes the actual topology of the network in a minimal way. In the exceptional case in which a complete solution is not available under the actual circumstances, a partial solution is evaluated, again taking into account all electrical and operational requirements. The results are displayed in the XPS report list and in the XPS balance list, and a switching procedure is created and inserted in the switching procedure management.
7.2.2 Common Model Management System (CMMS)

In parallel with the liberalization of the energy markets, there is an ever-increasing need for data sharing, not just to serve the own enterprise, but also to respond to needs from outside entities. Sometimes this need is driven by industry entities. Sometimes, and lately more than others, this need is driven by industry requirements passed by governing bodies such as NERC and FERC.

Siemens has been alert to the need for common modeling language and integration platforms for optimizing the benefit also to smart grid implementation across the power delivery network. In developing the first product of its kind, the Common Model Management System (Spectrum Power CMMS), Siemens has compiled within a single data model both planning and operations network models for both transmission and distribution and presents model editing and tracking on a time-synchronized basis – allowing a model of the system to be derived for any point in time in the future or history, in either a planning or an operations protocol.

Siemens is now changing the mindset of modelers from thinking in terms of traditional network models where individual assets properties are aggregated into a larger component in the model (i.e. wave traps, underground cable segments, overhead line segments are all aggregated into one “transmission line” in the network model – resulting in the individual assets loosing their identity) to terms of the network really being a series of interconnected assets. This transitional thinking results in significant reliability, efficiency and resource optimization.

The Siemens Spectrum Power CMMS provides tools and automation to efficiently manage the exchange, validation, approval, and commissioning of transmission network model changes within and between RTO/ISO and Transmission Distribution Service Provider (TDSP) operations and planning departments. CMMS enables generating, managing, and synchronizing network model information from a single shared source to support utility systems and applications, such as network planning, energy management, market operations, congestion revenue rights, outage scheduling and more. CMMS also provides a foundation for smart grid information management. The CIM-based architecture provides a unified model, auditable model change records, approval levels for model changes, as well as rich model documentation capabilities. It allows chronological model tracking in a fully open environment allowing all applications to share services and data. This greatly reduces modeling errors, improves coordination, and streamlines processes for transmission network changes. This enables exchanging information on a level far above the paper or file exchanges that are in use to day.

The CMMS integrates Spectrum Power Information Manager (IMM) and Siemens Model on Demand (MOD) products into a single package. The IMM generates and maintains the operations network model changes, while MOD tracks the planning model and all planning changes. The integrated package provides consistent, coordinated models for any point in time based on the planned energization dates provided to the system (fig. 7.2-17). Point of time models can be exported to most popular applications using CIM (IEC 61970 and IEC 61968) and CIM for planning and dynamics international standards.

The key features and capabilities are:
- Industry standard CIM-based model representation
- Synchronized chronological model tracking from future to past horizons
- Single model integration of planning, engineering, operations, market, etc.
- Electronically submit network model changes to facilitate exchange between the RTO/ISO and the regional TDSP
- Develop a planning model for the RTO/ISO combining the current regional operating model with the region’s proposed plans. This model can be used as the basis for evaluating network reliability as network changes are implemented over time.
- Electronic Approval/Rejection Notification provides electronic notification to the TDSP when a plan is approved or rejected. If the plan is rejected, it identifies the reasons so the TSDP can modify and resubmit the plan in a timely manner.
- Approved plans are placed in a secure accessible repository. The TDSP can access its approved plans from the repository and use these to develop the commissioning plan necessary to put them into operations.

Managed changes between planning and operations within the TDSP provides streamlined electronic coordination of planning model changes to be commissioned with the real-time operating model.

![Fig. 7.2-17: Common Model Methodology](image-url)
7.2.3 Decentralized Energy Management Systems (DEMS)

In parallel with the liberalization of the energy markets, the decentralized generation of electrical power, heat and cold energy becomes more and more important. The generation of these types of energy near to the consumers offers economical and ecological benefits. In this context, interest is directed to so-called virtual power plants. A virtual power plant is a collection of small and very small decentralized generation units that is monitored and controlled by a superordinated energy management system. In general, these generation units produce heating and cooling energy as well as electricity (fig. 7.2-18).

A successful operation of a virtual power plant requires the following technical equipment:

1. An energy management system that monitors, plans and optimizes the operation of the decentralized power units

2. A forecasting system for the loads that is able to calculate very short-term forecasts (1 hour) and short-term forecasts (up to 7 days)

3. A forecasting system for the generation of renewable energy units. This forecast must be able to use weather forecasts in order to predict the generation of wind power plants and photovoltaics

4. An energy data management system which collects and keeps the data that is required for the optimization and the forecasts, e.g., profiles of generation and loads as well as contractual data for customer supply

5. A powerful front end for the communication of the energy management system with the decentralized power units

First, a virtual power plant needs a bidirectional communication between the decentralized power units and the control center of the energy management system. For larger units, conventional telemetry systems based on protocols such as IEC 60870-5-101 or 60870-5-104 can be used. In the future, with an increasing number of small decentralized power units, the communication channels and protocols will play a more important role. It is likely that the costly conventional telemetry technique will be substituted by other techniques based on simple TCP/IP adapters or based on power line carrier techniques. Siemens is contributing to the upcoming standard "IEC 61850-7-420: Communications networks and systems in substations – Part 7-420: Communications systems for distributed energy resources (DER) – Logical nodes."

All operation planning and scheduling applications require forecasts with sufficient accuracy. For the characterization of the forecasts, several operating figures are used, such as the average forecast error per day or the absolute error per day or per forecasting time period. Depending on the main purpose of the virtual power plant, the requirements for the forecast methods may change. If the primary purpose is to reduce the peak load or the balance energy, the forecast has to be very exact in the peak time or times with the high prices for balance energy. Furthermore, the forecast algorithms must be able to adapt rapidly to new situations. For example, a virtual power plant operated by an energy service company must be able to consider changes in the customer structure.

Based on the results of the forecast algorithms and the actual situation of the virtual power plant, the load to be covered can be dispatched by using the decentralized power units and the existing energy contracts. This is a complex and recurrent task. Therefore, computer-based methods of operations research are used. This is the most important component in a virtual power plant, because it realizes and uses the optimization leeway.

The special structure of a virtual power plant places high demands on the mathematical models for the optimization. The models must be very precise because rough models could yield optimization results that cannot be realized by the power system. Because the virtual power plant must provide an automatic mode for online control of the decentralized power units, e.g., for compensating the imbalance, no operator can check and correct the results. Furthermore, the optimization leeway can only be used if the optimization package is able to determine the solution cyclically within the settlement period.

Based on the requirements defined in the preceding section, a Software package for decentralized energy management called DEMS was developed. The DEMS system is not meant to be a substitute for all possible automation equipment necessary for operating the components of a virtual power plant. There must be at least that much local automation equipment available to
allow the basic operation of the decentralized power units in order to ensure component and personal safety in the absence of the DEMS system.

The components/units of a virtual power plant and their energy flow topology are modeled in DEMS by some classes of model elements, e.g., converter units, contracts, storage units, renewable units and flexible loads.

The DEMS planning application models all cost/revenue and constraint-relevant energy and media flows, regardless of their type (e.g., electricity, hot water, steam, cooling, emissions, hydrogen).

The DEMS control applications provide control and supervision capability of all generation units, storage units and flexible demands as well as control capability to maintain an agreed-upon electrical interchange energy profile. Fig. 7.2-19 illustrates the modeling of a decentralized power generation system by using DEMS model elements (rectangular objects with unit names), and connecting them via balance nodes (circular objects with node numbers).

The functions of DEMS (fig. 7.2-20) can be subdivided into planning functions and control functions. The respective planning functions are the weather forecast, the load forecast, generation forecast and the unit commitment. Furthermore, DEMS provides generation and load management as an exchange monitor and online optimization and coordination.

The planning functions consider a time period of one to seven days with a time resolution depending on the settlement periods for energy sales and purchases, e.g., 1 5, 30 or 60 minutes. The planning functions run cyclically (e.g., once a day or less frequently), on manual demand and can be spontaneously triggered.

The DEMS weather forecast function provides the forecasted weather data import/calculation that is used as an input for the other DEMS function modules. The weather forecast function has import capability for forecasted (and maybe also historical) weather data provided by external sources like weather forecast Services. If there is local weather data measurement equipment located in the virtual power plant, the external imported weather forecast is adapted to the local site measurements by using a moving average correction algorithm that minimizes the difference of the deviation between the external forecast and locally measured weather data around the actual time step. The resulting internal weather forecast is provided as an input to the other DEMS planning functions.

The DEMS load forecast provides a forecast calculation for multiple load classes. The basic data is the continuous historical measured load data in the time resolution of the planning functions. A piecewise linear model is set up explaining the modeling of the demand behavior as a function of influencing variables such as day types, weather variables or production schedules from industrial loads. The model equation coefficients are estimated cyclically each day after new measurements are available.

For each time stamp of the day (e.g., 96 time stamps for a 15-minute time resolution), a separate coefficient analysis is done. The data used for the analysis starts from yesterday for a parameterized time range in the past (from 0 to 84 days). The mathematical method for calculating the model coefficients is a Kalman filter. By using the Kalman filter, the definition of fully dynamic, partial static and fully static forecast models is possible.
The DEMS generation forecast calculates the expected output of renewable energy sources dependent on the forecasted weather conditions. The forecast algorithm is a piecewise linear transformation of two weather variables to the expected power output according to a given transformation matrix (e.g., wind speed and direction for wind power units, light intensity and ambient air temperature for photovoltaic systems). The transformation matrix can be parameterized according to the unit technical specifications and/or is estimated on the basis of historical power and weather measurements by applying neural network algorithms (in an offline analysis step).

The DEMS unit commitment function calculates the optimized dispatch schedules (including the commitment) for all flexible units such as contracts, generation units, storage and flexible demands. The objective function is the difference of revenue minus costs, the profit. The scheduling considers the parameters of the model elements and their topological connection, which defines the financial Information, as well as the technical, environmental and contractual parameters and constraints of the virtual power plant. The unit commitment uses mixed integer linear programming to calculate the results of the optimization problem.

The DEMS generation management function allows for the control and supervision of all generation and storage units of the virtual power plant. Dependent on the control mode of the respective unit (independent, manual, schedule or control mode) and the unit parameters (minimum/maximum power, power gradients, energy content), the actual state (start-up, online, remote controllable, disturbed) and the actual power output of the unit, the start/stop commands and power set-points for the units are calculated and transmitted via the command interface. Furthermore, the command response and the setpoint following status of the units are supervised and signaled. In the event of a unit disturbance, the generation management can start a spontaneous unit commitment calculation to force a rescheduling of the remaining units under the changed circumstances while also considering all integral constraints.

The DEMS load management function allows the control and supervision of all flexible loads in the virtual power plant. A flexible load class can contain one or several load groups of the same priority, where one load group is supposed to be switched on or off completely with one switching command. Dependent on the control mode of the load class (independent, schedule or control mode) and the actual switching state, the actual control state, the actual power consumption and the allowed control delay time of the load groups, the required switching controls to fulfill the overall load class setpoint are calculated and transmitted via the command interface (applying a rotational load shedding of the load groups of one load class). The optimized load class schedules calculated by the unit commitment function are the basis for load class control in the operation modes "schedule" and "control".

The DEMS exchange monitor function calculates the expected deviation of the agreed-upon electrical interchange schedule of the current accounting period (15 or 30 or 60 minutes) and the necessary power correction value to keep the interchange on schedule. On the basis of the actual energy consumption of the running accounting period and the actual interchange power trend, the expected energy interchange at the end of the accounting period is calculated. The difference between this value and the agreed-upon interchange value, divided by the remaining time of the accounting period, gives the necessary overall power correction value that is needed to be on schedule with the agreed interchange at the end of the accounting period. This value is passed to the online optimization and coordination function for further processing.

The DEMS online optimization and coordination function dispatches the overall power correction value to all individual generation units, storage units and flexible load classes that are running in control mode. The distribution algorithm works according to the following rules: First, the actual unit constraints (e.g., minimum and maximum power, storage contents, power ramp limitations) must be considered. Second, the overall power correction value should be reached as fast as possible. And third, the cheapest units should be used for control actions. “Cheapest” in this context means that the incremental power control costs of the units around their scheduled operating points are taken as a reference. The incremental power control costs of the individual units are calculated by the unit commitment function along with the respective dispatch schedules. The individual unit’s power correction values are passed to the generation management function and load management function for execution. DEMS is based on widespread software components running on Microsoft Windows-based computers with standardized interfaces and protocols (fig. 7.2-21). This secures the owner’s investment in the virtual power plant, because it is easy to extend the system with new modules.
Fig. 7.2-22 depicts the main components of DEMS. As basic SCADA engine, SIMATIC WinCC (Windows Control Center) is used.

The application algorithms are realized with Siemens ECANSE (Environment for Computer-Aided Neural Software Engineering). A Microsoft Excel interface exists for time series data input and output. The time series data is stored in the process database of WinCC (using a commercial relational database system). DEMS uses CPLEX for solving the mixed integer linear programming problem. By configuring WinCC, ECANSE and Excel files, a concrete DEMS application system can be configured according to the specific structure of the virtual power plant.

The user interface plays an important role in operator acceptance. It must be user-friendly in order to reduce the training effort and to avoid faulty operations. Therefore, the user Interface of DEMS is created using the basis of the WinCC user interface builder (fig. 7.2-23).

In addition to this, for more complex and flexible graphical analysis of time series information, Excel report files for result presentation can be used. By using either a remote desktop software tool or by using the WinCC web navigator option, ISDN or Web-based remote access to the DEMS system is possible. Fig. 7.2-23 shows some examples of the user interface.

As just stated, the interface and protocols of the communication front end are essential for the success of an energy management system in a virtual power plant. Therefore, DEMS provides several interface process data interfaces and protocols:

- OPC
- MODBUS Protocol Suite, MODBUS Serial
- PROFIBUS DP, PROFIBUS FMS
- SIMATICS5, S7, TI
- Windows DDE
- PLC protocols

In addition, DEMS has a SOAP-based XML Web interface that allows data exchange of process values and time series data from DEMS to DEMS or DEMS to Web applications. Furthermore, DEMS allows the import/export of process values and time series data from/to ODBC data sources, Excel and ASCII files.

- Synchronizing T&D and RTO/ISO operating models electronically provides TDSP operating model changes to the RTO/ISO when ready to be commissioned.
## 8 Communication Network Solutions for Smart Grids

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8 Communication Network Solutions for Smart Grids

8.1 Introduction

A secure, reliable and economic power supply is closely linked to a fast, efficient and dependable communication infrastructure. Planning and implementation of communication networks require the same attention as the installation of the power supply systems themselves (fig. 8.1-1).

Telecommunication for utilities has a long history in the transmission level of the power supply system and Siemens was one of the first suppliers of communication systems for power utilities. Since the early 1930s Siemens has delivered Power Line Carrier equipment for high-voltage systems. In today’s transmission systems, almost all substations are monitored and controlled online by Energy Management Systems (EMS). The main transmission lines are usually equipped with fiber-optic cables, mostly integrated in the earth (ground) wires (OPGW: Optical Ground Wire) and the substations are accessible via broadband communication systems. The two proven and optimal communication technologies for application-specific needs are Synchronous Digital Hierarchy (SDH) and Ethernet. Fiber-optic cables are used whenever it is cost-efficient. In the remote ends of the power transmission system, however, where the installation of fiber-optic cables or wireless solutions is not economical, substations are connected via digital high-voltage power line carrier systems.

The situation in the distribution grid is quite different. Whereas subtransmission and primary substations are equipped with digital communication as well, the communication infrastructure at lower distribution levels is very weak. In most countries, less than 10% of transformer substations and ring-main units (RMU) are monitored and controlled from remote.

The rapid increase in distributed energy resources today is impairing the power quality of the distribution network. That is
why system operators need to be able to respond quickly in critical situations. A prerequisite for this is the integration of the key ring-main units as well as the volatile decentralized wind and solar generation into the energy management system, and thus into the communication network of the power utilities. Because the local environment differs widely, it is crucial that the right mix of the various communication technologies is deployed. This mix will need to be exactly tailored to the utilities’ needs and the availability of the necessary infrastructure and resources (e.g., availability of fiber-optic cables, frequency spectrum for wireless technologies, or quality and length of the power cables for broadband power line carrier).

In the consumer access area, the communication needs are rising rapidly as well. The following Smart Grid applications request a bidirectional communication infrastructure down to consumer premises.

- Exchange of conventional meters with smart meters, which provide bidirectional communications connections between the consumer and energy applications (e.g., meter data management, marketplace, etc.)
- Management of consumers’ energy consumption, using price signals as a response to the steadily changing energy supply of large distributed producers
- If a large number of small energy resources are involved, the power quality of the low-voltage system must be monitored, because the flow of current can change directions when feed conditions are favorable

The selection of a communication solution depends on the customer’s requirements. If only meter data and price signals are to be transmitted, narrowband systems such as narrowband power line carriers or GPRS modems are sufficient. For smart homes in which power generation and controllable loads (e.g., appliances) or e-car charging stations are to be managed, broadband communication systems such as fiber-optic cables, broadband power line carriers or wireless solutions are necessary.

For these complex communication requirements, Siemens offers tailored ruggedized communication network solutions for fiber optic, power line or wireless infrastructures, based on the standards of the Energy Industry. Naturally, this also includes a full range of services, from communication analysis to the operation of the entire solution (fig. 8.1-2).
8.2 Communication Network Solutions for Transmission Grids (Communication Backbone)

8.2.1 Synchronous Digital Hierarchy (SDH)/Ethernet Solutions

For communications at transmission and subtransmission levels, Siemens offers the latest generation of SDH (Synchronous Digital Hierarchy) equipment, commonly referred to as NG (Next Generation) SDH (fig. 8.2-1).

NG SDH technology combines a number of benefits that make it well-suited to the needs of energy utilities. Among those benefits are high availability, comprehensive manageability and monitoring features, and last but not least SDH’s unique ability to seamlessly support both legacy applications and new, primarily packet-based emerging standards. Ethernet-over-SDH provides the capacity to transport packet-based traffic over the SDH backbone with high reliability and low latencies. As a result, Ethernet-over-SDH is the solution of choice for enabling IEC61850 across the entire communication backbone.

State-of-the-art NG SDH systems are highly integrated, providing all of the above-mentioned capabilities in a single device. In order to address the varying needs and requirements of the energy utilities, Siemens offers a wide range of products, from a single-board CPE to a multiservice platform for PDH (Plesiochronous Digital Hierarchy), SDH, WDM (Wavelength Division Multiplexing), and Ethernet.

Benefits at a glance
• High availability
• Very short delay times in protection signal transmission
• For both legacy and packet-based applications/systems
• Supports IEC 61850 standard
• Full-spectrum network management system

Fig. 8.2-1: Typical Next Generation SDH solution for transmission grids
8.2.2 Access Multiplexer

Today there is still a need to operate a number of different conventional communication interfaces in one substation (e.g., a/b phone, ISDN, V.24, X.21, etc.) and this will also apply in the near future. For this purpose, access multiplexers are used to bundle these communication signals and pass them on to the backbone system.

An access multiplexer can be employed to create flexible networks which can react rapidly to changes in network requirements. The modular design enables channel units to be combined as required for telephone, data and ISDN signal transmission. The multiplexer allows free assignment of user interfaces to the channels in the 2-Mbit/s signal and rapid configuration. Fig. 8.2-2 shows an overview of the interfaces provided by an typical access multiplexer.

---

### 8.2.3 PowerLink – Power Line Carrier for High-Voltage Lines

The digital power line carrier system PowerLink from Siemens uses the high-voltage line between substations as a communication channel for data, protection signals and voice transmission (table 8.2-1). This technology, which has been tried and tested over decades, and adapted to the latest standards, has two main application areas:

- As a communication link between substations where a fiber-optic connection does not exist or would not be economically viable
- As backup system for transmitting the protection signals, in parallel to a fiber-optic link

Fig. 8.2-3 shows the typical connection of the PowerLink system to the high-voltage line via the coupling unit AKE 100, coupling capacitor.

**Flexibility – the most important aspect of PowerLink**

Versatility is one of the great strengths of the PowerLink system. PowerLink can be matched flexibly to your infrastructure (table 8.2-2).

**Multi-service device**

PowerLink offers the necessary flexibility for transmitting every service the customer might want in the available band. All services can be combined in any way within the available bandwidth/bit rate framework.
8.2 Communication Network Solutions for Transmission Grids (Communication Backbone)

**Bridge to IP**
IP functionality is best suited for the migration from TDM to packet-switched networks. PowerLink offers electrical and optical Ethernet interfaces, including an integrated L2 switch, extending the IP network to remote substations with a bit rate up to 320 kbps.

**Optimal data throughput under changing environmental conditions**
PowerLink adapts the data rate to changes in ambient conditions, thus guaranteeing maximum data throughput. Thanks to PowerLink’s integral prioritization function, which can be configured for each channel, routing of the most important channels is assured even in poor weather conditions.

**Variable transmission power**
The transmission power can be configured via software in two ranges (20 – 50 W or 40 – 100 W), based on the requirements of the transmission path. This makes it easy to comply with national regulations and to enable optimized frequency planning.

**Maximum efficiency:**
**The integrated, versatile multiplexer (vMUX)**
A large number of conventional communication interfaces today (e.g., a/b telephone, V.24, X.21, etc.) and in the foreseeable future must be operated in a switching station. For this purpose, PowerLink uses an integrated versatile multiplexer that

<table>
<thead>
<tr>
<th>Application</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission of protection signals, telecontrolling information, data and voice via HV transmission lines</td>
<td>Cost-effective for small to medium data volumes over long distances</td>
</tr>
<tr>
<td></td>
<td>Processes analog and digital signals</td>
</tr>
<tr>
<td></td>
<td>Adjustable transmission power</td>
</tr>
<tr>
<td></td>
<td>Variable bandwidth</td>
</tr>
<tr>
<td></td>
<td>Integrated TCP/IP interface</td>
</tr>
<tr>
<td></td>
<td>Voice compression</td>
</tr>
<tr>
<td></td>
<td>Versatile multiplexer</td>
</tr>
<tr>
<td></td>
<td>Integrated teleprotection systems</td>
</tr>
<tr>
<td></td>
<td>Cross-functional management system for all integrated services</td>
</tr>
<tr>
<td></td>
<td>Can be used effectively in combination with broadband technologies for optimal availability</td>
</tr>
</tbody>
</table>

*Table 8.2-1: Progressive PLC technique with PowerLink*

![Fig. 8.2-3: PowerLink high-voltage line communication](image-url)
bundles these communication forms together and transmits them by PLC. The vMUX is a statistical multiplexer with priority control. Asynchronous data channels can be transmitted in “guaranteed” or “best effort” modes, to guarantee optimum utilization of available transmission capacity. The priority control ensures reliable transmission of the most important asynchronous and synchronous data channels and voice channels even under poor transmission conditions. Naturally, the vMUX is integrated in the management system of PowerLink, and is perfectly equipped for the power line communication requirements of the future with extended options for transmitting digital voice and data signals.

**Voice compression**

Voice compression is indispensable for the efficient utilization of networks. Naturally, quality must not suffer, which is why PowerLink offers comprehensive options for adapting the data rate to individual requirements. PowerLink offers different compression stages between 5.3 and 8 kbit/s. To prevent any impairment of voice quality, the compressed voice band is routed transparently to PowerLink stations connected in line, without any further compression or decompression.

**Protection signal transmission system SWT 3000**

A maximum of two independent SWT 3000 systems can be integrated into each PowerLink. Every integrated teleprotection system can transmit up to four protection commands. The command interface type for distance protection devices can be either standard binary or compliant with IEC 61850. Even a combination of both command interface types is supported. For highest availability, an alternate transmission path via a digital communication link can be connected. SWT 3000 systems are also fully integrated into the user interface of the PowerLink administration tool.

**One administration system for all applications**

PowerLink not only simplifies your communications, but also makes communications cost-efficient. The PowerSys software administers all integrated applications of PowerLink under a standard user interface. This ensures higher operating security while cutting training times and costs to the minimum.

**Integration of PowerLink in network management systems via SNMP**

PowerLink systems can also be integrated in higher level management systems via the IP access by means of the SNMP protocol (Simple Network Management Protocol). System and network state data are transferred, for example, to an alarm, inventory or performance management system.

<table>
<thead>
<tr>
<th>Features</th>
<th>Digital PLC system</th>
<th>Analog PLC system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universally applicable in analog, digital, or mixed operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency range 24 kHz–1,000 kHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bandwidth selectable 2–32 kHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data rate up to 320 kbit/s at 32 kHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission power 20/50/100 W, fine adjustment through software</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation with or without frequency band spacing with automatic cross talk canceller</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Digital interface</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchronous X.21 (max. 2 channels)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asynchronous RS 232 (max. 8 channels)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCP/IP (2 x electrical, 1 x optical)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1 (2 Mbps) for voice compression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G703.1 (64 kbps)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analog interface</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VF (VFM, VFO, VFS), max. 8 channels for voice, data, and protection signal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asynchronous RS232 (max. 4) via FSK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Miscellaneous</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Adaptive dynamic data rate adjustment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCP/IP layer 2 bridge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated versatile multiplexer for voice and data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. 5 compressed voice channels via VF interface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. 8 voice channels via E1 interface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>StationLink bus for the cross-connection of max. 4 PLC transmission routes (compressed voice and data without voice compression on repeater)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse FSK analog RTU/modem data via dPLC (2 x)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8.2-2: Overview of features
8.2.4 SWT 3000 – Teleprotection for High-Voltage Lines

The SWT 3000 is an highly secure and reliable system for transmitting time-critical distance protection commands via analog and digital transmission channels (fig. 8.2-4). This enables faults in the high-voltage grid to be isolated selectively as quickly as possible. The SWT 3000 system can be integrated in the PowerLink system or be operated as a stand-alone system.

Security, reliability and speed of protection signal transmission is one of the central factors in the operation of high-voltage grids. For maximum operating reliability, SWT 3000 can be configured with two separately fed power supplies. If possible, protection signals should be transmitted over two alternative communication paths to safeguard maximum transmission security. Fig. 8.2-5 shows the different analog and digital transmission paths between SWT 3000 systems.

The SWT 3000 also demonstrates its high degree of flexibility when existing substations are migrated to protection devices via the IEC 61850 communication standard. The SWT 3000 has all necessary command interfaces – both as binary interfaces and as GOOSE. This always keeps investment costs economically manageable, because the substations can be updated step by step for a new network age.

---

**Application**
Transmission of protection signals to quickly identify, isolate and resolve problems in the transmission network of a utility

**Advantages**
- Keeps downtimes to an absolute minimum
- Supports IEC 61850 interfaces as well as conventional binary interfaces
- Flexible integration into various customer communication networks
- Path protection via two different transmission routes for increased reliability

---

**Pilot cable connections**
For operation via pilot cable, two SWT 3000 devices can be linked directly through the analog interfaces (CLE).

**Power line carrier connections**
The analog link (CLE) between two SWT 3000 devices can also be a PLC link. Depending on device configuration, SWT 3000 can be used with PowerLink in alternate multipurpose, simultaneous multipurpose, or single-purpose mode.

**Fiber-optic connections between SWT 3000 and PowerLink**
A short-distance connection between an SWT 3000 and Siemens’s PowerLink PLC terminal can be realized via an integrated fiber-optic modem. In this case, an SWT 3000 stand-alone system provides the same advanced functionality as the version integrated into PowerLink. Each PowerLink can be connected to two SWT 3000 devices via optical fibers.

**SWT 3000 digital connections**
The digital interface (DLE) permits protection signals to be transmitted over a PDH or SDH network.

**Alternative transmission routes**
SWT 3000 enables transmission of protection signals via two different routes. Both routes are constantly transmitting. In the event that one route fails, the second route still bears the signal.

**Direct fiber-optic connection without repeater**
SWT 3000 protection signaling incorporates an internal fiber-optic modem for long-distance transmission. The maximum distance between two SWT 3000 devices is 150 kilometers.

**Fiber-optic connection between SWT 3000 and a multiplexer**
A short-distance connection of up to two kilometers between SWT 3000 and a multiplexer can be realized via the integrated fiber-optic modem according to IEEE C37.94. Alternately, the multiplexer is connected via FOBox, converting the optical signal to an electrical signal in case the MUX does not support C37.94.

**SWT 3000 integration into the PowerLink – PLC system**
The SWT 3000 system can be integrated into the PowerLink equipment. Either the analog interface or a combination of the analog and the digital interfaces can be used.
Communication Network Solutions for Smart Grids

8.2 Communication Network Solutions for Transmission Grids (Communication Backbone)

<table>
<thead>
<tr>
<th>PowerLink</th>
<th>Power Line Carrier System</th>
<th>IFC</th>
<th>EN 100</th>
<th>Interface IEC 61850</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFC</td>
<td>Interface Command Binary</td>
<td>SDH</td>
<td>PDH</td>
<td>Plesiochronous Digital Hierarchy</td>
</tr>
<tr>
<td>DLE</td>
<td>Digital Line Equipment</td>
<td>FO</td>
<td>DLE</td>
<td>Digital Line Equipment</td>
</tr>
<tr>
<td>CLE</td>
<td>Copper Line Equipment</td>
<td>FO</td>
<td>CLE</td>
<td>Copper Line Equipment</td>
</tr>
<tr>
<td>PDH</td>
<td>Plesiochronous Digital Hierarchy</td>
<td>MUX</td>
<td>Multiplexer</td>
<td></td>
</tr>
</tbody>
</table>

**Analog transmission**

1. SWT 3000
2. SWT 3000
3. SWT 3000
4. SWT 3000

**Digital transmission**

5. SWT 3000
6. SWT 3000
7. SWT 3000
8. SWT 3000
9. SWT 3000
10. SWT 3000

**Analog & digital transmission**

11. SWT 3000
12. SWT 3000

**Integrated into PowerLink**

13. PowerLink
14. PowerLink

---

Digital network
Two routes via digital network
One path via fiber-optic cable, second path via digital network
Fiber-optic modem integrated
One path via integrated optical fibers, second via fiber-optic box, MUX, and digital network
Through digital network via MUX and fiber-optic C37.94

One path via digital network; second path via 4-wire (or 2-wire)
One path via power line and optical fibers; second path via optical fibers and digital network

Power line
One path via power line; second path via digital network
8.2.5 Coupling Unit AKE 100

The PLC terminals are connected to the power line via coupling capacitors, or via capacitive voltage transformers and the coupling unit. In order to prevent the PLC currents from flowing to the power switchgear or in other undesired directions (e.g., tapped lines), traps (coils) are used, which are rated for the operating and short-circuit currents of the power installation and involve no significant loss for the power distribution system.

The AKE 100 coupling unit from Siemens described here, together with a high-voltage coupling capacitor, forms a high-pass filter for the required carrier frequencies, whose lower cut-off frequency is determined by the rating of the coupling capacitor and the chosen matching ratio.

The AKE 100 coupling unit is supplied in four versions and is used for:
- Phase-to-earth coupling to overhead power lines
- Phase-to-phase coupling to overhead power lines
- Phase-to-earth coupling to power cables
- Phase-to-phase coupling to power cables
- Intersystem coupling with two phase-to-earth coupling units

The coupling units for phase-to-phase coupling are adaptable for use as phase to-earth coupling units. The versions for phase-to-earth coupling can be retrofitted for phase-to-phase coupling, or can as well be used for intersystem coupling.

8.2.6 Voice Communication with PowerLink

The TCP/IP protocol is gaining increasing acceptance in the voice communication area. However, considerably higher bandwidth requirements must be taken into account in network planning with VoIP compared with analog voice links. Table 8.2-3 shows the bandwidth requirement for a voice link via TCP/IP as a function of the codec used for voice compression.

In the office area today, the LAN infrastructure is usually sufficiently generously dimensioned to make VoIP communication possible without any restrictions. The situation is distinctly different if it is necessary to connect distant substations to the utility’s voice network. If these locations are not integrated in the corporate backbone network, Power Line Carrier connections must be installed. Fig. 8.2-6 shows the basic alternatives for voice communication via PowerLink.

### Table 8.2-3: Bandwidth requirement for VoIP

<table>
<thead>
<tr>
<th>Codec</th>
<th>Net bit rate</th>
<th>Gross bit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.711</td>
<td>64 kbit/s</td>
<td>87.2 kbit/s</td>
</tr>
<tr>
<td>G.722</td>
<td>32 kbit/s</td>
<td>55.2 kbit/s</td>
</tr>
<tr>
<td>G.728</td>
<td>16 kbit/s</td>
<td>31.5 kbit/s</td>
</tr>
<tr>
<td>G.729</td>
<td>8 kbit/s</td>
<td>31.2 kbit/s</td>
</tr>
<tr>
<td>G.723.1</td>
<td>5.3 kbit/s</td>
<td>20.8 kbit/s</td>
</tr>
</tbody>
</table>

**Fig. 8.2-6: Basic options of voice communication via PowerLink**
Analog connection
The telephone system is connected to the PowerLink via the analog E&M interface. A telephone system or an individual analog telephone can also participate in a PowerLink system at a different location. The bandwidth requirement can be reduced to about 6 kbit/s (including overhead) per voice link by means of voice compression in the PowerLink.

Digital connection
With digital connection, the telephone system is connected to PowerLink via the digital E1 interface. Because of the restricted bandwidth, up to 8 of the 30 voice channels (Fractional E1) can be used. This alternative is only suitable for communication between telephone systems. Individual telephones must be connected locally to the particular telephone system. The bandwidth requirement is made up of the user data per voice channel (e.g., 5.3 kbit/s) and the D-channel overhead for the entire E1 link (approximately 2.4 kbits/s), (i.e., for a voice channel less than 10 kbit/s).

In the case of series connected locations with both analog and digital connection, multiple compression/decompression of the voice channel is prevented by the unique PowerLink function “StationLink”.

TCP/IP connection
The telephone system, voice terminals and the PowerLink system are connected directly to the TCP/IP network. Voice communication is conducted directly between the terminals. Only control information is transmitted to the telephone system. Use of the TCP/IP protocol results in a broadband requirement per voice channel of at least 21 kbit/s (5.3 kbit/s voice plus TCP/IP overhead).

Telephone systems
To ensure the operation along high-voltage transmission lines or pipelines and power plants, voice communication is an important part of the entire solution. The Siemens Enterprise Communication portfolio addresses all the different requirements of utilities, and can be deployed in various scenarios.

The limited bandwidth availability of Power Line Carrier systems in the high-voltage area will ensure an important role for conventional telephone systems (e.g., HiPath 4000) with analog interfaces in this segment in the future as well (fig. 8.2-7).
8.2.7 Live Line Installation of OPGW (Optical Ground Wire)

The transformation of power supply systems into Smart Grids is closely related to the growing communication requirements (bandwidth demand) in the transmission and distribution areas.

To allow for quick data transfers between large substations in the transmission system, fiber-optic cables are being used to replace ground wires on high-voltage lines (OPGW: Optical Ground Wire).

As a result of the growing and often unpredictable feeding of energy into the power supply system by decentralized generators, it is becoming increasingly difficult and sometimes impossible for transmission companies to shut off line segments for installation measures to improve the communication infrastructure.

The Siemens Live Line Installation process makes it possible to perform such installations or repairs on energized power lines. This installation concept was developed in a joint effort by Siemens and a team at Dresden University in Germany.

The Siemens Live Line Installation process can be used for the following purposes:

- To replace the ground wire with an optical ground wire, in order to provide broadband communication even to smaller substations
- Additional installation of a second optical ground wire below the top of the tower, on especially communication-intensive segments
- To replace an obsolete or defective optical ground wire.

Safety of both personnel and equipment is the utmost priority: Live Line Installation supplies a new earthing concept as well as pulling machines and brakes on the ground (fig. 8.2-8).

With live line installation, optical ground wires can be installed either directly at the top of the tower or below the top between the power-carrying lines (fig. 8.2-9).

Special security precautions are taken when high-risk areas (highways, bodies of water, railways, etc.) are to be crossed when installing the optical ground wires below the top of the tower.

During live line installation, the existing ground wire serves as a messenger and carries all the installation equipment, such as pulleys, the full dielectric prepulling rope and the OPGW itself. Thus, the new hybrid cable can be pulled from tower to tower across the entire delivery length. In high-voltage lines, the usual delivery length is approximately 4 km.

Siemens is the most experienced and most successful supplier of live line installation of optical ground wires on high-voltage lines worldwide, and conducted the first live line installation already in the year 2000.
8.3 Control Center Communication

Redundant control center communication
A control center for power supply systems such as Spectrum Power (fig. 8.3-1) is typically configured with full redundancy to achieve high availability. This includes communications. Depending on the system operator’s requirements, various mechanisms are supported to achieve this goal for communication. This includes:
- Automatic failover of communication servers
- Configurable load sharing between two or more communication servers
- Automatic failover of communication lines
- Supervision of standby communication line, including telegram buffering

Process communication to substations and power plants
Process communication to the substations and to Remote Terminal Units (RTUs), e.g., in power plants or power supply systems, is implemented via serial interfaces or by means of TCP/IP-based network communication with a Communication Front End. The Communication Front End includes data-pre-processing functionality like:
- Routine for data reduction, e.g., old/new comparison, threshold check
- Data conversion
- Scaling and smoothing of measured values
- Integrity checks for incoming data
- Data completeness checks and cycle monitoring
- Statistical acquisition of the data traffic with the RTU.

All kinds of different protocols are used for historical reasons. However, as a result of international standardization there is also a market trend here towards standardized protocols like IEC 60870-5-104, DNP3i protocol or IEC-61850.

The more recent protocol standards all rely on TCP/IP-based communication. However, it must be possible today and in the near future to continue connecting conventional telecontrol devices (already installed RTUs) via serial interfaces.

Interface for industry automation/third-party applications
OPC (OLE for process control) and OPC UA provide a group of defined interfaces. OPC in general enables the overall data exchange between automation and control applications, field systems/field devices, as well as business and office applications.

OPC is based on OLE/COM and DCOM technology. OPC UA (Unified Architecture) is a continuation and further innovation of OPC. OPC UA is based on native TCP/IP and is available for multiple operating system platforms, including embedded devices.

Communication between control centers
The communication between control centers is provided via the communication protocols ICCP or ELCOM, and is based on TCP/IP.

The Inter Control Center Communication Protocol (ICCP) is an open and standardized protocol based on IEC 60870-6 and Telecontrol Application Service Element Two (TASE.2).

The exchanged data is primarily real-time system information like analog values, digital values and accumulator values, along with supervisory control commands.

Remote workstations/office communication
Remote workstations can communicate with the control center via the office LAN or an Internet connection. System and data integrity has to be ensured by the system security configuration for:
- Protection against external attacks
- Protection against unauthorized usage
- Protection against data loss

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**Fig. 8.3-1: Typical communication interfaces and communication partners of a control center using the example of Spectrum Power™**
8.4 Substation Communication

8.4.1 Overview of IEC 61850

Since being published in 2004, the IEC 61850 communication standard has gained more and more relevance in the field of substation automation. It provides an effective response to the needs of the open, deregulated energy market, which requires both reliable networks and extremely flexible technology – flexible enough to adapt to the substation challenges of the next twenty years. IEC 61850 has not only taken over the drive of the communication technology of the office networking sector, but it has also adopted the best possible protocols and configurations for high functionality and reliable data transmission. Industrial Ethernet, which has been hardened for substation purposes and provides a speed of 100 Mbit/s, offers bandwidth enough to ensure reliable information exchange between IEDs (Intelligent Electronic Devices), as well as reliable communication from an IED to a substation controller.

The definition of an effective process bus offers a standardized way to connect conventional as well as intelligent CTs and VTs to relays digitally. More than just a protocol, IEC 61850 also provides benefits in the areas of engineering and maintenance, especially with respect to combining devices from different vendors.

Key features of IEC 61850

As in an actual project, the standard includes parts describing the requirements needed in substation communication, as well as parts describing the specification itself.

The specification is structured as follows:

• An object-oriented and application-specific data model focused on substation automation.
• This model includes object types representing nearly all existing equipment and functions in a substation – circuit-breakers, protection functions, current and voltage transformers, waveform recordings, and many more.
• Communication services providing multiple methods for information exchange. These services cover reporting and logging of events, control of switches and functions, polling of data model information.
• Peer-to-peer communication for fast data exchange between the feeder level devices (protection devices and bay controller) is supported with GOOSE (Generic Object Oriented Substation Event).
• Support of sampled value exchange.
• File transfer for disturbance recordings.
• Communication services to connect primary equipment such as instrument transducers to relays.
• Decoupling of data model and communication services from specific communication technologies.
• This technology independence guarantees long-term stability for the data model and opens the possibility to switch over to successor communication technologies. Today, the standard uses Industrial Ethernet with the following significant features:
  – 100 Mbit/s bandwidth
  – Non-blocking switching technology
  – Priority tagging for important messages
  – Time synchronization
• A common formal description code, which allows a standardized representation of a system’s data model and its links to communication services.
• This code, called SCL (Substation Configuration Description Language), covers all communication aspects according to IEC 61850. Based on XML, this code is an ideal electronic interchange format for configuration data.
• A standardized conformance test that ensures interoperability between devices. Devices must pass multiple test cases: positive tests for correctly responding to stimulation telegrams, plus several negative tests for ignoring incorrect information
• IEC 61850 offers a complete set of specifications covering all communication issues inside a substation
• Support of both editions of IEC 61850 and all technical issues.

8.4.2 Principle Communication Structures for Protection and Substation Automation Systems

SIPROTEC – communication of protection relays and bay controllers

Communication interfaces on protection relays are becoming increasingly important for the efficient and economical operation of substations and networks.

The interfaces can be used for:

• Accessing the protection relays from a PC using the DIGSI operating program for aspects of configuration, access of operational and non-operational data.

Remote access via modem or Ethernet modem is possible with a serial service port at the relay. This allows remote access to all data of the protection relay.

By using the remote communication functions of DIGSI it is possible to access relays, e.g., from the office via the telephone network (fig. 8.4-1). For example, the error log can be transferred to the office and DIGSI can be used to evaluate it.

• Integrating the relays into control systems with IEC 60870-5-103 protocol, PROFIBUS DP protocol, DNP 3.0 protocol and MODBUS protocol.

The new standardized IEC 61850 protocol (section 8.3.1) has been available since October 2004, and with its SIPROTEC units Siemens was the first manufacturer worldwide to provide this standard.

• Thanks to the standardized interfaces IEC 61850, IEC 60870-5-
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8.4 Substation Communication

103, DNP 3.0 (serial or over IP), MODBUS, PROFIBUS DP, SIPROTEC units can also be integrated into non-Siemens systems or in SIMATIC S5/S7. Electrical RS485 or optical interfaces are available. The optimum physical data transfer medium can be chosen thanks to opto-electrical converters. Thus, the RS485 bus allows low-cost wiring in the cubicles and an interference-free optical connection to the master can be established.

- Peer-to-peer communication of differential relays and distance relays (section 8.5.2) to exchange real-time protection data via fiber-optic cables, communication network, telephone networks or analog pilot wires.

**Ethernet-based system with SICAM**

SIPROTEC is tailor-made for use with the SICAM power automation system together with IEC 61850 protocol. Via the 100 Mbit/s Ethernet bus, the units are linked electrically or optically to the station unit. Connection may be simple or redundant. The interface is standardized, thus also enabling direct connection of units from other manufacturers to the LAN. Units featuring an IEC 60870-5-103 interface or other serial protocols can be connected via the Ethernet station bus to SICAM by means of serial/ethernet converters. DIGSI and the Web monitor can also be used over the same station bus. Together with Ethernet/IEC 61850 an interference-free optical solution can be provided. Thus, the installation Ethernet interface in the relay includes an Ethernet switch. Thus, the installation of expensive external Ethernet switches can be avoided. The relays are linked in an optical ring structure (fig. 8.4-2).

**Further communication options for IED connection**

Apart from supporting IEC 61850, modern substation automation systems like SICAM also support the connection of IEDs (Intelligent Electronic Devices) with other protocol standards like the well-known standard IEC 60870-5-103 for protections units as well as DNP3 (serial or over IP), and also protocols such as PROFIBUS DP and MODBUS.

Specifically with SICAM PAS, the devices with serial communication can be reliably connected directly to the substation controller. Moreover it is also possible to use LAN for backbone communication throughout the substation, connecting such serial devices with serial hubs in a decentralized approach.

Additionally it is also possible to connect subordinated substations and Remote Terminal Units (RTU) using the protocol standards IEC 60870-5-101 (serial communication) and IEC 60870-5-104 (TCP/IP).

Especially for communication with small RTUs, dial-up connections can be established based on IEC 60870-5-101.

**Additional features of TCP/IP communication**

Besides the traditional protocols mentioned for data exchange with IEDs, in the world of Ethernet it is also important to be aware of the status of communication infrastructure devices such as switches. In this context, the protocol SNMP (Simple Network Management Protocol) helps a lot. SICAM PAS supports this protocol, thereby providing status information, e.g., to the control center, not only for IEDs and substation controllers, but also for Ethernet switches and other “SNMP devices”.

Another communication protocol, well-known from the industrial automation sector, is also required for substation automation applications: OPC (OLE for Process Control, see also Control Center Communication). Additional interoperable solutions are possible with OPC, especially for data exchange with devices and applications of industrial automation. SICAM PAS supports both OPC server and OPC client.

The linking of protection relays and/or bay controllers to the station level is chosen according to the size and importance of the substation. Whereas serial couplings with IEC 60870-5-103...
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are the most economical solution in small distribution substations (only medium voltage). Ethernet in compliance with IEC 61850 is normally used for important high-voltage and extra-high-voltage substations. In addition there are a number of different physical designs, based on the local situation as regards cable runs and distances, and on the requirements in terms of availability and EMC influences.

The simplest version is the serial bus wiring in accordance with RS 485 in which the field devices are electrically connected to a master interface on the SICAM central unit (fig. 8.4-3). This wiring is particularly recommended in new installations. Special attention should also be paid to correct handling of the earthing, and also to possible impact on the EMC due to the primary technology or power cables. Separate cable routes for power supply and communications are an essential basis for this. A reduction of the number of field devices per master to about 16 to 20 devices is recommended in order to be able to make adequate use of the data transfer performance.

A star configuration of the wiring is rather easy to handle and can be in the form either of electrical wiring as per RS 232, or optical fiber. Here again, the number of devices per master should be limited as before (fig. 8.4-4).

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**Fig. 8.4-3:** Serial bus wiring in accordance with RS 485

**Fig. 8.4-4:** Star wiring in accordance with RS 232 or per fiber-optic cable

**Fig. 8.4-5:** Ethernet: Star configuration electrical or optical

**Fig. 8.4-6:** Ethernet: Optical ring with external switches
The configurations with Ethernet are similar, with star and ring versions available. Variants with redundancy complete these configurations. The star configuration is especially recommended for central arrangements with short distances for the cable routes (fig. 8.4-5).

A fiber-optic ring can be made up of individual switches. That is especially advisable if several devices are to be connected in each feeder (fig. 8.4-6).

A more economical solution is the fiber-optic ring with SIPROTEC relays because these devices have a switch directly integrated (fig. 8.4-7). In this application, though, a suitable device from RuggedCom must be used for the central switch so that the fast switchover times can also be used in the case of a malfunction on the ring. The number of devices in the ring is restricted to 27.

Several rings can also be combined on the basis of this fundamental structure, e.g., one per voltage level. Usually these rings are combined to form a higher level ring which then communicates with redundant station devices. This version offers the highest availability for station-internal communication (fig. 8.4-8).

![Fig. 8.4-7: Optical ring with integrated switches](image1)

![Fig. 8.4-8: The combination of several rings offers the highest availability](image2)
8.4.3 Multiple Communication Options with SIPROTEC 5

The SIPROTEC 5 modular concept ensures the consistency and integrity of all functionalities across the entire device series. Significant features here include:

Powerful and flexible communication is the prerequisite for distributed and peripheral system landscapes. In SIPROTEC 5 this is a central element of the system architecture enabling a wide variety of communication requirements to be satisfied while providing utmost flexibility. Fig 8.4-11 shows a possible hardware configuration equipped with 4 communication modules. Fig 8.4-12 shows the CB202 expansion module with 3 slots for plug-in modules. Two of these slots can be used for communication applications.

Owing to the flexibility of hardware and software, SIPROTEC 5 features the following system properties:
• Adaptation to the topology of the desired communication structure, such as ring or star configurations
• Scalable redundancy in hardware and software (protocols)
• Multiple communication channels to various superordinate systems
• Pluggable communication modules that can be retrofitted
• The module hardware is independent of the communication protocol used
• 2 independent protocols on a serial communication module
• Up to 8 interfaces are available
• Data exchange via IEC 61850 for up to 6 clients using an Ethernet module or the integrated Ethernet interface.
Communication examples with SIPROTEC 5
Regardless of the desired protocol, the communication technology used enables communication redundancies to be tailored to the requirements of users. They can basically be divided into Ethernet and serial communication topologies.

Protocols
- Serial protocols
- Ethernet protocols

Different degrees of protocol redundancy can be implemented. The 4 plug-in module slots limit the number of independent protocol applications that run in parallel. For serial protocols, 1 or 2 masters are usually used.

Serial protocols
Redundant or different serial protocols are capable of running simultaneously in the device, e.g., DNP 3 and IEC 60870-5-103. Communication is effected to one or more masters.

Two serial protocols can run on a double module (fig 8.4-13). It is not relevant in this context whether these are two protocols of the same type or two different protocols.

The communication hardware is independent of the required protocol. This protocol is specified during parameterization with DIGSI 5.

Ethernet protocols
The Ethernet module can be plugged in once or multiple times in the device. This enables running identical or different protocol applications in multiple instances. Multiple networks are possible for IEC 61850 or DNP3 TCP, but they can also be operated in a common Ethernet network. A module implements the IEC 61850 protocol application, e.g., the data exchange between devices using GOOSE messages. The other module is responsible for the client-server communication over the DNP TCP protocol. The client-server architecture of IEC 61850 enables one server (device) to send reports to up to 6 clients simultaneously. In this case, only one network is used.
Examples
Redundancies to substation automation systems
- 2 redundant substation automation systems
- 2 different substation automation systems.

Example 1: Two redundant substation automation systems
Fig. 8.4-15 shows a serial optical network which connects the serial protocol interfaces of the device to one master, respectively. Transmission is accomplished in multipoint-star configuration and with interference-free isolation via optical fiber.

For the IEC 60870-5-103 protocol, the device supports special redundancy procedures. For instance, a primary master can be configured that is preferred to the second master in control direction. The current process image is transmitted to both masters.

The fig. 8.4-16 describes a fully redundant solution based on IEC 61850. 2 Ethernet communication modules are plugged into each SIPROTEC 5 device. 2 redundant fiber-optic rings are set up by means of the switches integrated in the module and connected to the redundant clients (substation automation systems). Alternatively, the redundant IEC 61850 communication could also be accomplished via a common optical ring.

Fig. 8.4-15: Redundant IEC 60870-5-103 or DNP3 communication

Fig. 8.4-16: Redundant communication to two IEC 61850 or DNP3 TCP clients
Example 2: Two substation automation systems with different protocols
Since both the serial protocols and the Ethernet-based protocols are only specified during parameterization, the configuration described previously can also be implemented using mixed protocols. This can be a particularly interesting case of application if different control centers are connected via different protocols. This could be, for example, the control center of the transmission system and the control center of the distribution system. Fig. 8.4-17 and fig. 8.4-18 show a possible combination.

Multiple substations buses
Substation-wide Ethernets are increasingly being used in modern substation automation systems in practice. These networks transport both the communication services to the central substation computer controller and the signals between the devices of the bay level. Usually, a single Ethernet subsystem is set up for this purpose since the bandwidth of today’s Ethernet networks is sufficient for the entire data traffic.

By using multiple communication modules and protocols in SIPROTEC 5 it is now possible to set up several subsystems, and to separate the different applications. For example, a separate process bus for process signals (GOOSE) could be implemented on bay level, and a separate bus to the central substation computer. See fig. 8.4-19 (2 substation buses).
8.4.4 Network Redundancy Protocols

Today’s configuration of a substation network – RSTP
The electrical and optical Ethernet modules of SIPROTEC devices support different network topologies. This applies independently of the selected protocol (IEC 61850 or DNP 3.0).

If the module operates in dual homing redundancy (without integrated switch), it can be connected to external switches either in simple or redundant configuration. Only one interface at a time processes the protocol applications (e.g., IEC 61850) in this case. The second interface operates in standby mode (hot standby), and the connection to the switch is monitored. If the interface which processes the protocol traffic fails, the standby interface is activated within a few milliseconds and takes over – (fig. 8.4-20).

When activating the integrated switch, SIPROTEC devices can be integrated directly into the optical communication ring consisting of up to 40 devices (fig. 8.4-21). In this case, both interfaces of the module send and receive at the same time. The ring redundancy procedure Rapid Spanning Tree Protocol (RSTP) ensures short switchover times if the communication is interrupted, allowing the protocol applications to continue operation virtually without interruption. This configuration is independent of the protocol application running on the Ethernet module.

Today, more than 250,000 Siemens devices in more than 3,000 substations are in operation worldwide in stations with RSTP. In case of ring interruptions, RSTP reconfigures the communication within a short time, and provides a secure operation of substations.

Seamless redundancy PRP and HSR
New technologies reduce the time for reconfiguration of communication networks in case of interruptions to about nothing. These technologies are:
- PRP = Parallel Redundancy Protocol
- HSR = High Available Seamless Ring Redundancy

Both systems have the same principle and are specified in IEC 62439-3.

The same information (Ethernet frame) is being sent over two ways. The receiver takes the first that comes in and discards the second one. If the first does not get through, the second one is still available and will be used. The mechanism is based deeply in the Ethernet stack, means one MAC and one IP address for both.
- PRP uses two independent Ethernet systems. This means double amount of network equipment and respectively cost, but it is simple.
- HSR is using the same principle, but in one Ethernet network in a ring configuration. The same information (Ethernet frame) will be sent in the two directions into the ring, and the receiver gets it from the two sides of the ring. This means some more effort in the devices but saves the costs for a second Ethernet network.
8.4 Substation Communication

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Fig. 8.4-23: Seamless redundancy by use of PRP only

Fig. 8.4-24: Seamless redundancy by use of PRP/HSR combined
HSR and PRP can be combined by so called RedBoxes (Redundancy Boxes).

The figs. 8.4-23 to 8.4-25 show some examples of PRP and HSR configurations.

This cost-effective solution of fig. 8.4-25 can be achieved by:
• 2 switches at the control room
• 2 switches in the field
• 2 Redboxes (RB) per HSR ring
• Up to 50 devices per HSR ring
• Easy expansion by additional 2 PRP switches

**Summary**
- Siemens offers redundancy solutions
  - Dual link redundancy
  - RSTP
  - PRP (seamless)
  - HSR (seamless)
- Dual link and RSTP: Field proven established technology
- PRP: High level redundancy through double network solution
- HSR: High level redundancy through cost effective ring network structure. Combinable with PRP network.
- Siemens Seamless Ethernet Media Redundancy Suite: SICAM PAS, SIPROTEC and Redbox
- SIPROTEC with integrated RSTP/PRP/HSR switches

--> Siemens solutions produce significant user advantage in terms of functionality.
8.4.5 Communication Between Substation Using Protection Data Interfaces

SIPROTEC 4 – differential and distance protection
Typical applications of differential and distance protection are shown in fig. 8.4-26. The differential protection relay is connected to the current transformers and to the voltage transformers at one end of the cable, although only the currents are required for the differential protection function. Direct connection to the other units is effected via single-mode fiber-optic cables and is thus immune to interference. Various communication modules are available for different communication media. In the case of direct connection via fiber-optic cables, data communication is effected at 512 kbit/s and the command time of the protection unit is reduced to 15 ms.

SIPROTEC 4 offers many features to reliably and safely handle data exchange via communication networks. Depending on the bandwidth available, a communication converter for G703-64 kbit/s or X21-64/128/512 kbit/s can be selected. For higher communication speed, a communication converter with G703-E1 (2,048 kbit/s) or G703-T1 (1,554 kbit/s) is available.

![Fig. 8.4-26: Protection Data Interface using direct FO connection](image)

Teleprotection using protection data interface
The teleprotection schemes can be implemented using digital serial communication. The distance protection SIPROTEC 7SA6 is capable of remote relay communication via direct links or multiplexed digital communication networks. The link to a multiplexed communication networks is made by separate communication converters (7XV5662). These have a fiber-optic interface with 820 nm and ST connectors to the protection relay. The link to the communication networks is optionally an electrical X21 or a G703.1 interface (fig. 8.4-27).

SIPROTEC 5 – transfer of data via the protection interface
The protection interface and protection topology enable data exchange between the devices via synchronous serial point-to-point links from 64 kbit/s to 2 Mbit/s. These links can be established directly via optical fibers or via other communication media, e.g., via dedicated lines or communication networks.

A protection topology consists of 2 to 6 devices, which communicate point to point via communication links. It can be structured as a redundant ring or as a chain structure (see fig. 8-4.20), and within a topology the protection links can have different bandwidths. A certain amount of binary information and measured values can be transmitted bi-directionally between the devices depending on the bandwidth. The connection with the lowest bandwidth determines this number. The user can route the information with DIGSI 5.

This information has the following tasks:
- Topology data and values are exchanged for monitoring and testing the link
- Protection data, for example differential protection data or direction comparison data of the distance protection, is transferred.
- Time synchronization of the devices can take place via the link, in which case a device of the protection topology assumes the role of timing master.
- The link is continuously monitored for data faults and failure, and the runtime of the data is measured.

Protection links integrated in the device have previously been used for differential protection (fig. 8-4.26) and for teleprotection of the distance protection. In addition to these protection applications, you can configure protection links in all devices in SIPROTEC 5. At the same time, any binary information and measured values can be transferred between the devices. Even connections with low bandwidth, e.g., 64 kbit/s can be used for this.

Use of the protection link for remote access with DIGSI 5
Access with DIGSI 5 to devices at the remote ends is possible via the protection interface. This allows devices at the remote ends to be remotely read out, or parameters to be set using the existing communication connection.

![Fig. 8.4-27: Protection Data Interface using digital communication networks](image)
### Communication Network Solutions for Smart Grids

**8.4 Substation Communication**

**Fig. 8-4.28:** Protection communication of the differential protection and transfer of binary signals

**Fig. 8-4.29:** Protection communication via a communication network with X21 or G703.1 (64 kbit/s), G703.6... (2 Mbit) interface

**Fig. 8-4.30:** Protection communication via a copper connection

**Fig. 8-4.31:** Protection communication via an IEEE C37.94 (2 Mbits/s) interface – direct fiber-optic connection to a multiplexer

**Fig. 8-4.32:** Protection communication via single-mode fiber and repeater

**Fig. 8-4.33:** Protection communication via direct fiber-optic connections
8.4.6 Requirements for Remote Data Transmission

In principle, both RTUs and station automation are very flexible for adapting to any remote communication media supplied by the user.

- Small substations are usually associated with small data volumes and poor accessibility of communication media. Therefore, dial-up modems are often used, also radio (if no lines available) or PLC communication. Sometimes even GPRS is an alternative, depending on the availability of a provider. Protocols also depend on the capabilities of the control center, but are mostly based on international standards like IEC 60870-5-101 (serial) and IEC 60870-5-104 (Ethernet), although DNP 3.0 is also found in some places (serial or over TCP/IP). Some small substations do not necessarily need to be online continuously. They can be configured to occasional calls, either locally or by external polling from the control center.

- Medium-size substations are generally connected via communication cables or optical fibers with serial end-end links. Serial lines with 1,200 Bd or higher are sufficient for IEC ...-101 or DNP. Sometimes, multiple lines to different control centers are necessary, while redundant communication lines are reserved for important substations only. WAN technology is increasingly used in line with the trend towards more bandwidth.

- Large substations, especially at transmission level, can have serial links as before, but with higher transmission rates. Anyway there is a trend towards wide area networks using Ethernet. For IEC ...-104 or similar protocols a minimum of 64 kbit/s should be taken into account. If large data volumes are to be exchanged and additional services (e.g., Voice over IP, Video over IP) provided, the connection should have more bandwidth (64 kbit/s < Bandwidth ≤ 2,048 kbit/s).

Fig. 8-4.34: Protection communication via a single-mode fiber

Figs. 8-4.28 to 8-4.34 show possible communication variants for establishing protection communications.
8.5 Communication Network Solutions for Distribution Grids (Backhaul/Access Communication)

8.5.1 Introduction

In the past, electricity was mainly produced by bulk generation at central locations, and distributed to consumers via the distribution systems. Energy peaks (e.g., at midday) were well known and balanced out by reserve capacity of central power plants. It was therefore usually not necessary to specially control the lower-level distribution networks, or even to integrate the consumers into the grid monitoring system.

Ever since renewable energy has been significantly expanded, electricity is being fed into both the medium-voltage and low-voltage systems, depending on changing external conditions (e.g., weather, time of day, etc.). These fluctuating energy resources can severely impair the stability of the distribution grids.

Buildings account for 40% of the world’s energy consumption and 20% of total CO₂ emissions. Therefore, smart buildings also play a central role in the Smart Grid as they provide a huge potential for energy efficiency. Actively influencing their consumption and generation, smart buildings support the system stability and allow generators to consider other options before adding new generation facilities.

One of the key challenges of a Smart Grid therefore is quickly balancing out the energy supply and energy consumption in the distribution system (fig. 8.5-1).

A prerequisite for implementing a solution for this demand is monitoring and managing as many components of a power supply system as possible all the way to the consumer. The basis for this is a reliable communication infrastructure. For medium voltage, at least the following system components must be integrated into a Smart Grid and managed:

- The key ring-main units
- All large distributed producers (solar/wind farms, biogas/hydroelectric power plants, etc.)
- Large buildings, campuses, refrigerated warehouses, etc.

For low voltage, primarily households and small producers of renewable energy are involved.

With respect to their role in the power supply system, consumers can be divided into two groups:

- “Standard consumers”, who have smart meters and optimize their electricity costs via ongoing price signals depending on supply and demand
- “Prosumers” (prosumer = producer + consumer), who can feed surplus energy into the power grid – such as solar power or energy generated by combined heat and power systems (CHP); many can also intermediately store energy using possibilities such as night storage heaters or e-cars.

While the communication requirements for standard consumers are concentrated on smart metering including price signals, time-critical control signals and power quality data must also be transmitted for prosumers. Therefore, in addition to smart meters, prosumers have energy gateways, which process and forward these control signals accordingly.

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**Communications infrastructure**

- Fiber optics/SHD/Ethernet BPLC WIMAX Wireless mesh GSM/UMTS/LTE Router, switch

**Applications**

- Control Center (EMS/DMS)
- Virtual Power Plant
- Micro Grid Controller
- Distribution Automation
- Condition Monitoring
- Marketplace
- Demand Response Management System
- Asset Management
- Meter Data Management
- Billing/Call Center
- E-Car Operation Center
- etc.

*Fig. 8.5-1: Typical power distribution network integrating ring-main units, consumers, prosumers, distributed energy resources, etc.*
The young history of Smart Grids has already shown that utilities do not implement it as a whole from the scratch. They usually start with smart metering projects with later extensions of Smart Grid applications.

Already with the first roll-out, the design of the communication infrastructure has to consider the growing requirements for these extensions. After a large deployment of metering infrastructure in the first step, it is not acceptable to replace the communication network a few years later because the requirements for the next subsets of Smart Grid applications cannot be met anymore.

**Communications infrastructures for all conditions**

The communication infrastructure in the medium-voltage and low-voltage distribution systems is usually heterogeneous, and the suitable technologies depend to a large extent on the local topology (large city, rural region, distances, etc.). It must therefore be specifically tailored for each customer.

In general, the following communication technologies are available:

- Fiber-optic or copper cables are the best option, if present
- Narrowband Power Line Carrier (NPLC) systems for transmitting meter data; they are frequently already integrated into the smart meters
- Broadband PLC systems offering IP connectivity with > 1 Mbps
- Setup of own private wireless networks (e.g., wireless mesh, private WiMAX), when spectrum is available at reasonable prices or local regulations allow for it
- Public wireless networks, depending on the installation for narrowband communication in the kbps range (e.g., GPRS), or in the future in the Mbps range (LTE, WiMAX providers). Attractive machine-to-machine (M2M) data tariffs and robust communication in case of power outages are key ingredients to make this communication channel a viable option.

Depending on the applications being installed inside the RMU, an Ethernet switch/router might be needed in order to concentrate the flow of communications. These data concentrators can be implemented as customized solutions or integrated, for example, in the RTU (remote terminal unit). To meet these requirements, Siemens offers a full range of all above-mentioned communication technologies including rugged switches and routers that comply with energy industry standards.

**8.5.2 Communication Infrastructures for Backhaul and Access Networks**

**Optical fibers**

*The best choice for all communication needs*

Optical fibers is the best transmission medium for medium-voltage and low-voltage applications because it is robust and not susceptible to electromagnetic disturbances or capacity constraints. That is why system operators who choose this technology will be well prepared when their communication needs multiply in the future.

Fiber-optic cables are laid underground to connect individual substations. This work is associated with heavy civil works, and therefore with great expense. However, when new power cables are installed, the cost-benefit analysis paints a clear picture. Fiber-optic cables should generally be the first choice in this case.

**Benefits in detail**

- At the core of a variety of communication systems, from passive optical networks (PON) to Ethernet and SDH
- Durable, insusceptible to electromagnetic disturbances
- Practically unlimited transmission capacity

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Fig. 8-5.2: Fiber-optic infrastructure for distribution network
8.5 Communications network solutions for distribution networks (Backhaul/Access communication)

Broadband power line carrier
For low-voltage to medium-voltage applications, using the existing power line

BPLC is an attractive alternative for many applications in medium-voltage and low-voltage Smart Grid scenarios.

It uses the utility-owned infrastructure in the distribution system, and thus has no continuous OPEX for the communication channel (operational expenditure). Therefore it is especially useful for connecting elements in the power supply system where there are no other communication media available.

Battery buffers allow the use of remote control with automation systems, even in cases of power loss.

Initially, the BPLC uses the medium-voltage lines between the distribution substation and the transformer substations as a communication infrastructure for process control in the medium-voltage domain.

In addition, the BPLC can use low-voltage lines as a communication infrastructure for applications linking the transformer substations and consumers/households (for example, the integration of smart homes). The BPL modules feature both IP and RS 232 interfaces, and can therefore be used flexibly for diverse communication applications. Transmission range and bandwidth are heavily depending on the quality and the age of the power cable. As a rule of thumb, if the bandwidth in MV systems is in the range of up to 5 Mbps, a distance of up to 1.5 km is possible.

WiMAX
For RMU backhaul and prosumers

The main application area for WiMAX is considered to be RMU backhaul. It also serves to connect scattered consumers or endpoints with more demanding communication requirements – in other words, prosumers.

WiMAX (worldwide interoperability for microwave access) is a standards-based telecommunication protocol (IEEE 802.16 series) that provides fixed and mobile broad-band connectivity. Originally designed as a wireless alternative to fixed network broadband Internet access, it has evolved over the past ten years into an advanced point-to-multipoint system that also supports mobile applications like workforce management. The technology is field-proven, globally deployed, and continues to evolve. WiMAX networks can be scaled from small to large, which allows for privately owned networks even on regional and local levels.

Detailed requirements as well as specific regional conditions and spectrum availability must be carefully assessed in order to select the best-suited technology and product combination from a wide variety of options.

Basic technical data

- Average data rate: ~10 Mbps;
- can be extended with IEEE 802.16m to over 50 Mbps
- Average coverage:
  - up to 10 km in non-line-of-sight and
  - up to 30 km in line-of-sight conditions
- Radio spectrum in licensed or license-exempt frequency bands
Communication Network Solutions for Smart Grids

8.5 Communications network solutions for distribution networks (Backhaul/Access communication)

Wireless mesh
From consumer access to RMU backhaul

The applications for wireless mesh networks stretch from consumer access to RMU backhaul. Wireless mesh networks are composed of cooperating radio nodes organized in a mesh topology. The underlying technology for communication from one hop to another can be standardized (for example, the IEEE 802.11 series [Wi-Fi] or IEEE 802.15.4 [low-rate wireless personal area network, LoWPAN]) or proprietary (for example, U.S. 900-MHz technologies). The mesh protocols and corresponding routing mechanisms are, on the other hand, more recent developments and therefore are still predominantly proprietary. Thanks to their mesh properties along with self-setup and self-healing mechanisms, mesh networks inherently offer ease of operation and redundancy for fixed applications — but performance is limited in terms of either coverage or bandwidth.

Detailed requirements as well as specific regional conditions must be carefully assessed in order to select the best-suited technology.

Basic technical data
- Average data rate per hop:
  - from ~100 kbps (U.S. 900-MHz) up to ~10 Mbps (Wi-Fi);
  - net data rates per hop decrease with increasing number of hops
- Average range hop-to-hop:
  - ~1 km nLoS/~5 km LoS (U.S. 900-MHz);
  - ~100 m nLoS/~1 km LoS (Wi-Fi) coverage extension by means of mesh
- Radio spectrum primarily in license-exempt frequency bands

Public cellular networks
For the extension of private communication networks

The main application areas for public mobile radio networks in the Smart Grid context are meter reading and energy grid monitoring functions.

In contrast to constructing new, proprietary networks for Smart Grid communication, there is also the option of using existing cellular radio networks owned by communication service providers. These networks are standards-based, deployed worldwide, and continuously upgraded and expanded. Activities like acquiring spectrum licenses, building, operating and maintaining the network as well as assuring sufficient coverage and bandwidth on a nationwide scale are naturally managed by the communication service providers. Data rates normally available range from 50 kbps (GPRS), over 10 Mbps (HSPA), to over 50 Mbps (upcoming LTE). Attractive data tariffs and the availability of the network are key to use public cellular networks for Smart Grid applications.

![Wireless mesh network](image1)

![Public cellular network](image2)
8.6 IT Security

If you imagine plant availability as an equation with a large number of variables, dependable IT security is one of the essential variables. It comprises, in particular, protection against unauthorized access, physical attacks and operator errors, as well as internal or external threats. What counts more than anything ultimately, though, is the result, namely a functioning energy automation system. That is precisely the philosophy of Integrated Energy Automation (IT Security). Integral solutions combine the individual variables to create a transparent equation that is maximized with regard to system uptime. With Integrated Energy Automation, Siemens offers an IT security concept that not only ensures the confidentiality and integrity of data, but most importantly its availability. Users profit especially from the simplified workflow, reliable operation and significantly reduced total costs of ownership.

8.6.1 Integral Approach

The graphical display of the security network or network blueprint, as it is called, forms the infrastructure and architecture of a system. It is the basis for a clear segmentation with which the risk for every link in the automation chain can be analyzed precisely – while still keeping an eye on the impact on the system as a whole.

The network is therefore divided up into manageable zones in order to equip them with precisely the IT security that is necessary and worthwhile in order to protect the data in this zone, as well as ensuring smooth operation of the system at the same time (fig. 8.6-1).

The zones are protected at network level by a SCADA firewall that controls data traffic between the zones and blocks dangerous packets. Suspicious network activities within critical zones themselves, for example, the control center network or field level can be detected and signaled by an intrusion detection system.

Fig. 8.6-1: Zoned IT security concept
Computers exposed to special risks, for example, in the demilitarized zone (DMZ), can also be protected with a host-based intrusion prevention system. All computer systems are equipped with virus scanners in order to withstand the permanent threat due to malware. The remote administration and connection of other networks is effected by VPN tunnels that guarantee access protection at the highest level.

The load-carrying network infrastructure itself (routers, switches) also undergoes system hardening in order to match up to the consistently high security requirements for the system as a whole.

**8.6.2 Secure throughout from Interface to Interface**

With the advent of the Internet and increasing networking within the systems, every interface represents a potential risk. These risks must be easy to estimate in the system. With Integrated Energy Automation, Siemens therefore applies the philosophy of IT security offering simple protection. For this reason, Siemens attaches greatest importance to homogenization by means of standardized and reproducible processes for authentication, authorization, intrusion detection and prevention, malware protection, effective patch management for third-party components, standard logging and continuous security tests.

**8.6.3 Continuous Hardening of Applications**

Reliable products are an essential basis for a secure network. Siemens therefore continuously hardens its products to protect them against attacks and weak points. Individual risk analyses and regular tests – also specially for third-party components – with a defined combination of IT security test programs for detecting weak points (Test Suite) are used for this.

**8.6.4 In-House CERT as Know-how Partner**

Siemens has its own in-house Computer Emergency Response Team (CERT). An organization such as this that discusses subjects critical to IT security and issues current warnings is normally only maintained by universities or governments in order to provide users with cross-industry information.

The Siemens in-house CERT was established in 1997 and since then has issued warnings about security loopholes, while offering approaches for solutions which are processed especially for the company’s areas of competence. As know-how partner, the work of the Siemens CERT also involves drawing up rules for the secure development and programming of in-house products and the continuous further training of in-house programmers.

CERT checks the products for weak points by means of selective hacker attacks. The team also collects and distributes reports on weak points and upgrade reports for third-party components and links them to recommendations, concrete proposals and implementation specifications.

**8.6.5 Sensible Use of Standards**

The object of standards is to guarantee quality, to increase IT security in the long term, and to protect investment. There are now hundreds of IT security standards in existence, but only some of them are really necessary and worthwhile for a system.

On the basis of its many years experience in the market, Siemens chooses those standards and guidelines that protect a network reliably and effectively. This also includes advising customers on which IT security standards need to be observed at international and also at regional level.

The object of Integrated Energy Automation (IT Security) is permanent IT security for the system in the long term. Therefore reliable and secure products and infrastructures are not enough. With Integrated Energy Automation, Siemens also implements appropriate security processes that ensure that IT security is actively implemented throughout, both internally and at the plant operator’s, and is guaranteed over the entire life cycle of the plant.

**8.6.6 IT Security Grows in the Development Process**

The integral approach with Integrated Energy Automation not only involves keeping an eye on the entire system, but also means that security of products is already integrated in the entire development process, and not just in the test phase.

IT security guidelines for development, processing, service and other functions ensure that IT security is actively implemented throughout all processes. Examples of this are security briefings for product management before a product is developed or programmed in the first place. Programmers operate according to defined guidelines for secure coding, which are specified by the Siemens CERT.

For an effective patch management, Siemens tests updates of third-party security products, for example, firewalls, already in the development process of the products. Continuous penetration tests of all relevant products are stipulated in a test plan. This also includes the definition and establishment of a security test environment and matching test cases.

In this way, Siemens subjects its products to an objective and critical certification process with which IT security is guaranteed and made transparent on the basis of suitably selected standards.
8.6.7 Integrating IT Security in Everyday Operations

A system is only as secure as the user operating it. A high standard of security can therefore only be achieved by close cooperation between manufacturers and operators. The patch management process is also important after acceptance testing of a system. For this purpose, the Siemens CERT issues automated reports on newly discovered weak points that could affect third-party components in the products. This enables the Siemens customers to be informed promptly, and allows time to define any service activities arising from this.

A very wide choice of helpful tools is available to enable users to make IT security a regular part of everyday operation of a system. Standardized security processes, for example, for updates and system backups, are implemented directly. At the same time, efficient tools are provided for administering access in a system network. This includes effective management of rights as well as reliable logging tools. Automatically created protocols or log files are not only stipulated by law, but also help determine at a later time how damage to a system occurred.

With Integrated Energy Automation, Siemens offers an intelligent interaction of integral solutions for simple and reliable energy automation.
8.7 Services

Business with communication solutions for power supply companies does not only mean to provide state-of-the-art products, but to offer a complete range of build and professional services. With more than 75 years of experience and know-how, Siemens offers a wide range of products for communication solutions, and a comprehensive portfolio of services tailored to the demand of our customers (fig. 8.7-1).

Consult
Finding the right communication solution in a pre-sales or after sales phase for the customer requires planning and analysis. Siemens consultants offer every support in planning and realization of the best technical and economic solution for communication networks, system configuration, and integration of the new equipment into the existing network.

Design
Designing a telecommunication network means much more than just supplying hardware and software. The Siemens experience makes it possible to create a and prove a communication solution designed exactly for the operator's purposes.

Build
The fast implementation of a project depends crucially on effective management. It ensures that the build-up of a network will be completed quick and effective.

Maintain/Care
The Siemens hotline, its technical level supports, and repair and replacement concept for defective modules as part of the after-sales service, gives full support and provides the required hardware and software for updating or upgrading communication systems already in operation in existing networks.

Educate
Well-trained staff that knows how to bring the communication network to its optimal use is crucial in obtaining the full benefits from the investments. Siemens therefore focuses not only on providing custom-made communication network solutions, but also on sharing its knowledge and experience with its others. Siemens offers a comprehensive training program for the complete area of communication solutions for power supply companies. Training is always tailored to the area of responsibility, as well as to the corresponding technology and practice.

Fig. 8.7-1: Service portfolio
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9 Network Planning

9.1 Introduction

Every society today is highly dependent on electricity – as becomes evident when blackouts or large disturbances occur. In our increasingly "digital societies," almost all aspects of business and private life are based on the availability of electricity. The reliability of power supply systems cannot be taken for granted – especially not with a target reliability of 99.9% or higher, a value not often met by any other technical system of comparable complexity.

The challenge to provide electricity – any amount required, at any time, at any customer’s premises, and with the appropriate quality – is achieved by a large and complex system of power plants and power systems. Building and operating the power supply system are comprehensive tasks of their own, and several trends in large parts of the world today require special attention:

- In several countries, the electricity sector has been liberalized, which means that the economic and legal framework has been thoroughly changed, and in many cases, it has caused a complete restructuring of power supply companies.
- Whether it be a consequence of liberalization or not, in most electricity markets the economic pressure on utilities has increased tremendously.
- The ecological awareness of societies is increasing, posing new questions for power utilities. Especially, the continuing growth of distributed generation and of generation from renewable energy sources requires also massive changes to the current network structure and configuration.
- E-mobility is a trend that on its own has the potential to spur substantial modifications to today’s power system architecture. The integration of a large number of e-cars and the related charging stations calls for analysis of network compatibility, of the required network reinforcement – and of new concepts for network operation, possibly making intelligent use of the storage capacity provided by the e-cars.
- Customer appliances are becoming ever more complex and thus sensitive to power quality issues, while at the same time the devices are also emitting ever more quality disturbances into the power supply systems.
- All these new requirements – together with new technologies and concepts for network equipment, network planning and network operation – motivate the transition of today’s power systems into smart grids. Increasing the power system’s capabilities for communication, control and automation is a key prerequisite for meeting the upcoming requirements. Detailed analysis of system performance and the designing of smart grid network structures will become key tasks for utilities.

Considering these trends and inherent requirements for changes in the power supply system, based on variations in customer structure (location and power demand), new technologies in generation (renewable generation by wind energy converters) and network equipment (devices based on power electronics) as well as the age of system components, it is obvious that the power supply system is the subject of constant modification, redesign and extension. Despite the multitude of different requirements of power supply systems and their different states of development in different parts of the world, there is a typical high-level structure common to almost any power supply system, as shown in fig. 9.1-1.

- The typical hierarchical structure of power supply systems resembles a pyramid. The base is formed by the low-voltage (LV, up to 1 kV) distribution networks, to which most customers are connected. Starting from household customers requiring a few kW on average up to large commercial or industrial customers in the range of a few MW, the large number of customers demands a significantly wide range of power requirements and components in the LV system. Typically, highly standardized design concepts are used in very simple network structures (mostly radial networks) in order to cope with the large amount of equipment and with the economic constraints. While a large number of small generation units are installed at several different places (called distributed generation) – and many of those distributed generation (DG) units are being driven by renewable energy sources (RES) like solar or wind power – most of the power demand is supplied from the higher-level medium-voltage (MV, above 1 up to 50 kV) distribution network.

- The geographic distribution of the load demand defines the locations for the MV/LV substations commonly known as ring main units (RMU), and for the direct MV connection of larger commercial or industrial customers. The electrical configuration and overall network structure of the MV distribution system is mainly governed by these load requirements, and by the placement of larger DG units or groups of DG units, e.g., wind parks, or of small power plants.

![Hierarchical structure of power supply systems](Fig. 9.1-1: Hierarchical structure of power supply systems)
Standardized design concepts and simple network structures are primarily used; however, it is also common to use individual and more complex solutions for special areas like important HV/MV or MV/MV substations, or customers with special power quality requirements.

- The subtransmission system typically consists of regional high-voltage (HV, above 50 up to 200 kV) networks and medium-sized power plants. Power is supplied to the separate HV/MV substations feeding the subordinate MV networks. While failures in distribution networks often lead to individual or local supply interruptions for customers, failures in the subtransmission level can lead to more widespread, regional supply interruptions. Therefore, these networks are typically operated in a meshed structure.

- Finally, the transmission level contains HV and extra-high-voltage (EHV, 200 up to 750 kV and above) networks with interconnections to neighboring systems and countries, where possible. The networks are characterized by a comparatively low number of components and by customized concepts. Large power plants providing the bulk of the power generation are connected to the transmission-level structure. Interconnected operation enables the system operators to make use of the balancing effects of different load patterns and different characteristics of power plants in different areas, e.g., pump storage hydropower plants in the Alps. Such an approach is a highly economical way to provide reserve generation capacity and support in emergency situations. Failures in the transmission system involve the risk of blackouts in large areas or even whole countries. Besides meshed operation, special attention is also paid to the substation design in transmission networks.

9.2 Network Consulting

Network planning process

The key characteristic of network planning is always the system context. The power supply system is more than just a combination of switchgear, transformers, overhead lines, cables, and secondary equipment for protection, control and communication. It is the integration of all these components in an overall solution meeting the customers’ requirements with respect to load demand and power quality. While there are highly complex and important tasks to be addressed in the detailed planning and design work on the equipment level, it is the task of network planning to define the functional specifications for each separate component and to ensure the safe and secure operation of the system as a whole.

The complexity of the power supply system requires very thorough and precise planning in order to meet the following requirements:

- Adequacy, the ability of the system to supply all customers in normal operation
- Safety, protection of people and equipment against harm and damage caused by electricity
- Security, the stability of the system, especially after disturbances like load shifts or electrical failures
- Power quality, continuous supply of electricity within constant frequency, voltage level and other quality parameters – also in disturbed operation
- Economical performance, keeping defined budgets and other economic performance criteria
- Ecological performance, preventing pollution and minimizing the impact of electrical equipment (e.g., lines) on the environment

Network planning is required to develop and support the strategic perspective of any renewal, extension or modification project in a power supply system, and it links to all steps in the life cycle of such projects (fig. 9.2-1). Initially, it is obvious that network planning assists in the development of the general project idea and in feasibility studies, as well as in the subsequent planning phase. During operation of the equipment, issues like failure investigations, performance analyses and definition of maintenance strategies call for network planning support. Finally, the requirement for modification, extension or renewal closes the life cycle and/or triggers new projects supported by the input of network consulting.

The complexity of network planning does not only arise from the significant geographic extent of power supply systems and the different hierarchical levels of their distinctive functions. It is also complex because of the fact that different objectives are often contradictory, e.g., technical performance vs. economical performance. Network planning covers a wide range of different time horizons – far future, near future and the next few days, hours or minutes.

![Fig. 9.2-1: Project life cycle and network planning tasks](image-url)
In a running system, time and cost constraints are often the most relevant targets in planning the required modifications and updates. Typically, each of those cases will involve smaller changes to the network – but there is a continuous demand for such projects. Often the system develops into more and more complex network structures and operating principles.

Strategic network planning projects are required at regular time intervals. The goal is to re-assess the load demand and quality expectations to be met by the system, to integrate the latest developments in equipment technology and system design principles and totrim the expected technological and economical performance of the network to the current requirements and budget – that is, to make the network “fit for the future.” In this context, the development of suitable long-term concepts is a key requirement, and typically this is the first task requested in planning projects – following initial data collection and analysis of the existing system model (fig. 9.2-2), which may reveal certain weak points requiring immediate action. Actual network planning needs to start with the long-term view to be able to develop the strategic perspectives that then act as guidelines for the development of short- and medium-term concepts, as appropriate for all concepts following the defined planning criteria.

The development and analysis of such network concepts are the core tasks of strategic network planning (fig. 9.2-3). As indicated, this process starts with the compilation of the system model, which in most cases is the model of the system in its current condition. This network planning model has to consider at least the topological and electrical data of the equipment, and may be extended to several other data items as required for technical analyses to be conducted in the study. In practice, the condition and availability of data are often the most critical aspects in network planning, especially for more sophisticated analysis and the corresponding data requirements.

Based on this network model for a precisely defined base scenario, new variants are developed. This process defines the basic system architecture, considering planning criteria and standard equipment configuration as identified by separate investigations of, for example, pilot areas of the system or abstract network models. This process covers very basic questions, such as those relating to voltage levels and network structures, and also very detailed aspects of individual solutions where needed. Several different system variants – each meeting the relevant requirements with respect to overall network structure and equipment types – result from this step.

In order to arrive at a final solution, a detailed technical and economical analysis of these different system variants is required. Here, various technical network calculations and economic evaluations are performed, such as:

- Power flow calculation and reactive power analysis, identifying, for example, voltage levels at all busbars, the loading of lines and transformers, transformer tap changer settings, losses
- Short-circuit current calculation, evaluating, for example, indices for maximum and minimum short-circuit currents for different failure types in various failure locations
- Probabilistic reliability calculation, delivering the expected values of reliability indices such as SAIDI (system average interruption duration index), and frequency of interruption
- Dynamic stability calculation, investigating, for example, the effect of failures on the stability of generators in the system
- Protection coordination, defining concepts and suitable parameters for selective and fast disconnection of electrical failures
- Economic analysis, assessing, for example, the required CAPEX (capital expenditure) and OPEX (operational expenditure) for a network
- Development of automation and control concepts, ensuring that operational performance requirements are met
- Other investigations and calculations, depending on the scope of study

The technical calculations have to follow the international and national standards relevant to the respective project, as well as...
customer-specific standards and requirements. It might not be sufficient to execute the defined set of calculations only once – typically, several different system scenarios need to be analyzed for each variant. Different system scenarios are characterized by, for example, different load situations (winter/summer) or operating conditions (normal/disturbed operation), or as different phases in the transition of the present network state into the desired target state. In the end, comprehensive information on the technical and economic performance of the various network variants is available. Assessing these results will lead to the final solution, or recommendation, for the problem addressed in the study.

Typical issues addressed in a network planning project

Network planning projects are highly individual, because in each case the special conditions of the supply area, load demand and geographic distribution, technical standards and requirements, current status of the existing system, etc., have to be considered. The actual scope and goal of each project are different as well. Typical topics that may be addressed in network planning include:

- **Strategic network planning**
  Completing new structures, modifications or extensions are to be developed for individual plants, certain areas within the system, or even for whole power supply systems need to be examined. The project scope can comprise anything from the selection of general network structures and voltage levels down to detailed functional specifications for substation design. The typical aspects of the system level under consideration – transmission network, distribution network or industrial network – need to be considered as well.

- **Dynamic performance of generators and transmission networks**
  Transmission networks are responsible for the secure operation of the power supply system in large areas. A major concern is system stability, including several different aspects such as inter-area and intra-area oscillations of generators, transient stability or voltage stability. In large power systems, several generators or groups of generators may start to oscillate against each other as a result of operational changes or system disturbances. These inter-area oscillations need to be damped effectively in order to prevent system instability. By suitable calculations, the oscillations are analyzed and the optimal placement and settings of damping devices is evaluated.

- **Dynamic performance of industrial networks**
  In industrial networks comprising local generation, the dynamic performance is of crucial importance. Besides the requirement to run the local generation in operation, special scenarios like decoupling from the public network, island operation, or system recovery after voltage dips need appropriate planning. In addition, the start-up of large motors may pose challenges to the dynamic performance of the system.

- **Protection design and coordination**
  Electrical failures in power supply systems occur rarely, but nevertheless regularly, e.g., lightning strikes. They need to be cleared as fast and as selectively as possible in order to minimize safety risks and disturbances of system operation. The design of suitable protection systems, considering also backup protection functionality, and the calculation of appropriate functional parameters for each protection relay ensure that these requirements are met.

- **Asset management**
  The systematic and comprehensive consideration of technical and economic performance indicators of both individual equipment and the entire system over the complete life cycle requires detailed data. Certain information can only be provided by appropriate network calculations and supports, e.g., the prioritization of equipment in maintenance schedules or renewal programs, or the prognosis of expected technical system performance.

- **Power quality**
  Today, many electrical appliances are becoming increasingly sensitive to power quality issues, like harmonics, voltage fluctuations or voltage dips. It is important to identify the current status of such power quality aspects in the system through evaluation, and to include these facets in the system model in order to derive suitable mitigation measures, such as filters. Harmonics are becoming an even more widespread problem, because new kinds of electrical appliances often generate significant levels of harmonics. As a result, the total harmonic distortion is increasing, and certain network configurations may even lead to resonances.

- **Earthing and interferences**
  Earthing is an important aspect of power supply systems and highly relevant for safety issues. Appropriate earthing has to ensure that fault currents are limited to acceptable levels, and in the design of earthing systems the local geological features have to be considered. Fault currents or magnetic fields may also cause disturbing interferences with other technical networks. Such interferences on other electricity, pipe or communication networks, for example, need to be studied in order to delineate suitable mitigation and protection measures (called electromagnetic compatibility, EMC).

- **Insulation coordination, switching transients**
  Electrical phenomena related to switching and lightning strikes, for example, can lead to high transient overvoltages in power supply systems. In order to prevent significant equipment damage, a suitable insulation level for all components is required. Related studies can include measurements of such transient phenomena, suitable modeling in special network analysis tools and the placing and rating of surge arresters and other mitigation equipment.

- **Special power supply systems**
  Alongside the generally known networks for public and industrial power supply, special power supply systems are employed for exceptional tasks, such as oil-drilling or pumping platforms and vessels, underwater systems in wind parks or oil and gas plants, or isolated supply of ore mines. For all these systems, different planning tasks need to be defined and performed in order to ensure a safe and reliable operation despite the many components and aspects involved.
Siemens network consulting competences

Siemens Power Technologies International (Siemens PTI), the provider of network consulting, software solutions and T&D training within the Smart Grid Division of the Siemens Infrastructure & Cities Sector, offers network consulting services for any aspect relating to the planning and operation of power supply networks. With more than 100 dedicated consulting engineers employed in various international locations, there are experienced and internationally recognized experts available for any project.

Such projects vary from small studies, e.g., determining the functional parameters for one protection relay to be installed in a container crane – to very large projects, e.g., developing a master plan for the transmission system of a complete country, and to long-term partnerships with clients. The common thread is the high quality of the technical results and the high level of professionalism and objectivity in the execution of the consulting project.

The Siemens PTI scope of competences is illustrated in Fig. 9.2-4:

- Expertise and experience in any system level, from LV distribution networks to EHV transmission systems – in three-phase AC systems, of course, but also in single-phase AC or DC systems and in the integration of DC devices like HVDC lines or FACTS
- Familiarity with the special requirements of both public utilities in distribution as well as transmission levels, and of industrial or commercial customers in any branch and of any size
- Consideration of both primary equipment, i.e., network structure and functional requirements for switchgear, transformers and lines, and of secondary equipment, i.e., protection system design, relay coordination, or network automation
- PSS®E provides transmission planning and operations engineers a broad range of methodologies for use in the design and operation of reliable networks.

9.3 Software Solutions

Various calculations of technical and economic characteristics of the actual system or of planning variants are part of the network planning process. The availability of suitable tools is highly important. Besides the obvious requirement that calculation results should be as accurate and reliable as possible, particularly with regard to the quality of both calculation tools and input data, several other aspects are also relevant for the successful and efficient use of network planning tools:

- Network model

  The quality of calculation is dependent, above all, on the quality of the input data. The structure and complexity of the data model must support the various calculations, including those for very large network models. In large systems, the question of how the network and the data are structured and presented to the user is of crucial importance for the effective use of the software tools.

- User interface

  Calculation algorithms implemented in the software tools have reached a very high level of complexity and are controlled by a multitude of different parameters. The handling and management of large network models is a complex task on its own. Therefore, an intuitive but comprehensive user interface is a key requirement for modern software tools.

- Management of calculation results

  After the actual calculations have been performed, the results need to be analyzed and presented. In many cases, this means more than printing tables or network diagrams with certain result values attached to the respective components. The compilation of comprehensive graphical representations, tables and reports – both according to predefined and user-defined structures – provide significant support in the execution of network planning projects and should be supported by the software tools.

Siemens has used its great experience and know-how in network planning to develop powerful system simulation and analysis tools to assist engineers in their highly responsible work. The software tools of the Power System Simulator PSS®Product Suite are leading products with respect to technical performance and user-friendliness. Comprehensive interfaces enable the interaction of all PSS®Product Suite tools, and also support the integration with other IT systems.

PSS®E

With over 800 customers and 10,000 users in more than 100 countries, PSS®E (Power System Simulator for Engineering) is the premier software tool used by electrical transmission utilities and consultants worldwide.

PSS®E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance – providing transmission planning and operations engineers a broad range of methodologies for use in the design and operation of reliable networks.
PSS®E has a modern, easy-to-use, graphical user interface (GUI). The GUI contains command recording capability to aid the user in building macros, which can be used to automate repetitive calculations. PSS®E has been used in production mode on the largest network-size models being simulated. Common reports in readable formats are standard. Most data can be entered and modified via the one-line diagram (fig. 9.3-1).

PSS®E Program Sections:
- Power flow
  - PV/QV Analysis
  - Sensitivity Analysis
  - FACTS/HVDC Modeling
  - Advanced Contingency Analysis with Corrective Actions and support of Multi-Processors
- Dynamics
  - Graphical Model Builder (GMB)
  - Small Signal Analysis
  - Wind Turbine Modeling
  - Eigenvalue Analysis (NEVA)
- Reliability
- Short Circuit
- Optimal Power Flow (OPF)
- Preventive Security Constrained OPF
- Python Scripting
- Scenario Manager
- Interactive Data Checking

PSS®SINCAL
PSS®SINCAL (Siemens Network Calculation) is a high-performance planning tool for the simulation, evaluation and optimization of supply systems. It is successfully applied by more than 300 municipal utilities, regional and national power supply companies, industrial plants and consultants worldwide.

PSS®SINCAL offers state-of-the-art software technology and a fully featured scope of analysis methodologies for electrical networks as well as gas, water and district heating / cooling networks – integrated in one powerful and intuitive user interface (fig. 9.3-2). Using a commercial data base as data repository allows easy integration into the customer’s IT environment. High-end automation features based on COM-server technology allow for the implementation of user-specific solutions. The availability of many ready-to-use interfaces facilitates the integration into existing IT architectures. PSS®SINCAL also serves as the foundation for the main database of all Siemens power system analysis products. Its fully unbalanced network model makes it the perfect tool for the simulation of distributed generation and wind modeling.

PSS®SINCAL Program Sections:
- Electrical networks (balanced and unbalanced)
  - Power flow
  - Smart power flow interfacing with metering database systems
  - Short circuit according to main standards and pre-fault loading
  - Modules for protection coordination, simulation and setting calculation, arc flash hazard
- Pipe networks
  - Gas/water/heating / cooling steady state calculations
  - Gas/water/heating / cooling contingency analysis
  - Gas/water/heating / cooling quasi-dynamic simulation
  - Fire water simulation
  - Water tower filling
- Multi-user project management
PSS®PDMS – Protection Device Management System

PSS®PDMS (Protection Device Management System) is a universal program to centrally manage protection devices and their settings. All data is stored in a central relational database and is available for data exchange with other programs, such as relay parameterization software, network planning tools and asset management systems.

Numerous settings are needed to parameterize different functions of modern protection devices (impedance, differential, (back-up/directional) overcurrent time, overload, standby earth-fault protection, monitoring measurements, etc.). At any point in time – from setting calculation, to parameterization and testing – settings and accompanying documents must be traceable and the workflow state clearly indicated. PSS®PDMS is designed to facilitate the complex protection data management process comprising the involvement of different staff members, the management of different parameter sets for changing network configurations as well as the handling of different firmware. Fig. 9.3-3 shows the PSS®PDMS user interface and fig. 9.3-4 illustrates the typical protection data flows in a utility.

PSS®PDMS key features

- Multi-user enterprise application
- All data stored in one central relational database (either Microsoft® Access®, Oracle® Database or Microsoft® SQL Server®)
- Modern Microsoft® Windows® user interface for optimal data management
- Protection devices modeled comprehensively with all functions and settings, including different parameter sets for each relay
- Settings are checked against available setting ranges
- Straightforward creation and management of protection device templates
- Easy connection to external documents (parameter files, protection devices manuals etc.)
- Extensive functions for relay import and export
- Specification and customization of user roles and access rights
- Supports user defined workflows (e.g. planned, approved or active settings), including historical settings
- Data exchange with power system simulation software

PSS®SINCAL enables protection engineers to verify the settings through simulation directly in the network model.

PSS®NETOMAC

The deregulation of the energy market is creating new demands on system planning engineers and system operators in power utilities and industrial companies. Traditional areas of activity have to be rethought and new ones acquired. In order to succeed in the open competitive markets of today, it is extremely important to have all required information available at the right time and in the right place. Also the protection against wide-area black-outs becomes more and more important (fig. 9.3-5).

PSS®NETOMAC (Network Torsion Machine Control) is a professional network planning tool designed to address any kind of steady-state and dynamic analysis of a power system. A variety of preprocessing options are provided, such as the parameter-
izing of overhead lines, cables or motors and the identification of model parameters. The system analysis facilities are supplemented by user definable methods for optimization.

As a result, PSS®NETOMAC offers a great variety of possibilities:
- Simulation of electromagnetic and electromechanical transient phenomena in the time domain
- Handling of balanced / unbalanced and d.c. networks
- Steady-state load-flow and short-circuit current calculations
- Frequency range analysis
- Eigenvalue and modal analysis (NEVA)
- Simulation of torsional vibration systems
- Parameter identification and optimization
- Reduction of passive and active networks
- Interactive network training simulator
- Real-time simulation (DINEMO)
- Extended user interface for the graphical input of network and controllers structures and results documentation
- Data import and export from and to other planning packages, e.g. PSS®E, PSS®SINCAL, etc.
- Graphical Model Builder (GMB)
- Interface to dynamic models built with Simulink®

DINEMO

DINEMO (Digital Network Model) is an intelligent signal treating device that works as a real-time transceiver between protection relays or turbine controllers and simulation programs for electrical power systems like PSS®NETOMAC. DINEMO runs on a standard Windows® PC and allows real-time simulation with up to sixteen analog output signals that are continuously calculated in PSS®NETOMAC. Four analog or sixteen digital feedback signals of the equipment under test can be treated, allowing a closed-loop interaction between protection relays or controllers and the simulation program. Such real-time tests, with round-trip times of up to 0.15 ms, are possible using PSS®NETOMAC with its high-speed calculation algorithms running on Dual Core CPUs. DINEMO is used for tests with analog controllers with input voltages of max. ±10 V and with frequencies of up to 5 kHz. With additional power amplifiers, close-to-reality tests can be accomplished with standard protection relays. DINEMO allows extensive tests on protection relay configurations using detailed models of all network elements (fig. 9.3-6).

SIGUARD®Solutions

SIGUARD®Solutions offer a combination of software, training and consulting to prepare the customer for the new challenges and the upcoming security requirements in power system operations. Applying SIGUARD®Solutions provides the following benefits:
- Blackout prevention
- Increase of power system utilization
- Improvement of situational awareness

SIGUARD®Solutions support the decision making process of the power system operator. The basic idea is to increase the observability and the controllability of the system and to perform an automatic, intelligent security assessment. An overview of SIGUARD® software tools is given in fig. 9.3-7.
• Adaptation to the control room applications of any vendor,
• Adaptation of the power system models of any vendor to the SIGUARD® format,
• Adaptation to the power system specific requirements (e.g. grid code).

Within the SIGUARD® Solutions trainings on the following topics are offered:
• Power system dynamics
• Voltage stability assessment
• Transient stability assessment
• Small signal stability assessment
• Handling of the SIGUARD® software components

In addition, as consultants we provide ongoing support when it comes to system studies regarding special protection schemes, remedial actions, power system and protection planning.

PSS®ODMS
PSS®ODMS is a data management and network applications suite centered on the international standards Common Information Model (CIM) and Generic Interface Definition (GID). Siemens PTI’s Operational Database Maintenance System (ODMS) and Power System Simulator for Operations (PSS/O) have been integrated into PSS®ODMS, making this product one of the most advanced network modeling and applications tools for network operation and network planning (fig. 9.3-8).

PSS®ODMS is designed to create or install into a CIM environment, and optionally to either create or install into a GID-based enterprise platform. It offers the user tools to:
• Decipher models from many different sources
• Import and export a full model, partial models and incremental models
• Aggregate the models
• Create future study scenarios
• Apply an extensive set of business rules to increase the accuracy of the resulting model
• Store that model in an open, industry-standard database structure that may be used by many current and future applications
• Convert operations models to planning models.

The integrated PSS®O functionality comprises:
• Topology processor
• State estimation
• Real-time power flow
• Contingency analysis
• Outage ranking
• Real-time mode and study mode.

MOD®
MOD® (Model On Demand) significantly extends the capabilities of PSS®E by enabling the user to manage a great number of change cases for PSS®E. MOD® assembles sets of model changes into “projects” (fig. 9.3-9). Projects can then be managed and organized in various fashions depending on the needs of the PSS®E user.

These modeling projects are coupled with MOD® seasonal and annual profiles to provide the PSS®E user with a procedure for organizing and reorganizing system investigations. All this can be done without generating a great number of PSS®E base cases or repeatedly rerunning PSS®E cases when planning sequence changes.

MOD® delivers PSS®E formatted power flow models which can be processed and utilized by the full PSS® Product Suite. MOD® revolutionizes transmission planning data manipulation and the generation of major study data sets.

MOD® allows the system study engineer to:
• Organize and reorganize study cases without the need to generate a multitude of PSS®E “base cases”
• Store a single master network model
• Accommodate seasonal and annual profile data sets
- Treat projects as sets of data changes that are applied serially in any order specified by the user
- Export a PSS®E file with equipment commissioning/decommissioning dates, out-of-service and in-service dates
- Provide an unlimited number of ratings to be applied as Rate A, B, C in the exported PSS®E case

SIGRADE
SIGRADE (Siemens Grading) is a software program for overcurrent protection coordination of high, medium and low-voltage networks. It allows the selection of grading paths and drawing of tripping characteristics of fuses and protection relays into a log-log current-time diagram. SIGRADE guides the user from the initial simple sketch of the project through the collected information and data to short-circuit calculations, supports the user in developing a protection concept, and documents the complete relay coordination of overcurrent protection devices (fig. 9.3-10).

CTDim
CTDim (Current Transformer Dimensioning) is a software program for current transformer (CT) dimensioning, dynamic simulation of CT behavior and drawing of saturation curves (fig. 9.3-11). Reports are prepared automatically. The optimization of current transformers with regard to technical requirements and economic aspects is becoming more and more important. CTDim makes current transformer dimensioning more efficient. CTDim saves engineering and production costs by optimizing the current transformer data.

CTDim comprises the following features:
- Easy dimensioning of CT data
- Dynamic simulation of saturation curves
- Input of CT data according to IEC, VDE, BS and ANSI standards
- Database of protection device-specific CT requirements
- Automatically customized documentation

PSS® MUST
The capability to move power from one part of the transmission grid to another is a key commercial and technical concern in the restructured electric utility environment. Engineers determine transmission transfer capability by simulating network conditions with equipment outages during changing network conditions. Many uncertainties remain in the process.

The purpose of the PSS®MUST (Managing and Utilizing System Transmission) software is to efficiently calculate:
- Transaction impacts on transmission areas, interfaces, monitored elements or flowgates
- Generation redispatch factors for relieving overloads
- Incremental transmission capability (FCITC)
- FCITC variations with respect to network changes, transactions and generation dispatch
- The impact of transmission element outages on power flow by both DC and AC contingency analysis

PSS®MUST complements PSS®E data handling and analysis functions with the most advanced linear power flow and user interface available (fig. 9.3-12). The program’s speed, ease-of-use and versatile Microsoft Excel interface, coupled with the ability to run automated scripts, simplifies and reduces data setup time, and improves both results display and understanding.
10.1 Asset Services
10.1.1 Network Services
10.1.2 Substation Modernization Projects
10.1.3 Monitoring and Diagnostics
10.1.4 Transformer Services
10.1.5 Switchgear Services
10.1.6 Service Programs
10.1.7 Energy Customer Support Center

10.2 Siemens Power Academy TD

10.3 Metering Services
10.3.1 Portfolio Overview
10.3.2 Data Collection
10.3.3 Data Management
10.3.4 Revenue Management
10.3.5 Smart Metering
10.3.6 Meter Data Management Solution
10 Services & Support
10.1 Asset Services

Asset Services provide expert solutions and services for power supply systems in the areas of power transmission, power distribution and industrial energy supply that keep the network infrastructure on cutting edge in terms of lifecycle, reliability and environmental friendliness. Such expert solutions and services include Siemens state-of-the-art retrofit.
10.1.1 Network Services

Network Services solutions from Siemens deliver the decisive plus in reliability, quality and efficiency throughout the entire power system.

The comprehensive portfolio of Network Service solutions comprises advisory services, asset management and a wide array of operation, management and maintenance packages – all provided by professionals with many years of experience, and a proven track record in power technology applications and the energy business. In a nutshell: Siemens helps make the most of a given power system in terms of efficiency, reliability and profitability (fig. 10.1-1).

Operation and maintenance (O&M) services
Siemens provides a wide array of operation and maintenance services as well as “care-free packages” that deliver a guaranteed level of performance for power supply infrastructure facilities.

Siemens works closely with system operators to develop balanced service solutions tailored to each specific situation. These solutions are designed to meet the needs and expectations of customers as far as the technical, financial and regulatory performance of their assets are concerned.

The Siemens approach to the provision of O&M services is proven every day. The key to success is combining the organization’s global expert knowledge of asset management and network analysis with local knowledge of the specific network conditions (that is, global competence delivered locally).

Customers include public or private utilities, industrial organizations, private/equity investors, or real estate development companies from many countries around the world.

Siemens’s portfolio of O&M services includes the following elements (fig. 10.1-3):
10.1 Asset Services

- Operation services (e.g., control room operation 24/7, metering, energy automation)
- Long-term maintenance services (e.g., field services, emergency response, supply chain management)
- Management services (e.g., asset strategy planning, transition & change management)
- Asset services (e.g., lifecycle management, network extensions, substation refurbishments).
- Customer services (e.g., call center, customer support, billing, revenue collection)
- Support services (e.g., financial services, human resources, logistics, quality management).

In a typical engagement, the management of an entire power supply system or specific targeted portions/functions thereof is transferred to Siemens for a fixed period of time. Investment decisions and individual core functions may remain with the asset owner or may be assumed by Siemens. The operational risk is transferred to Siemens and Key Performance Indicators (KPI’s) and/or Service Programs are established to guarantee the agreed technical and budget performance.

Siemens provides O&M services for:
- T&D networks
- Wind farms and solar power electrical balance of plant systems
- HVDC and FACTS facilities.

O&M services for wind farms:
Siemens provides O&M services for onshore or offshore wind farms interconnected to the power system using conventional AC or HVDC technology.

Examples of the scope of O&M services for wind farms include (fig. 10.1-4):
- Electrical balance of plant (HV, MV, LV and DC systems, SCADA and telecommunication systems)
- Buildings and other civil infrastructure (e.g., roads, drainage systems, etc.)
- Ancillary facilities (e.g., lighting equipment, network data systems, etc.).

O&M services for HVDC and FACTS:
Siemens provides services for a wide range of power-electronics-based facilities including long distance (overhead and underground/undersea) and back-to-back HVDC installations, as well as Static VAR Compensators (SVC), Thyristor Controlled Static Compensators (TCSC), and other similar FACTS devices.

Examples of customized services for HVDC and FACTS installations include the following (fig. 10.1-5):
- Maintenance (preventive, corrective)
- First line of support (for immediate fault analysis and repair)
- Second line of support (for complex fault analysis and repair)
- Development of maintenance strategies
- Remote maintenance activities, such as monitoring, fault analysis and diagnostics/repairs of control and protection systems
- Spare parts management.

Fig. 10.1-3: O&M service elements

Fig. 10.1-4: Wind farm in Italy operated and maintained by Siemens

Fig. 10.1-5: HVDC system in Scotland operated and maintained by Siemens
Asset management services

Siemens’s asset management experience, processes and methodologies enable system operators to increase the profitability and efficiency in the use of their assets while at the same time safeguarding required quality levels and minimizing life-cycle costs.

Asset management support services by Siemens leverage a number of advanced methodologies and tools, including independent condition assessments, RCAM (Reliability-Centered Asset Management) and MBR (Management Business Review). Siemens’s asset management support services include (fig. 10.1-6):

* Independent assessment of Asset Management Programs (AMP)
* Development of Asset Management Programs (AMP)
* Implementation assistance of Asset Management Programs (AMP)
* Performance follow-up of Asset Management Programs (AMP)

Siemens provides recommendations that are completely independent from product, construction or equipment sales of other affiliates. Indeed, our recommendations are vendor-neutral and are well accepted by third parties such as lenders and other financial institutions.

Advisory services

Siemens’s advisory services enable power asset owners and operators to get the most out of their assets while providing options to improve performance. The analysis looks at every material issue from a holistic vantage point. Answers and recommendations explicitly recognize that every decision has technical, economical and regulatory implications.

The results provided by our due diligence/advisory services enable Siemens’s customers to:

* Gain an insight into the correlation between technical decisions and their business implications (e.g., on network cost and service quality)
* Build a sound approach for evaluating relevant aspects of the system expenditures program, with objective and documented decisions
* Increase the efficiency of resource utilization while safeguarding required quality of service levels in the long run.

Fig. 10.1-7 provides an overview of the core elements of Siemens Advisory Services.
10.1 Asset Services

10.1.2 Substation Modernization Projects

Because top priority is given to operational continuity in substations and power systems, any long-term maintenance, modernization and system rehabilitation must be precisely planned. These are the right opportunities for OEM-driven service projects. Siemens offers a variety of corresponding service solutions for extending the lifespan and size of the substation, or for its modernization. Countless examples worldwide serve as references for successfully executed service projects.

10.1.3 Monitoring and Diagnostics

Monitoring systems

The condition of your assets is highly relevant to your decision-making about service or replacement. With insight into condition, the transition to Condition Based Maintenance (CBM) can take place. Pending failures can be repaired before a breakdown occurs. Siemens offers both on-site audits and also online condition monitoring as a stand-alone or integrated system.

With Integrated Substation Condition Monitoring (ISCM®), Siemens provides online asset condition information through a comprehensive range of innovative tools for diagnostic analysis. Through prediction and prevention of equipment failures, ISCM® protects the customer’s company image as well as his investment. The integrated monitoring system guarantees minimum downtime, maximum asset performance, nearly real-time rating, and extended lifespan. ISCM® is a fundamental prerequisite for securing the customer’s required performance level, and with it, long-term entrepreneurial success.

The Siemens ISCM® solution, customized to the individual requirements of the substation, monitors all relevant components of the power supply system – from transformers (e.g., SITRAM integrated condition monitoring system) and switchgear to overhead lines and cables. It can be seamlessly integrated into the existing substation communication and visualization infrastructure, from simple bay controllers to high-end control center applications. Siemens offers one integral solution for all network assets.

ISCM® provides a highly reliable solution, based on expert knowledge and advanced technology. With its unique proficiency and experience along the entire energy conversion chain, Siemens is ideally positioned to supply a sophisticated, comprehensive monitoring concept that covers all equipment within the power supply.

SAFE™ – Audits and Assessments

With SAFE asset audits, Siemens personnel visit substations for an inspection – ranging from visual inspection all the way to extended diagnostics, providing the basis for a targeted maintenance strategy for important substation assets like high-voltage gas-insulated switchgear (GIS), high-voltage circuit-breakers, and power transformers.

Cable and line services

In principle all service offerings by Siemens, such as installation and repair, also apply to power cables in the T&D environment. Currently, Siemens is focusing on cable diagnostics with different detection methodologies.

Namely high-frequency partial discharge (PD) diagnostics and frequency response analysis (FRA) are considered as a field of activity for Siemens. For the second methodology, Siemens uses patent-pending Line Resonance Analysis (LIRA®) technology.

The LIRA® system assesses and monitors the general degradation of the cable insulation caused by harsh environmental conditions (high temperatures, humidity, radiation). It also detects local degradation of the insulation material as a result of mechanical impact or local abnormal environmental conditions. These diagnostics services are valuable for specific applications in power transmission and distribution systems, for subsea cable installations like in offshore windfarms, or in the oil and gas industry, as well as in power plants.

Remote Operational Support (ROS)

Remote services are performed by our Remote Diagnostics Center – in short, RDC. On the one hand, remote services assist the customer in daily business with remote expert consulting, troubleshooting and fault investigation, and on the other hand support. Siemens O&M contracts with online Integrated Substation Condition Monitoring (ISCM®), and with innovative services for substations as well as for transmission and distribution systems.

At a glance, the RDC offers:

- ISCM®, including expert diagnostics
- Remote supervision
- Remote services for operation and maintenance contracts
- Online asset data
- Remote troubleshooting

The RDC enables asset data management tailored to the system operator’s needs. With these elements, the implementation of efficient maintenance concepts like condition-based maintenance and minimization of reaction times are applicable to Siemens’s O&M offerings.

Due to its flexible configuration, operation can take place nearby the customer, and advanced condition analysis can take place centrally. System operators can share condition data, but keep control and protection data private. Close co-operation between the Remote Diagnostic Center and the Energy Customer Support Center offers Siemens’s customers one central point of contact.
10.1.4 Transformer Services

The remaining lifetime of transformers decreases continuously as a consequence of normal ageing processes. The transformer’s rate of ageing varies considerably from one type of construction to the next. It depends on several different facts such as transformer design, capacity, service and load history, climate, and environmental conditions. The critical factors which influence the rate of ageing are:

- Operating temperatures (under load, ambient)
- Moisture content and increases (e.g., decomposition product of hydrocarbons in insulation)
- Oxygen level and inrush (e.g., trough conservator)
- Mechanical and electrical stress (e.g., short circuit events, harmonics, system overvoltage).

That is why Siemens offers transformer services including:

- Condition assessment and diagnostics
- Online monitoring
- Consulting and expertise
- Maintenance and lifecycle extension
- Spare parts, accessories
- Repair and retrofit

For details please refer to Transformers, Transformer Lifecycle Management.

10.1.5 Switchgear Services

Worldwide customer-focused Siemens service centers are able to manage all product-related services for Siemens products, as well as for Magrini Galileo, Merlin Gerin, Elin Holec and Reyrolle products.

Whether in industrial companies, public or private power supply and infrastructure, or building technology – power distribution plants must basically be available continuously, and they must provide the highest degree of operational safety. Switchgear in particular must handle the steadily increasing demand for electrical energy; but their aging and wear can significantly impact their functioning.

Quick and cost-effective retrofits make switchgear fit for the future, with minimal disruption of ongoing operations.

**Retrofit made easy – rely on an experienced partner**

Siemens is the experienced partner to depend on when it is time to retrofit medium-voltage switchgear and other related equipment. The offering includes:

- Evaluation of all required technical information. The switchgear to be retrofitted remains in place and in operation.
- Measurement and development of the most suitable solution, testing, and verifications in AutoCAD.
- Transport of the ready-to-use trucks to the system operator’s plant, installation, and commissioning.
- Thorough testing of prototype; series production begins after all tests are successfully passed.

Retrofits quickly pay off. Solutions from Siemens provide many benefits – and the most important is the high level of system availability that can be achieved with the new equipment. In addition to prolonging the equipment’s service life and securing the customer’s investments, retrofitting also reduces maintenance costs, as it uses modern vacuum circuit-breaker technology. In addition, retrofitting with Siemens also means a secure and cost-effective supply of spare parts anywhere in the world.

Retrofit benefits at a glance:

- Minimized downtimes for greater availability of the switchgear
- Increased security of energy supply
- Cost reduction for maintenance and fault clearance
- No additional cost for plant and building modifications
- Secure global supply of spare parts for crucial wear components.

**Preventive maintenance and repairs**

Equipment and systems with a long service life and continuous fault-free operation provide the best conditions for efficient utilization of the operator’s system. Siemens’s maintenance services ensure that all components work safely and reliably, and include major revisions and overhauls to bring assets back to reference condition. Siemens keeps customer network assets like switchgear, transformers, and the substation secondary equipment well maintained at all times through regular inspections and revisions.

![Fig. 10.1-7: Examples for retrofit](image-url)
10.1.6 Service Programs

Service programs serve as an umbrella spanning the entire Siemens portfolio. They are one way for system operators to ensure that they receive the best possible service. Guaranteed availability of staff and spare parts, as well as short response times can all be included.

These agreements minimize the customer’s operational risk to a calculable factor by defining which individual maintenance and emergency response services will be provided. Remote services and even O&M based on KPIs can be incorporated in a service program.

With the available service programs, an exact match with the system operator requirements can be achieved in several areas: from single assets to entire networks, from preventive maintenance to remote services, and from short-term contracts to long-term agreements.

Referring to fig. 10.1-1 Siemens has prepared four service programs which can be adapted in scope and volume exactly to the system operator’s requirements.

PMI
The focus here is on scheduled OEM maintenance and inspections to become a calculable operational factor.

ROS
This program includes all remote service offerings. The focus point is on alarming and reaction times for advisory and field services.

LTM
This refers to project-like managed services with the need for a service team to be recruited.

O&M
In this highest degree of service, Siemens takes over the operational responsibility. All operational risk is taken by the service provider.

### Modifications, upratings and extensions for modernizing switchgear

Naturally, the system operator cannot upgrade equipment at the same rapid pace that technology changes. However, Siemens’s modification, upgrading and extension capabilities offer many opportunities for optimization, so that the system operator can profit from the latest technical improvements. With these cost-effective solutions, the system operator will be investing capital wisely and taking advantage of the experience offered by Siemens in adapting older systems to new technical standards, resulting in reduced lifecycle costs.

The primary objectives of the maintenance services offered by Siemens are to avoid emergency repairs and ensure fault-free operations. If a failure does occur, Siemens will be on site rectifying the fault as quickly as possible. Operators can contact Siemens at any time 24/7 via the on-call duty service.

### Spare parts, components and kits

The prerequisite for successful and fast fault recovery is, of course, the availability of required spare parts. Siemens delivers spare parts, components and kits for all asset series – from current production to series that have been phased-out.

### Installation and commissioning and other field services

Siemens manages all associated network assets and processes like cable connections and overhead lines, as well as decommissioning and recycling. Installation and commissioning are, of course, a part of the standard portfolio.

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*Table 10.1-1: Retrofit solutions*
10.1.7 Energy Customer Support Center

“Good morning, Energy Customer Support Center, Betty Smith speaking. How can I help you? – ¡Buenos días! Le atiende Pedro García. ¿En qué le puedo ayudar?“ This is what customers hear when visiting the Customer Support Center based in Nuremberg. Inquiries are answered 24/7 in numerous languages by the support agents. The Energy Customer Support Center is the central contact channel for all inquiries regarding the Energy Sector. This has been a service of the Energy Sector to answer questions and point people in the right direction helping to achieve best-in-class customer satisfaction for more than 10 years.

“The only way we can convince our customers to use this contact channel is performance and quality. Test it and get convinced!” Michael Freitag, director of the Energy Customer Support Center points out.

The Energy Customer Support Center ensures the availability of the entire Energy Sector around the clock. All customer inquiries are taken according to the defined processes, entered in the Customer Support Management (CSM) tool, and forwarded to the person in charge. The processing of the inquiries takes place during the locally prevailing office hours.

This ensures a quick and for the customer satisfactory processing of all inquiries. Periodically conducted customer satisfaction surveys give customers the possibility for feedback, and for actively forming the process.
10.2 Siemens Power Academy TD

The Siemens Power Academy specializes in power supply related training for customers and Siemens employees. Training programs range from power generation to power transmission and distribution. As part of the Siemens Power Academy, the Siemens Power Academy TD offers professional training in the areas of power transmission and distribution, all the way to industrial and commercial consumption, including smart grids.

Training from experts
Customers will find trained and certified instructors, a well-designed instructional and methodical approach, and product-oriented exercises using the latest Siemens technology.

Many subjects – even more development opportunities
In addition to training classes, workshops, and certification for technical employees, the Siemens Power Academy TD program also includes courses for non-technical employees working in power transmission and distribution. One of our focus areas is the training program for competence development. In addition to individual courses, Siemens Power Academy TD also offers several curricula that features a logically structured series of classes that help efficiently and systematically build knowledge.

An overview of the training portfolio is presented in table 10.2-1. For detailed information on the standardized training portfolio, please visit www.siemens.com/poweracademy. Customized training is developed and defined on demand in close cooperation with the customer.

Our core competence: The right mix of theory and practice
In the Siemens Power Academy TD training programs, theory and practice go hand-in-hand. This means that theoretical approaches are always supplemented by practical exercises on real devices and systems. To make that possible, the training centers use original components, devices and systems from the transmission & distribution product portfolio. This hands-on training principle guarantees a maximum learning effect.

Our strength: flexibility
• Product-oriented training:
  The latest products and solutions from Siemens
• Comprehensive teaching material:
  The use of professional presentation methods, lecture notes, slides and course documents

<table>
<thead>
<tr>
<th>Training portfolio Transmission &amp; Distribution and Smart Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary technology</strong></td>
</tr>
<tr>
<td>• High and medium-voltage networks</td>
</tr>
<tr>
<td>• Switching technology and gas- and air-insulated switchgear</td>
</tr>
<tr>
<td>• Switches, circuit breakers</td>
</tr>
<tr>
<td>• Surge arresters</td>
</tr>
<tr>
<td>• Power transformers</td>
</tr>
<tr>
<td>• On-load and off-load tap changers</td>
</tr>
<tr>
<td>• Innovative power transmission and distribution concepts</td>
</tr>
<tr>
<td><strong>Protection technology</strong></td>
</tr>
<tr>
<td>• Protection technology – principles</td>
</tr>
<tr>
<td>• Distance protection</td>
</tr>
<tr>
<td>• Transformer differential protection</td>
</tr>
<tr>
<td>• Line differential protection</td>
</tr>
<tr>
<td>• Busbar protection</td>
</tr>
<tr>
<td>• Generator/motor protection</td>
</tr>
<tr>
<td>• IEC61850</td>
</tr>
<tr>
<td>• Secondary testing</td>
</tr>
<tr>
<td><strong>Substation automation (Control technology)</strong></td>
</tr>
<tr>
<td>• Power system control, telecontrol, substation control</td>
</tr>
<tr>
<td>• Monitoring</td>
</tr>
<tr>
<td>• Energy automation</td>
</tr>
<tr>
<td>• Power quality</td>
</tr>
<tr>
<td>• Energy meters</td>
</tr>
<tr>
<td>• Communication</td>
</tr>
<tr>
<td><strong>Smart Grid</strong></td>
</tr>
<tr>
<td>• Wind power, farms &amp; grid connection/compliance</td>
</tr>
<tr>
<td>• Solar plants monitoring</td>
</tr>
<tr>
<td>• HVDC and FACTS</td>
</tr>
<tr>
<td>• Electromobility</td>
</tr>
<tr>
<td>• Smart metering</td>
</tr>
<tr>
<td><strong>Software</strong></td>
</tr>
<tr>
<td>• PSS®SINCAL</td>
</tr>
<tr>
<td>• PSS®NETOMAC</td>
</tr>
<tr>
<td>• PSS®E</td>
</tr>
<tr>
<td>• Other Software Courses</td>
</tr>
<tr>
<td><strong>General trainings</strong></td>
</tr>
<tr>
<td>• Principles of electrical energy</td>
</tr>
<tr>
<td>• Smart Grid technology at a glance</td>
</tr>
<tr>
<td>• Transmission and distribution networks</td>
</tr>
<tr>
<td>• Oil and gas fundamentals</td>
</tr>
</tbody>
</table>

Fig. 10.2-1: Siemens Power Academy TD: Training portfolio for transmission & distribution
Services & Support
10.2 Siemens Power Academy TD

- Tests and certification:
  Certificates for demonstrated performance
- Subject-specific curricula:
  An integrated continuing education concept
- Combining technology + business learning:
  Interdisciplinary courses optimally prepare for day-to-day business operations
- Personal coaching:
  Identifying technical expertise and determining the training required.

Curriculum – competence development program of the Siemens Power Academy TD
Well-trained employees are vital for successful companies. The challenge comes from increasingly rapid transformation of the economic environment and technologies. Faced with changes like this, continuously improvement of skills and knowledge is essential if you are to be a reliable resource who contributes to the success of the company.

Therefore the Siemens Power Academy TD has developed a competence development program. This program is based on the curricula approach.

Unlike individual training seminars, a curriculum provides incremental learning through a structured, logical combination of various classes on a specific topic. This allows the necessary skills and abilities to be developed.

<table>
<thead>
<tr>
<th>Qualification levels</th>
<th>Professional experience</th>
<th>Expert level</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 5 years</td>
<td></td>
<td></td>
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<tr>
<td>&gt; 2 years</td>
<td>Advanced level</td>
<td></td>
</tr>
<tr>
<td>&gt; 1 years</td>
<td>Associate level</td>
<td></td>
</tr>
</tbody>
</table>

Objectives:
- The participant can independently perform technical tasks as part of his/her professional routine and can develop the necessary solutions on his/her own.

| Fig. 10.2-2: Qualification levels of competence development program |

What does the “Curriculum” consist of?
- Training program for competence development
- The possibility to apply and be certified in three different qualification levels

Associate – Advanced – Expert
- Per qualification level: Series of aligned courses and associated e-tests
- Certificate is valid for 5 years

<table>
<thead>
<tr>
<th>Benefit for employers</th>
<th>Benefit for participants</th>
<th>Benefit for the industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employers meet the requirements of ISO 9001 as employees obtain specialist knowledge and skills through certification.</td>
<td>Participants can certify their skills and knowledge to enhance their professional market value at home and abroad.</td>
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</tr>
<tr>
<td></td>
<td>Enhancements of employee competence (participant receives a certificate confirming achieved knowledge)</td>
<td>Recruiters can aim at certified applicants to ensure adequate capabilities of future employees.</td>
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<tr>
<td></td>
<td>More confidence and less mistakes in daily operation through practice and exercise increases safety and reliability of operation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enhancement of one’s own market value</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stay technically up-to-date</td>
<td></td>
</tr>
</tbody>
</table>

Table 10.2-1: Siemens Power Academy TD: Benefits of Curricula program
10.3 Metering Services

The Siemens metering services portfolio delivers measurable improvements to the acquisition and processing of meter data, to meter management and to customer communications. Siemens supplies integrated solutions right through the value chain, from metering to billing. The key offering is high-quality, accurate meter data and the services which provide it. As a leading provider of metering services, Siemens works in partnership with some of the largest global utilities for electricity, gas and water. All Siemens services are provided within the framework of strict industry and regulatory standards.

The following sections provide an overview of customer requirements and the different elements of Siemens service portfolio. Fig. 10.3-1 summarizes the ranges of services Siemens offers in the UK and globally.

10.3.1 Portfolio Overview

Services offered by Siemens include "meter-to-cash" services to power supply companies as well as to business-to-business (B2B) customers.

The role of meter operations for utilities and B2B customers is fundamentally concerned with meter installation, meter functionality changes, meter fault resolution, meter removals and connection of new supplies. Siemens installs both credit and prepayment meters. The provision, installation and operation of fiscal meters has to be carried out only by a fully accredited service provider like Siemens.

Before meter purchasing takes place, Siemens carries out site surveys to determine the best design, sizing and location of meters. Siemens configures and commissions the metering systems (fig. 10.3-2) and provides ongoing maintenance, including calibration, storage, removal and repair of equipment as needed.
Siemens offers expert advice in high-accuracy metering, grid metering and submetering solutions to monitor the consumption levels of equipment.

Typical users of Siemens metering services include large energy and water retailers and millions of residential, commercial and industrial customers – potentially everybody who has an interest in their meter equipment for gathering up-to-date and accurate data. The Siemens meter operations service supports the data collection process. All these services together help to ensure the highest levels of data quality.

**Meter asset maintenance and provision**
Siemens provides energy and gas distribution companies with meter equipment and ongoing maintenance service, an additional service that is frequently used by meter operations customers. Siemens also has experience in financing and leasing meter assets, and has access to expert knowledge regarding meter asset purchasing.

**Prepayment**
Some domestic customers prefer to pay for their energy before they use it, adopting a "pay-as-you-go" approach to energy. This can be done via a special prepayment meter that uses a top-up card or key mechanism.

The UK has the world’s largest meter system, with over 2 million meter points.

Siemens is responsible for maintaining the system as well as for installing new prepayment meters and for distributing top-up cards to customers. The latest technologies and process knowledge are combined in this prepayment meter in order to ensure that the customer is completely satisfied (fig. 10.3-3).

**Grid metering**
Siemens is a leading provider of grid metering and high-accuracy metering solutions in the electricity value chain. Siemens offers services to power generation and transmission companies worldwide, which enables them to get the most accurate view of the electricity they produce and put through the network. This product and service offering fits perfectly with the meter operations element of the value chain, and enables power generation and distribution customers to manage and maintain their revenue stream.

**Submetering**
Siemens provides meter operations services for non-fiscal purposes, including submetering applications. These can be installed and integrated into energy management systems for individual or multi-utility (gas, water, electricity) applications.

Siemens provides accurate consumption information at the point of use and visibility via Web-based solutions. Siemens offers tailored solutions and enables the system operator to monitor and control energy usage in different business locations. Large retailers and industrial customers use this service, which can be linked to their billing or finance system.
10.3.2 Data Collection

Data collection services comprise meter reading (data retrieval), data processing and data aggregation services. Siemens data collectors carry out routine reads, special request reads and change of tenancy reads as well as re-programming of meters.

The data processing system has been developed to comply with strict industry standards and fully supports all work scheduling, validation and distribution of meter readings for up to 12 million meters. To meet special needs and requirements, ad-hoc projects such as providing solutions for “hard-to-read” sites can be performed upon request. The field force consists of 750 Siemens employees. Siemens reads over 14 million residential meter points in the UK on behalf of energy and water suppliers. Systems are continually being enhanced to provide greater flexibility and adaptability, which enables Siemens to meet the constantly evolving market requirements. The automated remote collection systems utilize a range of technologies (e.g., in-field mobile data terminals), providing affordable data collection solutions.

10.3.3 Data Management

In this section of the meter-to-cash value chain, Siemens ensures that the data is accurate. That means Siemens aggregates and processes the data, deletes duplicates in the database and verifies the data before passing it on to the system operator. In most cases, the system operator uses this data directly for billing purposes.

For commercial and industrial customers, Siemens provides a full range of utility metering data – from electricity to gas and water meters. Large nationwide retail chains are particularly interested in this service so that they can monitor and control the energy consumption of their stores. The IT warehouse enables Siemens to collect a wide variety of data, and Siemens can provide custom-designed solutions based on the operator’s in-house IT system. Siemens also offers custom-designed reporting systems and works with various communication interfaces to transfer data to the system operator.

10.3.4 Revenue Management

In this section of the meter-to-cash value chain, Siemens ensures that the data is meaningful to the system operator. For instance, revenue protection affects the whole value chain – from energy generation, transmission and distribution down to the energy retailers.

The key features of the Siemens revenue protection service are investigation of power theft, selective and sensitive targeting and helping to increase the rate of loss discovery, with special focus on high non-residential usage. Siemens packages these features as a non-technical losses solution and offers loss assessments and training to data collection agents.

Property management is part of the revenue protection services portfolio. Siemens is a member of the UK Revenue Protection Association and can offer these services internationally.

10.3.5 Smart Metering

Smart metering is the combination of automatic meter reading with the ability to control and update the meter point. Having two-way communications between the meter and the central communications “hub” allows data to be collected on demand whilst enabling critical actions to be taken without having to make a visit to the property.

It is anticipated that smart metering will drive:
• Consumers to become more aware of their consumption and to participate in energy saving initiatives
• Energy retailers to bill more accurately with few, if any, estimated readings, and even to forecast and settle their energy based on actual rather than synthesized energy profiles

As the global competency center within Siemens for metering services, Siemens has a smart metering portfolio which is “meter independent” enabling a variety of devices to be used for electricity, gas and water metering.

Siemens also has the ability to support a number of different communications technologies – GPRS, Power Line Carrier (signaling wire for the low-voltage cables) and fixed radio technologies – depending upon what the customer or market requires.

The core of the offering is the smart metering “scheme”. This is a business process solution combining IT technology, business process execution and field force management.

The smart metering scheme brings together the data processing and device control systems with business processes designed to optimize the operation of the smart meter asset and the skills to transition from a dumb meter to an installed base of smart meters.

Smart metering is an important global trend, and our regional capability and sales network combined with specialist resources makes Siemens the ideal provider of smart metering and smart grid solutions.
10.3.6 Meter Data Management Solution

The need for a Meter Data Management Solution (MDMS) has increased dramatically over the last 12 months, especially in the US energy market.

What does MDMS mean?

MDM is:

- A platform to enable fundamental changes in the operating company using near real-time information
- The integration point for current and future Automated Meter Infrastructure (AMI) technologies
- The information toolkit required to empower AMI operations department
- Step one toward a smart grid

MDM is NOT:

- Just a data warehouse of meter data
- Just for commercial and industrial meters and complex billing systems
- Limited to utility metering data

A smart metering solution has three distinct elements: the meter, a communication network and a data hub. MDM systems provide a necessary link between metering communication networks and other utility IT systems, e.g., billing, call center and distribution automation. In March 2008, Siemens entered into a partnership agreement with eMeter for the sale and promotion of the EnergyIP™ Meter Data Management software worldwide.

Siemens is seeking to establish a market leading position by combining the MDM systems with other elements of the metering services portfolio.
<table>
<thead>
<tr>
<th><strong>A</strong></th>
<th><strong>B</strong></th>
<th><strong>C</strong></th>
<th><strong>D</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air circuit-breaker</strong></td>
<td>A circuit-breaker in which the contacts open and close in air at atmospheric pressure.</td>
<td><strong>Ambient temperature</strong></td>
<td>Temperature (measured under specific conditions) of the air surrounding an item of electrical equipment. The ambient temperature affects heat dissipation, which can make it necessary to reduce the rated current.</td>
</tr>
<tr>
<td><strong>Air-insulated outdoor switchyards of open design (AIS)</strong></td>
<td>High voltage substation where all live parts are insulated by air and are not covered. AIS are always set up in a fenced area with access for authorized personal only.</td>
<td><strong>Auto-reclosing (of a mechanical switching device)</strong></td>
<td>The operating sequence of a mechanical switching device whereby, following its opening, it closes automatically after a predetermined time.</td>
</tr>
<tr>
<td><strong>Automatic multiple shot reclosing</strong></td>
<td>An automatic reclosing repeated two or three times (usually not more) if it is not successful.</td>
<td><strong>Back-up protection</strong></td>
<td>Interaction of two carefully matched overcurrent protective devices connected in series at points where, in the event of a fault, a single device is not capable of switching the prospective short-circuit current. If a correspondingly high short-circuit current occurs, the back-up overcurrent protective device relieves the next downstream overcurrent protective device, thus preventing it from being overloaded.</td>
</tr>
<tr>
<td><strong>Blackout</strong></td>
<td>Complete power outage.</td>
<td><strong>Breaking capacity</strong></td>
<td>Highest current a switching device is capable of breaking under specific conditions.</td>
</tr>
<tr>
<td><strong>Breaking operation</strong></td>
<td>Interruption of an electric circuit as a result of the contact members of a switching device being opened.</td>
<td><strong>Busbar</strong></td>
<td>A low impedance conductor, to which several electric circuits can be connected separately.</td>
</tr>
<tr>
<td><strong>Busbar trunking system</strong></td>
<td>Extended enclosed busbars, equipped with outgoing points for supplying machines and other loads with power via variable tap-off units.</td>
<td><strong>Bushing</strong></td>
<td>Device that enables one or several conductors to pass through a partition such as a wall or a tank and insulate the conductors from it.</td>
</tr>
<tr>
<td><strong>Capacitor voltage transformer (CVT)</strong></td>
<td>A voltage transformer comprising a capacitor divider unit and an electromagnetic unit designed and interconnected so that the secondary voltage of the electromagnetic unit is substantially proportional to the primary voltage, and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections.</td>
<td><strong>Dead tank circuit-breaker</strong></td>
<td>A circuit-breaker with interrupters in an earthed metal tank.</td>
</tr>
<tr>
<td><strong>CAPEX</strong></td>
<td>Capital expenditures of an enterprise for fixed assets, e.g. means of production, buildings etc. → OPEX.</td>
<td><strong>DCF77</strong></td>
<td>A longwave time signal and standard-frequency radio station. The transmitted data repeats each minute the current date and time, a leap second warning bit, a summer time bit, a primary/backup transmitter identification bit, and several parity bits. The callsign DCF77 stands for D=Deutschland (Germany), C=long wave signal, F=Frankfurt, 77=frequency: 77.5 kHz.</td>
</tr>
<tr>
<td><strong>Continuous improvement process (CIP)</strong></td>
<td>→ Kaizen</td>
<td><strong>Current limiting</strong></td>
<td>Ability of an overcurrent protective device (fuse or circuit-breaker) to reduce the peak current in a circuit beyond the value of the peak short-circuit current expected on the basis of the circuit constants (R, L), by opening and clearing the fault in a sub-cycle time frame.</td>
</tr>
<tr>
<td><strong>Circuit-breaker</strong></td>
<td>A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit.</td>
<td><strong>Current limiting circuit-breaker</strong></td>
<td>A circuit-breaker with a break-time short enough to prevent the short-circuit current reaching its otherwise attainable peak value.</td>
</tr>
<tr>
<td><strong>Common information model (CIM)</strong></td>
<td>The Common Information Model (CIM) is an open standard that defines how managed elements in an IEC environment are represented as a common set of objects and relationships between them. This is intended to allow consistent management of these managed elements, independent of their manufacturer or provider.</td>
<td><strong>Current transducer</strong></td>
<td>Transducer used for the measurement of an alternating current.</td>
</tr>
<tr>
<td><strong>Contactor</strong></td>
<td>Load breaking device with a limited short-circuit making or breaking capacity, used for high switching rates.</td>
<td><strong>Current transformer (CT)</strong></td>
<td>Type of instrument transformer designed to provide a current in its secondary winding proportional to the alternating current flowing in its primary. CTs facilitate the safe measurement of large currents, often in the presence of high voltages. The current transformer safely isolates measurement and control circuitry from the high voltages typically present on the circuit being measured.</td>
</tr>
<tr>
<td><strong>Continuous Function Chart (CFC)</strong></td>
<td>A Siemens engineering tool that offers graphical interconnection and parameterization of off-the-shelf or user-defined function blocks to solve sophisticated continuous control applications → SFC.</td>
<td><strong>Dielectric strength</strong></td>
<td>Capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages).</td>
</tr>
<tr>
<td><strong>Demilitarized zone (DMZ)</strong></td>
<td>A subnetwork between an organization’s LAN and an external network, usually the internet. The hosts in the DMZ contain and provide all external services of an organization such as e-mail or web server, but are not allowed to connect directly to the internal LAN.</td>
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<tr>
<td><strong>Disconnector (isolator)</strong></td>
<td>Mechanical switching device which, in the open position, disconnects all the poles of an electric circuit. Disconnectors are used for no-load closing and opening operations, e.g., to isolate downstream devices so they can be worked on.</td>
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<tr>
<td><strong>Distributed generation units</strong></td>
<td>Generation units, such as PV panels, wind turbines, or cogeneration units, which are connected to the LV or MV distribution network.</td>
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<tr>
<td><strong>E</strong></td>
<td><strong>Ear and mouth (E&amp;M)</strong> A technology in voice over IP (VoIP) that uses a traditional telephone handset with an earphone (or earpiece) for listening to incoming audio and a microphone (or mouthpiece) for transmitting audio. Calls using an E&amp;M interface can be made from, received from, or disconnected by a private branch exchange (PBX) as well as from a VoIP-capable computer. The term ear and mouth interface is sometimes used as a synonym for a telephone handset itself, or for a headset-and-microphone combination that allows hands-free operation.</td>
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<tr>
<td><strong>Earth fault</strong></td>
<td>Occurrence of an accidental conductive path between a live conductor and the earth.</td>
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<tr>
<td><strong>Earthing switch</strong></td>
<td>Mechanical switching device for earthing parts of an electric circuit, capable of withstanding for a specified duration electric currents under abnormal conditions such as those of short-circuit, but not required to carry electric current under normal conditions of the electric circuit.</td>
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</tr>
<tr>
<td><strong>ECR</strong></td>
<td>A zero boron glass that is free of added fluorides. It conforms to ASTM D578-1999 specification for E glass. It combines the electrical and mechanical properties of E glass with superior inherent corrosion resistance. ECR glass fiber is an electrical grade corrosion resistant glass fiber.</td>
<td></td>
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<tr>
<td><strong>F</strong></td>
<td><strong>Feeder</strong> An electric line originating at a main substation and supplying one or more secondary substations.</td>
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<td></td>
</tr>
<tr>
<td><strong>Flexible AC transmission system (FACTS)</strong></td>
<td>A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.</td>
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</tr>
<tr>
<td><strong>File transfer protocol (FTP)</strong></td>
<td>Transfer protocol for exchanging files over any -&gt; TCP/IP based network.</td>
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</tr>
<tr>
<td><strong>Fuse</strong></td>
<td>A protective device that by the fusing of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a particular period of time. The fuse comprises all the parts that form the complete device.</td>
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</tbody>
</table>

| **G** | **Gas-insulated switchgear (GIS)** Indoor and outdoor switchgear of compact design and small dimensions for substations up to 550 kV to be installed in urban or industrial loadcenters. All components are housed in earthed metal enclosures filled with sulfur hexafluoride (SF6) gas for insulation. |
| | **Gas-insulated transmission line (GIL)** Transmission lines composed of pipes that house conductors in highly insulative sulfur hexafluoride (SF6) gas, which have high load-transfer capacity. |
| | **Generic Interface Definition** A set of common services used for enterprise integration in the utility industry, defined in IEC standard IEC 61970. |
| | **GPRS** A packet oriented mobile data service available to users of -> GSM. |
| | **Grid-connected photovoltaic system** A photovoltaic system in which the photovoltaic array acts like a central generating plant, supplying power to the grid. |
| | **Grid power flow controller (GPFC)** A concept in system technology within the -> FACTS family of devices that provides an economic solution for the purpose of power transmission between two or more adjacent AC systems. The AC systems can be either synchronous or nonsynchronous. The most proper power rating is between 10 MW and 300 MW, although higher ratings are also achievable. |
| | **GSM** A worldwide standard for mobile phones. |
| **H** | **Harmonics** The sinusoidal (harmonic) oscillations in the Fourier analysis of non-sinusoidal, periodic oscillations that oscillate at a frequency which is an integer multiple of the fundamental (=system) frequency. The amplitudes of harmonics are considerably smaller than the fundamental frequency. |
| | **High voltage** In general a set of voltage levels in excess of -> low voltage (< 1 kV). In a more restrictive sense HV is used for voltage levels typically used for bulk transmission of electricity (> 60 kV). |
| | **HTTP/HTTPS** The hypertext transfer protocol/hypertext transfer protocol secure is a communications protocol for the transfer of information on the intranet and the World Wide Web; HTTPS is widely used for security-sensitive communication. |
| **I** | **Incoming feeder** In a substation a feeder bay which is normally used to receive power from the system. |
| | **Instrument transformer** Transform high currents and voltages into small current or voltage values for measuring or protection purposes. |
| | **Inter-Control Center Communication Protocol (ICCP)** The Inter-Control Center Communications Protocol (ICCP or IEC 60870-6/TASE.2) is being specified by utility organizations throughout the world to provide data exchange over wide area networks (WANs) between utility control centers, utilities, power pools, regional control centers, and non-utility generators. |
**Glossary**

<table>
<thead>
<tr>
<th>Insulated gate bipolar transistor (IGBT)</th>
<th>A three-terminal power semiconductor device, noted for high efficiency and fast switching.</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRIG timecodes</td>
<td>Family of standardized timecodes used by the U.S. Government and the private industry for the correlation of data and time.</td>
</tr>
<tr>
<td>IT system</td>
<td>Power supply system that does not provide a direct connection between live conductors and earthed parts; exposed conductive parts are earthed.</td>
</tr>
<tr>
<td>J</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
<tr>
<td>Kaizen</td>
<td>A Japanese philosophy that focuses on continuous improvement throughout all aspects of life, which was first implemented in several Japanese businesses as a management strategy after World War II, adopted to businesses throughout the world also as Continuous Improvement Process (CIP).</td>
</tr>
<tr>
<td>Konnex (KNX)</td>
<td>Standardized bus system for home and building applications according to EN 50090 and ISO/IEC 14543, comprising switching, signaling, controlling, monitoring, and indicating functions in the electrical installation.</td>
</tr>
<tr>
<td>L</td>
<td></td>
</tr>
<tr>
<td>LCAS</td>
<td>Link Capacity Adjustment Scheme or LCAS is a method to dynamically increase or decrease the bandwidth of virtual concatenated containers to effectively transfer asynchronous data streams over SDH.</td>
</tr>
<tr>
<td>Live tank circuit-breaker</td>
<td>A circuit-breaker with interrupters in a tank insulated from earth.</td>
</tr>
<tr>
<td>Low voltage (LV)</td>
<td>Set of voltage levels used for the distribution of energy up to 1,000 V AC, or 1,200 V DC.</td>
</tr>
<tr>
<td>L-tripping</td>
<td>Overload protection.</td>
</tr>
<tr>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Miniature circuit-breaker (MCB)</td>
<td>Automatically-operated low-voltage switching device designed to protect an electrical circuit from overload or short-circuit. Also used to manually connect or disconnect an electric circuit at will. Rated current not more than 125 A.</td>
</tr>
<tr>
<td>Molded-case circuit-breaker (MCCB)</td>
<td>A circuit-breaker having a supporting housing of molded insulating material forming an integral part of the circuit-breaker.</td>
</tr>
<tr>
<td>Medium voltage (MV)</td>
<td>Set of voltage levels lying between low voltage (LV) and high voltage (HV). The boundaries between HV and LV depend on local circumstances and history or common usage. The band 1kV to 52 kV is commonly accepted in Europe. The term medium voltage is not used in the U.K. nor in Australia.</td>
</tr>
<tr>
<td>Metall oxide varistor (MOV)</td>
<td>A discrete electronic component that is commonly used to divert excessive current to the ground and/or neutral lines.</td>
</tr>
<tr>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Neutral conductor (N)</td>
<td>A conductor connected to the neutral point of a system, which is suitable for transmitting electrical energy.</td>
</tr>
<tr>
<td>N-tripping</td>
<td>Neutral conductor protection.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>OASIS</td>
<td>System for reserving transmission capacities in the US power transmission networks.</td>
</tr>
<tr>
<td>ODBC</td>
<td>Standard database access method for using database management systems.</td>
</tr>
<tr>
<td>OLE</td>
<td>Object Linking and Embedding (OLE) is a technology that allows embedding and linking to documents and other objects developed by Microsoft.</td>
</tr>
<tr>
<td>OPC</td>
<td>A set of connectivity standards for industrial automation from the OPC Foundation, which offers interoperability between gauges, databases, programmable logic controllers (PLCs), distributed control systems (DCSs) and remote terminal units (RTUs).</td>
</tr>
<tr>
<td>Operating voltage (in a system)</td>
<td>The value of the voltage under normal conditions, at a given instant and a given point of the system.</td>
</tr>
<tr>
<td>OPEX</td>
<td>On-going cost for running a product, business, or system.</td>
</tr>
<tr>
<td>OSCOP® P</td>
<td>A PC program for retrieving and processing of records made with the SIMEAS R digital fault and power quality recorder, the SIMEAS Q power quality recorder, or with numerical protection relays using the IEC 60870-5-103 protocol.</td>
</tr>
<tr>
<td>OSI</td>
<td>A layered, abstract description for communications and computer network protocol design.</td>
</tr>
<tr>
<td>Outgoing feeder</td>
<td>A feeder bay in a substation which is normally used to transmit power to the system.</td>
</tr>
<tr>
<td>Overcurrent</td>
<td>Any current in an electric circuit that exceeds the rated current.</td>
</tr>
<tr>
<td>Overload</td>
<td>Operating conditions in an electrically sound, fault-free electric circuit that give rise to an overcurrent.</td>
</tr>
<tr>
<td>P</td>
<td></td>
</tr>
<tr>
<td>PABX</td>
<td>A telephone exchange that serves a particular business or office, as opposed to one that a common carrier or telephone company operates for many businesses or for the general public.</td>
</tr>
<tr>
<td>Pulse-code modulation (PCM)</td>
<td>A digital representation of an analog signal where the magnitude of the signal is sampled regularly at uniform intervals, then quantized to a series of symbols in a numeric (usually binary) code.</td>
</tr>
<tr>
<td>PDH</td>
<td>An international multiplexing standard.</td>
</tr>
<tr>
<td>PE conductor</td>
<td>Conductor provided for purposes of safety, for example protection against electric shock. In an electrical installation, the conductor identified PE is normally also considered as protective earthing conductor.</td>
</tr>
<tr>
<td>Phase-shifting transformer</td>
<td>A device for controlling the power flow through specific lines in a complex power transmission network.</td>
</tr>
<tr>
<td>(Photovoltaik) Peak Watt</td>
<td>Maximum &quot;rated&quot; output of a photovoltaic cell, module, or system. Typical rating conditions are 1000 W/m² of sunlight, 20 °C ambient air temperature and 1 m/s wind speed.</td>
</tr>
<tr>
<td>PEN (conductor)</td>
<td>Combined PE and N conductor.</td>
</tr>
<tr>
<td><strong>Power-line carrier</strong></td>
<td>A device for producing radio-frequency power for transmission on power lines.</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Potential transformer (PT)</strong></td>
<td>A device required to provide accurate voltages for meters used for billing industrial customers or utility companies.</td>
</tr>
<tr>
<td><strong>Python</strong></td>
<td>A dynamic object-oriented programming language.</td>
</tr>
</tbody>
</table>

**Glossary**

<table>
<thead>
<tr>
<th><strong>Resistance temperatur device/detector (RTD)</strong></th>
<th>Device for temperature detection based on the resistance change in a metal, with the resistance rising more or less linearly with temperature.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remote terminal unit (RTU)</strong></td>
<td>An electronic device to transmit data to a distributed control system or a SCADA-system and to alter the state of connected objects based on control messages received from the system.</td>
</tr>
</tbody>
</table>

**S**

<table>
<thead>
<tr>
<th><strong>Switch-disconnector</strong></th>
<th>A switch which, in the open position, satisfies the isolating requirements specified for a disconnector.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Switch-disconnector-fuse (SDF)</strong></td>
<td>A switch-disconnector comprising a -&gt; switch-disconnector and (connected in series to this) fusebases for insertign fuse-links.</td>
</tr>
<tr>
<td><strong>SDH</strong></td>
<td>A multiplexing protocol for transferring multiple bit streams over the same optical fiber.</td>
</tr>
<tr>
<td><strong>Selectivity</strong></td>
<td>Combined operation of overcurrent protective devices connected in series to provide graded disconnection.</td>
</tr>
<tr>
<td><strong>Series reactor</strong></td>
<td>A reactor intended for series connection in a network, either for limiting the current under fault conditions or for load-sharing in parallel circuits.</td>
</tr>
<tr>
<td><strong>SFC</strong></td>
<td>A graphical programming language used for PLCs. It is one of the five languages defined by IEC 61131-3 standard. The SFC standard is defined in IEC 848, &quot;Preparation of function charts for control systems&quot;.</td>
</tr>
<tr>
<td><strong>Short-circuit</strong></td>
<td>Connection of two or more points of an electrical circuit that are meant to be at different voltages across a negligible small resistance or impedance.</td>
</tr>
<tr>
<td><strong>Short-circuit current</strong></td>
<td>Overcurrent which flows through the -&gt; short-circuit which may result in thermal or mechanical overloading of the electrical equipment.</td>
</tr>
<tr>
<td><strong>Short-circuit strength</strong></td>
<td>The mechanical resistance of switching devices to short-circuit stress, particularly of busbars in switchgear stations and distribution boards.</td>
</tr>
<tr>
<td><strong>Shunt release</strong></td>
<td>A release energized by a source of voltage.</td>
</tr>
<tr>
<td><strong>Shunt reactor</strong></td>
<td>A reactor intended for shunt connection in a network to compensate for capacitive current.</td>
</tr>
<tr>
<td><strong>Single-line diagram (SLD)</strong></td>
<td>A simplified notation for representing a three-phase power system in which the polyphase links are represented by their equivalent single line.</td>
</tr>
<tr>
<td><strong>Smart grid</strong></td>
<td>Evolving intelligent power distribution network using communication, advanced sensors, and distributed computers to improve the efficiency, reliability and safety of power delivery and use. It includes the possibility for demand side management, facilitating grid connection of distributed generation power (with photovoltaic arrays, small wind turbines, micro hydro, or even combined heat power generators in buildings), grid energy storage for distributed generation load balancing, and improved reliability against many different component failure scenarios.</td>
</tr>
</tbody>
</table>
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNCP</td>
<td>A protection mechanism used in → SDH</td>
</tr>
<tr>
<td>SNMP</td>
<td>SNMP is used in network management systems to monitor network-attached devices for conditions that warrant administrative attention. It consists of a set of standards for network management, including an Application Layer protocol, a database schema, and a set of data objects.</td>
</tr>
<tr>
<td>SOAP</td>
<td>A protocol for exchanging → XML-based messages over computer networks, normally using → HTTP/HTTPS. Formerly SOAP was an acronym for Simple Object Access Protocol, which was dropped with Version 1.2.</td>
</tr>
<tr>
<td>SONET</td>
<td>Multiplexing protocol for transferring multiple bit streams over the same optical fiber.</td>
</tr>
<tr>
<td>SQL</td>
<td>Database computer language designed for the retrieval and management of data in relational database management systems.</td>
</tr>
<tr>
<td>STM</td>
<td>Synchronous Transport Module (STM), the basic unit of framing in → SDH</td>
</tr>
<tr>
<td>S-tripping</td>
<td>Short-time delay short-circuit protection.</td>
</tr>
<tr>
<td>Substation</td>
<td>A part of an electrical system, confined to a given area, mainly including ends of transmission or distribution lines, electrical switchgear and controlgear, buildings and transformers. A substation generally includes safety or control devices (for example protection).</td>
</tr>
<tr>
<td>Surge arrester</td>
<td>A device designed to protect the electrical apparatus from high transient overvoltages caused by lightning strikes or switching operations.</td>
</tr>
<tr>
<td>Switch-switching device</td>
<td>Device for making or breaking a current in an electric circuit.</td>
</tr>
<tr>
<td>Switch-disconnector</td>
<td>A switch which, in the open position, satisfies the isolating requirements specified for a → disconnector.</td>
</tr>
<tr>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Total harmonic distortion (THD)</td>
<td>The THD of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.</td>
</tr>
<tr>
<td>TN-S, TN-C, TN-C-S</td>
<td>Power supply systems; in the TN-S system the neutral conductor and the protective-earth-conductor-function is separated throughout the system; in the TN-C system neutral-conductor and protective-earth-conductor-function are combined throughout the system; the TN-C-S system is a combination of a TN-C and a TN-S system. In one part of the system neutral-conductor and protective-earth-conductor function are combined, in another part, they are separate.</td>
</tr>
<tr>
<td>Total harmonic distortion (THD)</td>
<td>The THD of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.</td>
</tr>
<tr>
<td>Transformer substation</td>
<td>A substation containing power transformers interconnecting two or more networks of different voltages.</td>
</tr>
<tr>
<td>Transient overvoltage</td>
<td>Very short duration increase in voltage, between two or more conductors. Transient overvoltages are mainly caused by the secondary effects of lightning or by electrical switching events and may cause serious damages to components of the electrical supply network.</td>
</tr>
<tr>
<td>Tripping current</td>
<td>Current value at which a tripping element trips within a particular time.</td>
</tr>
<tr>
<td>TT system</td>
<td>Power supply system; in the TT system one point is directly grounded, all exposed conductive parts are connected to grounding electrodes which are separated from the system grounding.</td>
</tr>
<tr>
<td>TTA</td>
<td>Type-tested low voltage switchgear assembly.</td>
</tr>
<tr>
<td>Type-tested LV controlgear and switchgear assembly (TTA)</td>
<td>Assembly of low-voltage controlgear and switchgear built and type-tested according to IEC 60439-1/EN 60439-1/DIN VDE 0660-500.</td>
</tr>
<tr>
<td>U</td>
<td></td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System; third-generation cell phone standard that allows significantly higher data transfer rates than GSM.</td>
</tr>
<tr>
<td>USB</td>
<td>Serial bus standard to interface devices.</td>
</tr>
<tr>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Virtual power plant (VPP)</td>
<td>A cluster of distributed generation installations which are collectively run by a central control entity. The concerted operational mode shall result in an extra benefit as to deliver peak load electricity or balancing power at short notice.</td>
</tr>
<tr>
<td>Visual Basic for Applications (VBA)</td>
<td>An event-driven programming language and associated integrated development environment (IDE) which is built into most Microsoft Office applications.</td>
</tr>
<tr>
<td>Voltage divider</td>
<td>Device comprising resistors, inductors, capacitors, transformer(s) or a combination of these components such that, between two points of the device, a desired fraction of the voltage applied to the device as a whole can be obtained.</td>
</tr>
<tr>
<td>(Line) voltage drop</td>
<td>The difference at a given instant between the voltages measured at two given points along a line.</td>
</tr>
<tr>
<td>Voltage regulator</td>
<td>A tapped step autotransformer used to maintain a desired voltage level all the time.</td>
</tr>
<tr>
<td>Voltage surge</td>
<td>A transient voltage wave propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease of the voltage.</td>
</tr>
<tr>
<td>Voltage transducer</td>
<td>Transducer used for the measurement of an alternating voltage.</td>
</tr>
<tr>
<td>Voltage transformer</td>
<td>An instrument transformer in which the secondary voltage, in normal conditions of use, is substantially proportional to the primary voltage and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections.</td>
</tr>
<tr>
<td>W</td>
<td>WDM</td>
</tr>
<tr>
<td>----</td>
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</tr>
<tr>
<td>WiBro</td>
<td>South Korean service name for the international standard IEEE 802.16e (mobile WiMAX).</td>
</tr>
<tr>
<td>WiMAX</td>
<td>A wireless broadband telecommunications technology based on the IEEE 802.16 standard.</td>
</tr>
<tr>
<td>X</td>
<td>extensible markup language (XML)</td>
</tr>
</tbody>
</table>
## Abbreviations, Trademarks

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## 12.1 Abbreviations

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<tr>
<th>Letter</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AAC</td>
<td>All-aluminum conductor</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td></td>
<td>ACB</td>
<td>Air circuit breaker</td>
</tr>
<tr>
<td></td>
<td>ACSR</td>
<td>Aluminum conductor, steel-reinforced</td>
</tr>
<tr>
<td></td>
<td>ADC</td>
<td>Analog-to-digital-converter</td>
</tr>
<tr>
<td></td>
<td>ADM</td>
<td>Asynchronous digital multiplexer</td>
</tr>
<tr>
<td></td>
<td>AF</td>
<td>Air-forced; (cooling type [of cast-resin] transformers)</td>
</tr>
<tr>
<td></td>
<td>AI</td>
<td>Aluminum</td>
</tr>
<tr>
<td></td>
<td>AN</td>
<td>Air-natural</td>
</tr>
<tr>
<td></td>
<td>AIS</td>
<td>Air-insulated switchyard</td>
</tr>
<tr>
<td></td>
<td>AMI</td>
<td>Automated meter infrastructure</td>
</tr>
<tr>
<td></td>
<td>AMIS</td>
<td>Automated consumption data acquisition and information system</td>
</tr>
<tr>
<td></td>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td></td>
<td>AR</td>
<td>Auto-reclosure</td>
</tr>
<tr>
<td></td>
<td>ASC</td>
<td>Arc suppression coil</td>
</tr>
<tr>
<td></td>
<td>ASCII</td>
<td>American Standard Code for Information Interchange</td>
</tr>
<tr>
<td></td>
<td>ATM</td>
<td>Asynchronous transfer mode</td>
</tr>
<tr>
<td></td>
<td>ATM-IMA</td>
<td>Inverse multiplexing over ATM</td>
</tr>
<tr>
<td></td>
<td>AVR</td>
<td>Automatic voltage regulator</td>
</tr>
<tr>
<td>B</td>
<td>BCU</td>
<td>Bay control unit</td>
</tr>
<tr>
<td></td>
<td>BF (protection)</td>
<td>Breaker failure (protection)</td>
</tr>
<tr>
<td></td>
<td>BF (time)</td>
<td>Breaker failure initiation (time)</td>
</tr>
<tr>
<td></td>
<td>BFT (time)</td>
<td>Breaker failure tripping (time)</td>
</tr>
<tr>
<td></td>
<td>BIL</td>
<td>Basic impulse level</td>
</tr>
<tr>
<td></td>
<td>BIPV</td>
<td>Building-integrated photovoltaik system</td>
</tr>
<tr>
<td></td>
<td>BOSL</td>
<td>Block oriented simulation language</td>
</tr>
<tr>
<td></td>
<td>BPL</td>
<td>Broadband over powerlines</td>
</tr>
<tr>
<td></td>
<td>B2B</td>
<td>a) Building-to-building; b) Business-to-business</td>
</tr>
<tr>
<td></td>
<td>BS</td>
<td>British Standard</td>
</tr>
<tr>
<td>C</td>
<td>CAD/CAE</td>
<td>Computer aided design/computer aided engineering</td>
</tr>
<tr>
<td></td>
<td>CAPEX</td>
<td>Capital expenditure</td>
</tr>
<tr>
<td></td>
<td>CB</td>
<td>Circuit-breaker</td>
</tr>
<tr>
<td></td>
<td>CCS</td>
<td>Cubicle for customized solutions</td>
</tr>
<tr>
<td></td>
<td>CERT</td>
<td>Computer emergency response team</td>
</tr>
<tr>
<td></td>
<td>CFC</td>
<td>Continuous Function Chart</td>
</tr>
<tr>
<td></td>
<td>CM</td>
<td>Communication front end</td>
</tr>
<tr>
<td></td>
<td>CHP</td>
<td>Combined heat and power</td>
</tr>
<tr>
<td></td>
<td>CIM</td>
<td>Common information model</td>
</tr>
<tr>
<td></td>
<td>CIP</td>
<td>Continuous improvement process</td>
</tr>
<tr>
<td></td>
<td>CIT</td>
<td>Combined instrument transformer</td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td></td>
<td>CSA</td>
<td>Canadian Standards Association</td>
</tr>
<tr>
<td></td>
<td>CVT</td>
<td>Capacitor voltage transformer</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>Current transformer</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>Copper</td>
</tr>
<tr>
<td>D</td>
<td>DAC</td>
<td>Digital-to-analog converter</td>
</tr>
<tr>
<td></td>
<td>DAU</td>
<td>Data acquisition unit</td>
</tr>
<tr>
<td></td>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td></td>
<td>DEMS</td>
<td>Decentralized energy management system</td>
</tr>
<tr>
<td></td>
<td>DER</td>
<td>Distributed energy resources</td>
</tr>
<tr>
<td></td>
<td>DG</td>
<td>Distributed generation</td>
</tr>
<tr>
<td></td>
<td>DIN</td>
<td>germ.: Deutsches Institut für Normung e. V.; German Institute for Standardization</td>
</tr>
<tr>
<td></td>
<td>DINEMO</td>
<td>Digital network model</td>
</tr>
<tr>
<td></td>
<td>Dip</td>
<td>Distributed interface processor</td>
</tr>
<tr>
<td></td>
<td>DisCo</td>
<td>Distribution company</td>
</tr>
<tr>
<td></td>
<td>DMAIC</td>
<td>Define-measure-analyse-improve-control</td>
</tr>
<tr>
<td></td>
<td>DMS</td>
<td>Distribution management system</td>
</tr>
<tr>
<td></td>
<td>DMZ</td>
<td>Demilitarized zone</td>
</tr>
<tr>
<td></td>
<td>DN</td>
<td>Damping network</td>
</tr>
<tr>
<td></td>
<td>DNP</td>
<td>Distributed network protocol</td>
</tr>
<tr>
<td></td>
<td>DQS</td>
<td>germ.: Deutsche Gesellschaft zur Zertifizierung von Managementsystemen; German registrar for management systems</td>
</tr>
<tr>
<td></td>
<td>DSL</td>
<td>Digital subscriber line</td>
</tr>
<tr>
<td></td>
<td>DT</td>
<td>Distribution transformer</td>
</tr>
<tr>
<td></td>
<td>DTC</td>
<td>Dead tank compact</td>
</tr>
<tr>
<td>E</td>
<td>E&amp;M interface</td>
<td>Ear and month interface</td>
</tr>
<tr>
<td></td>
<td>EAF</td>
<td>Electric arc furnace</td>
</tr>
<tr>
<td></td>
<td>ECANSE</td>
<td>Environment for Computer Aided Neural Software Engineering</td>
</tr>
<tr>
<td></td>
<td>ECR (glass fiber)</td>
<td>Electrical grade corrosion resistant (glass fiber)</td>
</tr>
<tr>
<td></td>
<td>EDP</td>
<td>Electronic data processing</td>
</tr>
<tr>
<td></td>
<td>EHV</td>
<td>Extra high voltage</td>
</tr>
<tr>
<td></td>
<td>EIB</td>
<td>European Installation Bus</td>
</tr>
<tr>
<td></td>
<td>EIRP</td>
<td>Effective isotropic radiated power</td>
</tr>
<tr>
<td></td>
<td>ELCOM</td>
<td>Electricity utilities communication</td>
</tr>
<tr>
<td></td>
<td>EM</td>
<td>Environmental management</td>
</tr>
<tr>
<td></td>
<td>EMC</td>
<td>Electromagnetic compatibility</td>
</tr>
<tr>
<td></td>
<td>EMS</td>
<td>Energy management system</td>
</tr>
<tr>
<td></td>
<td>EN</td>
<td>germ.: Europa-Norm; European Standard</td>
</tr>
<tr>
<td></td>
<td>EPC (contract)</td>
<td>Engineering, procurement, construction (contract)</td>
</tr>
<tr>
<td></td>
<td>EPROM</td>
<td>Erasable programmable read-only-memory</td>
</tr>
<tr>
<td></td>
<td>ERIP (design)</td>
<td>Epoxy resin impregnated paper (design)</td>
</tr>
<tr>
<td></td>
<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
</tr>
<tr>
<td></td>
<td>ETU</td>
<td>Electronic trip unit</td>
</tr>
<tr>
<td></td>
<td>EU</td>
<td>European Union</td>
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</table>
### Abbreviations, Trademarks

#### 12.1 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>FACTS</td>
<td>Flexible AC transmission system</td>
</tr>
<tr>
<td>FCITC</td>
<td>First contingency incremental transfer capability</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>FEM</td>
<td>Finite element method</td>
</tr>
<tr>
<td>FMS</td>
<td>Fieldbus message specification</td>
</tr>
<tr>
<td>FO</td>
<td>Fiber optic</td>
</tr>
<tr>
<td>FR</td>
<td>Filter reactor</td>
</tr>
<tr>
<td>FRP</td>
<td>Fiber glass reinforced polyester</td>
</tr>
<tr>
<td>FSC</td>
<td>Fixed series capacitor</td>
</tr>
<tr>
<td>FTP</td>
<td>File transfer protocol</td>
</tr>
<tr>
<td>GA</td>
<td>Generator connection cabinet</td>
</tr>
<tr>
<td>GenCo</td>
<td>Generation company</td>
</tr>
<tr>
<td>GFP</td>
<td>Generic framing procedure</td>
</tr>
<tr>
<td>GID</td>
<td>Generic interface definition</td>
</tr>
<tr>
<td>GL</td>
<td>Gas-insulated transmission line</td>
</tr>
<tr>
<td>GIS</td>
<td>Gas-insulated switchgear</td>
</tr>
<tr>
<td>GMB</td>
<td>Graphical model builder</td>
</tr>
<tr>
<td>GMS</td>
<td>Generation management system</td>
</tr>
<tr>
<td>GOOSE</td>
<td>Generic object oriented substation event</td>
</tr>
<tr>
<td>GPFC</td>
<td>Grid power flow controller</td>
</tr>
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</table>
| GPS          | a) General power supply;  
|              | b) Global positioning system |
| GPRS         | General packet radio service |
| GSM          | Global system for mobile communications (originally from French: groupe spécial mobile) |
| GSU transformer | Generator step-up transformer |
| G-tripping   | Ground-fault tripping |
| GUI          | Graphical user interface |
| HF           | High frequency |
| HIGS         | Highly integrated generator switchgear |
| HIS          | Highly integrated switchgear |
| HMI          | Human machine interface |
| HRC (fuse)   | High-rupturing-capacity (fuse) |
| HTTP/HTTPS   | Hypertext transfer protocol/ hypertext transfer protocol secure |
| HTV (silicone rubber) | High-temperature-vulcanizing (silicone rubber) |
| HV           | High voltage |
| HVDC         | High voltage direct current |
| HVDCT        | High voltage direct current transmission |
| IAC          | Internal arc classification |
| ICCP         | Inter-control center communication protocol |
| IDS          | Intrusion detection system |
| IEC          | International Electrotechnical Commission |
| IED          | Intelligent electronic device |
| IEEE         | Institute of Electrical and Electronics Engineers |
| IGBT         | Insulated gate bipolar transistor |
| ILSA (protocol) | Industrial link state advertisement (protocol) |
| IMM          | Information model management |
| IP (code)    | Ingress protection (code) |
| IP           | Internet Protocol |
| IPP          | Independent power provider |
| IRIG timecodes | Inter Range Instrumentation Group timecodes |
| ISCM         | Integrated Services and Support Condition Monitoring |
| ISDN         | Integrated services digital network |
| ISO          | a) International Organization for Standardization;  
|              | b) independent system operator |
| IT           | Information technology |
| I-tripping   | Instantaneous short-circuit protection |
| KNX          | Konnex |
| LAN          | Local area network |
| LCAS         | Link Capacity Adjustment Scheme |
| LCD          | Liquid crystal display |
| LED          | Light emitting diode |
| LF           | Ladle furnace |
| LI           | Lightning impulse |
| LPVTG        | Low power voltage transducer for medium-voltage GIS systems |
| LSC (category) | Loss of service continuity (category) |
| LTTR         | Light-triggered thyristors |
| LV           | Low voltage |
| LVMD         | Low-voltage main distribution |
| MBR          | Management Business Review |
| MCB          | Miniature circuit-breaker |
| MCCB         | Molded-case circuit-breaker |
| MD           | Main distribution |
| MFC          | Microsoft foundation class |
| MMC          | Modular multilevel converter |
| MO           | Metal oxide |
| MOD          | Model on demand |
| MOV          | Metal oxide varistor |
| MPCB         | Motor protection circuit breaker |
| MPDSL        | Maximum permissible dynamic service load |
| MPSL         | Maximum permissible service load |
| MSC          | Mechanically switched capacitor |
| MSCDN        | Mechanically switched capacitor bank with damping network |
| MSP          | Motor starter protector |
## Abbreviations, Trademarks

### 12.1 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>MSPP</td>
<td>Multi-service provisioning platform</td>
</tr>
<tr>
<td>MSR</td>
<td>Mechanically switched reactor</td>
</tr>
<tr>
<td>(2F-) MS-SPRing</td>
<td>(2 fiber) Multiplex section-shared protection ring</td>
</tr>
<tr>
<td>MTBF</td>
<td>Meantime between failures</td>
</tr>
<tr>
<td>MUX</td>
<td>Multiplexer</td>
</tr>
<tr>
<td>MV</td>
<td>Medium voltage</td>
</tr>
<tr>
<td>N</td>
<td>Neutral (conductor)</td>
</tr>
<tr>
<td>N₂</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>NERC</td>
<td>North American Electric Reliability Corporation</td>
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<tr>
<td>NEVA</td>
<td>Eigenvalue analysis</td>
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<td>NIP</td>
<td>Network interface processor</td>
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<tr>
<td>NLTC</td>
<td>No-load tap changer</td>
</tr>
<tr>
<td>NTP</td>
<td>Network time protocol</td>
</tr>
<tr>
<td>N-tripping</td>
<td>Neutral conductor protection</td>
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<tr>
<td>O</td>
<td>Object linking and embedding</td>
</tr>
<tr>
<td>OASIS</td>
<td>Open Access Same Time Information System</td>
</tr>
<tr>
<td>ODBC</td>
<td>Open Database Connectivity</td>
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<tr>
<td>ODMS</td>
<td>Operational database maintenance system</td>
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<tr>
<td>OHL</td>
<td>Overhead power line</td>
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<td>OIP (design)</td>
<td>Oil impregnated paper design (of transformer bushings) (--&gt; ERIP)</td>
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<tr>
<td>OLE (--&gt; OPC)</td>
<td>Object linking and embedding</td>
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<td>OLTC</td>
<td>On-load tap changer</td>
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<tr>
<td>ONAF</td>
<td>Oil-natural/air-forced; cooling type of transformers</td>
</tr>
<tr>
<td>ONAN</td>
<td>Oil-natural/air-natural; cooling type of transformers</td>
</tr>
<tr>
<td>OPF</td>
<td>Optimal power flow</td>
</tr>
<tr>
<td>OPEX</td>
<td>Operational expenditure</td>
</tr>
<tr>
<td>OPGW</td>
<td>Optical ground wire</td>
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<tr>
<td>OSI</td>
<td>Open Systems Interconnection Basic Reference Model</td>
</tr>
<tr>
<td>P</td>
<td>Polyethylene;</td>
</tr>
<tr>
<td>PA/BX</td>
<td>Private Automatic Branch Exchange</td>
</tr>
<tr>
<td>PCI</td>
<td>Peripheral Component Interconnect</td>
</tr>
<tr>
<td>PCM</td>
<td>Pulse code modulation</td>
</tr>
<tr>
<td>PDH</td>
<td>Plesiochronous digital hierarchy; an international multiplexing standard</td>
</tr>
<tr>
<td>PD value</td>
<td>Partial discharge value</td>
</tr>
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<td>PE</td>
<td>Polyethylene;</td>
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<tr>
<td>PE (conductor)</td>
<td>Protective earth (conductor)</td>
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<tr>
<td>PEHLA</td>
<td>germ.: Prüfung elektrischer Hochleistungsapparate; an association of owners of high-power testing laboratories in Germany and Switzerland</td>
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<tr>
<td>PEN (conductor)</td>
<td>combined --&gt; PE and --&gt; N conductor</td>
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<td>PLC</td>
<td>a) Power-line carrier; b) programmable logic controller</td>
</tr>
<tr>
<td>POD</td>
<td>Power oscillation damping</td>
</tr>
<tr>
<td>POTT</td>
<td>Permissive overreach transfer trip</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>PQ</td>
<td>Power quality</td>
</tr>
<tr>
<td>PROFIBUS</td>
<td>Process Fieldbus</td>
</tr>
<tr>
<td>PROFIBUS DP</td>
<td>PROFIBUS for Decentralized Peripherals</td>
</tr>
<tr>
<td>PROFIBUS FMS</td>
<td>PROFIBUS with --&gt; FMS protocol</td>
</tr>
<tr>
<td>PST</td>
<td>Phase-shifting transformer</td>
</tr>
<tr>
<td>PTC (thermistor)</td>
<td>Positive temperature coefficient (thermistor)</td>
</tr>
<tr>
<td>PT</td>
<td>Potential transformer</td>
</tr>
<tr>
<td>PTI</td>
<td>--&gt; Siemens PTI</td>
</tr>
<tr>
<td>PUTT</td>
<td>Permissive underreach transfer trip</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaics</td>
</tr>
<tr>
<td>PV/QV (analysis)</td>
<td>Power/voltage var/voltage (analysis)</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>Q</td>
<td>Quality management (system)</td>
</tr>
<tr>
<td>OSI (system)</td>
<td>Open Systems Interconnection Basic Reference Model</td>
</tr>
<tr>
<td>R</td>
<td>Research and development process</td>
</tr>
<tr>
<td>R&amp;D process</td>
<td>Research and development process</td>
</tr>
<tr>
<td>RCAM</td>
<td>Reliability-centered asset management</td>
</tr>
<tr>
<td>RCD</td>
<td>Residual current protective device</td>
</tr>
<tr>
<td>RC voltage divider</td>
<td>Resistive-capacitive voltage divider</td>
</tr>
<tr>
<td>RES</td>
<td>Renewable energy sources</td>
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<tr>
<td>RMS; rms</td>
<td>Root mean square</td>
</tr>
<tr>
<td>RMU</td>
<td>Ring main unit</td>
</tr>
<tr>
<td>RPS</td>
<td>Redundant power supply</td>
</tr>
<tr>
<td>RSTP</td>
<td>Rapid spanning tree protocol</td>
</tr>
<tr>
<td>RTD</td>
<td>Resistance temperatur device/detector</td>
</tr>
<tr>
<td>RTU</td>
<td>Remote terminal unit</td>
</tr>
<tr>
<td>S</td>
<td>Siemens PTI Siemens Power Technologies International</td>
</tr>
<tr>
<td>SAIDI</td>
<td>System average interruption duration index;</td>
</tr>
<tr>
<td>SAS</td>
<td>Station automation system</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory control and data acquisition</td>
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<tr>
<td>SCCL</td>
<td>Short circuit current limiter</td>
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<tr>
<td>SCL</td>
<td>Substation configuration description language</td>
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<tr>
<td>SD</td>
<td>Switch-disconnector</td>
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<tr>
<td>SDF</td>
<td>Switch-disconnector-fuse</td>
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<tr>
<td>SDH</td>
<td>Synchronous digital hierarchy; multiplexing protocol for transferring multiple bit streams over the same optical fiber</td>
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<tr>
<td>SFC</td>
<td>Sequential function chart</td>
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<tr>
<td>SF₆</td>
<td>Sulphur hexafluoride</td>
</tr>
<tr>
<td>SIC</td>
<td>Silicium carbide</td>
</tr>
<tr>
<td>SIM</td>
<td>Serial module interface</td>
</tr>
<tr>
<td>SIP</td>
<td>Serial interface processor</td>
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<tr>
<td>SLD</td>
<td>Single-line diagram</td>
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<td>SNCP</td>
<td>Sub-network connection protection</td>
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<td>SNMP</td>
<td>Simple network management protocol</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<td>--------------</td>
<td>------------</td>
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<tr>
<td>SONET</td>
<td>Synchronous optical network</td>
</tr>
<tr>
<td>SPS</td>
<td>Safety power supply</td>
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<tr>
<td>SQL</td>
<td>Structured Query Language</td>
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<tr>
<td>SSR</td>
<td>Subsynchronous resonance</td>
</tr>
<tr>
<td>STATCOM</td>
<td>Static synchronous compensator</td>
</tr>
<tr>
<td>STM</td>
<td>Synchronous transport module</td>
</tr>
<tr>
<td>STL</td>
<td>Short-circuit Testing Liaison</td>
</tr>
<tr>
<td>S-tripping</td>
<td>Short-time delay short-circuit protection</td>
</tr>
<tr>
<td>SVC</td>
<td>Static var compensator</td>
</tr>
<tr>
<td>TAI</td>
<td>Technical applications integration</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission control protocol</td>
</tr>
<tr>
<td>TCR</td>
<td>Thyristor-controlled shunt reactor</td>
</tr>
<tr>
<td>TCSC</td>
<td>Thyristor controlled series capacitor</td>
</tr>
<tr>
<td>THD</td>
<td>Total harmonic distortion</td>
</tr>
<tr>
<td>(Siemens) TLM</td>
<td>(Siemens) Transformer Lifecycle Management</td>
</tr>
<tr>
<td>TM (tripping)</td>
<td>Thermal-magnetic (tripping)</td>
</tr>
<tr>
<td>TM (bus)</td>
<td>Terminal module (bus)</td>
</tr>
<tr>
<td>TPSG</td>
<td>Thyristor-protected series capacitor</td>
</tr>
<tr>
<td>TransCo</td>
<td>Transmission company</td>
</tr>
<tr>
<td>TRV</td>
<td>Transient recovery voltage</td>
</tr>
<tr>
<td>TSC</td>
<td>Thyristor-switched capacitor reactor</td>
</tr>
<tr>
<td>TSR</td>
<td>Thyristor-switched reactors</td>
</tr>
<tr>
<td>TSSC</td>
<td>Thyristor-switched series capacitor</td>
</tr>
<tr>
<td>TTA</td>
<td>Type-tested low voltage switchgear assembly</td>
</tr>
<tr>
<td>UCTE</td>
<td>Union for the Co-ordination of Transmission of Energy</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra high frequency</td>
</tr>
<tr>
<td>UHVDC</td>
<td>Ultra-high-voltage direct-current</td>
</tr>
<tr>
<td>UI</td>
<td>User interface</td>
</tr>
<tr>
<td>UML</td>
<td>Unified modeling language</td>
</tr>
<tr>
<td>UMITS</td>
<td>Universal Mobile Telecommunications System</td>
</tr>
<tr>
<td>USB</td>
<td>Universal serial bus; serial bus standard to interface devices</td>
</tr>
<tr>
<td>UPS</td>
<td>Uninterruptible power supply</td>
</tr>
<tr>
<td>VBA</td>
<td>Visual Basic for Applications</td>
</tr>
<tr>
<td>VCAT</td>
<td>Virtual concatenation</td>
</tr>
<tr>
<td>VDE</td>
<td>germ.: Verband der Elektrotechnik, Elektronik und Informationstechnik; German association for electrical, electronic and information technologies</td>
</tr>
<tr>
<td>VDU</td>
<td>Visual display unit</td>
</tr>
<tr>
<td>VF</td>
<td>Voice frequency</td>
</tr>
<tr>
<td>VHF</td>
<td>Very high frequency</td>
</tr>
<tr>
<td>VPP</td>
<td>Virtual power plant</td>
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<tr>
<td>VSC</td>
<td>Voltage-sourced converter</td>
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<td>VT</td>
<td>Voltage transformer</td>
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<tr>
<td>WAN</td>
<td>Wide area network</td>
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<td>WDM</td>
<td>Wavelength division multiplex</td>
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<td>WLAN</td>
<td>Wireless local area network</td>
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<tr>
<td>WiBro</td>
<td>Wireless broadband</td>
</tr>
<tr>
<td>WiMAX</td>
<td>Worldwide interoperability for microwave access</td>
</tr>
<tr>
<td>XML</td>
<td>Extensible markup language</td>
</tr>
<tr>
<td>ZnO</td>
<td>Zinc oxide</td>
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<td>ET 200®</td>
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<tr>
<td>GEAFOL®</td>
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<tr>
<td>Kiellinie®</td>
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<tr>
<td>MOD®</td>
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<tr>
<td>Model On Demand®</td>
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<td>NETOMAC® (Network torsion machine control)</td>
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<td>NXAIR®</td>
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<td>NXPLUS®</td>
</tr>
<tr>
<td>OSCILLOSTORE®</td>
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<td>OSCOP®</td>
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<tr>
<td>PSS® (Power System Simulator)</td>
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<td>PSS®E (PSS for Engineering)</td>
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<tr>
<td>PSS®MUST (Managing and Utilizing System Transmission)</td>
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<tr>
<td>PSS®NETOMAC® (Network Torsion Machine Control)</td>
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<td>PSS®ODMS (Operational Database Maintenance System)</td>
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<td>PSS®O (... for Operations)</td>
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<td>SIMEAS SAFIR®</td>
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<td>SIMOBREAKER®</td>
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<tr>
<td>SINVERT®</td>
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<tr>
<td>SION®</td>
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<td>SIPLINK® (Siemens multifunctional power link)</td>
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<td>SIPROTEC®</td>
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<tr>
<td>SIRIUS®</td>
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<td>Totally Integrated Power™</td>
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