Modern Subterranean Substations in GIS Technology – Challenges and Opportunities in Managing Demographic Change and Infrastructure Requirements

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1. Summary

This paper outlines the opportunities the use of modern subterranean substations offers and the challenges we face.

For more than 40 years proven gas-insulated switchgear (GIS) has helped to secure efficient energy supply. It is suitable for various urban or industrial settings, e.g.

- Vicinity of public buildings
- Subway stations, plazas or parking lots
- Stadiums, parks or recreation areas
- Historic or religious places
- Off-shore wind parks or oil platforms
- Hydropower stations

Furthermore, the adaption to different design-concepts, e.g.

- Underground substation
- Semi-underground substation
- On-top building

provides additional architectural flexibility.

Modern subterranean substations have to be “invisible”, i.e. perfectly integrated in the surrounding area. Challenges such as access routes, emission control, fire protection, soil or ground water have to be solved by combining established know-how and experience. Local expertise and partnership are essential for obtaining approval from the respective authorities without problems as well as for on-time completion and reliable long-term operation of the substation.

Examples of existing installations and installations under construction are presented. These references show a wide range of situations and solutions and document how modern subterranean substations contribute to assuring economical and environmentally friendly power supply.
2. Introduction

Energy supply today and in the future presents major challenges to the infrastructure. Demographic dynamics, scarcity of resources and the increasing environmental focus are three global trends in the energy sector.

- Population growth followed by an increasing demand for power and power supply in urban and rural areas require reliable transmission of large amounts of electricity as well as grid stability.
- The shortage of fossil fuels warrants cost-effective energy solutions, long service life and low lifecycle costs.
- Climate change calls for low energy losses, and environmental protection.

Modern high voltage products and solutions provide answers to these multifaceted market requirements. Space-saving gas-insulated switchgear with 25-year maintenance cycles, high-power gas-insulated lines, low-noise transformers and state-of-the-art energy automation systems contribute to managing the global challenges.

<table>
<thead>
<tr>
<th>Demographic dynamics</th>
<th>Resource scarcity</th>
<th>Environmental focus</th>
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<tbody>
<tr>
<td><strong>Population growth:</strong> 7.5 bn in 2020 (+1.1 bn)</td>
<td><strong>Geopolitics:</strong> 70% of world oil and gas supplies only in a few countries</td>
<td><strong>Global emissions:</strong> 40% increase in air pollution over past 20 years</td>
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<td><strong>Power consumption:</strong> +5.2% p.a. in emerging regions and 1.4% in developed world</td>
<td><strong>Fuel diversity:</strong> 100% increase in oil prices over last 2 years accelerates shift to broader fuel mix</td>
<td><strong>Climate change:</strong> Global warming limited to an average increase of 2 degrees Celsius</td>
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<td><strong>Megacities (&gt;10 million): 22 new megacities in 2015</strong></td>
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*Figure 1: Three global megatrends in the energy sector*
3. Substation Site Constraints and Implementation Criteria

The cost reduction facilitated by getting high-capacity connections at transmission voltage close to a city’s distribution network and its load makes up for design-related challenges. These are due to the fact that certain issues, such as environmental impact and public safety need to be addressed when designing substations and their components for inner cities.

The following parameters have been identified as important for inner city substations:

- Limited size of the substation area due to limited availability of space and the high cost of land: This calls for a very compact multi-level substation design.
- The proximity and number of neighbors and neighboring activities require a very low environmental impact of the substation in terms of visibility and noise as well as electric and magnetic fields.
- For the same proximity reasons public safety requirements of the substation are very high and the assessment of failure consequences is a major criterion for component and substation design.
- The high-voltage switchgear installed in the substation must be of the highest quality based on proven designs. Its implementation requires extensive operational experience.

4. Subterranean Substations – a Solution Providing Great Benefit

More and more areas in the world require suitable solutions that fulfill their individual demands. Gas-insulated switchgear (GIS) is known for its efficient energy-supply capabilities. It can be used for a great variety of urban or industrial situations. Thanks to its compact and modular design GIS allows directly connecting inner city nodes to the high-voltage and extra-high-voltage networks, reducing transmission losses and enhancing energy efficiency. Furthermore, GIS provides great architectural flexibility as it can be adapted different subterranean design concepts, such as

- Underground substations
- Semi-underground substations
- On-top buildings
Subterranean substations can decide the feasibility of urban and inner city projects. Subterranean substations

- are suitable for limited space or special site geometries
- fit into the surrounding architecture or scenery
- operate silently and are invisible to the surroundings
- provide additional benefits as commercial facilities can be built on top of them
- create additional value for people due to landscaping and parks on top of them
- meet environmental requirements in areas where traditional solutions can not be integrated.

5. Main Electrical Components

While the focus of substation specification and design has been on providing innovative solutions that meet safety and environmental requirements, the focus with regard to specifications for the main electrical components has been on selecting established designs with excellent operational track records. This combination is considered to provide the best mix of innovation, proven design and performance when it comes to meeting the criteria critical for subterranean substations.
Gas-Insulated Switchgear (GIS)

Efficiency, safety, and reliability are the factors that characterize modern gas-insulated switchgear for rated voltages from 72.5 to 550 kV. The high standard of the products results from the comprehensive experience gained in over 40 years of operation. The latest improvements from research and production are incorporated into the development and manufacture of our products to ensure they are state of the art at all times. Thus, even with the existing feeder designs and a high busbar rating the switchgear remains very compact and does not require additional space for the GIS installation.

Figure 2: The Siemens Standard GIS portfolio covers short-circuit currents up to 63 kA for voltages up to 550 kV.

A fundamental feature of gas-insulated switchgear is the high degree of versatility its modular design provides. Only few basic modules are necessary to implement any circuit variant owners may desire. The circuit-breakers are based on dynamic-self-compression interrupter technology and dry spring-operated mechanisms, which include vibration-free latches and load-free decoupling of the charging mechanism. Meanwhile, this technology has become the standard solution for the entire Siemens GIS portfolio (Figure 2). The same applies for the GIS encapsulation made of corrosion-free cast aluminum that provides the highest-possible SF₆ tightness and minimum SF₆ volumes. Furthermore the cast-aluminum housings used for the enclosure make the system lightweight and corrosion-resistant while
the low bay weight ensures minimal floor-loading and eliminates the need for complex foundations. Control and protection systems to suit all particular needs, from conventional to process-bus-capable digital bay control systems, can be provided. Electromagnetic compatibility of the switchgear design, both externally and internally, prevents interference voltages and overvoltages.

Easy installation of the pre-assembled and factory tested GIS modules as well as minimum loss of sulphur-hexafluoride (SF₆) gas during operation are basic requirements for GIS. Thanks to its high performance level and quality, modern GIS are practically maintenance-free. The corrosion-free enclosures and self-lubricating motor drives ensure a long service life. The main contacts of the circuit-breakers, disconnectors, and earthing switches are designed for that purpose. The first time-based maintenance is due after 25 years.

The expected GIS lifetime is 50 years and more, with a low operating cost due to minimum maintenance requirements, high availability and reliability.

6. Examples of Existing Subterranean Installations and Installations under Construction

Subterranean Substations secure electric power supply in many difficult locations around the world. They can be found in the caverns of hydropower plants, in subway stations or sports stadiums, in the basements of office buildings or hidden below community parks.

Figure 3: Breitfeld Substation located in the 1st and 2nd ground floor of the AFG Arena St. Gallen / Switzerland.
The following is a selection of innovative projects based on different concepts and installed at different locations, each presenting different challenges and that required different solutions. Some of the projects are in Switzerland, where the terrain frequently poses a challenge. Others are installations in the United States and Australia.

Park Station, City of Anaheim, USA (underground design)

Hidden within view – the underground Park Substation built for the power supplier "City of Anaheim" comprises a 69-kV GIS with 8 bays, two 56-MVA transformers and a 12-kV medium voltage system with 18 panels, all housed in a basement building under Roosevelt Park in Anaheim, California.

Challenges and Solutions:

Anaheim Public Utility concluded that implementing a substation in the densely populated area was required to reliably and economically satisfy the increasing current and future load demand. In this area, the equipment’s ability to withstand seismic events is critical. Complying with all applicable codes and standards (including fire rating, moisture proofing, safety requirements and noise abatement) required an according design of the substation building structure and the electrical equipment. It was decided to build an underground GIS substation, which made the installation quiet and virtually invisible to the public.
Only a single, partially exposed section of wall provides access and a clue as to the location of Park Substation. The park and the adjoining slopes are landscaped and terraced to blend with the surrounding hillsides.

Benefits

Adding to the uniqueness of Park Substation is the fact that it sits below the new Roosevelt Park, an 80 m x 90 m community park that serves the surrounding east Anaheim neighborhood.

Wuelfingen, City of Winterthur, Switzerland (semi-underground design)

Design adapted to the environment – the special site geometry in the city of Winterthur leads to triangle semi-underground substation architecture. The Wuelfingen 110-kV GIS Substation is embedded between a school playground and a highway 4 meters above. The substation building is used to compensate the height difference and muffle the noise from traffic.

Challenges and Solutions:

To meet the requirements posed by the site located close to a motorway exit and adjacent to a school playground and a cemetery a special triangle substation building was designed. All functions of the substation are arranged in the basement, on the ground floor and the top floor. This concept makes for a very compact substation design and is
perfectly matched to the surrounding architecture and the environment. Due to the proximity to the school and the cemetery the authorities have prescribed specific noise limits. Therefore, sound absorbers were installed in the wall openings above the transformer entry.

**Benefits**

The outstanding concept for the Wuelfingen semi-underground substation has been nominated for a Swiss award for technical buildings. The concept not only fits the surroundings, but also keeps the noise away. To improve the energy balance, the heat dissipated from the transformers is used for heating the substation building.

**Haymarket, Sydney, Australia (on-top building)**

Standards in safety – 330/132-kV GIS in Sydney's Central Business District. The Haymarket subterranean substation has a key position in the TransGrid network and was erected in limited space on several stories, most of which are underground.

A unique safety concept unites modern building management systems with monitoring facilities for the GIS. Civil engineering and the latest redundant safety systems meet the highest demands to protect the surrounding area and the people living and working in Sydney's lively business district. To match the required capacity the Haymarket Substation
has three 400-MVA transformers with a mesh 330-kV bus of 4 GIS bays. In addition a 132-kV double-bus GIS with 24 bays and a shunt reactor connected to the 132-kV bus for reactive power support and voltage control are installed.

**Challenges and Solutions:**

Given the city-center location of the bulk-power substation, not only was space at an absolute premium, but extremely strict conditions also had to be met to protect the immediate area and the people living and working there. The Haymarket Substation building is divided into three underground floors and two, above-ground, mezzanine floors. This arrangement makes it possible to have an as-small-as-possible footprint for the substation and to functionally locate the equipment throughout the substation building. The technologies deployed in this project, ranging from the actual building and integrated SCADA-based monitoring system, through the compact gas-insulated switchgear and transformers with integrated control and protection equipment to the SF6 Gas Management Plan (GMP) built around the ModSam monitoring system, all meet the most sophisticated safety standards conceivable today.

**Benefits**

With all incoming and outgoing feeders taking the form of cables, the building has no high-voltage-carrying elements on its outer walls; its high-tech interior is invisible from the outside. Inside, a building management system monitors all functions such as ventilation, airconditioning, water pumps, fire protection, lighting and power supply, as well as gas and oxygen concentrations on all floors.

**Proven Global Experience in Subterranean Substations**

For more than 30 years subterranean substations with Siemens GIS technology have operated below ground or embedded in their environment in many regions of the world providing the highest-possible reliability (Figure 4).
Figure 4: Overview of subterranean Siemens GIS installations from 72 kV to 550 kV worldwide.

7. **Subterranean Substations – Challenges and Special Requirements**

In addition to the standard criteria for design, construction and operation, the decision for a subterranean substation requires the special attention to:

- Ground water table and soil pressure as these are crucial factors for design and cost. Depending on the site’s specific situation, dewatering, shoring or other measures may become necessary.

- Fire Hazards in confined rooms underground. Passive measures for fire protection (e.g. the use of non-flammable, nontoxic materials or the installation an independent ventilation system for the transformers) need to be combined with active measures for firefighting and extinguishing as well as emergency exits and health and safety regulations.

- Due to the lack of windows, heating, ventilation and air conditioning (HVAC) is important with regard to air circulation, cooling and to the humidity of the air in the building.
• Emissions such as noise and electromagnetic radiation have to be managed. Sound absorbers and measures to reduce echoing inside the building are essential. Electromagnetic compatibility (EMC) requirements have to be considered right from the start.

• Access for heavy equipment and the architectural design of visible parts. Furthermore, planning the sequence in which equipment is brought in as well as adequate service access is necessary.

8. Conclusions

Whenever a new substation is planned, the individual demands of the specific project have to be considered. Thanks to its highly compact design, GIS can be installed wherever space is limited or costly. Different applications, outdoor or indoor installations in containers or buildings, are possible. Due to the extremely low noise level and field emissions (EMC) this switchgear can be implemented even in sensitive environments, residential quarters or city centers for utility and industrial customers. The design even allows application in areas prone to earthquakes.

With its comprehensive benefits – space-saving, high flexibility and reliability, GIS offers owners new options for urban and industrial solutions, especially with regard to subterranean installations.

Subterranean substations have many benefits. They allow directly connecting inner city nodes to the high-voltage and extra-high-voltage networks, which reduces transmission losses and enhances energy efficiency. Not only do they provide great architectural flexibility, they operate silently and are invisible to the surrounding area. Challenges such as

• ground water tables and soil pressures,
• access for heavy equipment,
• architectural design of visible parts,
• emission control and HVAC requirements,
• fire hazards in confined rooms

need to be solved by combining established know-how and experience. Local expertise and partnership are essential for obtaining approval from the respective authorities without problems as well as for on-time completion and reliable long-term operation of the substation.
While the focus of substation specification and design has been on providing innovative solutions that meet safety and environmental requirements, the focus with regard to specifications for major electrical components has been on selecting established designs with excellent operational track records. This combination is considered to provide the best combination of innovation, proven design and performance when it comes to meeting the criteria critical for subterranean substations.

Last, but not least, when searching for the best-suited economic substation solution, owners should always consider the total life-cycle cost and never fail to look for turnkey switchgear expertise.

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