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6 Protection, Substation Automation, Power Quality and Measurements

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 300,000 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
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.
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. 6.2-1). 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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>1902</td>
<td>Schückert &amp; Co. (1887): DC metering device based on Georg Hummel's principle</td>
</tr>
<tr>
<td>1925</td>
<td>First overcurrent relay R41 and delayed action relay R5S</td>
</tr>
<tr>
<td>1940</td>
<td>Introduction of new overcurrent relay RAS</td>
</tr>
<tr>
<td>1970</td>
<td>Introduction of analog electronic relays</td>
</tr>
<tr>
<td>1977</td>
<td>First digital application in Würzburg, Germany</td>
</tr>
<tr>
<td>1980s</td>
<td>The digital era for relays begins</td>
</tr>
<tr>
<td>1985</td>
<td>Introduction of first numerical relay in combination with control technology SINAUT LSA</td>
</tr>
<tr>
<td>1998</td>
<td>Introduction of SIPROTEC 4 family</td>
</tr>
</tbody>
</table>
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.

For further information please visit:
www.siemens.com/protection
SIPROTEC Compact – Maximum protection – minimum 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
- Integrated switch for low-cost and redundant optical Ethernet rings
- Ethernet redundancy protocols RSTP, PRP and HSR for highest availability
- 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.
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. 6.2-6 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. 6.2-6: 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 FLISR (Fault Location, Isolation, and Service Restoration) 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 disconnection.

**Activation of individual line sections**
Isolate a dedicated section of a feeder for maintenance without affecting other sections. Fig. 6.2-7 shows an example of a typical ring main application with overhead lines and 5 sections. Every section is protected and automated by the SIPROTEC 7SC80 Feeder Protection.

Fig. 6.2-7: Fields of application with feeder protection SIPROTEC 7SC80
6.2 Protection Systems

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.
Construction and hardware of SIPROTEC Compact

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 predefined menu entries, switching sequences, etc. The assigned function of the function keys can be shown in the display of the relay.

With overcurrent protection SIPROTEC 7SJ81 there is also a device for low-power current transformer applications.

<table>
<thead>
<tr>
<th>Current terminals – ring cable lugs</th>
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<tbody>
<tr>
<td>Connection</td>
<td>( W_{\text{max}} = 9.5 \ \text{mm} )</td>
</tr>
<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>

<table>
<thead>
<tr>
<th>Current terminals – single conductors</th>
<th></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>
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<tr>
<th>Voltage terminals – single conductors</th>
<th></th>
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<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>
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Table 6.2-1: Wiring specifications for process connection
SIPROTEC 5 – the new benchmark for protection, automation and monitoring of 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. Synchronized pulses (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
• Integrated switch for low-cost and redundant optical and electrical Ethernet rings
• Ethernet redundancy protocols RSTP, PRP and HSR for highest availability
• Efficient operating concepts by flexible engineering of IEC 61850 Edition 2
• Comprehensive database for monitoring of modern power grids
• Optimal smart automation platform for grids based on integrated synchronized measurement units (PMU) and power quality functions.
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. 6.2-17).

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 that pays dividends in daily use
• 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 SIPROTEC 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 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 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
• "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 61850-3 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. 6.2-18 shows the possible functional expansion of a SIPROTEC 5 device.

**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.

![Fig. 6.2-18: Possible functional expansion of SIPROTEC 5 devices](image-url)
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).

**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.

**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.

The SIPROTEC 5 hardware building blocks offer a freely configurable device. You have the choice: Either you use a pre-configured device with a quantity structure already tailored to your application, or you build a device yourself from the extensive SIPROTEC 5 hardware building blocks to exactly fit your application.

The flexible hardware building blocks offer you:

- 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

**Flexible and modular**

With SIPROTEC 5, Siemens has also taken a new path with the design. Proven elements have been improved and innovative ideas have been added. When looking at the new devices, the modular structure is evident. In this way, the scope of the process data can be adapted flexibly to the requirements in the switchgear assembly. You can choose: Either you use a pre-configured device with a quantity structure already tailored to
your application, or you build a device yourself from the extensive SIPROTEC 5 hardware building blocks to exactly fit your application. Pre-configured devices can be extended or adapted as needed.

With the devices SIPROTEC 7xx85, 7xx86 and 7xx87 you can also combine different base and expansion modules, add communication modules and select an installation variant that fits the space you have available. The devices SIPROTEC 7xx82 and 7xx84 can not be extended with expansion modules.

With this modular principle you can realize any quantity structures you desire. In this way, hardware that is tailored to the application can be selected. Fig. 6.2-19 shows a modular device consisting of a base module and 4 expansion modules.

The advantage of modular building blocks
The SIPROTEC 5 hardware module building blocks provides the cumulative experience of Siemens in digital protection devices and bay controllers. In addition, specific innovations were realized that make the application easier for you, e.g. recorder and PQ functionalities.

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.

**User-friendly operation panel**
- Eight freely assignable function keys for frequently required operator control actions
- Separate control keys for switching commands
- Context-sensitive keys with labeling in the display
- Complete numeric keypad for simple entry of setting values and easy navigation in the menu
- Up to 80 LEDs for signaling, 16 of which are in two colors.

**Application-friendly design**
- No opening of device necessary for installation and servicing
  - Easy battery replacement on the back of the device
  - Simple exchange of communication modules with plug-in technology
- Electronically settable (no jumpers) threshold for binary inputs
- Rated current (1 A / 5 A) of current transformer inputs configurable electronically (no jumpers)
- Removable terminal blocks
  - Pre-wiring of terminals is possible
  - Simple replacement of current transformers, e.g. with sensitive ground current transformers if neutral grounding method is changed.
  - Increased safety, since open current transformer circuits are no longer possible (safety CT plug).

**Hardware building blocks with a system**
SIPROTEC 5 offers a modular, freely configurable device design. This maximum flexibility is guaranteed by the SIPROTEC 5 modular system. This contains coordinated components which you can combine to configure your individual device:
- Base modules and expansion modules, each with different I/O board
- Various front operation panels, e.g. with large display
- A large number of modules for communication, measured value conversion and memory extension.
With reference to SIPROTEC 5, the term device always designates all the basic, extension and plug-in modules as well the matching front panels combined together.

A base module together with a front operation panel is already a standalone device in itself. In order to obtain additional functionality, and above all more connections for process integration, you can supplement a base module with expansion modules. Fig. 1.4/1 shows you a single line sample configuration with a base module and 4 expansion modules.
6.2 Protection Systems

**Base and expansion modules**
A SIPROTEC 5 device can consist of exactly one base module, and in the case of a two-tier device, optionally up to 9 expansion modules and a power-supply module. Base and expansion modules are distinguished firstly by their width. A base module takes up a third of the width of a 19-inch frame, while an expansion module takes up a sixth. The larger width of the base module creates sufficient space at the rear for connection to the process (terminals) as well as plug-in modules. The expansion module can provide either additional process connections or additional communication connections.

Fig. 6.2-20 shows the rear side of a device consisting of a base module in which the power supply, the CPU module and an I/O board are permanently installed, as well as 4 expansion modules for extending the I/O quantity structure, and communication modules. Each expansion module contains an I/O board. The components are connected by bus connector plugs and mechanical interlockings.

Such a device can be ordered pre-configured from the factory. In this context you can choose between the standard variants predefined by Siemens and the devices you have combined yourself. Every SIPROTEC 5 device can also be converted or extended according to your wishes. The modular concept absolutely ensures that the final device meets all standards, particularly with regard to EMC and environmental requirements.

**On-site operation panels**
The on-site operation panel is a separate component within the SIPROTEC 5 modular system. This allows you to combine a base or expansion module with a suitable front operation panel, according to your requirements. The modular system offers 3 different on-site operation panels for selection, both for base modules and for expansion modules.

The following variants are available for base modules (Fig. 6.2-21):

- With a large display, keypad and 16 multi-colored LEDs
- With a small display, keypad and 16 multi-colored LEDs
- 16 multi-colored LEDs.

The following variants are available for expansion modules (Fig. 6.2-22):

Fig. 6.2-20: Rear view of base module with 4 expansion modules

Fig. 6.2-21: Operation panels with (from left) large and small display, and operation panel without display
• Without operating or control elements
• With 16 LEDs (single-colored)
• With 16 LEDs (single-colored) and key switch.

The SIPROTEC 5 module is flexible with regard to selection of the operation panel. You can order any device type with a large, graphical display or with a smaller, economical standard display. For applications without device operation an operation panel without display is also available. The operation panel with a small display seven lines for measured values or menu texts as well as the graphic representation of for example single busbar. All operation and control keys are available to the user, i.e. he can also control switching devices.

The operation panel with large display also enables representation of a more complex control display (Fig. 6.2-23) and thus offers more room for measured values and the display of event lists. This operation panel is therefore the first choice for bay controllers, busbar protection or combined protection and control devices.

As a third option, an economical variant is available without keypad and display. This variant is appropriate for devices that are seldom or never used by the operational crew.

**Elements of the on-site operation panels**
The operator elements are illustrated with the example of the on-site operation panel with a large display.

The central element is the generously sized display for text and graphics. With its high resolution, it creates ample space for symbols in graphical representations (Fig. 6.2-23).

Below the display there is a 12 key keypad. In combination with 4 navigation keys and 2 option keys you have everything you need to navigate conveniently and quickly through all information that is shown in the display. 2 LEDs on the upper border of the operation panel inform you about the current device operating state.

16 additional LEDs, to the left of the keypad, ensure quick, targeted process feedback. The USB interface enables fast data transfer. It is easily accessible from the front and well protected with a plastic cover.

---

**Fig. 6.2-22: Designs of the expansion modules**

1. Labeling field for LEDs
2. 16 LEDs (red)
3. Key switch S5 “Remote/Local”
4. Key switch S1 “Interlocking Off/Normal”

**Fig. 6.2-23: Display of measured values in the large display**

<table>
<thead>
<tr>
<th>Operational values</th>
<th>U/37</th>
</tr>
</thead>
<tbody>
<tr>
<td>VphA (U)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphB (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphC (V)</td>
<td>230.00 kV</td>
</tr>
<tr>
<td>VphA (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphB (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphC (V)</td>
<td>230.00 kV</td>
</tr>
<tr>
<td>VphA (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphB (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphC (V)</td>
<td>230.00 kV</td>
</tr>
<tr>
<td>VphA (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphB (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphC (V)</td>
<td>230.00 kV</td>
</tr>
<tr>
<td>VphA (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphB (V)</td>
<td>330.00 kV</td>
</tr>
<tr>
<td>VphC (V)</td>
<td>230.00 kV</td>
</tr>
</tbody>
</table>
Elements of the on-site operation panels (continued)
The keys O and I (red and green) for the direct control of equipment, a reset key for the LEDs, and the control key for switching to the control display (mimic diagram), complete the operation panel (Fig. 6.2-24).

Options
You can order any SIPROTEC 5 device, regardless of its individual configuration, in 3 different installation variants:
- As flush-mounting device
- As surface-mounting device with integrated on-site operation panel
- As surface-mounting device with the on-site operation panel detached.

The construction of the flush-mounting devices will be recognizable from the previous sections. We would like to briefly introduce you to the two other variants here.

Surface-mounting device with integrated on-site operation panel
For wall-installation the SIPROTEC 5 devices can be ordered in the surface-mounting housing (Fig. 6.2-25). Thanks to a new concept, these devices have terminal connection diagrams that are identical to the corresponding flush-mounting devices. This is achieved by installing the devices using the principle "with the face to the wall" and then attaching the operation panels to the terminal side. With the brackets that are used, sufficient space remains for the wiring, which can be routed away upwards and downwards.

Fig. 6.2-24: SIPROTEC 5 operation panel

Fig. 6.2-25: Display of measured values in the large display
**Surface-mounting device with the on-site operation panel detached**

If the operation panel is to be installed detached from the device, it can be installed as a separate part and connected to the device with a 2.5 m long connecting cable. In this way, the SIPROTEC 5 device can be situated, for example, in the low-voltage fixture and the operation panel can be installed precisely at the correct working height in the cabinet door. In this case, the device is fastened like a surface-mounting device on the cabinet wall. An opening must be provided in the door for the operation panel.

**The SIPROTEC 5 terminals**

Innovative terminals offering many advantages were developed for the SIPROTEC 5 family.

All terminals are individually removable (Fig. 6.2-26). This enables pre-wiring of the systems, as well as simple device replacement without costly re-wiring.

**Current terminals (safety CT plug)**

The 8-pole current terminal with 4 integrated current transformers is available in 3 designs:

- 4 protection-class current transformers
- 3 protection-class current transformers + 1 sensitive protection-class current transformer
- 4 instrument transformers.

The terminal design enables the following advantages for the connection of currents:

- Exchange of the current transformer type also possible retroactively on-site (e.g. protection-class current transformer for instrument transformer, sensitive for normal ground current transformers in cases of network conversions)
- Additional safety during tests or device replacement, since the secondary current transformer circuits always remain closed.

**Voltage terminal:**

The voltage transformers and the binary input and output signals are connected via the 14-pole voltage terminal. The cable entry to the terminal enables clear access to the terminal connection. Bridges precisely matching the current and voltage terminals are available for bridging contacts with common potential (Fig. 6.2-27).
Selection of the input/output boards
Which and how many process connections a base or expansion board has depends on the choice of a particular input/output board. The modular building block concept includes different input/output boards.

The IO202 input/output board is used e.g. as a base measuring module. By equipping several modules with this module, you can achieve up to 40 measuring channels per SIPROTEC 5 device.

In the module there are connections for:
• 4 voltage transformers
• 4 current transformers, optionally protection-class current transformer, sensitive protection-class current transformer or instrument transformers
• 8 binary inputs (BI)
• 6 binary outputs (BO), designed as 4 fast speed (Typ F) normally-open contacts and 2 fast speed change-over contacts.

The connections are distributed on (Fig. 6.2-28):
• 1 x 8-pole current terminal block
• 3 x 14-pole voltage terminal blocks

Select the modules suitable for your purposes so that you can build the SIPROTEC 5 device that precisely matches your application. You will find an overview of the modules that are available and their quantity structures in Table 6.2-3 Module quantity structures.

Second module tier
If the number of inputs and outputs of a unit with 4 expansion modules is not enough, a second tier can be added. This requires a PS203 power supply in the second tier on the first mounting position. The remaining 5 positions can be filled with expansion modules from the SIPROTEC5 module range. Exception: The CB202 must always be in the first tier and only one can be used with each unit.

Module CB202
Module CB202 represents a special case. CB202 (CB = Communication Board) provides 3 positions for plug-in modules. These can be used to plug in up to 2 communication modules or up to 3 measurement transducer modules. Combinations are also possible, e.g. 2 communication modules and one measurement transducer module.

The power supply is integrated, so that the CB202 can be powered independently of the main device. Communication with the main device is assured via an RJ45 connector and the bus connection on the front of the module.

The CB202 is always integrated in an expansion module (Fig. 6.2-29).
6.2 Protection Systems

Measuring ranges of the current transformer modules

The measuring range (full modulation) of the current transformers can be set to different values electronically – depending on the field of application. In all cases, you can choose between protection-class and instrument transformers. Only protection transformers can be used for busbar protection because of the large dynamic range involved. The possible measuring ranges according to rated current are shown in the following Tab. 6.2-2 “Measurement ranges according to rated current”.

A large dynamic range is necessary for network protection applications, so that short-circuit currents can be recorded without distortion. A value of $100 \times I_{\text{rated}}$ has proven optimal. For 5 A transformer rated current, this corresponds to a setting of 500 A, and consequently of 100 A for 1 A transformers. For applications in generator protection, while it is true that there are very large primary currents, a dynamic range of $20 \times I_{\text{rated}}$ is still quite sufficient. Thus a measuring range of 100 A is obtained for a setting $I_{\text{rated}} = 5$ A and a measurement range of 20 A for $I_{\text{rated}} = 1$ A.

A smaller dynamic range means that greater accuracy is achieved in the rated current range. Consequently, the dynamic range for instrument transformers and sensitive protection-class current transformer input for ground fault currents is extremely limited. In this case, limited means that the input current is chopped on the analog side. Of course, the inputs in this case are protected against overdriving.

Plug-in modules

Plug-in modules are available for communication or analog inputs. The communication modules are described in the “Communication” section.

The analog input module has four 20 mA inputs. It can be plugged into one of the slots in the PS201 or CB202. Multiple measured value modules can be used with each device (one in each available slot), but as a rule one slot is needed for a communication module. The connections are created via an 8-pole screwed terminal block (Fig. 6.2-30).

<table>
<thead>
<tr>
<th>Protection-class current transformers</th>
<th>Rated current $I_{\text{rated}}$</th>
<th>Measuring range</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 A</td>
<td>500 A</td>
<td></td>
</tr>
<tr>
<td>5 A</td>
<td>100 A</td>
<td></td>
</tr>
<tr>
<td>1 A</td>
<td>100 A</td>
<td></td>
</tr>
<tr>
<td>1 A</td>
<td>20 A</td>
<td></td>
</tr>
<tr>
<td>Instrument transformers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 A</td>
<td>40 A</td>
<td></td>
</tr>
<tr>
<td>1 A</td>
<td>8 A</td>
<td></td>
</tr>
<tr>
<td>1 A</td>
<td>1.6 A</td>
<td></td>
</tr>
</tbody>
</table>

| Sensitive ground-current input       |                                 |                 |
| 5 A                                  | 8 A                             |
| 1 A                                  | 1.6 A                           |

Table 6.2-2: Measuring ranges according to rated current

Fig. 6.2-30: Measuring-transducer input module ANAI-CA-4EL
### Module overview

<table>
<thead>
<tr>
<th>Designation</th>
<th>Description</th>
<th>U</th>
<th>BI (isolated)</th>
<th>BI (connected to common potential)</th>
<th>BO normally-open contacts</th>
<th>BO normally-open contacts type F</th>
<th>BO normally-open contacts type HS</th>
<th>BO change-over contacts</th>
<th>BO change-over contacts type F</th>
<th>BO change-over contacts type HS</th>
<th>Measuring transducer 20 mA/10 V</th>
<th>BO power relay</th>
<th>Number of slots for plug-in modules</th>
<th>Available in the base module</th>
<th>Available in the expansion module</th>
<th>Power supply</th>
<th>Implemented in device row</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS101</td>
<td>Power supply module for all 7xx82 devices</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS201</td>
<td>Power supply module for the first device row</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS203</td>
<td>Power supply module for the second device row</td>
<td>X</td>
<td>X</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CB202</td>
<td>Module with 3 additional slots for modules</td>
<td>3</td>
<td>–</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO101</td>
<td>Base module for all 7xx82 devices that require current measurement</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>X</td>
<td>–</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO102</td>
<td>Base module for all 7xx82 devices that require current and voltage measurement</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>X</td>
<td>–</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO110</td>
<td>Module for additional binary inputs and outputs for all 7xx82 devices</td>
<td>12</td>
<td>7</td>
<td>–</td>
<td>–</td>
<td>1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO201</td>
<td>Base module for protection applications that require no voltage measurement</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO202</td>
<td>Base module for all devices that require current and voltage measurement</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>1,2</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO203</td>
<td>Module for device numerous current inputs</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>–</td>
<td>X</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO204</td>
<td>This module contains 4 power relays for direct control of the operating mechanism motors of grounding switches and disconnectors</td>
<td>10</td>
<td>4</td>
<td>–</td>
<td>4</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO205</td>
<td>For protection applications with binary inputs and binary outputs</td>
<td>12</td>
<td>16</td>
<td>–</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO206</td>
<td>For protection applications with binary inputs and binary outputs</td>
<td>6</td>
<td>7</td>
<td>–</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>IO207</td>
<td>Geared toward bay controllers due to the predominant number of binary inputs (feedback from switchgear)</td>
<td>16</td>
<td>8</td>
<td>–</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO208</td>
<td>It is a typical module for protective applications. In contrast to the IO202, it is equipped with more relay outputs</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO209</td>
<td>This module is used when extremely fast tripping times (4 normally-open contacts, 0.2 ms pickup time) are required, such as, e.g., power system for very high voltages</td>
<td>8</td>
<td>4</td>
<td>–</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO211</td>
<td>Module for devices that require a numerous voltage inputs</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>–</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO212 *)</td>
<td>Module for devices that require a numerous, fast measuring transducer inputs (20 mA, 10 V)</td>
<td>8</td>
<td>–</td>
<td>8</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO214</td>
<td>Base module for all devices that require current and voltage measurement. In contrast to the IO202 it has a reduced quantity structure of binary inputs and outputs</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>X</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO215</td>
<td>Special module for connecting special high-resistance voltage dividers over 10 V voltage inputs</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO230</td>
<td>Module for acquisition of large volumes of data, for example, in the bay controller or busbar protection. Process connection is effected via special terminals</td>
<td>48</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>X</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Differentiation of relay types:**
- Type F – fast relay with monitoring (pickup time < 5 ms)
- Type HS – high-speed relay (contact with solid-state bypass) with monitoring (pickup time < 0.2 ms)

*) In preparation
1) 10 V voltage input for high-resistance RC-splitter
2) of which 1 life contact

The connection diagrams of the individual modules are included in the appendix.

---

Table 6.2-3: Module overview
6.2.3 Applications

Fig. 6.2-31 provides an overview of the application of SIPROTEC 5 devices in the grid. This is a simplified illustration. Particularly with the advent of regenerative suppliers, energy is being injected into the grid at all voltage levels.

The protection objects are the busbars, the overhead lines or cables, and the transformers. The corresponding protection devices have been assigned to these objects.

On the next pages you’ll find beside the SIPROTEC 5 relay selection guide the application examples for SIPROTEC 5 devices.

Device types

Now that you have been introduced to the innovation highlights of the SIPROTEC 5 devices, the following text will describe the devices. They are easily identified with the aid of a five-digit abbreviation code.

The first digit (6 or 7) stands for the digital equipment. The two letters describe the functionality, and the last two digits identify typical properties. Fig. 6.2-32 shows the definition of device types based on designation.

Application templates

Application templates allow you to fast track your solution. A library of application templates is available that can be tailored to the specific functional scope for typical applications.

Fig. 6.2-33 shows an example of a system configuration. Note that 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 your switchgear includes 2 circuit breakers, this is also represented by 2 “circuit breaker” functional groups – a schematic map of your actual system.
### 6.2 Protection Systems

#### Fig. 6.2-33: Protection of a transformer

#### Table 6.2-4: Available device types of the SIPROTEC 5 system

<table>
<thead>
<tr>
<th>Protection functions</th>
<th>Device types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overcurrent protection</td>
<td></td>
</tr>
<tr>
<td>Overcurrent protection with PMU and control</td>
<td>7SJ82, 7SJ85</td>
</tr>
<tr>
<td>Line protection</td>
<td></td>
</tr>
<tr>
<td>Distance protection with PMU and control</td>
<td>7SA82*, 7SA86, 7SA87</td>
</tr>
<tr>
<td>Line differential protection with PMU and</td>
<td>7SD82*, 7SD86, 7SD87</td>
</tr>
<tr>
<td>control</td>
<td></td>
</tr>
<tr>
<td>Combined line differential and distance</td>
<td>7SL86, 7SL87</td>
</tr>
<tr>
<td>protection with PMU and control</td>
<td></td>
</tr>
<tr>
<td>Circuit-breaker management device with</td>
<td>7VK87</td>
</tr>
<tr>
<td>PMU and control</td>
<td></td>
</tr>
<tr>
<td>Overcurrent protection for lines with PMU</td>
<td>7SJ86</td>
</tr>
<tr>
<td>Transformer differential protection</td>
<td></td>
</tr>
<tr>
<td>Transformer differential protection with</td>
<td>7UT82*, 7UT85, 7UT86, 7UT87</td>
</tr>
<tr>
<td>PMU, control and monitoring</td>
<td></td>
</tr>
<tr>
<td>Motor protection</td>
<td></td>
</tr>
<tr>
<td>Motor protection with PMU and control</td>
<td>7SK82, 7SK85</td>
</tr>
<tr>
<td>Busbar protection</td>
<td></td>
</tr>
<tr>
<td>Busbar protection</td>
<td>7SS85</td>
</tr>
<tr>
<td>Bay controller</td>
<td></td>
</tr>
<tr>
<td>Bay controllers for control/interlocking tasks</td>
<td>6MD85, 6MD86</td>
</tr>
<tr>
<td>with PMU and monitoring, optionally with</td>
<td></td>
</tr>
<tr>
<td>protection function</td>
<td></td>
</tr>
<tr>
<td>Fault recorders and power quality recorders</td>
<td></td>
</tr>
<tr>
<td>Digital recorder with PMU</td>
<td>7KE85</td>
</tr>
</tbody>
</table>

*) In preparation

#### Table 6.2-5: Extract of protection functions

<table>
<thead>
<tr>
<th>Protection functions legend</th>
<th>Function</th>
<th>Abbr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI Function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protection functions for 3-pole tripping</td>
<td>3-pole</td>
<td></td>
</tr>
<tr>
<td>Protection functions for 1-pole tripping</td>
<td>1-pole</td>
<td></td>
</tr>
<tr>
<td>21 Distance protection</td>
<td>Z&lt;</td>
<td></td>
</tr>
<tr>
<td>FL Fault locator</td>
<td>FL</td>
<td></td>
</tr>
<tr>
<td>25 Synchrocheck, synchronizing function</td>
<td>Sync</td>
<td></td>
</tr>
<tr>
<td>27 Undervoltage protection</td>
<td>V&lt;</td>
<td></td>
</tr>
<tr>
<td>32 Directional power supervision</td>
<td>P&gt;, P&lt;</td>
<td></td>
</tr>
<tr>
<td>37 Undercurrent, underpower</td>
<td>I&lt;, P&lt;</td>
<td></td>
</tr>
<tr>
<td>46 Unbalanced-load protection</td>
<td>I2&gt;</td>
<td></td>
</tr>
<tr>
<td>49 Thermal overload protection</td>
<td>θ, Iθ</td>
<td></td>
</tr>
<tr>
<td>50/50N Definite time-overcurrent protection</td>
<td>I&gt;</td>
<td></td>
</tr>
<tr>
<td>50Ns Sensitive ground-current protection</td>
<td>I&lt;sub&gt;NO&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>50L Load-jam protection</td>
<td>I&gt;_&lt;L</td>
<td></td>
</tr>
<tr>
<td>50BF Circuit-breaker failure protection</td>
<td>CBFP</td>
<td></td>
</tr>
<tr>
<td>51/51N Inverse time-overcurrent protection</td>
<td>I&lt;sub&gt;P&lt;/sub&gt;, I&lt;sub&gt;NP&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>51V Overcurrent protection, voltage controlled</td>
<td>I+I&lt;sub&gt;θ&lt;/sub&gt;+&lt;sub&gt;V&lt;/sub&gt;+&lt;sub&gt;I&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>67 Directional time-overcurrent protection,</td>
<td>I&gt;, I&lt;sub&gt;P&lt;/sub&gt;, I&lt;sub&gt;N&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>phase</td>
<td>(V, I)</td>
<td></td>
</tr>
<tr>
<td>67N Directional time-overcurrent protection</td>
<td>I&lt;sub&gt;N&lt;/sub&gt;, I&lt;sub&gt;N&lt;/sub&gt; &lt; (V, I)</td>
<td></td>
</tr>
<tr>
<td>for ground-faults</td>
<td></td>
<td></td>
</tr>
<tr>
<td>67Ns Sensitive ground-fault detection for</td>
<td>I&lt;sub&gt;N&lt;/sub&gt;, I&lt;sub&gt;N&lt;/sub&gt; &lt; (V, I)</td>
<td></td>
</tr>
<tr>
<td>systems with resonant or isolated neutral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79 Automatic reclosing</td>
<td>AR</td>
<td></td>
</tr>
<tr>
<td>87 Differential protection</td>
<td>ΔI</td>
<td></td>
</tr>
<tr>
<td>PMU Synchrophasor measurement</td>
<td>PMU</td>
<td></td>
</tr>
</tbody>
</table>
Application examples

Medium-voltage applications for all system grounding types

Fig. 6.2-34: Medium-voltage application for all system grounding types

Properties
- Reliable detection of transients and static ground faults
- Cost saving due to integrated transient function
- Directional and non-directional protection and control functions
- Acquisition and transmission of PMU variables possible.

Fast fault clearance in double-feed lines (closed) rings

Fig. 6.2-36: Fast fault clearance in double-feed lines (closed) rings

Properties
- Directional DMT/IDMTL protection without grading times
- Fast fault clearance
- Low-cost due to integrated protection interface
- Monitored data exchange
- Adaptable to different communication infrastructures.

Protection and control of multiple feeders with one device

Fig. 6.2-35: Protection and control of multiple feeders with one device

Properties
- Reduced investment because 1 device for multiple feeders
- Simple parameterization
- Shorter commissioning times
- Cost savings because up to 7 feeders possible with 1 device.

Central control of multiple feeders and dedicated protection

Fig. 6.2-37: Central control of multiple feeders and dedicated protection

Properties
- Protection for each bay
- Central control for multiple feeders
- High availability because backup protection functions can be activated in the controllers.
6.2 Protection Systems

Two-winding transformer

Fig. 6.2-38: Two-winding transformer

Properties
• Clear assignment of the functions to the primary element
• Reduced investment
• Simple parameterization
• Reduced wiring and faster commissioning.

Two-winding transformer with 2 incoming feeders (e.g. double circuit-breaker switchgear) protection

Fig. 6.2-39: Two-winding transformer with 2 incoming feeders (e.g. double circuit-breaker switchgear)

Properties
• Separate acquisition, monitoring and control of all circuit breakers
• High sensitivity with single line to ground-fault differential protection
• Cost savings due to 87T and 87T N in one unit.

Autotransformer bank

Fig. 6.2-40: Autotransformer bank

Properties
• Reduced investment due to integration of the differential and node protection function in one unit (87 and 87 Node)
• High sensitivity with single line to ground faults.

Protection and backup protection solution for 3-winding transformers

Fig. 6.2-41: Protection and backup protection solution for 3-winding transformers

Properties
• Free design of the protection and backup protection concept
• Inclusion of line protection devices
• Increased availability.
Induction motor: protection and control

Properties
- Reduced investment because protection and control in one device
- Thermal motor protection functions for reliable motor monitoring
- Thermal motor protection functions with direct connection of temperature sensors.

Motor protection with differential protection

Properties
- Autonomous differential protection functions
- High sensitivity and short tripping times due to differential protection function
- Separate acquisition and monitoring of the current transformers.

Motor protection and simplified differential protection

Properties
- High sensitivity and short tripping times due to differential protection function
- Cost saving due to integration of the differential protection function in a separate function group.

Motor differential protection with Krondorfer starter

Properties
- Acquisition, monitoring and control of all circuit breakers
- Differential protection function also available during starting.
Protection, Substation Automation, Power Quality and Measurements

6.2 Protection Systems

Protection and control separate

Fig. 6.2-46: Protection and control separate

Properties
- Clear assignment of protection and control in separate devices
- Less external components by detection and selection of busbar voltage in the device
- High reliability due to backup protection functions in the 6MD8 bay controller
- High availability due to emergency control in the 7SL8 protection device.

Distance protection of two parallel lines with one device

Fig. 6.2-48: Distance protection of two parallel lines with one device

Properties
- Low-cost due to protection of both lines in one device
- Stable due to consideration of the influences of the parallel line for the distance protection function.

Low-cost protection and device redundancy

Fig. 6.2-47: Low-cost protection and device redundancy

Properties
- High availability due to protection and device redundancy
- Low-cost because only 2 devices required for 2 lines
- Reliable because of parallel processing of the protection functions in the devices.

Self-restoring multi-leg configurations

Fig. 6.2-49: Self-restoring multi-leg configurations

Properties
- High availability because differential protection is also active when a communication link fails
- Self-restoring due to automatic switchover from ring to chain topology
- High ease of maintenance because single line ends can be taken out of the differential protection configuration for commissioning and servicing.
6.2 Protection Systems

Modular and distributed protection and control solution

Fig. 6.2-50: Modular and distributed protection and control solution

Properties
- Clarity due to clear assignment of protection and control
- High availability due to protection redundancy (Main 1 and Main 2)
- Simple reliable central control of the entire diameter
- Reliable due to emergency control in every line in the protection device
- Reduced wiring due to integrated voltage selection
  - System-wide diameter bus based on IEC 61850
  - Electrically isolated data exchange,
  - Reduced wiring
  - Easy expansion.

Low-cost device and protection redundancy in breaker-and-a-half switchgear

Fig. 6.2-51: Low-cost device and protection redundancy in breaker-and-a-half switchgear

Properties
- Clear assignment of the primary protection function (line differential protection 87) to a line in one device (Main 1)
- The distance protection function (21) is implemented in the protection device of the other line by a 2nd “line” function group
- High availability and reliability due to device and protection redundancy
- Low cost.
Protection Systems

Protection of a capacitor bank in an H-circuit

Properties
- Precisely adapted due to dedicated function group and application-specific protection function, such as peak overvoltage protection (ANSI 59C) and sensitive current-unbalance protection (ANSI 60C)
- Low cost due to integration of all required functions into one device.

Protection of a capacitor bank in an H-circuit and of an associated filter circuit

Properties
- Optimum protection of complex banks and filter circuits by flexible hardware and flexible function design
- Low cost due to integration of all necessary functions into one device with up to 7 3-phase measuring points.
Properties
- Central busbar protection
- Grouping of all primary components of a bay in the “bay image”
- Configurable busbar function group
- One device for up to 15 measuring points
- Flexible adaptation to the topology (up to 4 busbar sections and 4 couplings can be configured)
- Integrated disconnector image
- Convenient graphical configuration with DIGSI 5.
6.2 Protection Systems

**Grid monitoring and PMU**

Fig. 6.2-55: Principle of distributed phasor measurement

**Properties**
- Each SIPROTEC 5 device can be equipped or retrofitted with the PMU function
- Online and offline evaluation of the PMU data in the monitoring system, SIGUARD PDP.
6.2.4 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: 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. 6.2-56). 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. 6.2-56 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. Core-balance CTs are 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. The integrated sensitive directional earth-fault function allows settings as low as 1 mA.

Remark to Earth-Fault Protection with Cable Type CT’s:
Please notice the properties of a given Cable Type CT.

The setting of IE> must have sufficient margin against the maximum error current of the Cable Type CT.

Background:
Even in the case where the 3 conductors are centrally bundled, when passing through the cable type CT, an error current "I error" will arise in the secondary circuit. This error current is generally proportional to load current flowing through the CT.

In the case of non-bundled conductors or when the conductors are not in the center of the cable type CT, the error current "I error" may be substantially larger.
**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. 6.2-57.

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. 6.2-57 by an example for definite-time overcurrent relays.

**Inverse-time relays**
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. 6.2-58).

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**
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**
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. 6.2-60 and the associated load and short-circuit currents are given. Numerical overcurrent relays 7SJ80 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. 6.2-61.

The \( I_p/I_N \) settings shown in fig. 6.2-60 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 result is 7.47 for \( I/I_p \) at the overcurrent relay in location C. With this value and \( T_p = 0.05 \), an operating time of \( t_A = 0.17 \) s can be derived from fig. 6.2-58.

  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.

  \[ t_B = 0.11 + 0.3 = 0.41 \text{ s} \]

  Value of \( I_p/I_N = 1.395 \text{ A} / 220 \text{ A} = 6.34 \) (fig. 6.2-60)

  With the operating time 0.41 s and \( I_p/I_N = 6.34 \), \( T_p = 0.11 \) can be derived from fig. 6.2-61.

---

**Time grading**

\[ t_{TG} = t_{51M} - t_{51F} = t_{52F} + t_{OS} + t_M \]

**Example 1**
- Oil circuit-breaker \( t_{52F} = 0.10 \text{ s} \)
- Mechanical relays \( t_{OS} = 0.15 \text{ s} \)
- Safety margin for measuring errors, etc. \( t_M = 0.15 \text{ s} \)

**Example 2**
- Vacuum circuit-breaker \( t_{52F} = 0.08 \text{ s} \)
- Numerical relays \( t_{OS} = 0.02 \text{ s} \)
- Safety margin \( t_M = 0.10 \text{ s} \)

---

**Fig. 6.2-59: Time grading of overcurrent-time relays**

**Fig. 6.2-60: Time grading of inverse-time relays for a radial feeder**
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. 6.2-60). 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. 6.2-61).

**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. 6.2-62 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. 6.2-63 shows typical examples.

Simple distribution substations use a power fuse on the secondary side of the supply transformers (fig. 6.2-63a).

In this case, the operating characteristic of the overcurrent relay at the infeed has to be coordinated with the fuse curve.

![Fig. 6.2-61: Normal inverse-time characteristic of the 7SJ60 relay](image-url)
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. 6.2-64).

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.
6.2 Protection Systems

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. 6.2-59, page 335). 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:

\[
R_{arc} = \frac{2.5 \cdot I_{arc}}{I_{SCC \, Min}} \quad [\Omega]
\]

\[
I_{arc} = \text{Arc length in mm}
\]

\[
I_{SCC \, Min} = \text{Minimum short-circuit current in kA}
\]

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.

\[
X_{Prim \, Min} = X_{Relay \, Min} \times \frac{V_{T \, ratio}}{C_{T \, ratio}}
\]

\[
l_{min} = \frac{X_{Prim \, Min}}{X_{Line}}
\]

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 (7VK8) is used per breaker.

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).

The reset time is 1 cycle for EHV relays (7SA8, 7VK8) and 1.5 to 2 cycles for distribution type relays (7SJ**).

Fig. 6.2-64: Grading of distance zones

Fig. 6.2-65: Operating characteristics of Siemens distance relays

Fig. 6.2-66: Breaker failure protection, logic circuit
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/\sqrt{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. 1 A 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.
  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.

- Cores for billing values metering
  In this case, class 0.25 FS is normally required.

- Protection cores
  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.

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. As an example you find the current transformer requirements for SIPROTEC 7UT8 transformer protection devices. This example should give you an overview how to handle CT requirements during you protection calculation.

For all SIPROTEC 5 devices you find detailed requirement tables in the device manuals. Please refer to the latest manual version for your CT requirement calculation.

More accurate dimensioning can be done by more intensive calculation with Siemens’ CTDIM (www.siemens.com/ctdim) program. Results of CTDIM are released by the relay manufacturer.
### A.6 Requirements for Current Transformer (Phase Current Transformer)

<table>
<thead>
<tr>
<th>Transformer Type</th>
<th>Required factor ALF*</th>
<th>Minimum</th>
<th>Internal fault</th>
<th>External fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 5P, IEC 10P* (up to 80% remanence)</td>
<td>25</td>
<td>≥ 0.5 ( \frac{I_{	ext{internal max}}}{I_{p}} )</td>
<td>≥ 2 ( \frac{I_{	ext{external max}}}{I_{p}} )</td>
<td></td>
</tr>
<tr>
<td>IEC 5PR, IEC 10PR*</td>
<td>10</td>
<td>≥ 0.5 ( \frac{I_{	ext{internal max}}}{I_{p}} )</td>
<td>≥ 2 ( \frac{I_{	ext{external max}}}{I_{p}} )</td>
<td></td>
</tr>
</tbody>
</table>

**Required product \( K_{SC} \) \( K_{SSC} \)

<table>
<thead>
<tr>
<th>Transformer Type</th>
<th>25</th>
<th>≥ 0.5 ( \frac{I_{	ext{internal max}}}{I_{p}} )</th>
<th>≥ 2 ( \frac{I_{	ext{external max}}}{I_{p}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC TPX (up to 80% remanence)</td>
<td>10</td>
<td>&gt; 0.25 ( \frac{I_{	ext{internal max}}}{I_{p}} )</td>
<td>≥ 1 ( \frac{I_{	ext{external max}}}{I_{p}} )</td>
</tr>
<tr>
<td>IEC TPY</td>
<td>10</td>
<td>&gt; 0.25 ( \frac{I_{	ext{internal max}}}{I_{p}} )</td>
<td>≥ 1 ( \frac{I_{	ext{external max}}}{I_{p}} )</td>
</tr>
</tbody>
</table>

**Required knee-point voltage \( E_{k} \) (Vrms)

| IEC PX (up to 80% remanence) | \( 20 \cdot I_{p} \cdot R_{s} \) | \( > 0.4 \frac{I_{	ext{max}}}{I_{p}} \cdot I_{p} \cdot R_{S} \) | \( > 1.6 \frac{I_{	ext{max}}}{I_{p}} \cdot I_{p} \cdot R_{S} \) |
| IEC PXR | \( 10 \cdot I_{p} \cdot R_{s} \) |

**Required transformer terminal voltage \( V_{S} \) (Vrms)

| ANSI: C (I_{p} = 5 A) | \( 25 \cdot I_{p} \cdot R_{s} \) | ≥ 0.5 \( \frac{I_{	ext{internal max}}}{I_{p}} \cdot I_{p} \cdot R_{S} \) | ≥ 2 \( \frac{I_{	ext{external max}}}{I_{p}} \cdot I_{p} \cdot R_{S} \) |

As remanance leads to earlier saturation which is critical for differential protection relays in general, for new plants, an antiremanance class is recommended, e.g. PX, 5PR, TPY. If dc components are expected to be high, class TPZ is recommended.

**ALF** Operational accuracy limit factor

\[
ALF^* = \frac{R_{	ext{ex}} + R_{S}}{R_{	ext{ex}} + R_{S}}
\]

**ALF** Accuracy limit factor

\[
ALF = ALF^* \cdot R_{p} / R_{p}
\]

**R_{S}** Secondary winding resistance

**R_{p}** Rated resistive burden

**R_{S}** Actual (connected) burden

**R_{p}** Secondary loop resistance \( (R_{S} + R_{S}) \)

**I_{p}** Rated primary current

**I_{p}** Rated secondary current

**I_{	ext{internal max}}** Maximum symmetrical internal fault current

**I_{	ext{external max}}** Maximum symmetrical external fault current

**K_{s}** Transient dimensioning factor

**K_{SSC}** Rated symmetrical short-circuit current factor = \( I_{p} / I_{p} \)

---

*Angle of error is not specified in IEC 61869-2.

**Angle of error is not specified in IEC 61869-2.
6.2 Protection Systems

Example

![Diagram of a protection system](image)

Requirements for CT 1 (110 kV side):

- Nominal transformer current: \( I_{n,1} = \frac{200}{\sqrt{3}} \cdot 100 \text{ kVA} = 1050 \text{ A (110 kV side)}\)
- Rated transformer current: \( I_{n,k} = 1050 \text{ A (110 kV side)}\)
- Rated load current: \( I_{L} = 1050 \text{ A (110 kV side)}\)
- Transformer primary current: \( I_{p} = 1050 \text{ A (110 kV side)}\)
- Transformer primary current: \( I_{p} = 1050 \cdot 1250 / 1250 = 252, K_{\text{sec}} = 7498 / 1250 = 6.0\)

a) IEC class 5P
   1. Internal fault: \( ALF = 0.5 \cdot 31500 / 1250 = 12.6\)
   2. External fault: \( ALF = 2 \cdot 7496 / 1250 = 12 \rightarrow \text{at least however 25}\)

Result:
- Operational accuracy limit factor \( K_a \geq 25\), for example: \( 5P30, R_a = S / I_p^2 \geq \text{actual burden } R_{\text{n}}\) (for example: \( S = 2.6 \text{ VA or 5 VA}\)
- IEC class T2
  1. Internal fault: \( K_{\text{sec}} = 0.25 \cdot 31500 / 1250 = 6.3\)
  2. External fault: \( K_{\text{sec}} = 1 \cdot 7498 / 1250 = 6 \rightarrow \text{but minimum 10}\)

Result:
- \( K_{\text{sec}} = 10\), for example: \( K_{\text{sec}} = K_{\text{sec,1}} = 25 \) and \( K_{\text{sec}} = 0.5\)
- Rated resistive burden \( R_{\text{r}} \geq \text{actual burden } R_{\text{n}}\) (for example, \( R_a = 2.5 \Omega \) or \( 5 \Omega\)
- IEC class PX, assumption: \( R_{\text{r}} = 4.3 \Omega, R_{\text{n}} = 1.5 \Omega\)
  1. Internal fault:
     \[
     E_k \geq 0.4 \cdot \frac{I_{n,0}}{I_p} \cdot R_a \geq 0.4 \cdot \frac{31500 \cdot 1250}{1250} \cdot 1 \cdot (4.3 + 1.5) \geq 58.5 \text{ Veff}
     \]
  2. External fault:
     \[
     E_k \geq 1.6 \cdot \frac{I_{n,0}}{I_p} \cdot R_a \geq 1.6 \cdot \frac{7498 \cdot 1250}{1250} \cdot 1 \cdot (4.3 + 1.5) \geq 56.7 \text{ Veff}
     \]

At least however \( E_k = 20 \cdot I_p \cdot R_a = 20 \cdot 1 \cdot (4.3 + 1.5) = 116 \text{ Vrms}\)

Result:
- Required knee point voltage \( E_k \geq 116 \text{ Vrms}\), for example: \( E_k = 150 \text{ Vrms}\)

Fig. 6.2-69: Requirements for Current Transformer (Phase Current Transformer)

For further information please visit:
www.siemens.com/protection
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’ 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 RTU 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 RTUs represents the modular hardware-oriented design which bridges the gap between remote terminal units (RTUs) and substation automation (SA) (fig. 6.3-3).

![Fig. 6.3-2: Example of refurbishment and centralized data acquisition in an MV substation](image)

![Fig. 6.3-3: Basic principle of a SICAM station automation solution with alternative station controllers](image)
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.

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-
6.3 Substation Automation

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Protection, Substation Automation, Power Quality and Measurements

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.

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.

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)
- Access points for remote terminals connected to the station operation units
- Portable touch panels with wireless access in defined areas

At substation level:
- Single or redundant HMI
- Distributed server/client architectures with multiple and/or remote terminals
- Interface to office automation

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.

Automation functions support operation:
- Interlocking
- Feeder or remote blocking (option)
- Command sequences (option)
- Automatic recloser (option)
- Automatic switchover (option)
- etc.

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. 6.3-5).

Fig. 6.3-5: Human machine interface for every control level
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. 6.3-6).

### 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.

---

**Fig. 6.3-6: The worldwide engineering centers of Siemens**
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. 6.3-7).

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.

---

Fig. 6.3-7: Migration from LSA to PAS
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. 6.3-8).

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.

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.

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.

- **DNP3 (Master) – Level 3:**
  Apart from the IEC protocols -101 and -104, DNP3 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 und RTUs with this protocol, both via serial and TCP/IP based connections.

### Protocols

SICAM PAS supports the following communication protocols (optionally available):
- Control center connection IEC 60870-5-101, IEC 60870-5-104, DNP3, 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, DNP3, PROFIBUS FMS (SIPROTEC 4), PROFIBUS DP, Modbus, SINAUT LSA-ILSA

**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 DNP3 (Level 3) serially and over IP (DNPi), as well as Mobus (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 DNP3 via TCP/IP. For DNP3, 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 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. A redundant structure is also possible for process visualization with SICAM SCC and fault-record archiving with SICAM PQ Analyzer as shown in fig. 6.3-10.

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.

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 (fig. 6.3-11).

Fig. 6.3-10: Typical redundant configuration: The station unit and the HMI server are based on a redundant structure to boost availability

Fig. 6.3-11: 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 SP1 can also be used as a process visualization system for
- SICAM RTUs
- IEC 61850 devices (for example, SIPROTEC 4)

**SICAM SCC for SICAM RTUs**
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 and SICAM SCC 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 RTUs and IEC 61850 devices**
With SICAM SCC SP1, a common control and monitoring system for the systems SICAM PAS, SICAM RTUs and for IEC 61850 devices can be realized.

At its core, SICAM SCC uses one of the world’s leading process visualization systems: SIMATIC WinCC. SICAM SCC was developed as an add-on so that the electrical processes in both high- and medium-voltage systems could be operated from one station.

It runs together with SIMATIC WinCC on one computer. This integrated solution gives a parallel overview and control of both the industrial manufacturing process and the electrical energy process.

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*Fig. 6.3-12: Flexible station unit*
6.3.4 SICAM Station Unit

The SICAM Station Unit is the standard hardware platform for the SICAM PAS station control system and the SICAM PQS power quality system. It fulfills all requirements for the hardware for these applications. The big advantage is that the SICAM Station Unit complies with the highest IT security standards for energy automation, such as the specifications laid down in the BDEW Whitepaper or NERC CIP.

The SICAM Station Unit mirrors system memory and operating data according to RAID 1, enabling faulty data media to be easily exchanged – with no system downtime. The power supply unit, like the data storage, is of redundant design. Apart from optional equipment that may contain a hard disk, the SICAM Station Unit dispenses entirely with rotating parts and is not equipped with a fan – so you can rely on everything to work as it should.

SICAM Station Unit offers a number of different preconnectorized equipment variants to expand the platform at any time. For example add CompactPCI/CompactPCI serial modules like GPS time synchronizing cards, in line with the system’s requirements. Coordinated spare-part concepts ensure the long-term delivery of parts even after product versions have been discontinued.

The SICAM Station Unit relies on the latest embedded processor technology from Intel and four-gigabyte main memory. The modern bus technology for the embedded element is based on CompactPCI Serial. The use of solidstate disks (SSD) based on flash memory ensure extremely rapid startup and shutdown of the system.

As an alternative to the 16-GB SSD, the SICAM Station Unit can be equip with a 100-GB hard disk and an additional 100-GB hard disk for archive data. In this way, power quality applications are accommodated equally as well on the platform.

Features
• Optimized for the connection of field devices
• Meets all requirements with respect to electromagnetic compatibility (EMC) and operates even under the harshest environmental conditions
• BIOS password (compliant to NERC CIP)
• Windows Embedded Standard 7
• User documentation for emergency planning: reliable restoral of operation after a fault (recovery DVD)
• 5-year warranty
• Long-term availability of components and of the operating system version
• High degree of compatibility
• Kommunikationsschnittstellen
  – 7 USB ports
  – Up to 16 serial ports (RS232/RS485)
  – Up to 6 Ethernet ports (electrical)Up to 4 Ethernet ports (optical)

Further information
www.siemens.com/substationautomation

Fig. 6.3-13: SICAM Station Unit – Flexible hardware – high IT security
6.3 Substation Automation

6.3.5 SICAM RTUs (SICAM AK, TM, BC, EMIC, MIC, und CMIC)

Versatile functionality and high flexibility are fundamental for a modern remote control system. SICAM RTUs adds comprehensive options for communication, automation and process interfaces. The different components of SICAM RTUs 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.

- **SICAM CMIC** is a universal system. It is suitable for electrical distribution substations, gas distribution substations, hydropower plants, pipelines, railway power supplies, as well as in building protection or for alarm signaling.

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 DNP3 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 RTUs. 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 RTUs 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 RTUs 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.

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 (DNP3, 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 RTUs peripheral elements (fig. 6.3-14).

An essential feature of the SICAM RTUs 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.

Fig. 6.3-14: SICAM RTU family
6.3 Substation Automation

**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.

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.

**SICAM TM (fig. 6.3-15)**
SICAM TM is designed especially for easy installation and powerful application. Due to consequent development it fits optimally both for automation and telecontrol systems.

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 processing of the periphery
  • Change monitoring, signal creation and time-stamping of the event data of the periodical processing
  • Timely decoupling of the signal and prioritized transfer with the aid of a deterministic priority algorithm
  • Prioritization of messages
  • Energy metering value collection
  • Extended temperature range (–25°C to +65°C / –13 to 149°F)
  • High EMC (electromagnetic compatibility)
  • Increased electric strength (class 2)

System architecture
A SICAM TM forms an automation unit of the SICAM RTU family and is constituted of the following components:
• Master control element
• Modular, expandable and detachable peripheral elements
• Protocol elements for communications, mountable on the master control element (fig. 6.3-16).

![Fig. 6.3-16: SICAM TM mounted on 35 mm DIN rails](image-url)

![Fig. 6.3-15: SICAM TM system architecture: connection of up to 16 peripheral elements via bus interface (electrical)](image-url)
**Master control unit**

The master control element forms the heart of the SICAM TM automation module. Process input and output is connected externally via peripheral elements. The communication interfaces can be fitted directly onto the master control element.

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
- 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

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.

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**Peripherals**

A peripheral element is constituted of
- 1 power supply module,
- 1 peripheral control module, and
- up to 8 I/O modules (fig. 6.3-17)

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 TM 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 TM. This way, a multitude of communication options is available.

**SICAM EMIC (fig. 6.3-18)**
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 RTU family. The hardware consists of a master control element and various I/O modules, and is designed for DIN railmounting. The proven I/O modules can be used and fitted on all products in the SICAM RTU 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 RTU 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.

---

**Fig. 6.3-18:** SICAM EMIC – the new member of the proven SICAM RTU family
### 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)

### SICAM CMIC

Existing equipment has to be used more extensively and efficiently to meet the growing economic demands. For this reason, small network stations are increasingly becoming automated and integrated into existing network control systems. The SICAM CMIC device combines all the monitoring and control functions required (fig. 6.3-19, fig. 6.3-20).

### Applications

All the options offered by the SICAM CMIC device can be roughly subdivided into the following three applications:

- **Monitoring:** The first stage focuses on the monitoring of stations to enable rapid fault localization and high availability.
- **Telecontrol:** The second stage involves switchgear telecontrol in addition to monitoring, thus minimizing downtime. Thanks to this application, fault isolation and power supply restoration of de-energized network sections are no longer difficult tasks for power supply utilities.
- **Load flow control:** In the third stage, the effects of decentralized power feed-ins are managed via automation. Network losses can be in this way significantly reduced.

The SICAM CMIC device is designed for harsh environmental conditions and can be used in unheated, small local network stations, as it has a high degree of electromagnetic compatibility and is intended for the temperature range from -40 °C to +70 °C. If the number of integrated I/O is not sufficient, SICAM CMIC can be expanded with up to six proven SICAM I/O modules.

### Communication

The communication to the control center is possible in several ways and a multitude of protocols. It doesn’t make any difference whether via Multi-Point Traffic, Dial-Up Traffic or LAN/WAN/GPRS/UMTS.

### Device characteristics

**Communication interfaces and protocols**

- 2 x Ethernet LAN TCP/IP 10/100BASE-TX for communication and engineering
- 1 x RS-232, 1 x RS-485 (galvanically isolated)
- IEC 60870-5-101/-103/-104, Modbus
- IEC 61850 client & server
- SNMP V3
- Further protocols on request

**Operation and display**

- Local operation with 4 function keys and display (128x96 pixels)
- Power, ready and error LED, status LEDs of communication interfaces

**Real time clock**

- +/- 2 ppm, maintenance-free, buffered, time synchronization via SNTP (Network Time Protocol), automatic adjustment to daylight saving time

**Electromagnetic compatibility**

- IEC 60870-2-1, IEC 61010, IEC 60255-5, IEC 61000-4, EN 55022, CE marking

**Auxiliary voltage**

- DC 18 - 72 V

---

**Fig. 6.3-19: SICAM CMIC**
6.3 Substation Automation

**Inputs/outputs**
- 12 galvanically isolated digital inputs (24-60 VDC)
- 8 digital outputs

**Temperature range**:
- From -40°C to +70°C (basic unit)
- From -25°C to +70°C (SICAM I/O module)

**Housing specification (basic unit)**
- Plastic housing for DIN rail mounting
- Dimensions: 128 x 124 x 123 mm (W / H / D)
- Protection class: IP20, IP40 front

**Special features**
- Integrated web server for configuration and diagnostics
- Data storage via SD memory card (storage of parameters and device firmware)
- Freely programmable user programs according to IEC 61131-3
- Future security standard (BDEW white paper conformity and integrated crypto chip)

For further information:
www.siemens.com/sicam

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**Fig. 6.3-20: SICAM CMIC with expansion modules in operation**
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

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](image-url)
### 6.4 Power Quality and Measurements

#### 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>
</table>
| Frequency distortions          | A frequency variation involves variation in frequency above or below the normally stable utility frequency of 50 or 60 Hz | • Start-up or shutdown of very large item of consumer equipment, e.g. motor               • Loading and unloading of generator or small co-generation sites  
• Unstable frequency power sources | • Misoperation, data loss, system crashes and damage to equipment and motor  
• For certain kinds of motor load, such as in textile mills, tight control of frequency is essential |
| Supply interruption            | Planned or accidental total loss of power in a specific area                                      | • Switching operations attempting to isolate an electrical problem and maintain power to your area  
• Accidents, acts of nature, etc.  
• Fuses, actions by a protection function, e.g. automatic recloser cycle | • Sensible processes and system shutdown or damages  
• Loss of computer/controller memory  
• Production losses or damage |
| Voltage dip/sag or swell       | Any short-term (half cycle to 3 seconds) decrease (sag) or increase (swell) in voltage            | • Start-up or shutdown of very large item of consumer equipment, e.g. motor                  • Short circuits (faults)  
• Underdimensioned electrical circuit  
• Utility equipment failure or utility switching | • Memory loss, data errors, dim or bright lights, shrinking display screens, equipment shutdown  
• Motors stalling or stopping and decreased motor life |
| Supply voltage variations      | Variation in the voltage level above or below the nominal voltage under normal operating conditions | • The line voltage amplitude may change due to normal changing load situations                | • Equipment shutdown by tripping due to undervoltage or even overheating and/or damage to equipment due to overvoltage  
• Reduced efficiency or life of electrical equipment |
| Flicker                         | Impression of unsteadiness of visual sensation induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time | • Intermittent loads  
• Motor starting  
• Arc furnaces  
• Welding plants | • Changes in the luminance of lamps can result in the visual phenomenon called flicker on people, disturbing concentration, causing headaches, etc. |
| Transient                       | 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) | • Utility switching operations, starting and stopping heavy equipment, elevators, welding equipment static discharges, and lightning | • Processing errors  
• Data loss  
• Lock-up of sensitive equipment  
• Burned circuit boards |
| Noise                           | This is an unwanted electrical signal of high frequency from other equipment                  | • 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  
• Harmonic distortion is caused by non-linear loads | • Noise interferes with sensitive electronic equipment  
• It can cause processing errors and data loss  
• Harmonic distortion causes motors, transformers, and wiring to overheat  
• Improper operation of breakers, relays, or fuses |

## 6.4 Power Quality and Measurements

Protection, Substation Automation, Power Quality and Measurements
### 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>Regulatory 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+Irms, waveforms, status of binaries, power swing, MV transformers, busbars and loads</td>
</tr>
</tbody>
</table>

### Power quality recording steps

#### Project phases
- Defining PQ objectives
- System installation and configuration
- Start measuring
- Evaluation
- System improvement and/or countermeasures

#### Planning activities
- Define PQ measurement objectives (regulative, explanatory, or both) and define the targets
- Define measuring points and install devices and systems
- Automatic notification or systemic system check-up for events or standards violations
- Power quality compliance Reporting and/or event evaluation
- Analysis of information, controlling, action plan, adaptation to standards, comparison with defined targets

#### SICAM Q80 support
- Easy configuration with SICAM Q80 Manager
- Reliable measurement of defined quantities
- Remote access for automatic evaluation
- Automatic report generator in case of limit valuation

### 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**

- **EN 50160**
- **Guide to application of EN 50160**
- **IEC 61000-4-30** Measurement of voltage quality
- **Other local power quality standards**
- **IEC 61000-4-7** Harmonics
- **IEC 61000-4-15** Flickermeter

**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 ( \pm 1 % ) (49.5 – 50.5 Hz) for 99.5 % of week – 6 % / + 4 % (47 – 52 Hz) for 100 % of week</td>
</tr>
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<td>Voltage magnitude variations</td>
<td>LV, MV: ( \pm 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_{10} \leq 1 ) for 95 % of week MV: 4 % normal 6 % infrequently ( P_{11} \leq 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>
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<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>
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<td>LV, MV: (longer than 3 minutes) ( &lt; 10 – 50 / \text{year} )</td>
</tr>
<tr>
<td>Temporary, power frequency overvoltages</td>
<td>LV: ( &lt; 1.5 \text{kV r.m.s.} ) MV: ( 1.7 V_c ) (solid or impedance earth) ( 2.0 V_c ) (unearthed or resonant earth)</td>
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<tr>
<td>Transient overvoltages</td>
<td>LV: generally ( &lt; 6 \text{kV} ), occasionally higher; rise time: ( \mu \text{s} ) to ( \text{ms} ) MV: not defined</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>
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<td>Harmonic voltage / THD</td>
<td>Harmonics LV, MV THD: 8</td>
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<tr>
<td>Interharmonic voltage</td>
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**Table 6.4-3: Requirements according to EN 50160**

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**Table 6.4-4: Values of individual harmonic voltages at the supply terminals for orders up to 25, given in percent of \( V_N \)**

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</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 6.4-5: Measurement points and system location**

<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 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>
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 P50 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. (Sample application SICAM P fig. 6.4-8)

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
- 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 energ yrelated 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.

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**Fig. 6.4-7: Input/outputs for P50 Series**
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 P850**
SICAM P850 (fig. 6.4-9) is a new multifunctional device and is used to collect, display and transmit measured electrical variables such as AC current, AC voltage, power types, harmonics, etc. The communications interfaces can be used to output the measurands to a PC and the control center or display them on a display.

**Applications**
SICAM P850 device is used in single-phase systems, threephase systems and four-phase systems (with neutral conductors). It is used primarily in power utilities, but also in other industrial and commercial applications. The web server integrated into the device is used to configure the parameters and output measured values via HTML pages on a connected PC / laptop. In devices with displays, the parameters can also be configured with the function keys on the front of the device, and the measured values can be output to the display. The output variables can also be transmitted to control or other systems such as SICAM PQS V8.01 (planned) via the communications interfaces (Ethernet, e.g., IEC 61850) in the form of digital data. (Sample application SICAM P850 fig. 6.4-10)

**Mean features**
- Use in the IT, TT and TN power systems
- Ethernet communication via the Modbus TCP or IEC 61850 Edition 2 protocol; serial communication via Modbus RTU and IEC 60870-5-103 via the RS485 interface is optional
- External time synchronization via the Network Time Protocol (NTP).

**SICAM P850 system view**
SICAM P850 can communicate flexibly with automation systems and evaluation stations via open protocols such as IEC 61850 and Modbus TCP.

They are available directly from the device in the form of HTML pages on a connected PC.
6.4.3 SICAM T – Electrical Measurement Transducer

The SICAM T is a digital measurement transducer (fig. 6.4-11) 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.

**Signallization 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.

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**Fig. 6.4-11: SICAM T electrical measurement transducer**

**Fig. 6.4-12: Block diagram SICAM T 7KG9661**

**Fig. 6.4-13: SICAM T applications**
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 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.
6.4.4 Power Quality and Monitoring

**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!

**Application**

- **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.**
- **Transients** ¹ recording till 17 microseconds for 60 Hz and 20 microseconds in 50 Hz networks.

1) ¹) Option for transient recognition is OFF
   a. Sampling rate is 10 kHz
   b. Fault records with 10 kHz

2) ¹) Option for transient recognition is ON
   b. 2 sampling rates 10 kHz and 50 kHz
   c. 10 kHz data to calculate all mean values, flicker etc.
   d. 50 kHz only for U1, U2, U3 to detect transients. The fault records have a sampling rate of 50 kHz.
6.4 Power Quality and Measurements

**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.

**SICAM Q100**

The SICAM Q100 multifunctional measuring device is used for acquisition, visualization, evaluation and transmission of electrical measured variables such as alternating current, alternating voltage, frequency, power, harmonics etc. The acquisition, processing and accuracy of measured variables and events are performed according to the IEC 61000-4-30 Class A power quality measurement standard. The measured variables can be output to a PC or system control via communication interfaces or shown on a display. In addition to the monitoring function, the SICAM Q100 all-in-one device provides a combined recording and evaluating function: measured values can be recorded in parameterizable time intervals with various recorders such as power quality and fault recorders. Long-time data and events are evaluated directly in the device and displayed as a report according to the power quality standards (e.g., EN 50160).

**Application**

The SICAM Q100 device is used in single-phase as well as in three-wire and four-wire systems (with neutral conductor). The device is applied wherever comprehensive measurement of supply quality is necessary – at power utilities as well as in industry and trade sectors.

**Benefits**

- Comprehensive acquisition of relevant network parameters for early identification of supply quality problems.
- Manufacturer-independent, comparable measured values obtained by using the IEC 61000-4-30 Class A standard measurement methods.
- PQ reporting according to EN 50160 direct in web server.
- Easy operation via integrated web server for parameterization, diagnosis, evaluation and reporting.
- Interoperability is guaranteed by using standard interfaces and standard protocols (IEC 61850, MODBUS TCP) and data formats (PQDIF, Comtrade and CSV).
**Device characteristics of SICAM Q100**

**Input measuring circuits**
- 4x alternating voltage, 4x alternating current

**Binary input/outputs**
- individually programmable binary inputs/outputs
- Binary expansion (up to additional 12 inputs and 12 outputs) by using SICAM I/O Unit devices

**Measured variables**
- Measured value acquisition according to the IEC 61000-4-30 Class A power quality measurement standard
- Mean value, event and fault recorder functionality
- Load Profile and TOU (Time of use, 2 x Tariffs)
- Power frequency, active, reactive and apparent power, power factor and active power factor, phase angle
- Alternating voltage and alternating current harmonic up to the 63rd order

**Communication interfaces and protocols**
- Ethernet: MODBUS TCP, IEC 61850 Edition 2
- MODBUS Master and Gateway function for RS485 devices (as Switcher 3WL, PAC3x00, SICAM P50)

**Operation and display**
- Full graphic display, operation via 4 function keys
- Integrated web server to interact with PC via HTML pages

**Time synchronization**
- Via Ethernet: NTP client (Network Time Protocol)

**Auxiliary voltage**
- DC 24 – 250 V and
- AC 110 – 230 V, 50 / 60 Hz

**Housing specification**
- ‘Compact dimensions: 96 x 96 x 100 mm (W/H/D)

**Special features**
- PQ reporting according to EN 50160 and CBEMA direct over HTML web server
- Evaluation of events directly in HTML via COMTRADE Viewer / SIGRA Plugin
- Flexible data export in the PQDIF, COMTRADE and CSV format
- Memory capacity of 2 GB for storage of the recorder data for years of power quality data
- MODBUS Master and Gateway function

**SICAM P855**

The SICAM P855 multifunctional device is used to collect, display and transmit measured electrical variables such as AC current, AC voltage, power types, harmonics, etc. The measured variables and events are collected and processed according to the Power Quality Standard IEC 61000-4-30. The communications interfaces can be used to output the measured variables to a PC and the control center or display them on a display.

In addition to the monitoring function, the SICAM P855 all-in-one device also provides a combined recording and evaluation function. It can record measurands at programmable time intervals, using a wide range of recorders, such as power quality and fault recorders. Long-term data and events are evaluated directly in the device according to the power quality standards (such as EN 50160) and output as reports.

**Applications**

SICAM P855 device is used in single-phase systems, threephase systems and four-phase systems (with neutral conductors). They are used primarily in power utilities but also in other industrial and commercial applications.

The web server integrated into the device is used to configure the parameters and output measured values via HTML pages on a connected PC/laptop. In devices with displays, the parameters can also be configured with the function keys on the front of the device, and the measured values can be output to the display. The output variables can also be transmitted to control or other systems such as SICAM PQS V8.01 (planned) via the communications interfaces (Ethernet, e.g., IEC 61850) in the form of digital data.

**Features**
- Robust and compact design according to IEC 62586-1, Class S (leading standard)
- Use of SICAM P850/P855 in the IT, TT and TN power systems
- Ethernet communication via the Modbus TCP or IEC 61850 Edition 2 protocol; serial communication via Modbus RTU and IEC 60870-5-103 via the RS485 interface is optional
- External time synchronization via the Network Time Protocol (NTP)
- The measurands and events are detected according to the Power Quality Standard IEC 61000-4-30. The measurement system corresponds to Class A. In terms of functional scope, measuring ranges and accuracy, SICAM P850/P855 are Class S devices.
- Additional measurands: Minimum / mean / maximum values, flicker, event detection, voltage dips (Udip), voltage interruptions and overvoltages (swells)
- Events are evaluated directly in HTML via the integrated web server
- 2-GB memory for recording recorder data
- Evaluations: Power quality reports and online viewer output directly on the HTML page
- Data export: PQDIF and COMTRADE data.
Device characteristics

Input measuring circuits
• 4x alternating voltage, 3x alternating current (max. 10A)

Measured variables
• True RMS alternating voltage and alternating current up to the 100th harmonic
• Power frequency, active, reactive and apparent power, power factor and active power factor, phase angle
• Alternating voltage and alternating current unbalance
• Alternating voltage and alternating current harmonic up to the 40th order
• THD (total harmonic distortion) of alternating voltage and alternating current

Communication interfaces and protocols
• Ethernet: MODBUS TCP, IEC 61850 Edition 2
• Serial: Modbus RTU, IEC 60870-5-103

Operation and display
• Full graphic display including operation via 4 function keys
• 4 LEDs for state and system messages
• Integrated web server to interact with PC via HTML pages

Time synchronization
• Via Ethernet: SNTP client (Simple Network Time Protocol)
• Via fieldbus
• Internal Real Rime Clock (RTC)

Auxiliary voltage
• DC 24 – 250 V
• AC 110 – 230 V, 50 / 60 Hz

Housing specification
• Plastic housing for DIN rail mounting, optional panel mounting, protection class max. IP51
• Dimensions: 96 x 96 x 100 mm (W / H / D)

Special features
• Measured value acquisition according to the IEC 61000-4-30 power quality measurement standard including flicker
• Automatic PQ reporting according to EN 50160
• Mean value, event and fault recorder functionality
• Data export in the PQDIF and COMTRADE format
• Memory capacity of 2 GB for storage of the recorder data
• Evaluation of events directly in HTML via the integrated web server

Fig. 6.4-17: SICAM P855 – multifunctional device
6.4.5 SIPROTEC 7KE85 – Fault Recorder, Measurement and Phasor Measurement Unit (PMU)

SIPROTEC 7KE85 fault recorder is designed to suit present and future requirements in a changing energy sector. Powerful and reliable monitoring combined with flexible engineering and communication features provide the basis for maximum supply reliability.

Commissioning and maintenance work can be completed safely, quickly and thus cost-effectively with high-performance test functions. Due to a modular design, the SIPROTEC 5 fault recorder can always be flexibly adapted to specific requirements.

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 × FastScan recorder
  – 2 × SlowScan recorder
  – 5 × 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

*in preparation

Fig. 6.4-18: Fault Recorder SIPROTEC 7KE85 (1/3 device with 1/6 expansion module and LED operation panel)

Fig. 6.4-19: Rear view of a basic module
Application as Phasor Measurement Unit
With the fault recorder SIPROTEC 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.

Intelligent PMU placement is crucial for cost saving and for an optimum observability of the dynamic system behavior. Optimum PMU placement studies are offered as consulting services from Siemens PTI (see Chapter 9.1).
6.4 Power Quality and Measurements

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. There 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 SIPROTEC 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 SIPROTEC 7KE85 system has been designed in such a way as to allow both centralized or decentralized installation.

The SIPROTEC 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 SIPROTEC 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. 6.4-23).
- 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).
Protection, Substation Automation, Power Quality and Measurements

6.4 Power Quality and Measurements

Solution 1:

Evaluation with:
SICAM PQS PQ Analyzer
SIPROTEC 7KE85

Solution 2:

Evaluation with:
SICAM PQS PQ Analyzer
SIPROTEC 7KE85

Fig. 6.4-23: Monitoring the power feed

Fig. 6.4-24: Monitoring the infeed

Solution:

Evaluation with:
SICAM PQS PQ Analyzer
SIPROTEC 7KE85

Fig. 6.4-25: Monitoring the quality in power distribution systems

Fig. 6.4-26: Monitoring the power quality in an industrial enterprise
6.4.6 SICAM PQS – Fault Recorder and Power Quality Analysis Software

**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 SIPROTEC 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 SIPROTEC 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.

**Fig. 6.4-27: SICAM PQS – One System for all Power Quality Data**
• Automatic and precise fault location with parallel line compensation
• Structured, consistent and permanent data documentation and archiving
• Automatic generation of cyclic power quality report

**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 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. 6.4-29).

**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. 6.4-30).

**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. 6.4-31).
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 (fig. 6.4-33)

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).

Fig. 6.4-32: Fault location with parallel line compensation

Fig. 6.4-33: SICAM PQS V7.01 / SICAM Diamond V4.0 HF1 goes Web via SICAM Diamond
6.4.7 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.

Advantages for the user:

• SIGUARD PDP, a fast monitoring system, detects the events and trends in grids with fluctuating load flows or highly loaded lines which conventional systems cannot detect at all or can detect too late.

• Detailed search of causes can take place after failures.

• Investment decisions for new equipment can be taken based on valid dynamic measurements.

• Protection settings can be checked and improved using the measured dynamic processes.

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

• Intelligent functions for problem display and analysis (e.g. power swing recognition, island state detection)

• 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

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.

• Monitoring of power swings
  All measured values from PMUs can be displayed and monitored with easy-to-configure phasor diagrams and time charts (see fig. 6.4-35). Any power swings that occur are detected quickly and reliably. The monitored zone can be flexibly adjusted to the current situation in terms of time, geography, and content.

• Evaluation of the damping of power swings
  Using the function “Power Swing Recognition” an incipient power swing is detected and the appropriate damping is determined. Detection of a power swing and, if applicable, its insufficient or non-existing damping is signaled (alarm list). There are two ways of detecting a power swing: Based on angle differences between two voltages (two PMUs necessary) or based on power swing recognition of the active power (one PMU for current and voltage measured values is adequate).

• 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.
6.4 Power Quality and Measurements

Fig. 6.4-35: Monitoring diagrams from the application "power sing recognition"

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Location</th>
<th>Network Subsplit</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:09:52....</td>
<td>2010-... Island detection</td>
<td>ISD potential</td>
<td>appearing</td>
</tr>
<tr>
<td>11:09:52....</td>
<td>2010-... Island detection</td>
<td>ISD network</td>
<td>appearing</td>
</tr>
<tr>
<td>11:09:52....</td>
<td>2010-... Island detection</td>
<td>ISD potential</td>
<td>disappearing</td>
</tr>
</tbody>
</table>

Fig. 6.4-36: Voltage stability curve

Fig. 6.4-37: Island state detection
Possible applications (cont.)

- Island state detection
  This function automatically indicates if parts of the network (fig. 6.4-37) 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 generated. In addition, the islands are marked in the graphic overview as colored areas.

- Line thermal estimation
  The "Line Thermal Estimation" function calculates the line resistance and the average line temperature with the help of the current and voltage measured values of two PMUs at the line ends. This principle is applicable for short and medium lines (up to ca. 300 km). Fig. 6.4-38 shows the principle in the event of a sudden current variation on a line. The upper curves show the current and the calculated line resistance, the lower curve shows the line temperature calculated from them.

- Retrospective event analysis
  SIGUARD PDP is ideal for analyzing critical events in the network. After switch over 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 compiled quickly and precisely. 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.

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**Fig. 6.4-38: Calculated line temperature and current/resistance curve**
Possible applications (cont.)

- **Phase Angle Display (in preparation, V3.10)**
  The Phase Angle Display Function can be activated in the geographic overview (fig. 6.4-39). It shows the voltage phase angle values between PMUs in a colored area. Together with the color scale for the voltage phase angles, the operator can check immediately the stability situation in the system. Colouring as well as min- and max-values can be set with the SIGUARD PDP Engineer (fig. 6.4-40).

- **Event-Triggered Archiving**
  Use SIGUARD PDP to automatically save recordings of abnormal system events. Define trigger events such as limit violations, recognized power swings etc. Select Lead Time and Follow-up time with SIGUARD PDP Engineer (fig. 6.4-41). The system then automatically saves all measurements in case the predefined event happens.

Intelligent PMU placement is crucial for cost saving and for an optimum observability of the dynamic system behavior. Optimum PMU placement studies are offered as consulting services from Siemens PTI (see Chapter 9.1).

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**For further information:**

[www.siemens.com/powerquality](http://www.siemens.com/powerquality)
6.5 Protection and Substation Communication

6.5.1 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 up 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.

6.5.2 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 network. 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 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 60870-5-103, 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 6.5.1) 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. 6.5-1).

**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 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.

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**Fig. 6.5-1: Ethernet-based system with SICAM**
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. 6.5-2). 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. 6.5-3).

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. 6.5-4).

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. 6.5-5).
A more economical solution is the fiber-optic ring with SIPROTEC relays because these devices have a switch directly integrated (fig. 6.5-6). 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. 6.5-7).
6.5.3 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 6.5-8 shows a possible hardware configuration equipped with 4 communication modules. Fig 6.5-9 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 6.5-10). 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.
6.5 Protection and Substation Communication

Examples
Redundancies to substation automation systems
- 2 redundant substation automation systems
- 2 different substation automation systems.

Example 1: Two redundant substation automation systems
Fig. 6.5-12 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. 6.5-13 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. 6.5-12: Redundant IEC 60870-5-103 or DNP3 communication

Fig. 6.5-13: 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. 6.5-14 and fig. 6.5-15 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. 6.5-16 (2 substation buses).
6.5.4 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 TCP).

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. 6.5-17).

When activating the integrated switch, SIPROTEC devices can be integrated directly into the optical communication ring consisting of up to 40 devices (fig. 6.5-18). 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.

Seemless 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.
HSR and PRP can be combined by so called RedBoxes (Redundancy Boxes).

The figs. 6.5-20 and 6.5-21 show some examples of PRP and HSR configurations.

This cost-effective solution of fig. 6.5-21 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.
6.5 Protection and Substation Communication

Fig. 6.5-20: Seamless redundancy by use of PRP only

Fig. 6.5-21: Most cost-effective seamless n-1 structure
6.5.5 Communication Between Substation Using Protection Data Interfaces

SIPROTEC 4 – differential and distance protection

Typical applications of differential and distance protection are shown in fig. 6.5-22. 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.

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. 6.5-23).

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, 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. 6-5.22) 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.
6.5 Protection and Substation Communication

**Fig. 6.5-24:** Protection communication of the differential protection and transfer of binary signals

**Fig. 6.5-25:** Protection communication via a communication network with X21 or G703.1 (64 kbit/s), G703.6... (2 Mbit) interface

**Fig. 6.5-26:** Protection communication via a copper connection

**Fig. 6.5-27:** Protection communication via an IEEE C37.94 (2 Mbits/s) interface – direct fiber-optic connection to a multiplexer

**Fig. 6.5-28:** Protection communication via single-mode fiber and repeater

**Fig. 6.5-29:** Protection communication via direct fiber-optic connections
6.5.6 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).
6.6 Integrated Advanced Cyber Security

The importance of Cyber Security

Increased networking of systems, standardization of communication protocols and operating systems – simplifying processes ensures efficient operation. But the other side of the coin is that these trends also make our networks vulnerable.

What can effectively protect our energy supply from attack? A solution which takes security into account at every stage of the development process. And at the end, contains exactly the security features that are needed. Looking at security as an integral component is important for a secure infrastructure – during both network planning and the design process.

Siemens offers well-thought-out products, systems and solutions to ensure the security of the energy automation infrastructure. From the outset, they meet the most stringent security requirements – including those of the BDEW Whitepaper (German Association of Energy and Water Industries) and NERC CIP (North American Electric Reliability Corporation, Critical Infrastructure Protection), and certification in accordance with the process industry security standard WIB 2.0 ("Working-party on Instrument Behaviour"). The main parts of the WIB requirements will be merged under the roof of IEC 62443.

Our systems and solutions:
Covered from end to end

The more comprehensively IT security is taken into account in energy automation systems, the more effective and cost-effective the solutions. Siemens offers complete designs for efficient security architecture in your plant.

- End-to-end designs for security architectures including the requisite ruggedization measures
- Well tested security architectures
- Recommendations for network components
- Security updates, virus protection
- Solutions for system-wide user and computer management
- End-to-end solutions for monitoring and logging security events
- Secure remote access solutions
- Patch management.

Our products:
Integrated Advanced Cyber Security

SICAM PAS and PQS
- Encrypted communication with network control center optionally via VPN/IPSEC or in accordance with IEC 62351 for IEC 60870-5-104 or DNP3 TCP
- Protection from malware through virus scanner or application whitelisting solutions
- Role-based access controls with fixed roles
- Integration into central user and computer management (Microsoft Active Directory Server).

SIPROTEC 5 and DIGSI 5
- Encrypted communication between engineering tool and protection device
- Secure communication password
- Password protection for system-critical actions
- Secure storage of key material
- Firmware integrity protection with digital signature.

Siemens solutions offer:
- Secure operational management of plants and systems
- Integrated security at the product, system and solution level
- Experience gained from multiple projects and international committee work
- Siemens CERT as partner for security-related incidents
- Well tested security architectures (blueprints)
- Certified complete solution in accordance with WIB 2.0 (fig. 6.6-1)
- Future-proof according to IEC 62443 and IEC 62351.

Fig. 6.6-1: Achilles Practices Certification (APC)* based on WIB 2.0

For further information:
www.siemens.com/protection
www.siemens.com/sicam
www.siemens.com/powerquality
6.7 Efficient Network and Energy Automation Systems (ENEAS)

6.7.1 Introduction, Portfolio Overview

The importance of energy automation for power grids today

Energy automation is a highly complex topic, not least of all because the considerable number of products and systems that make up a given solution must work perfectly together within the network. The change in energy grids, from generation to transmission and distribution, affects the structure and operation of power grids, as well as and the supporting functions and applications of energy automation. In addition to stabilizing power grids, intelligent energy automation helps to reduce energy consumption and costs. Due to this fact, the optimized capacity utilization of power grid assets takes the highest priority for utility companies, municipal utilities, and industry. Maximum reliability and availability are crucial, and it is important that redundant systems are only as good as the weakest part of it.

Main challenges and questions for the design of energy automation systems

To remain competitive from a cost perspective over the long term means to rely on a system with optimized total costs over the entire useful life of a system, from the initial investment through the operation.

There may be chances during the lifecycle of the energy automation system that are not known today. This future demand can be addressed already today by scalable systems that are easy to expand, updated and retrofitted.

A main value of an automation system is the data model. The data model still remains the same even if the automation system is changed, because it is based on the process level (e.g., switchgear). The value of the data model can be preserved on a long-term basis through systematic data transfer and an evolutionary development of existing systems.

To benefit from technological advances on a continuing base, while remaining flexible, it is necessary to work with standardized communications based on open interfaces.

For system integration without any problems, the right system architecture (redundancies, communication, system functions) and all interfaces have to be clearly defined and optimized.

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Fig. 6.7-1: ENEAS – system solutions portfolio for pathbreaking energy automation
Energy automation system landscape
ENEAS system solutions cover all areas of energy automation throughout the entire lifecycle of a power network, while also taking the growing importance of Smart Grids into consideration. Every individual component of an energy automation network should be optimized to coordinate with each other. Furthermore, the topics cyber security, engineering and communication must be handled for all the components in a homogeneous and consistent way. The energy automation system landscape consists of the following main parts:
• Solutions for substation automation and protection
• Solutions for distribution automation (primary & secondary distribution)
• Solutions for monitoring (monitoring of primary & secondary equipment and operation supporting systems)
• Solutions for control center
• Solutions for lifecycle management (service & maintenance, consulting & training)

Efficient engineering for less complexity and more investment protection
In the field of systems engineering, the demand for new and highly efficient engineering solutions is becoming more insistent, not least because of the continuing integration of different subsystems, and the resulting growth of the data volume in a wide variety of data models. Efficient engineering is characterized by its simple, straightforward operability. It offers users optimal support for creating and maintaining their system configuration and project planning data, based on international standards. Integrated energy automation guarantees the harmonized, optimized management of the project planning data thanks to migration-capable data structures and uniform, standardized data models such as IEC61850. The tool landscape has to be optimized to an engineering process with existing or given database.

For further information please visit:
www.siemens.com/eneas

6.7.2 Solutions for Substation Automation and Protection

Introduction

New challenges and dynamic market developments
Today, network operators and energy suppliers are confronted with steadily mounting challenges. Through energy efficiency and emission reduction requirements, legislators and regulatory agencies are exerting more and more influence on operating parameters. In addition, intelligent networks are emerging that require entirely new approaches to energy automation. The burgeoning number of distributed renewable energy generators is causing a bidirectional load flow and, in the foreseeable future, demand response will replace load-oriented power generation. But intelligent applications can be used to full advantage only if standardized communication and interfaces are in place. The use of networks and TCP/IP is making cyber security a priority topic as well. With appropriate solutions, these challenges can be transformed into opportunities and competitive advantages. And that is exactly the goal driving the development of ENEAS solutions from Siemens.

Always one step ahead with ENEAS solutions from Siemens
Comprehensive and efficient overall solutions for all areas of energy automation based on time-tested Siemens products – this is the idea behind Siemens ENEAS (Efficient Network and Energy Automation Systems). This integrated concept offers compelling benefits in all areas:
• Efficiency thanks to low costs throughout the entire lifecycle
• Sustainability through extensive performance reserves and open interfaces
• An ideal technical basis for the intelligent grids of the future
• The high level of safety only a demonstrably dependable business partner can guarantee.

Ready for Smart Grids with ENEAS
ENEAS solutions are an important element in the establishment of intelligent electricity networks with automated functions, distributed applications, and interlinked communication for the monitoring and optimization of network components. These intelligent networks meet societal and regulatory demands for highly efficient, environmentally sustainable network infrastructures. They also allow the optimization of work processes, enable more efficient operation management, and ensure a higher degree of supply security.

Use synergies and save costs
System solutions for substation automation technology and telecontrol systems form the basis for automation, metering, and power quality. They make it possible for plant operators to benefit from many synergistic effects when it comes to both investment and operation. They are especially effective in conjunction with other ENEAS solutions. The resulting synergies save time and costs, for example, when creating communication links among distributed components. Consistent workflow and ongoing data exchange across all areas of energy and network automation
provide a solid foundation for intelligent networks, and are also the keys to ensuring reliable, economical operation of transmission and distribution networks in an increasingly competitive market.

Overview

**Intelligent substation automation on a consistent basis**

Siemens’ ENEAS solutions for substation automation and protection incorporate a complete range of proven concepts for all substation automation tasks at all voltage levels and for all types of substations:

- Decentralized substation automation based on distributed bay units
- Compact systems for ring-main units and pole-mounted switches, for efficient network monitoring, troubleshooting, and fault correction
- Central telecontrol systems with integrated automation and node functions
- Multifunctional protection systems for the coordination and interaction of different protection devices

**Knowledge as a factor of success**

The most important factor in successful substation automation and network operation improvement is the rapid availability of the right information. As the market leader in energy automation, Siemens is spearheading the development. The Siemens specialists have hands-on experience with the world’s largest installed base, and play a major part in driving technological development. Siemens’ leading role in the development and implementation of the IEC 61850 communication standard is just one of many recent examples.

**An example of technology leadership in action: IEC 61850**

Siemens was the world’s first company to commit to full implementation of the IEC 61850 standard. The object-oriented structure of this standard includes protection and control, and it makes the operational management of substations significantly more efficient. IEC 61850 supports the interoperability and integration capability of substation automation systems, facilitates vendor independent substation engineering, and reduces planning effort at the same time. The first plant using this standard commenced operation in 2004, and since that time over 2,000 IEC 61850-compliant systems with over 120,000 devices have gone into operation.

**Experience and technology leadership**

Today, Siemens is one of the world’s leading companies in energy automation – due in no small measure to the company’s extraordinarily long practical experience in this field. Siemens has been working in protection technology for over 100 years, and for some 70 years in substation automation and telecontrol technology. Siemens has repeatedly set new benchmarks in energy automation. The introduction of the analog protection relay in 1957, or the first digital substation automation system in 1987, are just two striking examples. Today, over 5,000 Siemens digital substation automation systems are in operation around the world, along with over 100,000 telecontrol systems and over a million digital protection devices.

**Traditional T&D business**

**Digital substation automation systems**

The integrated concept of the ENEAS solutions covers the entire spectrum of substation automation. It can be adapted to any existing infrastructure, and special configurations can be developed for individual customer requirements. In addition, for many of the most widespread applications Siemens offers generic solutions that are preconfigured, and therefore especially economical. The extensive range of available applications allows intelligent, environmentally sustainable, reliable, and highly economical network operation. ENEAS solutions provide efficient, reliable digital substation automation technology everywhere – in transmission and distribution networks as well as municipal utilities, combined systems, and industry. The digital automation of substations is based on distributed devices, and it provides a wide range of functions for data acquisition, control and monitoring, as well as for protection and communication. ENEAS solutions are composed of Siemens components and products that from the start are coordinated to work together perfectly – especially the devices in the SIPROTEC, SICAM and SIMEAS product families. Third-party components that may be needed are qualified in system testing (fig. 6.7-2).

![ENEAS substation in transmission networks](image-url)
Telecontrol systems
Telecontrol systems designed as ENEAS solutions provide multi-hierarchical monitoring and remote control as well as automation functions at all levels. The modular system can be adapted to any primary processes and their spatial distribution. System solutions are available for both energy transmission and distribution to optimally perform telecontrol tasks for all aspects of data acquisition and process interfacing, communication, data concentration, and automation. From small substations using terminal block technology to large telecontrol stations with high signal density and numerous interfaces, ENEAS covers the entire spectrum. Its modular structure ensures long-term expandability. All components are based on a shared system architecture and technology, so that entire systems can be parameterized with a common tool throughout all project phases. Data point entry on individual devices is a thing of the past, and multiple entries are effectively prevented, even in mixed systems. All components deployed in ENEAS telecontrol systems utilize the same communication functions, so that the available protocols are usable in all telecontrol components. Along with the IEC 60870-5 series and IEC 61850 standard protocols, DNP 3.0 and Modbus are also available for all applications. In addition to these standards, numerous proprietary protocols for components by other manufacturers are also supported. The modular concept, distributed architecture, and evolutionary development principle ensure that these systems have long life expectancy and are open for future developments, thus providing a high degree of investment safety and enabling the creation of Smart Grids (fig. 6.7-3).

Protection systems
Reliable, efficient, adaptable substation protection systems are crucial for high- and medium-voltage power supply operations. They must react to faults in milliseconds in order to prevent damage to costly equipment such as switchgear, transformers and cables, ensure a high level of safety, and avoid failures of supply. ENEAS solutions for protection systems ensure a reliable, efficient power supply. They are designed to allow selective procedures for different network structures and changes in operational processes, and they provide much more than just the dependable fulfillment of the basic functions of protection, control and monitoring. ENEAS solutions incorporate innovative approaches such as harmonized interfaces and interoperability, multi-layered safety mechanisms, and efficient engineering. Intelligent functions form one of the key prerequisites for Smart Grids. ENEAS protection systems support network operation during fault tracking or power quality analysis, adding useful features to the proven benefits of older protection systems. ENEAS solutions for protection systems allow individual protection devices to work together perfectly using the powerful communication technologies available today. Examples are, among others, the complex protection requirements of 1.5 CB schemes or automatic load shedding between power plants in industrial networks (fig. 6.7-4).
ENEAS generic solutions
Siemens ENEAS generic solutions are “out of the box” solutions – the effective, comprehensive and modern total system answer for turnkey substation automation. They comprise pre-engineered and universally applicable components for substation layouts at various voltage levels – precisely tailored for a range of selected applications.

Siemens ENEAS generic solutions, all based on field proven engineering concepts, allow reduced project times, offer a high degree of economic efficiency, and afford the reliability of both the tried and proven Siemens solutions and products.

Benefits
Quality
• Multiple tested applications and templates provide improved quality to projects
• Increased quality of proposals
• More transparency of proposed services
• Improved quality of project documentation
• Improved quality of hotline and after-sales services.

Security
• Easier to adapt and enhance the system even after commissioning
• Safe operation from the user interface to the command output
• Secure maintenance: standardized documentation
• Secure lifetime support: longterm maintenance because of large installed base
• Security of investment: migration strategies thanks to a wide installed base.

Speed
• Faster project delivery
• Reduced effort in the definition of requirement and detail clarifications
• Faster project documentation
• Faster service and support-based on known project design (fig. 6.7-5).

ENEAS generic solutions for MV
ENEAS generic solutions for medium voltage are a set of modules for all typical substation automation purposes within the medium-voltage distribution grid for
• Air-insulated switchgear (carriage type)
• Gas-insulated switchgear
• Single busbar
• Double busbar (fig. 6.7-6).
The set of modules has been specially designed to provide off-the-shelf solutions for medium-voltage switchgear, and are applicable for greenfield projects as well as for refurbishment. Suitable for all market sectors such as utilities, industry and infrastructure, as well as for all MV plant types, ENEAS generic solutions for medium voltage considerably reduce planning and engineering efforts, increase the overall project quality and transparency, and speed up project planning and implementation.

Based on Siemens’ long-standing experience in automation of distribution substations of all sizes and configurations, ENEAS generic solutions for medium voltage offers a set of pre-engineered, universally applicable solutions for substation automation and protection that cover all types of medium-voltage switchgear. All system solutions are precisely tailored for a range of selected applications, and include the entire documentation in a standardized and pre-prepared format. On the bottom line, they make possible faster returns through reduced project times and faster project implementation, and they ensure long-term reliable operation and economic efficiency (table 6.7-1).

Geared towards state-of-the-art digital substation automation, Siemens ENEAS generic solutions for medium voltage are a comprehensive set of modules comprising tried and tested solutions for substation automation in distribution grid applications (fig. 6.7-7).

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**Table. 6.7-1: Defined bay typical – example for gas-insulated double-busbar switchgear**

**Fig. 6.7-7: ENEAS generic solutions for MV plant types**
ENEAS generic solutions for wind power

ENEAS generic solutions for wind power are a set of modules for all typical substation automation purposes within the power collection grid of all levels of a wind power plant power collection grid. The set of modules has been specially designed to provide off-the-shelf solutions for wind power purposes, and are applicable to onshore and offshore wind power projects of all sizes. ENEAS generic solutions for wind power considerably reduce planning and engineering efforts, increase the overall project quality and transparency, and speed up project planning and implementation (fig. 6.7-8).

Based on Siemens' long-standing experience in substation automation of wind power plants of all sizes, ENEAS generic solutions for wind power comprise a set of pre-engineered, universally applicable solutions for substation automation and protection that cover wind turbine tower switchgear as well as medium-voltage and high-voltage switchgear. All system solutions are precisely tailored for a range of selected applications, and include the entire documentation in a standardized and pre-prepared format. On the bottom line, they make possible faster returns through reduced project times and faster project implementation, and they ensure long-term reliable operation and economic efficiency (fig. 6.7-9).

Geared towards state-of-the-art digital substation automation, Siemens ENEAS generic solutions for wind power are a comprehensive set of modules comprising tried and tested solutions for

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**Fig. 6.7-8: ENEAS generic solutions wind power: HV plant types**

**Fig. 6.7-9: ENEAS generic solutions for wind power**

**Fig. 6.7-10: Example Automation of the power collection grid with ENEAS generic solutions for wind power**
substation automation in power collection grid applications. This modular kit covers the entire range of types and sizes of wind power plants – from a single turbine to large-scale wind farms (fig. 6.7-10)

**ENEAS generic solutions SIPROTEC 5 HV**

ENEAS generic solutions using the new generation of protection devices and bay controllers SIPROTEC 5 for high voltage (GS SIP5 HV) are a set of modules for basic typical substation automation purposes within the high-voltage transmission grid for:

- Gas-insulated switchgear
- Double-busbar systems (fig. 6.7-11)

The set of the three base modules has been specially designed to provide SIPROTEC 5 devices for off-the-shelf solutions for high-voltage switchgear.

This generic solution covers the most common substation typicals in 380 kV. It shows new features and solutions to find a cost-efficient, secure and future-proof solution. Furthermore, the generic solution shows different approaches of communication architectures to find the best configuration for the system operator’s requirements. The generic solution contains functional and non-functional features concerning a state-of-the-art substation automation system.

It supports and uses the following new SIPROTEC 5 system features:

- Direct tripping without external trip relays
- Synchrocheck with multiple voltage sources
- Flexible configuration of the device function
- Test disconnect terminal UTME 6-MP and test plug SMP
- User-friendly position of the device
- Migration of legacy systems

**Migration of legacy systems**

The product lifecycles of primary and secondary equipment differ substantially:

- Primary equipment: 30 ... 45 years
- Secondary equipment: 15 ... 20 years

One lifecycle for primary equipment may include 2 ... 3 lifecycles for the secondary equipment. However, a system including both primary and secondary equipment is unlikely to be modified, as long as its components function properly (fig. 6.7-12).

Product lifecycle and its impact:

- Components, operating systems, application software is available on the market for a limited time only
- Suppliers cannot deliver and maintain products and tools for an indefinite period
- No new systems can be implemented after phase-out declaration
- Siemens’ obligations for repair, replacement and maintenance cease typically 10 years after product cancellation (fig. 6.7-13).
6.7 Efficient Network and Energy Automation Systems (ENEAS)

Protection, Substation Automation, Power Quality and Measurements

To avoid faults or breakdowns, a proactive planning and timely execution of migrations is essential.

- Protection of existing investment – only such components are being replaced, for which an immediate need exists
- Minimization of the effort to renew or modify existing wiring or communication lines
- Retention of the original functionality with respect to protection, interlocking, switching sequences, automation functions, etc.
- Preparation of the systems for new functionalities and future requirements
- Re-use of engineering data, parameter settings and configuration data, wherever possible
- Reduced, partial or even no outage times
- Reliable and trouble-free execution of the migration
- Distribution of the migration activities and the associated cost over a certain period of time
- Simple and step-by-step readjustment and familiarization for the operating staff to the new solution.

The ENEAS migration concept and approach for the legacy systems takes all the relevant aspects for a smooth migration from the legacy systems

- LSA 676 (substation automation system)
- SINAUT LSA (substation automation system)
- 8TK (substation interlocking system)
- SICAM SAS (substation automation system) to the actual and future-proof system out of the SIEMENS substation automation portfolio.

Especially the following requirements are solved by the ENEAS migration approach

- Parallel operation of legacy system and target system components during migration, possibly with fallback solution
- Deployment of dismantled material as spare parts or for extensions in other parts of the system
- Look & feel of the target system resembles the legacy systems regarding user interface and operation
- Many legacy protocols, including those proprietary to Siemens, are being supported by the target systems
- A variety of conversion tools and procedures for parameter and configuration data is available
- In-house know-how within Siemens facilitates tailored migration solutions
- All components required to implement the migration solution can be provided by Siemens from one single source
- Migration steps and procedures can be tested in the Siemens lab, and in many cases offline on the live system
- Training of the operating personnel on-the-job in synchronization with the migration.

6.7.3 Solutions for Distribution Automation

ENEAS distribution automation

Distribution automation is the complete automation of all controllable equipment and functions in the distribution power system. Main tasks are the operation and maintenance of distribution system facilities to improve the quality of service, reduce the operating costs, increase the efficient use of energy, and fast adaption to the changing energy environment. Distribution automation also includes newer applications such as fault detection, fault location analysis, voltage control, and power quality measurements.

Medium- and low-voltage automation

Medium- and low-voltage solutions for distribution automation guarantee the cost-optimized operation and maintenance of primary equipment, increased supply safety and voltage quality, and a rapid adjustment to changes in the distribution network.

A major requirement on electricity supply systems is a high supply reliability for the customer which is mainly determined by the distribution network. Supply reliability is influenced by various technical and organizational factors, and typically quantified by criteria such as SAIDI and SAIFI. In general, customer expectations on supply reliability are steadily increasing. In some cases, explicit power quality criteria are even included in negotiated contracts between customers and utilities. Moreover, in liberalized markets, regulators typically require the utilities to report on the reliability performance, or define explicit performance targets that are even penalized in case of violations in several countries.

Given this background, the power quality performance of distribution networks is coming more and more into the focus of system operators. Cost-effective measures and concepts for system development and operation are necessary. Performance targets demanded by customers and regulators are becoming a key factor for economic system operation. Understanding the correlations between the respective measures and their detailed and quantitative impact on the systems reliability performance is therefore becoming more and more important.

Benefits of medium- and low-voltage automation:

- Increase of distribution reliability
- Improvement of distribution operations and maintenance
- Faster disturbance analysis and fault location
- Asset monitoring for ageing infrastructure and avoidance of asset overload
- Increase of distribution power quality to be in line with given voltage range, and avoidance of power quality issues for medium-sized industry
- Leverage of medium-sized distributed generation and small decentralized generation
- Clear view about power flow
- Active load balancing and rearrangement in distribution network for operational issues
- Utilization of up-to-date technology like communication node with broadband infrastructure
Portfolio:
• Medium- and low-voltage automation
• Self-healing applications and wide area monitoring

Monitoring, remote control, and self-healing application
High supply reliability for the customer – a major requirement for electricity supply systems – is mainly determined by the distribution networks, which typically feature a low degree of automation only. Even the automation of a smaller part of the network with Monitoring, remote control, and self-healing application can realize significant improvements. Intelligent automation equipment in primary and secondary substations allows for effective monitoring and decision-making without human intervention. Reliability of energy supply primarily depends on the distribution network, and its importance is growing. It is generally quantified by two indicators: SAIDI (non-availability) and SAIFI (interruption frequency).

Scalable distribution automation solutions start with simple monitoring and control of distribution substations, and end with closed-loop self-healing (Fault Location Isolation and Service Restoration). In cable networks, mainly RTUs and short-circuit detectors are used for the automation of ring-main units. For overhead line networks, IEDs and protection relays ensure control and monitoring of reclosers and sectionalizers. Self-healing automation can provide secure and reliable operation of overhead lines and cable networks, and can be used for all types of primary equipment: circuit-breakers, reclosers, disconnectors, sectionalizers and load breakers.

Principle of self-healing (Fault Location, Isolation and Service Restoration – FLISR)
• Fault location: Analysis and detection of permanent faults, broken jumpers, loss of substation source, and lockout due to miscoordinated protective devices
• Fault isolation: The distribution network is broken into feeder section zones that can be isolated or energized from one or more sources using fault-interrupting or switching devices (i.e., circuit-breaker, recloser, load breaker, etc.). Evaluation to determine if any unfauluted zones are de-energized
• Service restoration: Automatic restoring of unfauluted zones using alternative sources (if available). Change of settings groups to better coordinate the protective devices in the new network topology. Restoration of upstream zones that were de-energized due to miscoordination of the protective devices
• Return to initial conditions: @ Operator request.

Distribution automation architectures
• Centralized: Automation logic is implemented in the control center
• Semi-decentralized: Automation logic is implemented at the primary substation level
• Decentralized: Automation logic is implemented at RMU/feeder level (fig. 6.7-14).

![Semi-decentralized architecture](image-url)
Semi-decentralized Automation Architecture
The regional controller based on the SICAM substation automation system ensures local self-healing automation, and also provides additional supervisory information. It is located in the primary substation as a link between the central SCADA system and the intelligent field devices. Protection relays like SIPROTEC monitor and protect distribution feeders in the primary substation. Disconnectors and switches at the ring-main units can be controlled and monitored via a customized ENEAS distribution automation box including SICAM RTUs and SICAM FCM.

Standard ANSI protection functions in the SIPROTEC relay handle critical fault situations by tripping circuit-breakers at the in-feed point. The ENEAS distribution automation box sends the status of the distribution network to the regional controller for analysis and for taking further actions.

The regional controller is set up to:
• Detect fault location using fault indications from the field
• Manage standardized switching sequences for fault isolation
• Handle further actions for reconfiguration and service restoration (fig. 6.7-15).

Decentralized Automation Architecture
The system is designed to work using independent automated devices. The self-healing logic resides in individual SIPROTEC 7SC80 feeder automation controllers located in the feeder level. Each feeder section contains a SIPROTEC 7SC80 with a powerful programmable logic controller (PLC) that can be easily configured by the utility to operate the switching devices in response to local or network conditions. Because the relays communicate with each other in a peer-to-peer fashion, the system operates autonomously with no need for a master controller.

Modern communication systems primarily use the open IEC 61850 standard to support this decentralized application. IEC 61850 provides the required logic and flexibility for the realization of the self-healing functionality. Peer-to-peer functionality via IEC 61850 Generic Object Oriented Substation Events (GOOSE) messages not only provide binary data, but also analog values. Each SIPROTEC 7SC80 unit contains extensive programmable logic, which is designed with the FASE (Feeder Automation Sequence Editor) engineering tool to realize the automation functionalities. The IEDs then handle the self-healing functionality, attempting to clear and isolate the faults in order to initiate the service restoration logic (fig. 6.7-16).
Wide area monitoring application
In many cases, explicit power quality criteria are even being included in contracts between customers and utilities. Moreover, regulators in liberalized markets are requiring that utilities document network reliability, or they define explicit performance targets. Many countries even impose penalties for non-compliance. This being the case, power quality is becoming more and more of a focus. Operators are requiring suitable measures that allow them to acquire information from the distribution network at any time, and thus to control the distribution network more efficiently.

The regional controller based on the SICAM substation automation system ensures intelligent concepts for voltage regulation, and can help achieve the defined performance goals of a defined network area. The regional controller makes them a key factor in supplying energy cost-effectively and reducing investments in new lines. Knowing which measures supply which measurable added value for network operation is becoming increasingly important.

Our system solutions take all these topics into account and provide a secure voltage level. The primary transformer or a line voltage regulator will receive their tap changes from the wide area monitoring application of regional controller based on the basis of the distributed voltage measurement in the medium-voltage grid and low-voltage grid (fig. 6.7-17).

6.7.4 Solutions for Industry Grids

Industry solutions
Every industrial process relies on an adequate supply of electrical power. In large industrial plants, power is usually supplied via the company’s own grid. Such industry grids feature integrated electricity generation with on-site generator sets that can supply at least a large part of the energy required for production.

Industry grids are typically connected to a power utility’s external grid, but can also be operated in island mode. Several are designed as dedicated island grids – especially in the oil and gas industry, in remote regions, and in offshore locations.

ENEAS industry solutions covers the whole range of energy automation for industry grids: Monitoring, control, protection and power management are supporting the efficient grid operation, and cater for high reliability and quality of power supply for industrial production processes.

The base for ENEAS industry is the substation automation system: Proven components of the product families SICAM and SIPROTEC are connected with network communication based on IEC 61850 and distributed functions. They also cater for interfaces to external devices, such as LV feeders or the process control center (DCS).

Typically, ENEAS industry solutions are based on a 3-level configuration consisting of
• Feeder level
• Station level
• Plant level.

For more details of ENEAS substation automation and protection, please see chapter 6.7.2.

ENEAS power management
Reliable power supply and stability of the power grid are essential for an efficient industrial production. These requirements are met by ENEAS power management. The functions cater for stable frequency and voltage, keep power import within desired range according to load agreements with external power supplier, protect primary equipment from overloading, and cater for a secure power supply even in critical situations (fig. 6.7-18).

Automatic load shedding
In case of overload, the automatic load shedding stabilizes the power supply of industrial plants through the prioritized disconnection of consumers, thereby ensuring that core processes remain under power in critical situations, and expensive down-times are avoided. Load shedding is especially important when critical events, such as the tripping of a generator, endanger the grid stability. In such situations, low priority consumers are disconnected to restore the balance between energy generation and consumption.

ENEAS load shedding includes 3 different functional versions, which can be combined according to the operational needs of

For further information please visit:
ENEAS distribution/feeder automation
the grid, and which complement each other for a comprehensive and selective reaction (fig. 6.7-19).

**Fast power-based load shedding**

Power-based load shedding continuously calculates the necessary reactions to critical scenarios that could occur in the grid in advance. Therefore it is always prepared for such contingencies in a predictive way, and takes into account the actual distribution of power.

For every contingency, load shedding calculates how much power has to be shed, and which feeders are to be tripped according to their predefined priority. By this method, load shedding sheds only as much load as necessary for restoring the nominal frequency.

The predictive calculation enables a very fast reaction when a contingency occurs. Critical trigger events are transmitted to all feeder devices over Ethernet using IEC 61850 with GOOSE messages. This method is more reliable and economic than traditional parallel wiring, and caters for reaction times below 70 ms.

**Dynamic power-based load shedding**

Loads change as needed by the industrial production process. In island mode, these variations are balanced by the on-site turbines. As the need for power increases, the spinning reserve of the generators decreases, reducing the flexibility of the operator for starting additional big loads. Such a situation will still maintain balanced load and generation, and frequency will be stable, therefore fast reaction is not necessary. On the contrary it is required that dynamic load shedding includes a time delay avoiding too sensitive shedding activity.

Dynamic load shedding monitors the spinning reserve for a defined limit. By shedding low priority loads, the required reserve is restored. Dynamic load shedding includes supervision of gradual overload. This means that generators may be overloaded for a limited time and with limited value. As long as these limits are not exceeded, shedding will not be activated.

As an alternative to shedding, the start of big loads can be inhibited if the spinning reserve is not sufficient.

**Frequency-based load shedding**

This function reacts to a violation of a defined set of underfrequency limits. For every limit it can be defined which feeders have to trip in order to restore the nominal frequency. The assignment of feeders to the limits is stored in the bay devices, therefore they react independently of the central load shedding controller. The operator has full overview and control of the assignments on the HMI.

Frequency-based load shedding is often used as a backup function to the fast load shedding, because of this high availability, but it can be also used as an independent main function for smaller applications.

**Generation control**

Industry grids are often supported by several generators to support island mode in case of a fault of the intertie to the external utility. Beyond that, these generators are used to reduce energy production costs and improve the security of supply. In industry grids there are mainly gas turbines, steam turbines, and diesel engines to drive the generators. They all are typically equipped with their own primary controllers: the governor and the excitation with voltage control.

If several generators operate jointly in an islanded industry grid, they need to be coordinated to maintain nominal frequency and voltage. This is the task of a secondary control, which is the main part of generation control (fig. 6.7-20).

ENEAS generation control supports the grid operator in all modes:

- In connected mode it keeps power import and phase angle within contractual limits by controlling own production
- In island mode it stabilizes frequency and voltage in the grid.
In all modes, generation control shares the produced power between the running generators to maximize the spinning reserve (fig. 6.7-21).

ENEAS generation control runs on a central server, based on SICAM 230, and needs distributed controllers at each generator set to exchange the necessary data. Typically there is a mix of serial and parallel interfaces to the primary controllers, with raise/lower commands for the setpoints. A small SICAM controller can handle the interface and provide the necessary logics. It is connected with IEC 61850 to the central controller on plant level.

**Integrated solution**

ENEAS power management is totally integrated in ENEAS substation automation, and runs on a controller on plant level, which is often designed redundant. The system configuration can easily be adapted to the size and importance of the plant and its grid. There are no additional devices needed for power management, and the efficient communication structure is based on reliable fiber-optic cables with redundant ring structures. The communication reduces parallel wiring significantly, and is open for the future by using the international standard IEC 61850.

The system configuration is based on proven concepts, and includes certified security concepts (fig. 6.7-22).

There is only ONE user interface used for monitoring and control as well as for power management. Thus, operation is very efficient and fast to learn, with high ergonomics and clear screens guiding the operator in critical situations, and providing both overview and detailed cockpits for the electrical engineers.

ENEAS power management offers even more functions for project-specific solutions. These include automatic switchover to island mode in the event of faults, and synchronisation for reconnection. Protection schemes and interlocking are just to be mentioned here.

If energy costs are a large part of the production costs of the plant, it is possible to upgrade the system to optimize the schedule for the generators based on load forecasts.

ENEAS power management usually starts with a thorough analysis of the grid. Powerful tools to simulate and test the industry grid are available, combined with the expertise of skilled electrical engineers who can identify weak points in the grid and recommend measures to operate the grid in a safe way. Their analysis also delivers important parameters for ENEAS power management functions.

For further information please visit:
ENEAS power management for industry grids
6.7.5 Solutions for Monitoring and Control Center

Introduction

Flexibility, modularity and scalability – ENEAS solutions for monitoring and control center

The borders between substation automation, control center and branch systems like wind power, airport and industry are fluent because of the increased performance of modern host systems and the software architecture behind them. Also, customer demands require a highly flexible, scalable and reliable control center system that support the workflows of today and make them prepared for the requirements of the future.

ENEAS monitoring and control center solutions cover a large range of application fields. With the engineering experience of thousands of systems for:

- Substation automation
- Control center for utilities incl. electricity, gas, water and district heating
- Wind power application
- HVDC platform
- Condition monitoring
- Industry
- Airports
- Buildings and hospitals
- Data centers
- Smart Grid applications.

Monitoring and control center solutions are a powerful part of modern energy automation.

The Power Engineering Guide deals with three application fields concerning system solutions for control centers. It is focused on the requirements and features of the main system, and describes the basis for all control center applications.

The chapters “Solutions for renewable wind power” and “ISCM – Integrated Substation Condition Monitoring” describe more in detail two applications based on a common platform but covering totally different demands.

Only a flexible platform allows to implement a lot of different system solutions as provided in the ENEAS solution portfolio.

System solutions for control center

Modern control centers have to fulfill a large number of requirements. They gather a wide range of highly detailed information about the network and its current state. This assists operating personnel in controlling the central network, and allows rapid reaction and specific countermeasures to be taken in the event of a fault. Additional high-quality applications, such as energy management, metering, asset management, etc., can either be integrated directly in the control system, or can be linked to it via interfaces to offer further value added. This provides an efficient system for the small to medium-sized range of applications that enhance the large network control systems available from Siemens (fig. 6.7-23).

Control center basic functionalities:

- Editor
- Alarm and event lists
- Worldview
- Database management
- Topology

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Fig. 6.7-23: Flexibility and scalability of control center solutions
Protection, Substation Automation, Power Quality and Measurements

6.7 Efficient Network and Energy Automation Systems (ENEAS)

- All-in-one, server-client
- Redundancy
- Web server integration
- Power distribution calculation
- Message control (SMS, mail, etc.)
- Communication protocols
- Multi-touch applications
- Report generator.

With a powerful basis of functionalities it is possible to ensure the main workflows. But as a functional shaping, a lot of expansion modules that support the operator are needed. A flexible control center system also has to provide extension functions like:
- Topological coloring
- Fault localization out of protection data
- Switching sequence management
- EMS energy management system for electricity and gas
- Power distribution calculation
- Simulation
- Switching procedure management
- SQL outsourcing / Database connectivity
- Report generator
- Energy management for renewables
- Distribution automation functionalitites.

Modularity

Our control system software has always proven effective for traditional applications in substation automation and in power grids with electricity, gas, water, and district heating. It also serves as the basis for wind farm, industry, and airport technology. More importantly, we use the same platform for implementing application-specific solution packages, for example, condition monitoring, load shedding, network monitoring, meter integration, and power quality monitoring. These modules can be used in any combination, depending on the application.

Modularity allows to integrate new applications into proven systems without redesign of the existing system. That makes SCADA systems highly flexible.

Communication

Communication is a key factor for successfully integrating a wide variety of sensors into one control system. In the beginnings, control center systems started with proprietary vendor specific protocols. Interoperability was not provided. But to replace or update a control center it is necessary to implement the older communication protocols. In addition to the IEC 61850 and IEC 60870-5-104 standards, the Siemens solutions offer another 200 protocols, from the building automation bus to accepted industry protocols. Today’s control systems must serve as the hub for communication with other control and monitoring systems, thereby permitting the connection of higher-level systems with, for example, IEC 61850 servers, ICCP/TASE.2, and IEC 60870-5-104.

Maintenance and Cyber Security

Maintenance and Cyber Security are becoming increasingly important for command and control systems, which is why they are integrated into the operation and process areas as an integral component in the security concept. With control center solutions, customers benefit from tested updates and patches, as well as from continual development as per accepted cyber security standards. Because update and backup management is simple and fool-proof, system support is as simple as possible and as secure as necessary.

Furthermore, a long term upgrade strategy is a must. To protect the investment of the installations and applications, the systems have to be portable without engineering efforts to newer versions. For example, the SICAM 230 platform provides an upgrade over the last 20 years, thus ensuring software availability at least for the next 10 years.

Scalability – focus on small to medium-sized systems as expansions to large control centers

From industry PCs to multi-server solutions with over 100,000 data points, Siemens’ small to medium-sized control center solutions are all based on the same system platform. This platform can be installed on all current Windows operating systems from a DVD, in order to order to ensure a consistent system quality environment which is both simple and convenient.

In addition, the control center systems are more and more integrated in the company’s IT landscape. Not like in former times, where control center and business IT infrastructure were separated. This implies a nearly seamless integration into the company’s IT infrastructure (fig. 6.7-24).

Virtualization

Virtualization enabled the number of physical servers to be reduced substantially, with a commensurate decrease in maintenance costs. Hardware can be shared and jointly monitored. Only four physical servers are used for all of the virtual servers, with data stored on a RAID system that is shared by all of the systems.

For further information please visit:
Solutions for small control center
Solutions for renewable wind power

With the great experience from large onshore and offshore wind power projects over the last years, Siemens has engineered a lot of applications requested by wind power systems.

At the beginning, mainly substation automation and grid connection were the standard solutions covered by energy automation (see ENEAS generic solutions for wind power).

In addition, solutions are designed for asset monitoring, connectivity to turbine control systems, onshore and offshore applications, infeed controllers, and last but not least the integration of HVDC controllers into a SCADA system.

So finally it is possible to design a complete bundle of secondary applications for wind park solutions that represents a modular solution for wind power:

- Grid connection and grid code compliance, voltage/VAr controller – capacitor bank controller
- Energy automation solution for onshore and offshore substations
- Integration of auxiliary components
- Platform signals (pumps, engines)
- Fire protection
- Lighting
- Building heating and conditioning
- Asset monitoring
- SCADA workstation (onshore and offshore)
- Energy management (e.g. German EEG)
- Remote operation center for renewables
- Communication to wind power controller
- Communication to TSO grid operator (fig. 6.7-25)

Maintenance and remote operation

Maintenance and remote operation are becoming increasingly important for wind power systems. Two drivers for remote control centers are:

- Distributed wind turbines
  Operation and maintenance crews observe turbines that are installed across larger regions, up to a country or a continent. That kind of installations are not easy to reach. With a remote system, the fault diagnosis is much faster and crews are coordinated much more effectively.
- Large wind power plants onshore and offshore
  Especially in offshore installations, the platforms and wind turbines are hard to access. Thus, on-site work must be planned very carefully, and is very expensive. A well-implemented operation and maintenance system supports onshore and offshore crews in order to reduce working time on site, maintenance efforts, and downtimes of the plant (fig. 6.7-26).

Fig. 6.7-25: Offshore wind farm grid
Large control centers for renewables have a different view on the wind farms and platforms than just the part of energy automation or substation control. Nowadays it is possible to implement it with the Siemens ENEAS solution for renewable wind power:

- Operation of the wind farm
- Observation of the complete system with
  - Turbines
  - Energy automation
  - Platform or wind farm auxiliary signals
- Asset condition monitoring
- Fault management
- Remote operation.

Forced by effectivity and economical pressure, the wind power control center becomes a more complete and challenging application than any other control center application before.

**ISCM – Integrated Substation Condition Monitoring**

Maximum availability and reliability, along with knowledge of the maintenance condition, are vital for transmission and distribution networks. For this reason, equipment must be constantly monitored and analyzed with a view to keeping maintenance and outage costs to a minimum. There is no other way to optimize the performance of all technical equipment. With ISCM (Integrated Substation Condition Monitoring), Siemens offers a solution that integrates all technical equipment into one central condition monitoring system, thus helping customers to improve their reaction time when it comes to preventing failures (fig. 6.7-27).
ISCM – centralized condition monitoring of all equipment
Regardless of whether monitoring the condition of transformers, switchgear (gas- or air-insulated), overhead lines, cables, or surge arresters is required, ISCM offers suitable packages for monitoring the condition of all components used. Additional signals from a system (access control, battery standby supplies, emergency power supply equipment, etc.) can also be integrated.

Unlike conventional systems that only monitor individual components, Siemens’ integrated analysis system permits meaningful predictions about the future condition of all equipment – throughout the entire network.

In addition to its wide range of monitoring functions, ISCM excels in terms of scalability. Both these factors are essential when it comes to precisely adapting the condition monitoring package to the actual requirements of a particular system or network. The knowledge modules specially developed for ISCM provide exact analyses and calculations of the raw monitoring data, thereby permitting monitoring and timely alarm signaling that go far beyond mere limit monitoring.

ISCM can be integrated into any existing switchgear. As a complete, integrated solution, this innovative condition monitoring system delivers comprehensive information on the systems’s condition in a standardized data format.

**Transformer**
- Hot-spot temperature (ANSI/IEEE)
- Ageing/loss of lifetime
- Energy efficiency/cooling efficiency
- Gas-in-oil analysis
- Bushing monitoring.

**GIS (HV/MV)**
- Gas density monitoring
- Partial discharge monitoring.

**Circuit-breaker monitoring**
- CT/VT monitoring
- Performance monitoring (tripping and reaction time)
- Spring or hydraulic system monitoring
- Maintenance counter and alarms.

**Overhead line monitoring**
- Voltage and sag monitoring
- Icing monitoring
- Ampacity monitoring (fig. 6.7-28)

For further information please visit:
Condition Monitoring (ISCM)

Fig. 6.7-28: ISCM – example of a central system for monitoring information
Grid diagnostics

SIMEAS SAFIR – efficiency in grid analysis and monitoring

Changing market conditions, more and diverse tasks, and increasingly small windows of time for an adequate reaction to grid disturbances pose new challenges to power grid operators. The detailed real-time overview of a power system’s performance is of the utmost importance today due to increased bidirectional power flow and a need for real-time system awareness. This supports the grid operators in having a clearer picture of the network supporting blackout prevention, having clearer information of assets and infrastructure being used. The electrical markets are in the deregulation process and cost minimizing programs are put in place. In addition, more and more tasks must be fulfilled by the same crew (or by a reduced crew) at the system operator’s site. Users require fast fault identification and fault clearance.

SIMEAS SAFIR
• Is a web-based system giving real-time grid information for better situation awareness
• Is a software platform that provides the basis for optimal data integration of various devices within a power system
• Collects fault records, substation automation events, power quality measurements, and synchrophasors
• Enables manufacturer independent, system-wide access to measurements
• Analyses this data automatically
• Allows operators and experts to quickly focus on essential facts and take appropriate decisions.

Fault analysis, power quality and wide area monitoring – all under one roof (fig. 6.7-29)

SIMEAS SAFIR is a server-based solution which is scalable from a single-server up to a multi-server solution consisting of application servers and specific data collectors. The data collectors can connect to substation automation systems (e.g., SICAM PAS), dedicated data gateways, SCADA, lightning detection databases, disturbance recording and power quality systems (e.g., SICAM PQS), phasor data concentrators, data warehouses, etc., and collect both event-related and statistical data from these sources. Moreover, the software can be customized to take full advantage of existing infrastructure and legacy systems. SIMEAS SAFIR standardizes all data to make them fully understandable and usable for automatic processing of any kind.

Typical data sources:
• Technical data
  – Protection relays
  – Digital fault recorders
  – Power quality meters
  – Phasor measurement units
  – Power meters
  – RTU

Fig. 6.7-29: SIMEAS SAFIR analysis cores: fault analysis, power quality and wide area monitoring
• Business data
  – Data warehouses
  – Supervisory control and data acquisition
  – Geographic information systems.

Data processing with SIMEAS SAFIR provides a number of tangible advantages for all departments that have to work with system monitoring data:

• Control and protection staff benefit from the automatic reading and processing of all available data, and a unified report standard. This makes cumbersome and time-consuming manual reporting a thing of the past.
• The asset management benefits from consistent fault analysis and the drawn conclusions about faults related to assets. In this way, manual fault and power quality reports handling becomes obsolete, and maloperation or defects can be prevented beforehand.
• The management can act on the basis of more and more transparent data, which makes maintenance faster and more calculable.
• Control center operators benefit from automated data collection and processing that makes possible timely and well-informed decisions on the basis of full access to all relevant data.

**Fault analysis**
Collecting data and putting the pieces of the event analysis puzzle together does not need to be a tedious, time-consuming matter. SIMEAS SAFIR utilizes data from all sources for time- and cost-efficient grid control and maintenance. Line faults due to environmental influences cannot be prevented. SIMEAS SAFIR makes handling such faults faster, easier, and more efficient.

• SIMEAS SAFIR collects fault records from all data sources like protection relay or digital fault recorder automatically – usually in COMTRADE format. In this process, time synchronization is verified and optimized, so the records can be grouped in event folders. These records are pre-processed to facilitate further analysis. The software detects analog signal changes, and provides numerous measurements, such as phasors and loop impedances, for each electrical state of the power system. User can also flag fault records and hide them, which occur during commissioning or protection testing. SIMEAS SAFIR enables for the control and protection staff a time-efficient analysis and reporting. This reduces costs and contributes to a better system reliability through measures derived from comprehensive data (fig. 6.7-30).

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**Fig. 6.7-30: Information overview of a selected event**
• SIMEAS SAFIR also can collect the events at the source by using RTUs or dedicated IEC 61850 gateways, for instance. Alternatively, SCADA databases or exports from substation automation systems can be used. This way, SIMEAS SAFIR becomes a system-wide sequence of events (SOE) recorder, which is the optimum solution (fig. 6.7-33).
• SIMEAS SAFIR groups all data that are related to a power system event into a single folder, which considerably facilitates the analysis: fault records, slow-scan records, voltage dips, and others. The application can then determine critical event patterns. Users browse the list of events which draws the attention on the spots and patterns of interest for each event. Events are tagged as important based on several criteria, and users can register to receive notifications based on their own preferences.

Power quality
Addressing the new challenges power system operators have to master Power Quality (PQ) monitoring. Traditionally focused on the quality of supply at the lower voltage levels, PQ monitoring plays an increasing role on all voltage levels today. The reasons include the obligation to know the quality of supply to distribution systems or major customers, and to quickly assess the impact of voltage events. But the flow of harmonic currents or unbalanced currents often also needs to be understood, from the origin of disturbances to the locations where it may disturb proper operation of power electronics or controls. That is why control and protection staff requires continuous, accurate recording nowadays (fig. 6.7-31).

• SIMEAS SAFIR uses voltage and current quality measurements from various power quality devices and systems from Siemens and from other suppliers. The preferred data sources are configurable PQ recorders featuring TCP/IP communication and standard protocols, such as Modbus. SIMEAS SAFIR can fetch essential measurements directly from these devices, even at short intervals. Alternatively, measurements can be imported in PQDIF format or from vendor-specific PQ databases.
• SIMEAS SAFIR displays the measurements on the web interface, regardless of their origin, and facilitates easy browsing of numerous data channels. SIMEAS SAFIR also provides a scaled comparison between the PQ indicators and the relevant compatibility thresholds. For reference, the power quality measurements can be compared to regulatory thresholds (e.g., according to EN 50160).
• In the end, SIMEAS SAFIR can also send a PQ summary of the last seven days by e-mail to detect and understand quality issues.
Wide area monitoring
Automated data collection from PMU, enables transparent information about critical grid situations in order to react adequately – company-wide and web-based.

- SIMEAS SAFIR takes advantage of the increasing availability of phasor measurement units (PMU). By connecting to phasor data concentrators (PDC), the server can display synchrophasors just as easily as other online measurements on any connected client PC, thus allowing frequency tracking and phase monitoring (fig. 6.7-32), (fig. 6.7-33).

![Phasor diagram]

**Fig. 6.7-32: Phasor diagram**

![Event list]

**Fig. 6.7-33: Event list**
6.7.6 Solutions for Cyber Security

Protection against unauthorized access, operator errors, and other internal and external threats is becoming increasingly important in energy automation, because such threats can have serious consequences for the power supply.

ENEAS cyber security is the framework for various measures to increase the cyber security in customer projects.

ENEAS Secure Substation is a generic approach based on products with implemented cyber security functionalities, and adaptable to all kind of substation automation solutions.

ENEAS Secure Substation covers the base cyber security requirements, and defines measures for pre-acquisition, offering and project delivery, as well as the creation of the corresponding material. It contains documents for cyber security reference architecture, technical solution, and necessary process descriptions.

As a result of those activities, a typical ENEAS solution has been successfully WIB 2.0 certified by Wurldtech in September 2012, covering a typical energy automation configuration in the industrial environment.

ENEAS Secure Substation is integral part of the energy automation solutions for Smart Grid, see section 8.5 (IT-Security).

Using either power quality meters or phasor measurement units, SIMEAS SAFIR can compute the average value of power system frequency, and display trend diagrams with various time scales. Measured frequencies exhibiting significant deviations are partitioned in islands. The frequencies of each island are traced and compared to detect islanding and assess its gravity in numerous situations.

• SIMEAS SAFIR displays tables and geographical views of the positive-sequence voltage amplitudes and angles across the monitored power system. Furthermore, the user can select couples of PMU locations and appropriate thresholds in order to trigger phase events.

Further functionalities
• SIMEAS SAFIR keeps recorded measurements from PQ recorder and PMUs in a database buffer for several weeks. This makes it possible to capture recordings afterwards, even weeks after the event of interest.
• SIMEAS SAFIR can provide estimates of the source impedance whenever a significant power change takes place. This feature is especially useful with renewable generation units and HVDC stations that require the verification of short-circuit power.

SIMEAS SAFIR takes a broader approach toward voltage change than power quality recording, and looks at the changes of phase-to-earth, phase-to-phase, and sequence voltages altogether.

For further information please visit:
Cyber security