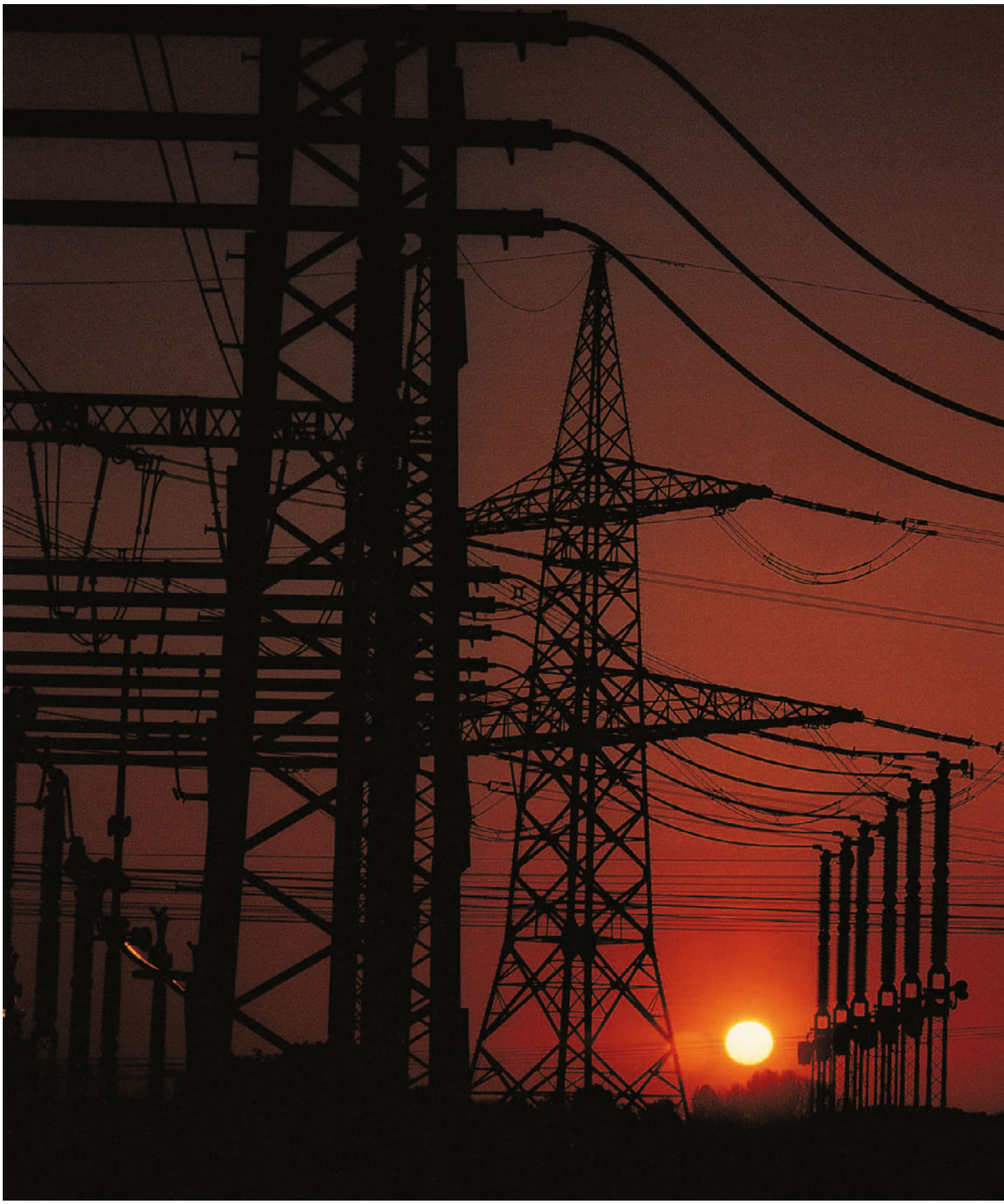


2 Power Transmission and Distribution Solutions

2

2.1 Overview of Technologies and Services

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

2.1.1 Solutions for Smart and Super Grids with HVDC and FACTS

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

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

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

Features of a future smart grid such as this can be outlined as follows:

- Flexible: fulfilling operator needs whilst responding to the changes and challenges ahead
- Accessible: granting connection access to all network users, particularly for RES and high-efficiency local generation with zero or low carbon emissions
- Reliable: assuring and improving security and quality of supply
- Economic: providing best value through innovation, efficient energy management and "level playing field" competition and regulation

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

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

2.1.2 AC/DC Transmission and Distribution

HVDC, FACTS and SIPLINK

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

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

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

For medium-voltage DC transmission, Siemens offers the SIPLINK system. Depending on the application and the configuration of the existing system, SIPLINK will reduce investment, system and lifecycle costs. The system controls the active power and optimizes voltage stability by providing reactive power (section 2.3).

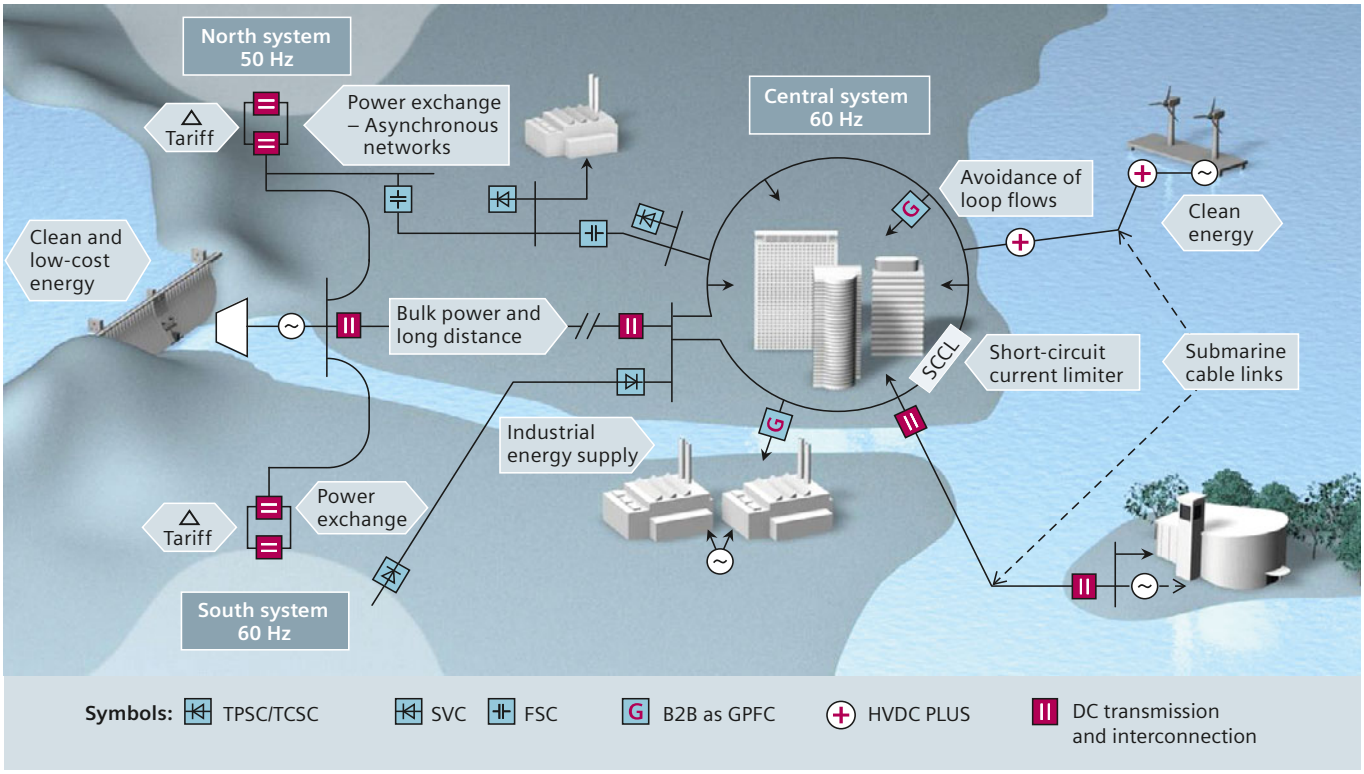


Fig. 2.1-1: **Power transmission and distribution solutions**

Power lines

Since the very beginning of electric power supply, overhead lines have constituted the most important component for transmission and distribution systems. Their portion of the overall length of electric circuits depends on the voltage level and on local conditions and practice. When environmental or structural factors make overhead lines impossible, Siemens's "underground" transmission path is the ideal solution. Siemens gas-insulated transmission lines (GIL) are an economically viable alternative to conventional power cables (section 2.5).

Grid access

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

Solar power

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

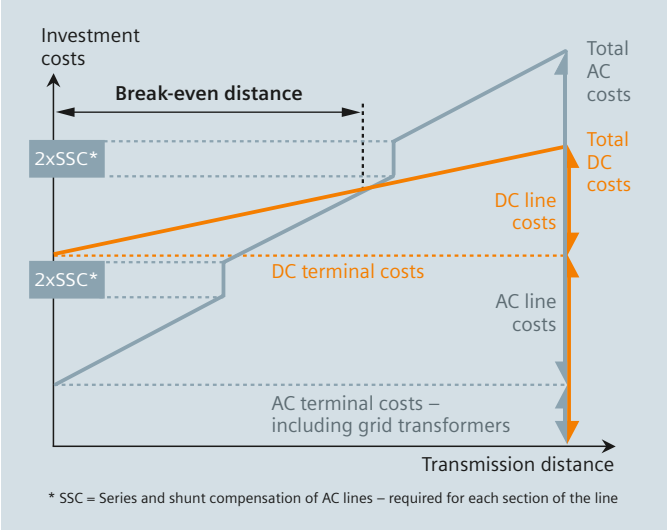


Fig. 2.1-2: **AC versus DC transmission cost over distance. The break-even distance amounts to 600 km for a power transmission of 1,000 MW**

2

2.1.3 Managing Entire Projects

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

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

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

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

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

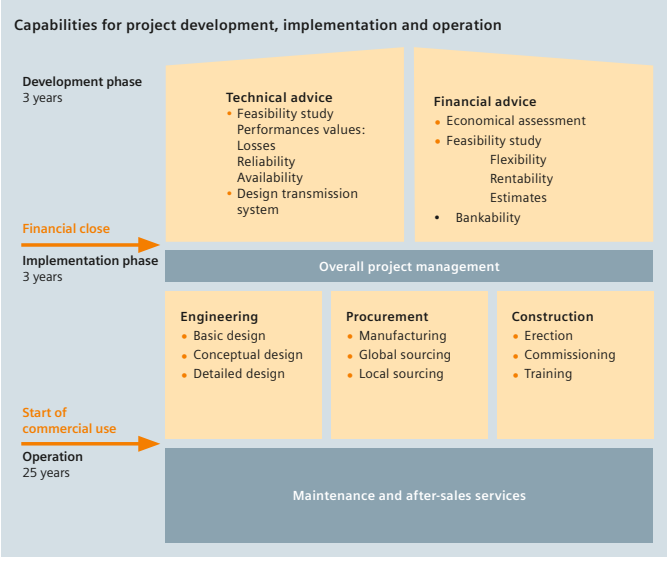


Fig. 2.1-3: **Siemens services for the entire system life cycle**

2.1.4 Partners Throughout the System Life Cycle

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

For further information:
http://www.siemens.com/energy/power-transmission-solutions
http://www.siemens.com/energy/hvdc-facts-newsletter

2.2 High-Voltage Direct-Current Transmission

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

Featuring its fast and precise controllability, a Siemens HVDC can serve the following purposes:

- Transmission of power via very long overhead lines or via long cables where an AC transmission scheme is not economical or even not possible
- Transmission of power between asynchronous systems
- Exact control of power flow in either direction
- Enhancement of AC system stability
- Reactive power control and support of the AC voltage
- Frequency control
- Power oscillation damping

2.2.1 Siemens HVDC Technologies

Depending on the converter type used for conversion between AC and DC, two technologies are available:

- Line Commutated Converter technology (LCC) based on thyristor valves
- Voltage Sourced Converter technology (VSC) based on IGBT valves, also known as HVDC PLUS

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

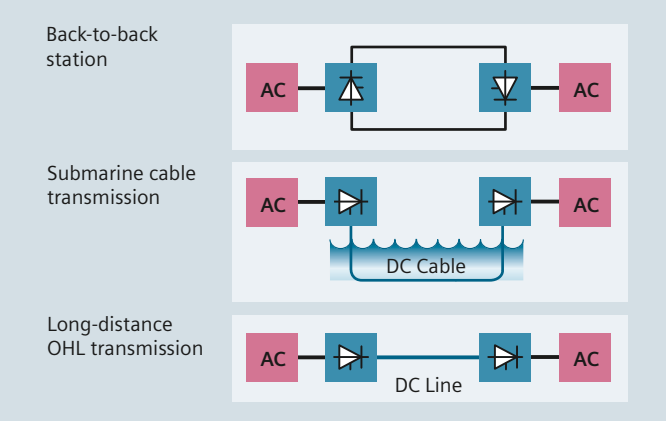


Fig. 2.2-1: **Overview of main power transmission applications with HVDC**

2.2.2 Main Types of HVDC Schemes

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

Back-to-back:
Rectifier and inverter are located in the same station. These converters are mainly used:

- To connect asynchronous high-voltage power systems or systems with different frequencies
- To stabilize weak AC links
- To supply more active power where the AC system already is at the limit of its short circuit capability
- For grid power flow control within synchronous AC systems

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

Long-distance transmission:
Whenever bulk power is to be transmitted over long distances, DC transmission is the more economical solution compared to high-voltage AC.

2.2.3 LCC HVDC – The "Classical" Solution

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

Technology

Thyristor valves

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

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

Filter technology

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

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

Applications

The primary application areas for LCC HVDC are:

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

Power ratings

Typical ratings for HVDC schemes include:

- Back-to-back: up to typically 1,200 MW
- Cable transmission: up to 800 MW per HVDC cable
- Long-distance transmission: up to typically 5,000 MW

Fig. 2.2-2: **Earthquake-proof and fire-retardant thyristor valves in long-distance transmission in Guizho-Guangdong, China**

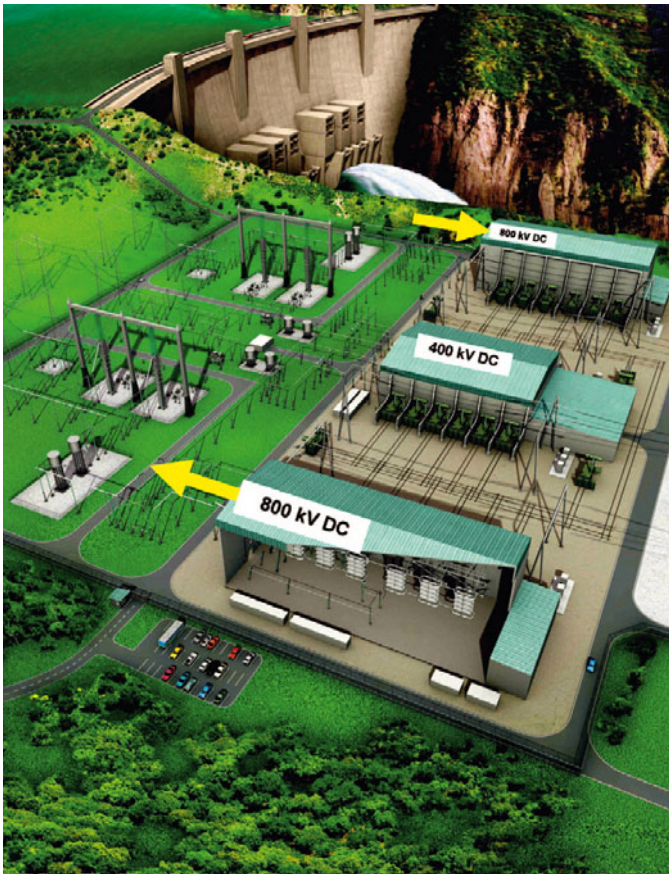


Fig. 2.2-3: **Two times two 400 kV converter systems connected in series form a ± 800 kV UHV DC station**

2.2.4 Ultra-HVDC Transmission (UHV DC) Bulk Power

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

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

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

Applications
UHV DC transmission is the solution for bulk power transmission of 5,000 MW or higher over some thousand kilometers. Compared to a 500 kV LCC HVDC system, the Siemens 800 kV UHV DC reduces line losses by approx. 60 % – an important aspect with respect to CO_2 reduction and operational cost.

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

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

Fig. 2.2-4: **A 20.8 m long wall bushing is required in order to connect the 800 kV terminal of the indoor thyristor valves to the outdoor HVDC equipment and overhead line**

Fig. 2.2-5: **UH voltage and power electronics – the thyristor valves are designed to operate at 800 kV voltage level. Yunnan-Guangdong, China**

2.2.5 HVDC PLUS – One Step Ahead

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

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

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

Features
HVDC PLUS provides important technical and economical advantages compared to LCC:
- HVDC technology in the smallest possible space:
  An HVDC PLUS station does not require any filters (fig. 2.2-6).

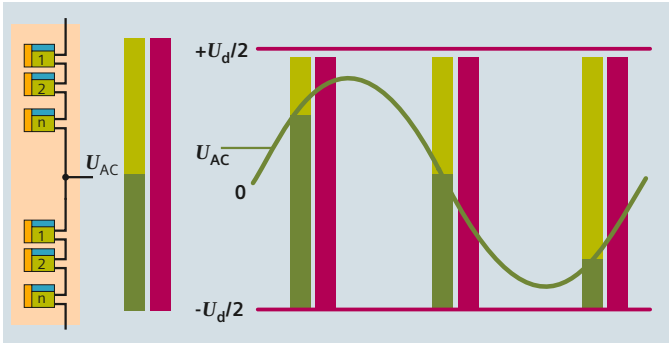


Fig. 2.2-6: **The HVDC PLUS multilevel converters achieve conversion between AC and DC virtually free from harmonics. The AC side converter terminal voltage is perfectly sinusoidal**

Together with a compact design of the MMC, this makes HVDC PLUS perfectly suitable for offshore platforms or stations with limited space (fig. 2.2-7, fig. 2.2-8).

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

Applications

HVDC PLUS can be applied in all fields of HVDC transmission – there are no technical restrictions. The advantages of HVDC PLUS will be most apparent in circumstances that require the following capabilities:

- Black start of AC networks
- Operation in AC networks with low short-circuit capacity
- Compact design, e. g., for offshore platforms
- Operation in DC multi-terminal systems or in a DC grid

Power ratings

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

2.2.6 Siemens HVDC Control System: Win-TDC

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

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

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

Fig. 2.2-7: **The heart of HVDC PLUS is a modular multilevel converter (MMC) which can be scaled according to the voltage or power requirements. Transbay Cable, USA**

Fig. 2.2-8: **Only a few power components are needed outside the converter hall to make up a complete HVDC PLUS station. In particular, HVDC PLUS can meet highest harmonic performance standards without any filters. Transbay Cable, USA**

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

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

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

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

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

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

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

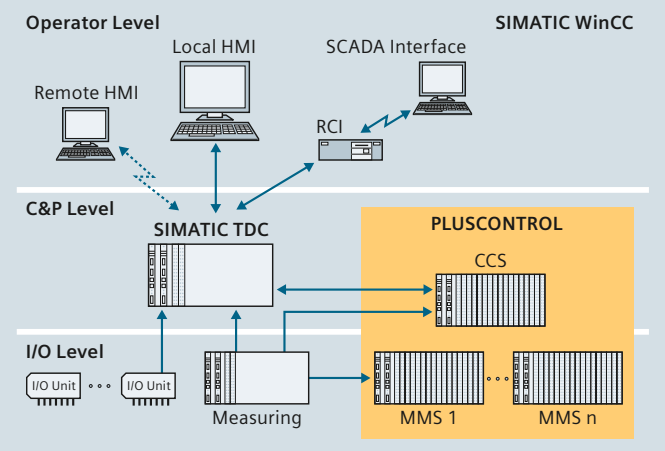


Fig. 2.2-9: **Win-TDC hierarchy – More than 30 years of experience are built into the hierarchical Siemens HVDC control system which is based on standard components most widely used also in other industries**

Fig. 2.2-10: **The control and protection cubicles are intensively tested in the Siemens laboratories before they are shipped to site assuring fast and smooth commissioning of the HVDC system**

2.2.7 Services

The following set of services completes the Siemens HVDC portfolio.

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

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

General services
Extended support is provided to customers of Siemens from the very beginning of HVDC system planning, including:
- Feasibility studies
- Drafting the specification
- Project execution
- System operation and long-term maintenance
- Consultancy on upgrading/replacement of components/redesign of older schemes, e. g., retrofit of mercury-arc valves or relay-based controls

Studies during contract execution are conducted on system engineering, power system stability and transients:
- Load-flow optimization
- HVDC systems basic design
- System dynamic response
- Harmonic analysis and filter design for LCC HVDC
- Insulation and protection coordination
- Radio and PLC interference
- Special studies, if any

For further information:
http://www.siemens.com/energy/hvdc
http://www.siemens.com/energy/hvdc-plus
http://www.siemens.com/energy/uhvdc

2.3 Medium-Voltage DC Links with SIPLINK

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

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

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

2.3.1 Shore-to-Ship Connection

Cost pressure and increasingly stringent environmental regulations are forcing many ports to supply ships in port with electrical power from an onshore source. To address this need, Siemens has developed SIHARBOR, a shore-to-ship connection system that meets the requirements of port operators, shipping companies, dockyards and power supply companies. Thanks to SIHARBOR, ships can shut down their diesel generating sets that

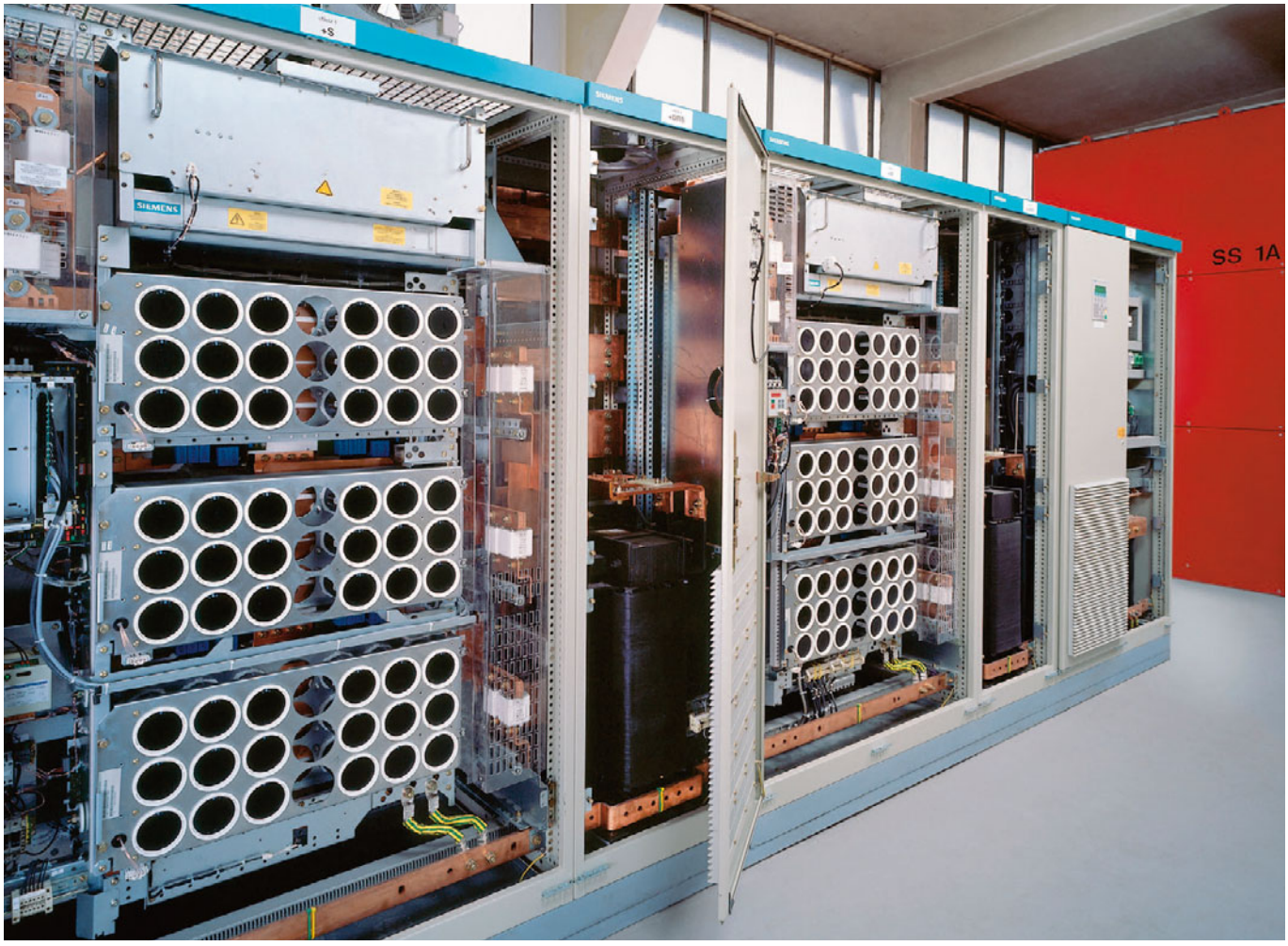


Fig. 2.3-1: **SIPLINK with opened cabinet doors**

would otherwise be needed, and that not only produce electricity but also produce exhaust gases, soot, fine dust and noise, thus contributing to "harbor smog" (fig. 2.3-3).

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

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

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

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

2.3.2 Power Transfer Between Distribution Networks

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

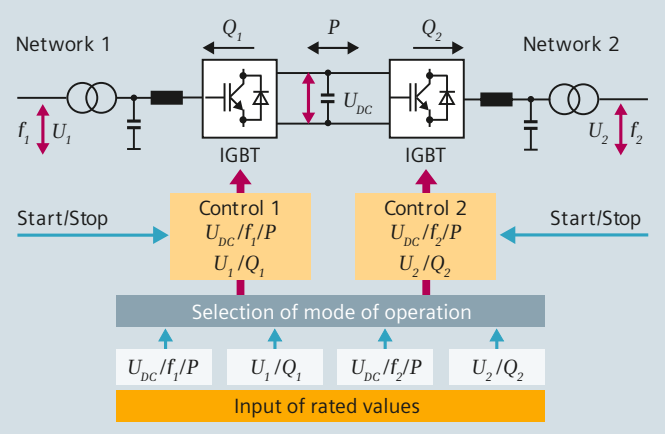


Fig. 2.3-2: **System configuration of SIPLINK with two self-commutated IGBT pulse-controlled converters for controlling the active power flow and for rapid reactive power regulation**

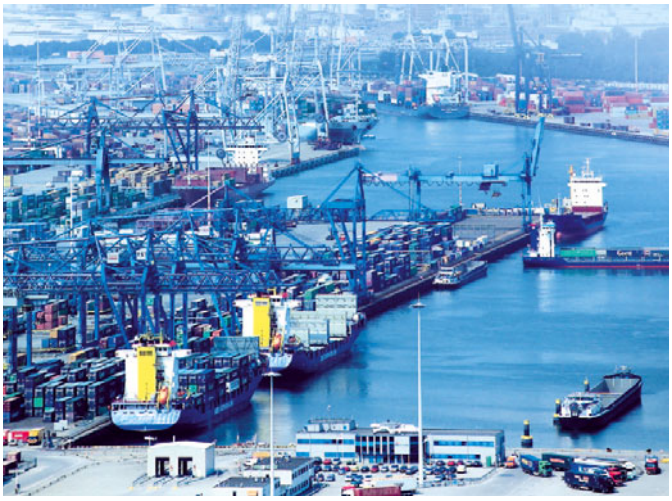


Fig. 2.3-3: **An innovative solution to counter "harbor smog": Siemens technology supplies ships in port with environmentally friendly electricity from the public network**

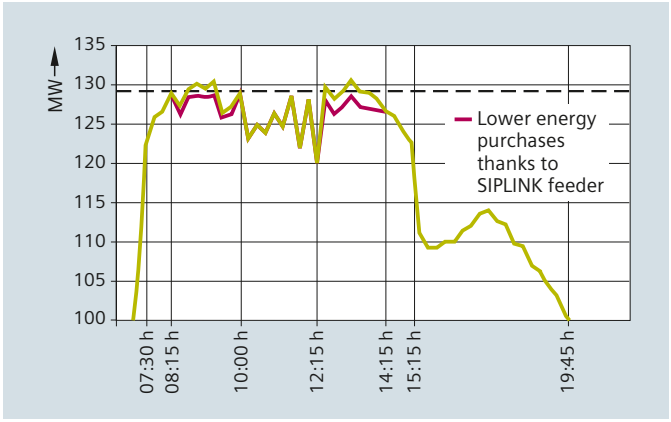


Fig. 2.3-4: **Lower daily peaks in the distribution system of a population center as a result of procuring power from another distribution network linked via SIPLINK**

2

2.3.3 High Availability of Industrial Networks

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

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

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

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

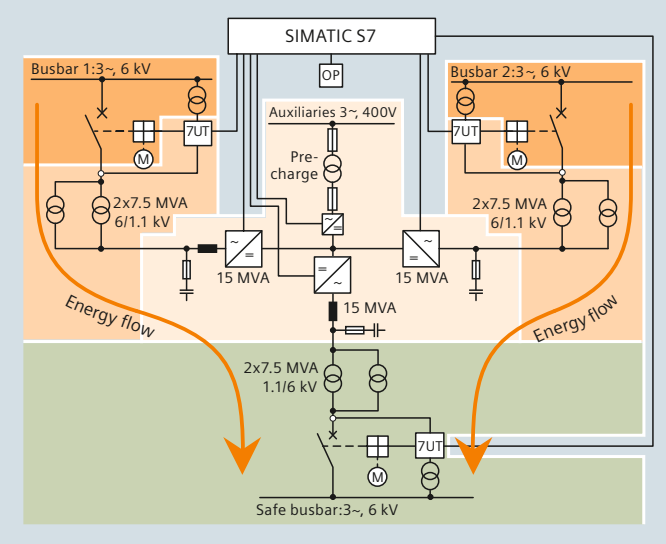


Fig. 2.3-5: **With the fault-tolerant energy supply, the safe busbar (or consumer) is connected simultaneously to two feeding busbars**

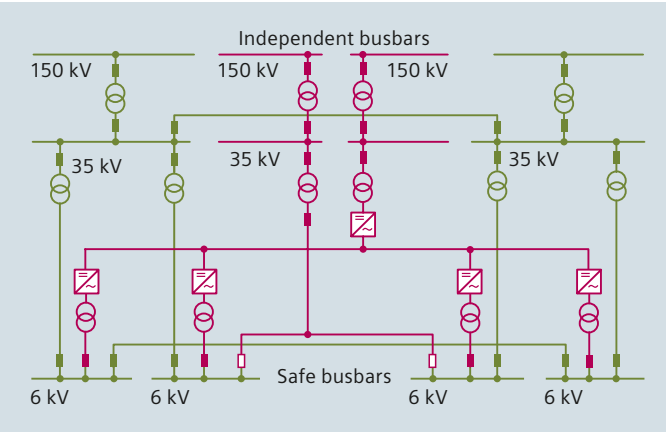


Fig. 2.3-6: **With the SIPLINK Multi Feed circuit arrangement, each of the safe busbars is connected simultaneously to three busbars and an independent feeder**

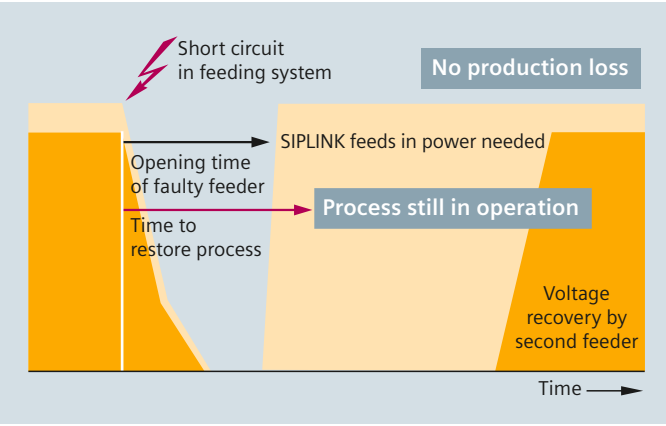


Fig. 2.3-7: **Voltage curve on the busbar in the case of a short circuit in the feeding system with support by SIPLINK**

2.4 Flexible AC Transmission Systems

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

FACTS can also help solve technical problems in the interconnected power systems. FACTS are available in parallel connection:
- Static Var Compensator (SVC)
- Static Synchronous Compensator (STATCOM)

  or in series connection:
- Fixed Series Compensation (FSC)
- Thyristor Controlled/Protected Series Compensation (TCSC/TPSC)

2.4.1 Parallel Compensation

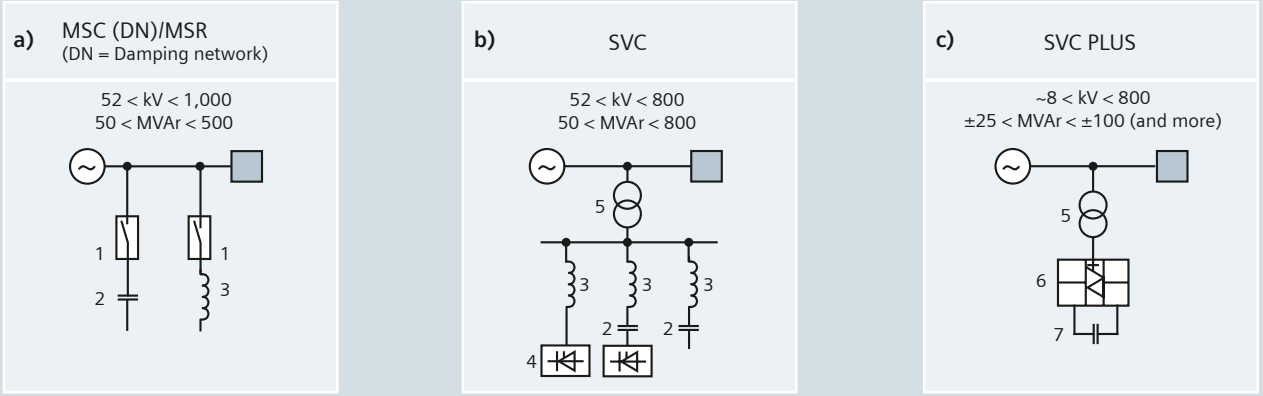
Parallel compensation is defined as any type of reactive power compensation employing either switched or controlled units that are connected in parallel to the transmission network at a power system node.

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

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

Fig. 2.4-2: **Static Var Compensator (SVC) installation**

Parallel compensation



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

Fig. 2.4-1a: **Mechanically switched capacitors (MSC) and mechanically switched reactors (MSR) connected to the transmission system**
Fig. 2.4-1b: **Static Var Compensator (SVC) with three branches (TCR, TSC, filter) and coupling transformer**
Fig. 2.4-1c: **SVC PLUS connected to the transmission system**

2

OFF by thyristor valves (TSC). Reactors can be either switched (TSR) or controlled (TCR) by thyristor valves.

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

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

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

SVC PLUS – new generation of STATCOM

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

Applications

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

Modular system design

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

Portfolio
- Standardized configurations are available: ± 25, ± 35, and ± 50 MVAr as containerized solutions. Up to four of these units can be configured as a fully parallel operating system.
- Easily expendable and relocatable
- Open rack modular system configuration enables transformerless grid connection up to 36 kV and ± 100 MVAr. For higher system voltages, standard AC transformers are used.
- Hybrid solutions with mechanically switched capacitors (MSC) or reactors (MSR) are available.

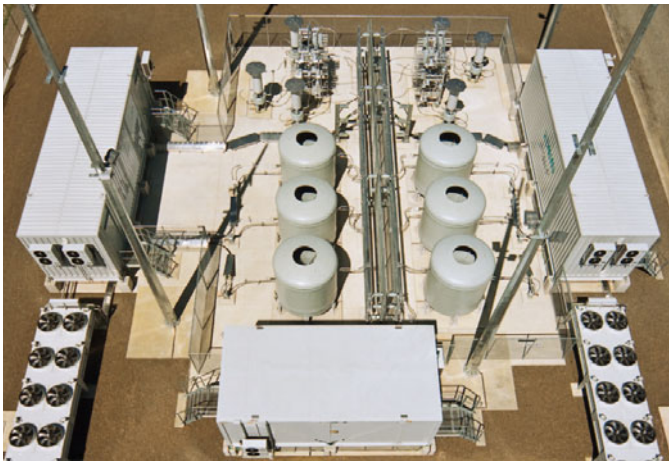


Fig. 2.4-3: **Two SVC PLUS units in New Zealand**

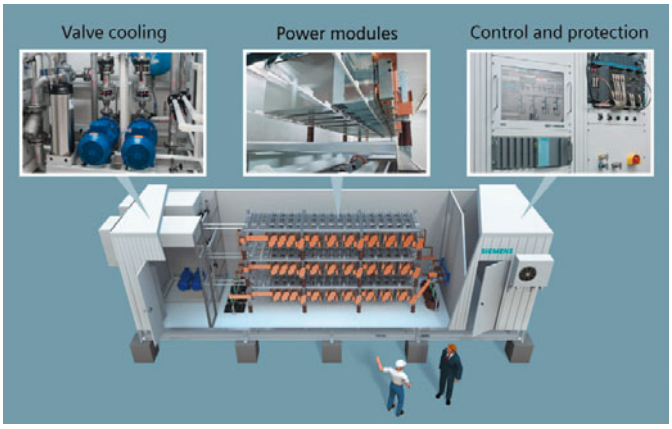


Fig. 2.4-4: **SVC PLUS containerized solution**

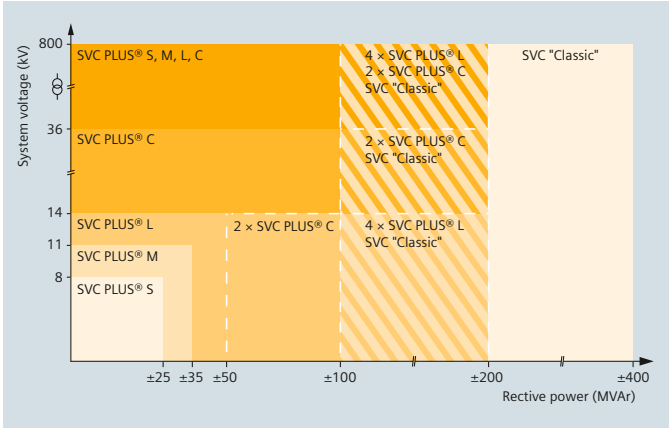


Fig. 2.4-5: **SVC PLUS portfolio**

2.4.2 Series Compensation

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

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

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

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

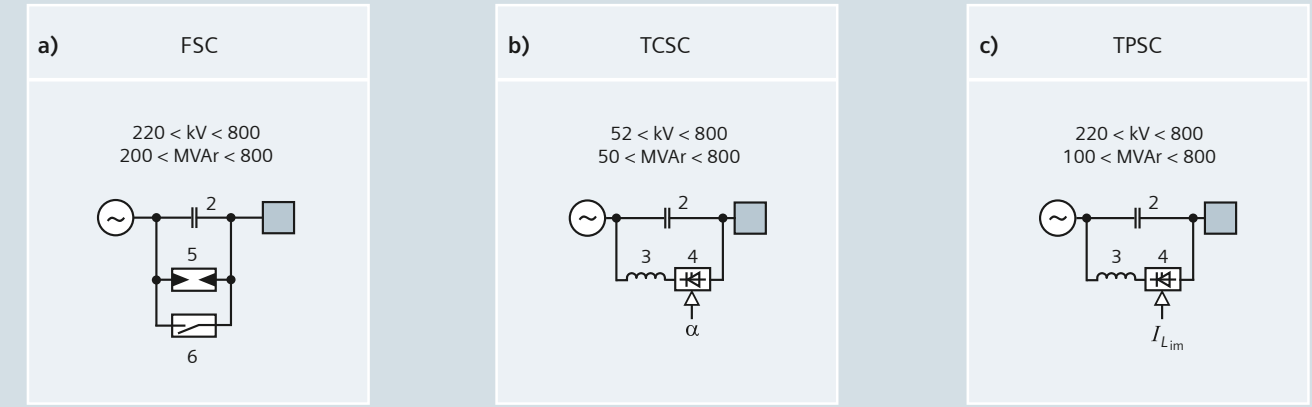
Additional benefits of thyristor-controlled series compensation:
- Damping of power oscillations (POD)
- Load flow control
- Increase in system stability
- Thyristor-Protected Series Capacitor (TPSC)

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

Fig. 2.4-6: **View of a TCSC system**

For further information:
http://www.siemens.com/energy/facts

Series compensation



1 Switchgear 2 Capacitor 3 Reactor 4 Thyristor valve(s) 5 Arrester 6 Circuit-breaker

Fig. 2.4-7a: **Fixed series compensation (FSC) connected to the network**
Fig. 2.4-7b: **Thyristor-controlled series capacitor (TCSC) connected to the network**
Fig. 2.4-7c: **Thyristor-protected series capacitor (TPSC) connected to the network**

2.5 Power Transmission Lines

2.5.1 Gas-Insulated Transmission Lines

For high-power transmission systems where overhead lines are not suitable, alternatives are gas-insulated transmission lines (GIL). GIL exhibit the following differences to cables:

- High-power ratings (transmission capacity up to 3,700 MVA per system)
- High overload capability
- Auto-reclosing functionality without overheating risk
- Suitable for long distances (70 km and more without compensation of reactive power)
- High short-circuit withstand capability (even in the theoretical case of internal arc faults)
- Possibility of direct connection to gas-insulated switchgear (GIS) and gas-insulated arresters without cable entrance fitting
- Non-flammable; no fire risk in case of failures
- Lowest electromagnetic field

History / Siemens' experience

When SF_6 was introduced in the 1960s as an insulating and switching gas, it became the basis for the development of gas-insulated switchgear. On basis of the experience collected with GIS, Siemens started to develop SF_6 gas-insulated lines to transmit electrical energy. The aim was to create alternatives to air insulated overhead lines with decisively smaller clearances. In the early 1970s initial projects were implemented. More installations in tunnels and above ground followed. In the course of product optimization, the initially used insulating medium SF_6 was replaced by a gas mixture where the majority of the insulating gas is nitrogen, a non toxic natural gas. Only a comparatively small portion of sulfur hexafluoride (SF_6) is still needed. Thus, the way was free for environmentally friendly long transmission projects with GIL. The latest innovation of Siemens GIL is the directly buried laying technique, which was a further milestone for long distance transmission with GIL.

Challenges now and in the future

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

The transmission systems of the future will be measured by their overall CO_2 balance, asking for the minimum possible environmental impact from production of the equipment through

Fig. 2.5-1: **GIL arrangement in the tunnel of the pumped-storage power plant in Wehr, Southern Germany (4,000 m length; in service since 1975)**

High EM compatibitity

Magnetic fields in microtesla [µT] for GIL, overhead transmission line and cable (XLPE, cross-bonding) for a 400 kV double system at 2 × 1,000 MVA load, GIL and cable laid at a depth of 1 m.

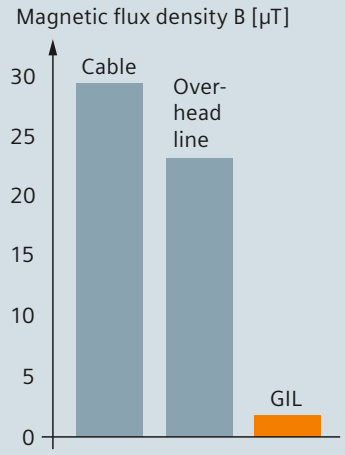


Fig. 2.5-2: **A comparison of the magnetic fields for different high-voltage transmission systems**

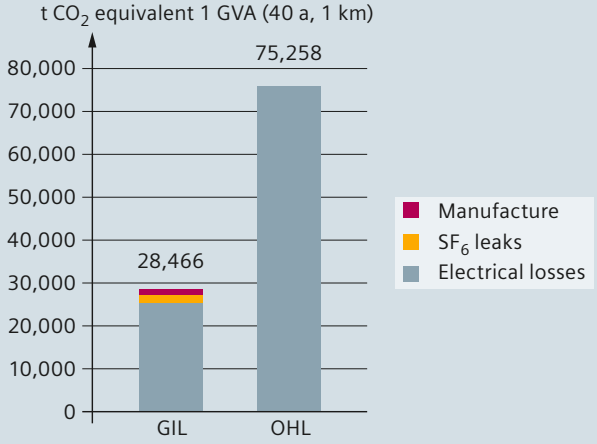


Fig. 2.5-2a: **Overall CO_2 impact of different transmission systems (one system)**

operational while in service until its end of service life. Due to its properties and low losses, the overall CO_2 impact of GIL is clearly lower than that of traditional overhead-lines, proving the GIL's environment friendliness.

Reliable technology

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

Basic design

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

Testing

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

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

Fault containment

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

Electromagnetic compatibility allows flexible route planning

The construction of the GIL results in much smaller electromagnetic fields than with conventional power transmission systems. A reduction by a factor of 15 to 20 can be achieved. This makes GIL suitable to follow new routings through populated areas (e.g., next to hospitals or residential areas, in the vicinity of flight monitoring systems, etc.). GIL can be laid in combined

Fig. 2.5-3: **Long-term test setup at IPH, Berlin**

Fig. 2.5-4: **Siemens lab sample for dielectric tests**

Technical data short-circuit capacity 63 kA	
Rated voltage	Up to 550 kV
Rated current	up to 5,000 A
Transmission capacity	up to 3,700 MVA
Capacitance	≈ 60 nF / km
Length	up to 70 km
Gas mixture SF_6/N_2	20 % / 80 % (400 kV), 60 % / 40 % (500 kV)
Laying	Directly buried
	In tunnels, sloping galleries, vertical shafts
	Open-air installation, above ground

Table 2.5-1: **Technical data of GIL**

2

infrastructure tunnels together with foreign elements (e.g., close to telecommunication equipment and similar). Thus, GIL provides maximum flexibility for the planning of transmission networks in EMC-sensitive environments, where magnetic fields have to be avoided. Siemens GIL systems can satisfy the most stringent magnetic flux density requirements, for example, the Swiss limit of 1 µT (fig. 2.5-2).

Jointing technique

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

Laying

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

Above ground installation

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

Tunnel installation

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

Vertical Installation

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

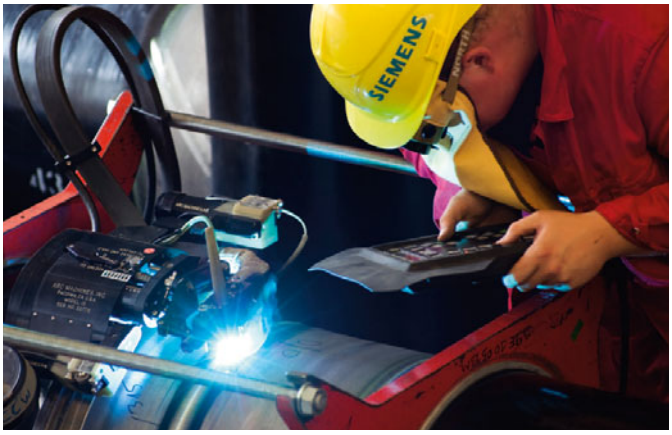


Fig. 2.5-5: **Orbital welding of GIL pipes**

Fig. 2.5-6: **Above ground installation**

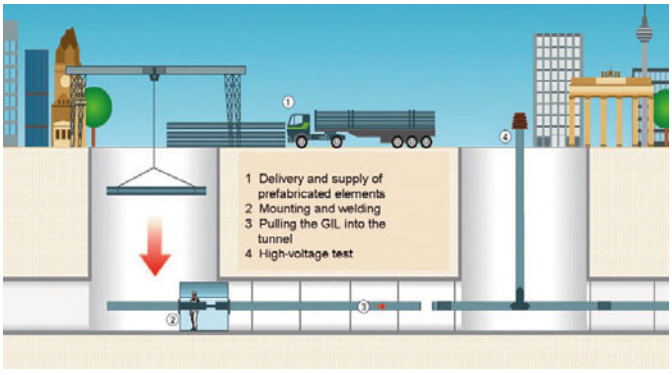


Fig. 2.5-7: **GIL laying technique for tunnel installation**

Fig. 2.5-8: **Directly buried GIL**

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

Direct burying

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

References

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

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

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

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

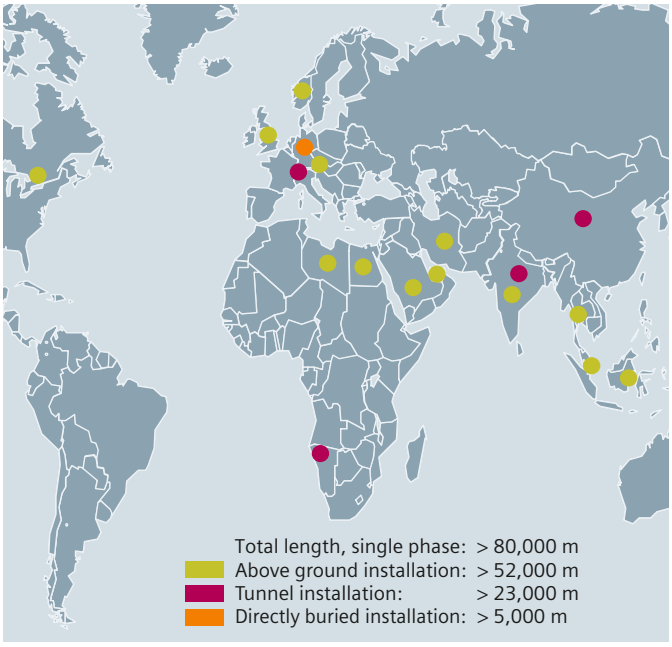


Fig. 2.5-9: **References: Gas-insulated transmission lines, status July 2010**

Fig. 2.5-10: **GIL laid in shaft with 42° gradient (Limberg, Kaprun, Austria)**

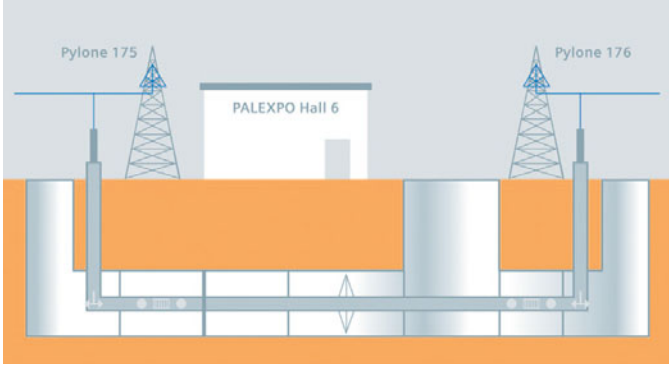


Fig. 2.5-11: **GIL replacing overhead line (Palexpo, Geneva, Switzerland)**

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2.5.2 Overhead Lines

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

Selection of line voltage
For the distribution and transmission of electric power, standardized voltages according to IEC 60038 are used worldwide. For 3-phase AC applications, three voltage levels prevail:
- Low voltage (up to 1 kV AC)
- Medium voltage (between 1 kV and 36 kV AC)
- High voltage (between 52 kV and 765 kV AC) and higher

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

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

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

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

HVDC transmission is used for bulk power transmission and for system interconnection. The line voltages applied for projects worldwide vary between ±300 kV, ±400 kV, ±500 kV, ±600 kV and recently (2007), ±800 kV. The selection of the HVDC line voltage is ruled by the following parameters:
- Amount of power to be transferred
- Length of the overhead power line
- Permissible power losses
- Economical conductor size

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

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

Conclusions:

- 300 kV voltage level:
  The range of 750 and 1,000 km with a power transfer of 600 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per MW power and km of transmission line. The result shows that for long-distance HVDC transmission, the 300 kV voltage level is not the optimal solution (refer to 400 kV below). However, this voltage level is useful in short HVDC interconnectors such as the Thailand-Malaysia Interconnector, which has a line length of 113 km.
- 400 kV voltage level:
  The range 750, 1,000 and 1,500 km with a power transfer of 600, 1,000 and 2,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 400 kV voltage level is a suitable solution for line lengths of 750 to 1,000 km with transmitted power of 600 to 1,000 MW.
- 500 kV voltage level:
  The range 1,000 and 1,500 km with a power transfer of 1,000, 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 500 kV voltage level is a suitable solution for the line lengths of 1,000 km to 1,500 km with transmitted power of 1,000 to 2,000 MW. However, the 400 kV voltage level can also be competitive in this range of power and line length.
- 600 kV voltage level:
  The range 1,500, 2,000 and 3,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 600 kV voltage level is a suitable solution for the line lengths of 1500 km to 3,000 km with transmitted power of 2,000 MW, and 3,000 MW for lines up to 2,000 km. However, the 500 kV voltage level can still be competitive in parts of this range.
- 800 kV voltage level:
  The range 2,000, 3,000 and 4,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line. The result shows that the 800 kV voltage level is a suitable solution for the line lengths of 2,000 km and above with transmitted power of 2,000 and 3,000 MW. However, shorter line lengths of 1,500 to 3,000 km with power rating of 3,000 to 7,000 MW can be economically covered with an 800 kV solution.

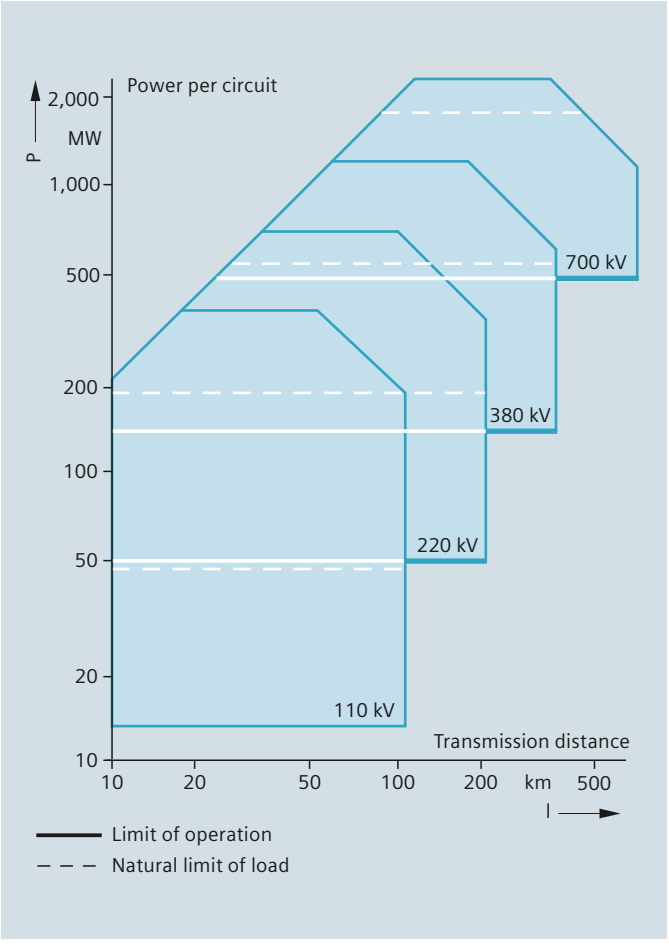

Fig. 2.5-12: **Selection of rated voltage for power transmission**

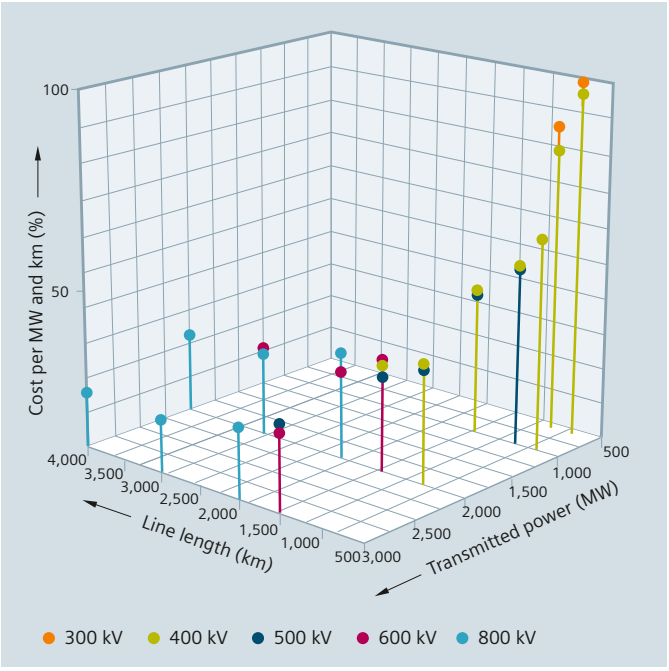

Fig. 2.5-13: **Economical application of DC voltages in relation to overhead transmission line length and transmitted power**

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Selection of conductors and earth wires

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

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

Experience has shown that ACSR conductors, just like aluminum and aluminum alloy conductors, provide the most economical solution and offer a life span greater than 40 years. Conductors are selected according to electrical, thermal, mechanical and economic aspects. The electric resistance as a result of the conducting material and its cross-section is the most important feature affecting the voltage drop and the energy losses along the line and, therefore, the transmission costs. The cross-section has to be selected so that the permissible temperatures will not be exceeded during normal operation as well as under short-circuit condition. With increasing cross-section, the line costs increase, while the costs for losses decrease. Depending on the length of the line and the power to be transmitted, a cross-section can be determined that results in the lowest transmission costs. The heat balance of ohmic losses and solar radiation against convection and radiation determines the conductor temperature. A current density of 0.5 to 1.0 A/mm^2 based on the aluminum cross-section has proven to be an economical solution in most cases.

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

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

Rated voltage	**[kV]**	**20**		**110**		**220**		**380**		**700**
Highest system voltage	[kV]	24		123		245		420		765
Nominal cross-section	[mm^2]	50	120	150	300	435	bundle 2x240	bundle 4x240	bundle 2x560	bundle 4x560
Conductor diameter	[mm]	9.6	15.5	17.1	24.5	28.8	2x21.9	4x21.9	2x32.2	4x32.2
Ampacity (at 80 °C conductor temperature)	[A]	210	410	470	740	900	1,290	2,580	2,080	4,160
Thermal capacity	[MVA]	7	14	90	140	340	490	1,700	1,370	5,400
Resistance at 20 °C	[Ω/km]	0.59	0.24	0.19	0.10	0.067	0.059	0.030	0.026	0.013
Reactance at 50 Hz	[Ω/km]	0.39	0.34	0.41	0.38	0.4	0.32	0.26	0.27	0.28
Effective capacitance	[nF/km]	9.7	11.2	9.3	10	9.5	11.5	14.4	13.8	13.1
Capacitance to earth	[nF/km]	3.4	3.6	4.0	4.2	4.8	6.3	6.5	6.4	6.1
Charging power	[kVA/km]	1.2	1.4	35	38	145	175	650	625	2,320
Earth-fault current	[A/km]	0.04	0.04	0.25	0.25	0.58	0.76	1.35	1.32	2.48
Surge impedance	[Ω]	360	310	375	350	365	300	240	250	260
Surge impedance load	[MVA]	–	–	32	35	135	160	600	577	2,170

Table 2.5-2: **Electric characteristics of AC overhead power lines (data refer to one circuit of a double-circuit line)**

ductor damage. The maximum working tensile stress should be limited to approximately 40 % of the rated tensile stress.

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

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

Selection of insulators

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

The electrical stresses result from:

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

Insulator types

Various insulator designs are in use, depending on the requirements and the experience with certain insulator types:

- Cap-and-pin insulators (fig. 2.5-14) are made of porcelain or pre-stressed glass. The individual units are connected by fittings of malleable cast iron or forged iron. The insulating bodies are not puncture-proof, which is the reason for a relatively high number of insulator failures.
- In Central Europe, long-rod insulators made from aluminous porcelain (fig. 2.5-15) are most frequently adopted. These insulators are puncture-proof. Failures under operation are extremely rare. Long-rod insulators show superior behavior, especially in polluted areas. Because porcelain is a brittle material, porcelain long-rod insulators should be protected from bending loads by suitable fittings.
- Composite insulators are the third major type of insulator for overhead power line applications (fig. 2.5-16). This insulator type provides superior performance and reliability, particularly because of improvements over the last 20 years, and has been in service for more than 30 years.

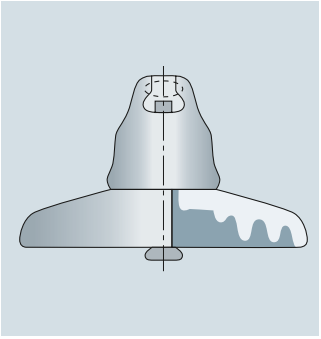

Fig. 2.5-14: **Cap-and-pin insulator (above)**

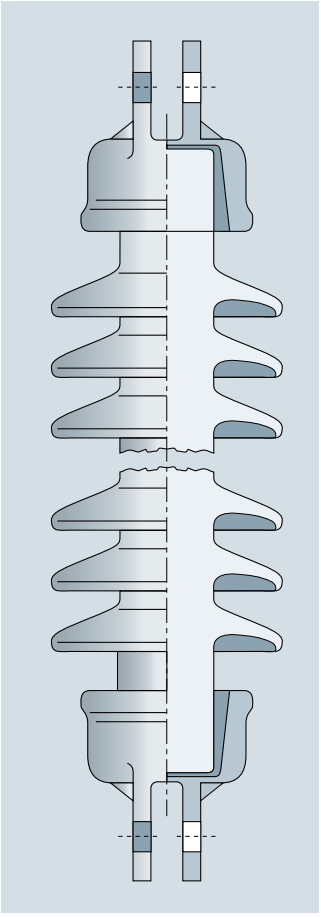

Fig. 2.5-15: **Long-rod insulator with clevis caps**

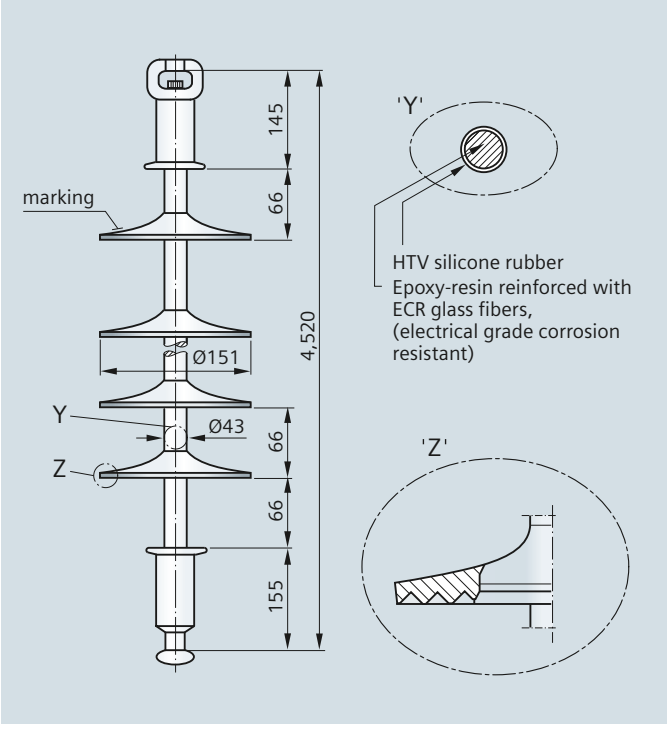

Fig. 2.5-16: **Glass fiber reinforced composite insulator with ball and socket fittings (lapp insulator)**

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The composite insulator is made of a glass fiber reinforced epoxy rod. The glass fibers applied are ECR glass fibers that are resistant to brittle fracture (ECR = electrical grade corrosion resistant glass fibers). In order to avoid brittle fracture, the glass fiber rod must additionally be sealed very carefully and durably against moisture. This is done by application of silicone rubber. Nowadays, high temperature vulcanized (HTV) silicone is used.

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

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

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

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

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

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

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

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

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

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

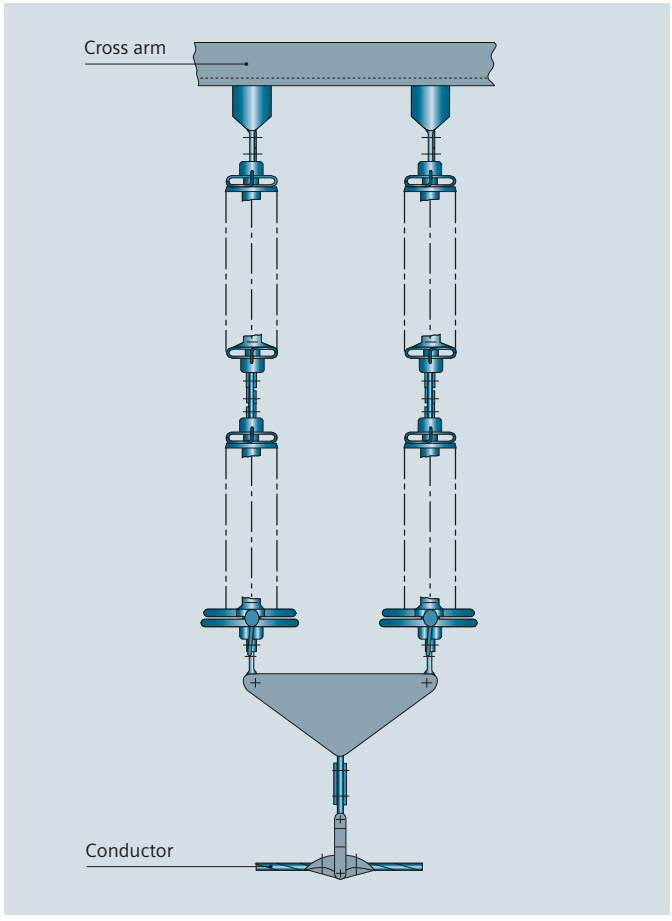

Fig. 2.5-17a: **I-shaped suspension insulator set for 245 kV**

IEC 60815 level		Porcelain and glass insulators		Composite insulators	
		AC system	DC system	AC system	DC system
I Light	[mm/kV]	16	39	12	29
II Medium	[mm/kV]	20	47	15	35
III Heavy	[mm/kV]	25	59	19	44
IV Very Heavy	[mm/kV]	31	72	24	54

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

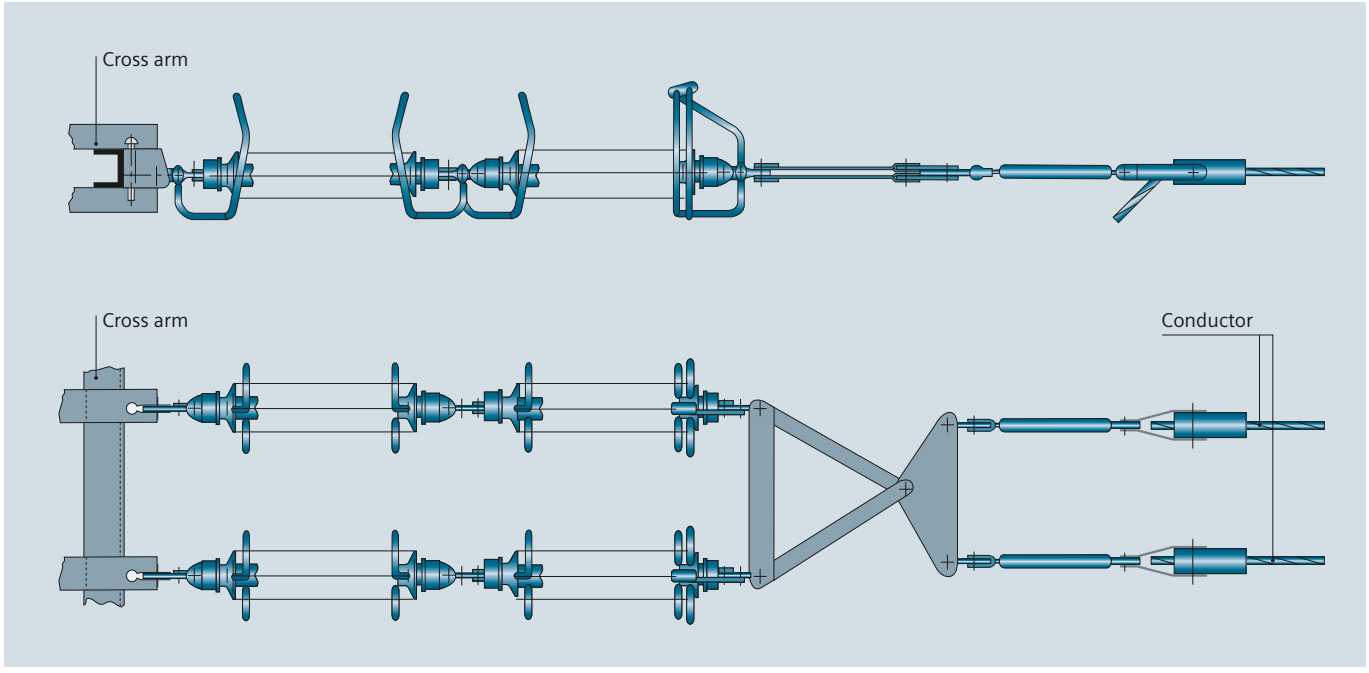

Fig. 2.5-17b: **Double tension insulator set for 245 kV (elevation, top)**
Fig. 2.5-17c: **Double tension insulator set for 245 kV (plan, bottom)**

2

sible and a narrow right-of-way, which can only be met by compromises. The minimum clearance of the conductors depends on the voltage and the conductor sag. In ice-prone areas, conductors should not be arranged vertically, in order to avoid conductor clashing after ice shedding.

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

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

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

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

- Conductor configuration
- Electric field requirements
- Insulation design

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

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

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

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

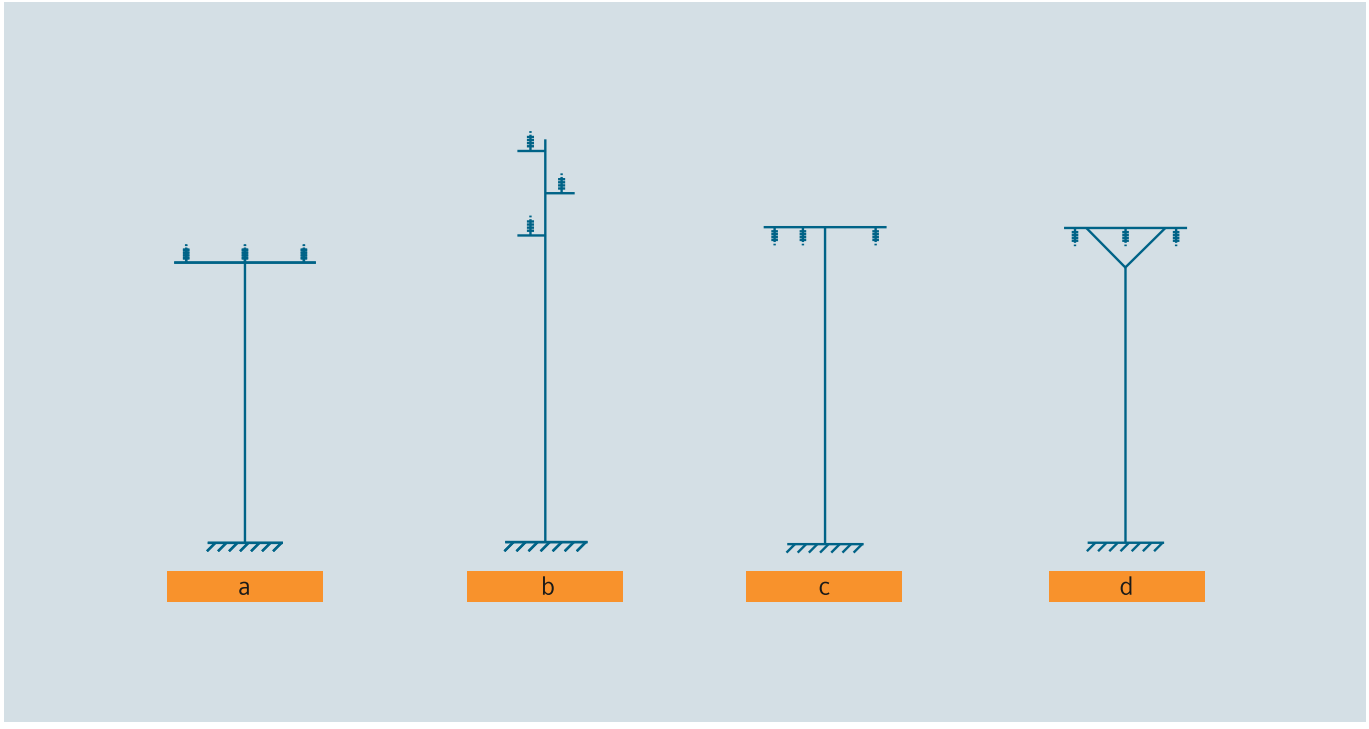

Fig. 2.5-18: **Configurations of medium-voltage supports**

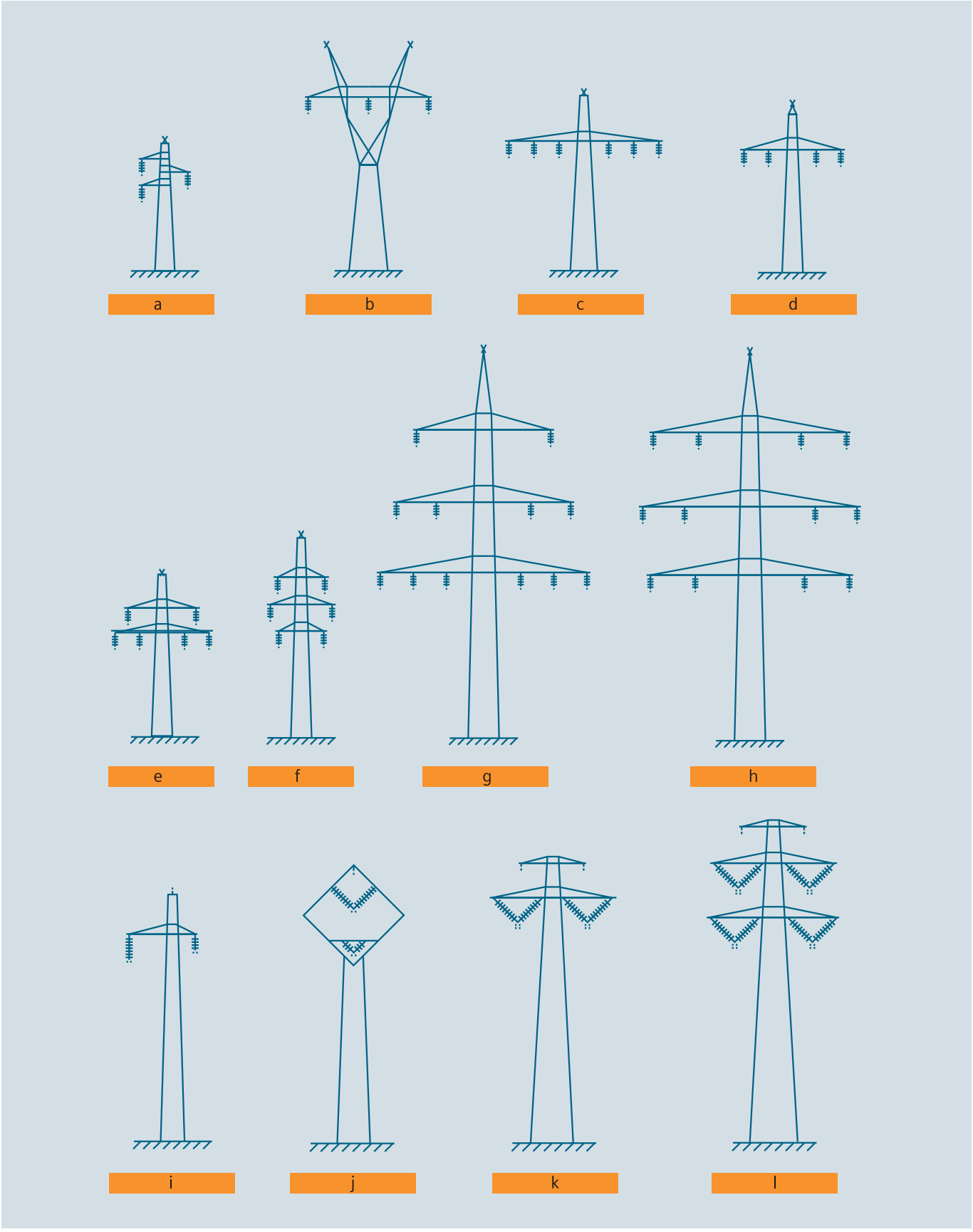

Fig. 2.5-19: **(a–h): tower configurations for high-voltage lines (AC); (i–l): tower configurations for high-voltage lines (DC)**

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conductor tensile forces can result in torsional loading. Additionally, special loading conditions are adopted for the purpose of failure containment, that is, to limit the extent of damage. Finally, provisions have to be made for construction and maintenance.

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

Foundations for the supports

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

The selection of foundation types and the design is determined by the:

- Loads resulting from the tower design
- Soil conditions on the site
- Accessibility to the line route
- Availability of machinery
- Constraints of the particular country and the site

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

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

Route selection and tower spotting

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

Route selection and approval depend on the statutory conditions and procedures prevailing in the country of the project. Route selection nowadays involves preliminary desktop studies with a variety of route alternatives, environmental impact studies, community communication hearings and acceptance approval from the local authorities.

Fig. 2.5-20: **Typical Central European AC line design with different voltage levels**

After the route design stage and approval procedure, the final line route is confirmed. Following this confirmation and approval, the longitudinal profile has to be surveyed, and all crossings over roads, rivers, railways, buildings and other overhead power lines have to be identified. The results are evaluated with a specialized computer program developed by Siemens that calculates and plots the line profile. The towers are spotted by means of the same program, which takes into account the conductor sags under different conditions, the ground clearances, objects crossed by the line, technical data of the available tower family, specific cost for towers and foundations and cost for compensation of landowners.

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

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

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

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

Furthermore, Siemens has constructed two HVDC interconnectors as turnkey projects that include HVDC overhead transmission lines. The two projects are the 300 kV HVDC interconnector from Thailand to Malaysia (bipole transmission line, fig. 2.5-24) and the 400 kV HVDC Basslink project in Australia (monopole transmission line, fig. 2.5-25a–c).

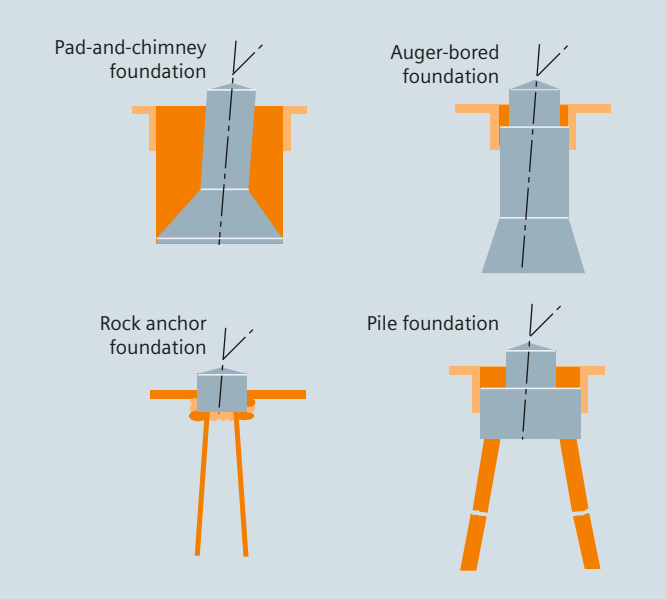


Fig. 2.5-21: **Foundations for four-legged towers**

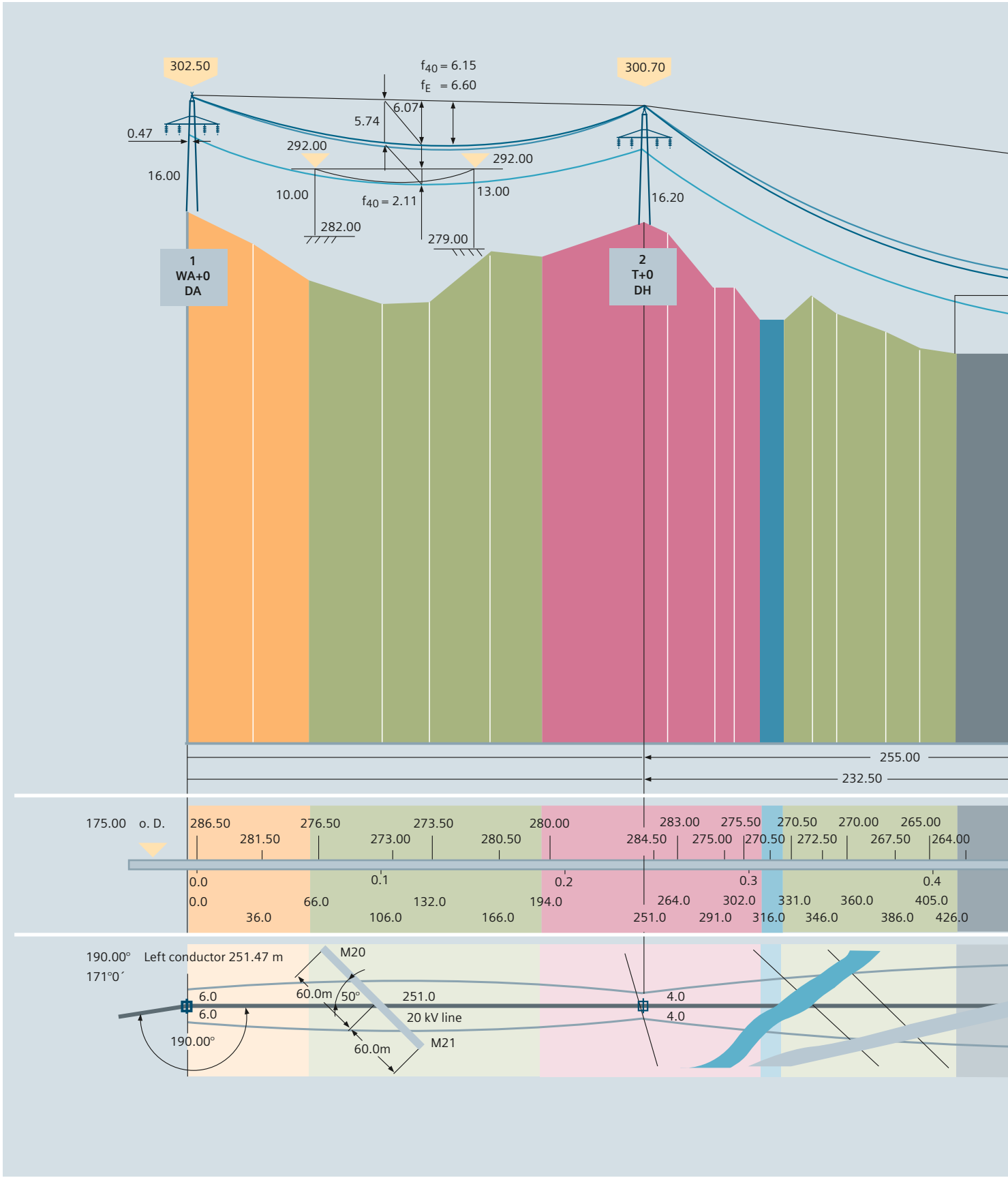
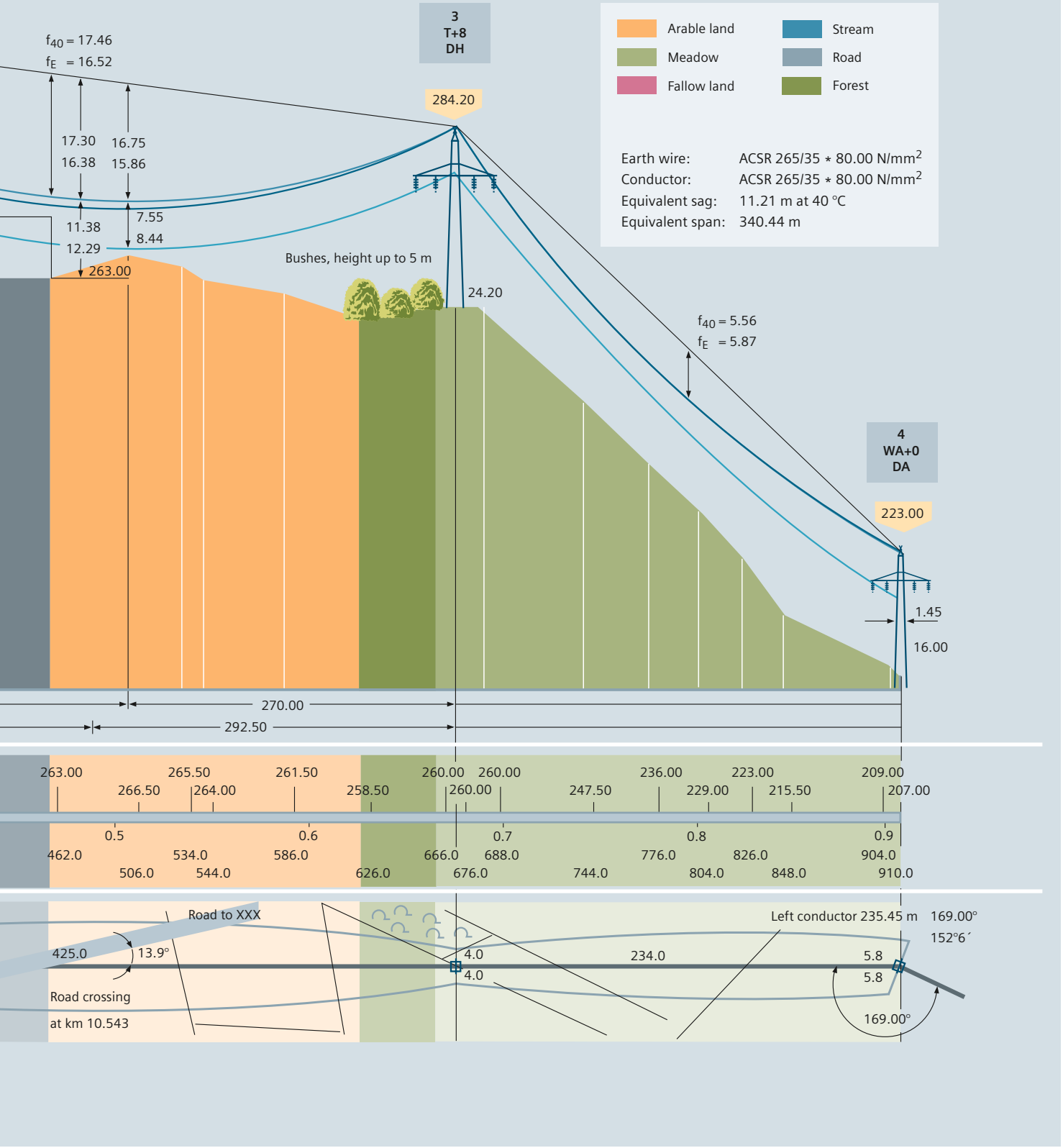


Fig. 2.5-22: **Line profile established by computer**


3
T+8
DH
4
WA+0
DA
Arable land
Meadow
Fallow land
Stream
Road
Forest
Earth wire: ACSR 265/35 * 80.00 N/mm2
Conductor: ACSR 265/35 * 80.00 N/mm2
Equivalent sag: 11.21 m at 40 °C
Equivalent span: 340.44 m
f40 = 17.46
fE = 16.52
17.30
16.38
16.75
15.86
11.38
12.29
7.55
8.44
263.00
284.20
Bushes, height up to 5 m
24.20
f40 = 5.56
fE = 5.87
223.00
1.45
16.00
270.00
292.50
263.00
265.50
266.50
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848.0
904.0
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Road to XXX
425.0
13.9°
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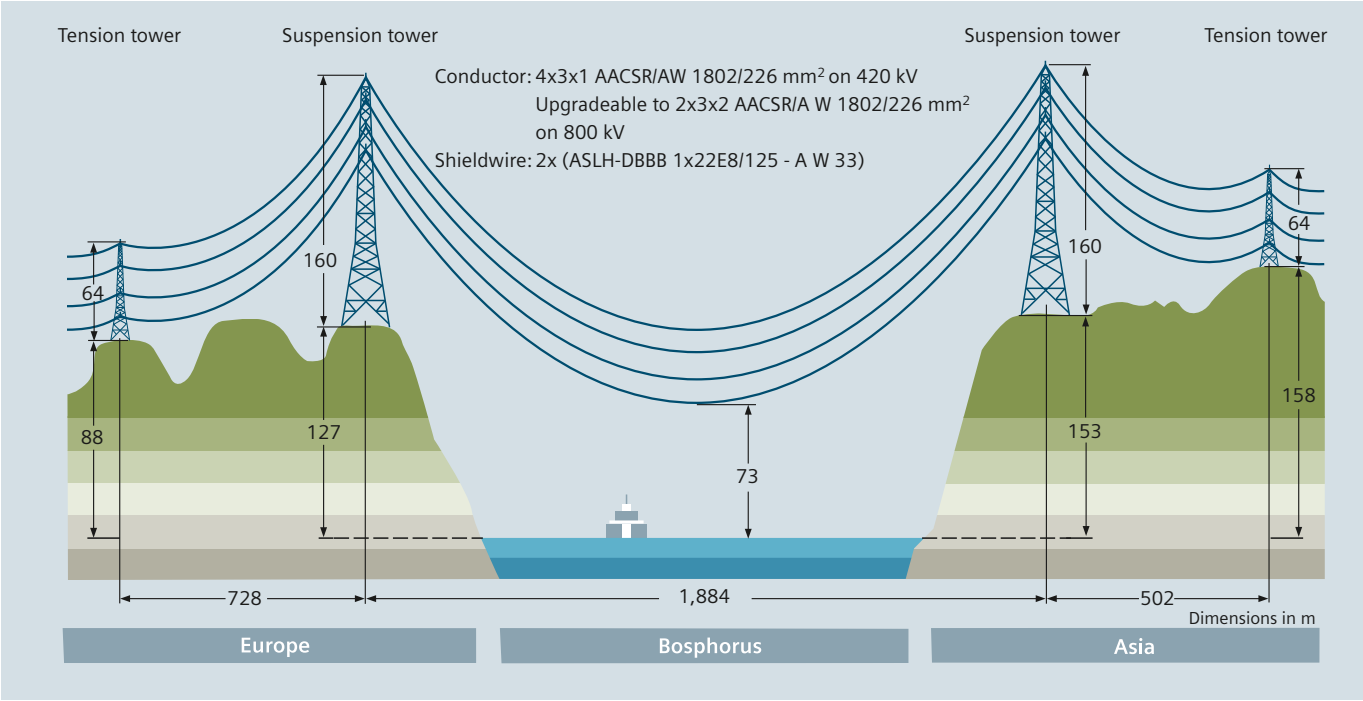

Fig. 2.5-23: **420/800 kV line across the Bosphorus, longitudinal profile**

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

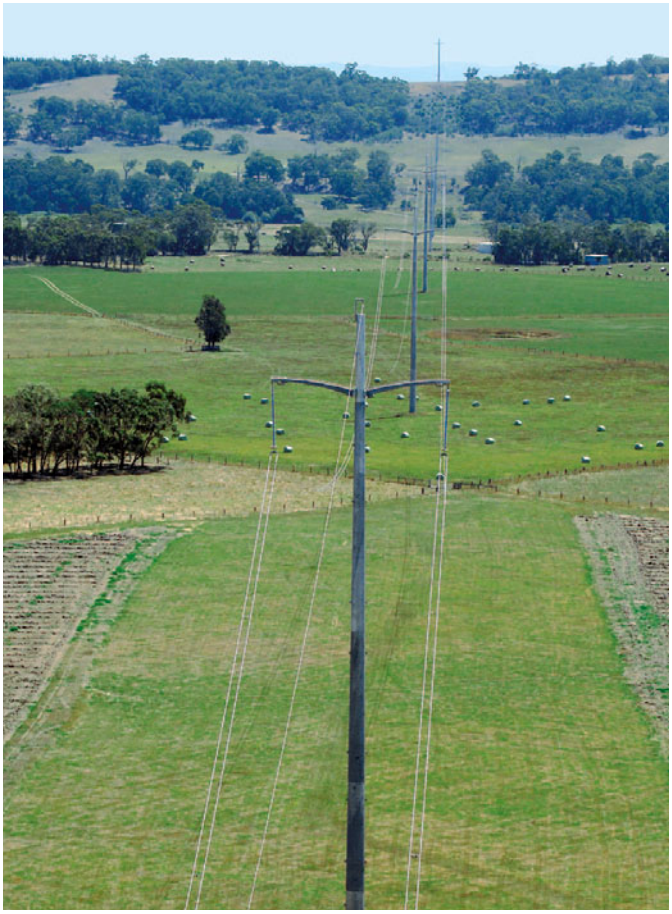

Fig. 2.5-25a: **400 kV HVDC Basslink project in Australia (monopole transmission line)**

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

For further information, please contact:
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E-mail: dirk.ettrich@siemens.com

2.6 Grid Access Solutions for Decentralized Power Generation

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

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

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

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

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

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

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

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

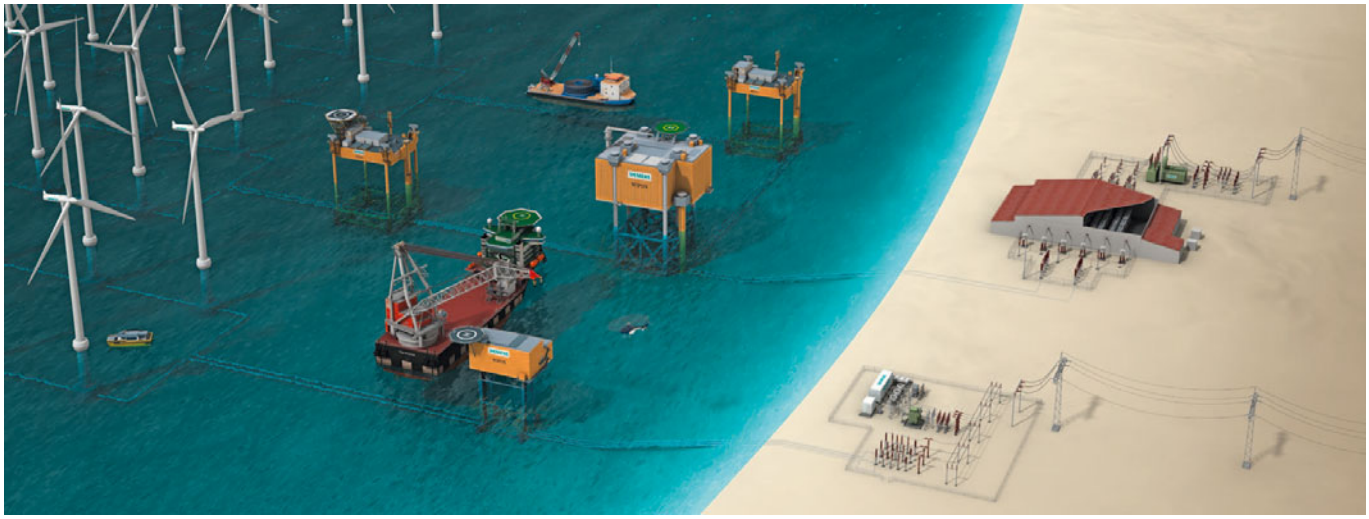

Fig. 2.6-1: **A comprehensive overview for both AC and DC offshore wind grid connections**

Fig. 2.6-2: **Siemens executes projects as on EPC Contractor**

A typical topside comprises a multi-deck construction with the main deck, where all electro-technical equipment is installed, as well as a helideck for helicopter landing designed to meet aviation regulations.

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

Siemens offers a family of WIPOS designs with the flexibility to meet various offshore weather, tide and seabed conditions with three main configurations:
- WIPOS self-lifting solution
- WIPOS topside solution (topside/jacket)
- WIPOS floating solution

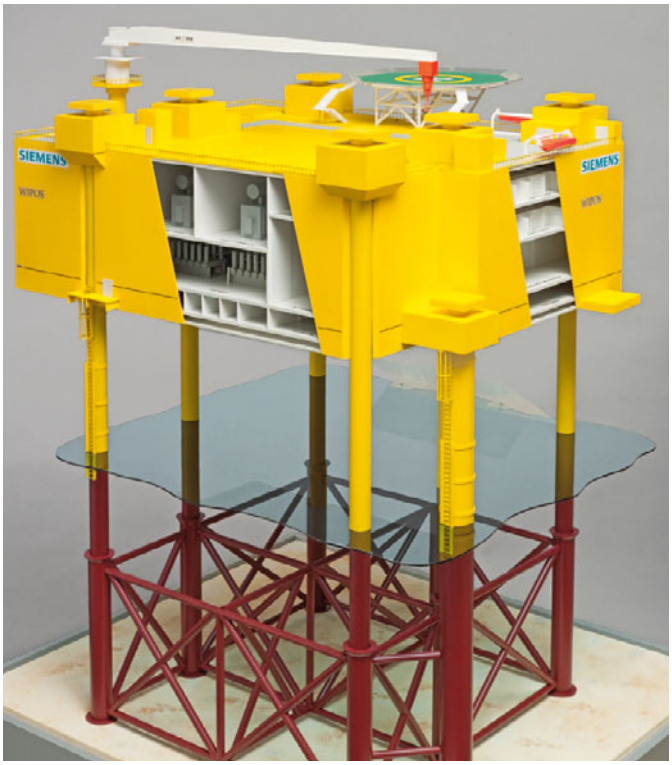

Fig. 2.6-3: **A model of Siemens' Windpower Offshore Substation (WIPOS): Siemens supplies comprehensive offshore grid connection solutions with flexible substation configurations for both AC and DC applications**

2.6.1 References

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

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

In service since late 2007, the Lillgrund Offshore Wind Farm provides enough energy for approximately 80,000 homes and reduces the CO_2 emissions by 300,000 tons a year.

Fig. 2.6-4: **2007 110 MW Offshore Wind Farm Lillgrund, Sweden**

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

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

Fig. 2.6-5: **2008 180 MW Offshore Wind Farm Lynn / Inner Dowsing, UK**

The grid connection was energized in January 2008. Both wind farms were in full service in autumn 2008. They provide enough energy for approximately 130,000 homes, and reduce the CO_2 emissions by 500,000 tons.

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

The 33/132 kV transformer substation with its two 180 MVA transformers is mounted on an offshore platform located within the wind farm area. Power transmission is realized via two three-phase 132 kV XLPE submarine cables. The point of coupling to the grid is a specific switchgear in Richborough, Kent.

Fig. 2.6-6: **2009 300 MW Offshore Wind Farm Thanet, UK**

Apart from the offshore transformer substation, the onshore substation with its compensation systems (two SVC PLUS) and harmonic filters, as well as the cable system, Siemens Energy Transmission also performed the grid studies as well as the design and performance studies for the entire wind farm and its grid connection.

The grid connection was energized in autumn 2009, with all 100 wind turbines running by autumn 2010. Now the offshore wind farm provides enough energy for approximately 215,000 homes, and reduces the CO_2 emissions by 830,000 tons a year.

Fig. 2.6-7: The Greater Gabbard offshore wind farm, planned with 140 wind turbines, each 3.6 MW, from Siemens Wind Power (Denmark), is located in the North Sea close to the Thames Estuary. It is roughly 26 km (respective 46 km) away from the coast line of Suffolk.

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

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

Here again, Siemens Energy Transmission performed the grid studies as well as the design and performance studies for the entire wind farm.

Now the offshore wind farm provides enough energy for approximately 350,000 homes and reduces the CO_2 emissions by 1,350,000 tons a year.

Fig. 2.6-8: In September 2009, Siemens was awarded a contract for the first phase of the offshore grid access solution to the prestigious London Array wind farm.

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

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

Fig. 2.6-7: **2010 500 MW Offshore Greater Gabbard, UK**

Fig. 2.6-8: **2012 630 MW London Array , UK**

Situated 24 km from Clacton-on-Sea, Essex, the system will generate 1,000 MW of green power, enough to supply the electricity needs for nearly 600,000 homes across the South East of England, and will be the largest offshore wind farm in the world in 2012.

For further information:
http://www.siemens.com/energy/grid-access-solutions
http://www.siemens.com/energy/wipos

2

BorWin2

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

Fig. 2.6-9: **BorWin 2, 800MW HVDC PLUS, North Sea**

HelWin1

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

Fig. 2.6-10: **HelWin 1, 576 MW HVDC PLUS, North Sea**

SylWin1

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

Fig. 2.6-11: **SylWin 1, 864 MW HVDC PLUS, North Sea**

HelWin2

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

Fig. 2.6-12: **HelWin 2, 690 MW HVDC PLUS, North Sea**

2.7 Solar Power Solutions

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

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

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

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

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

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

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

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

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

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

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

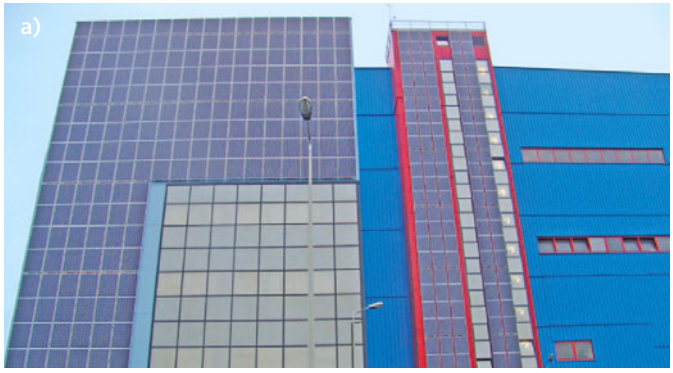

Fig. 2.7-1: **Example of photovoltaic system:**
a) Facade-integrated PV system in Italy
b) Installation of a earth-based PV system of 1 MWp in Italy
c) Example of a 30 m high stadium roof system

system solutions, based on many years of experience in the installation of grid-connected PV systems:

- (Lightweight construction) flat-roof photovoltaic system
- Building-integrated photovoltaic system (BIPV)
- Facade-mounted system (fig. 2.7-1a)
- Special structural engineering solutions (fig. 2.7-1b)
- Roof-mounted system (fig. 2.7-1c)
- Solar roofing SolarPark™

Turnkey solutions

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

For further information:
www.siemens.com/solar

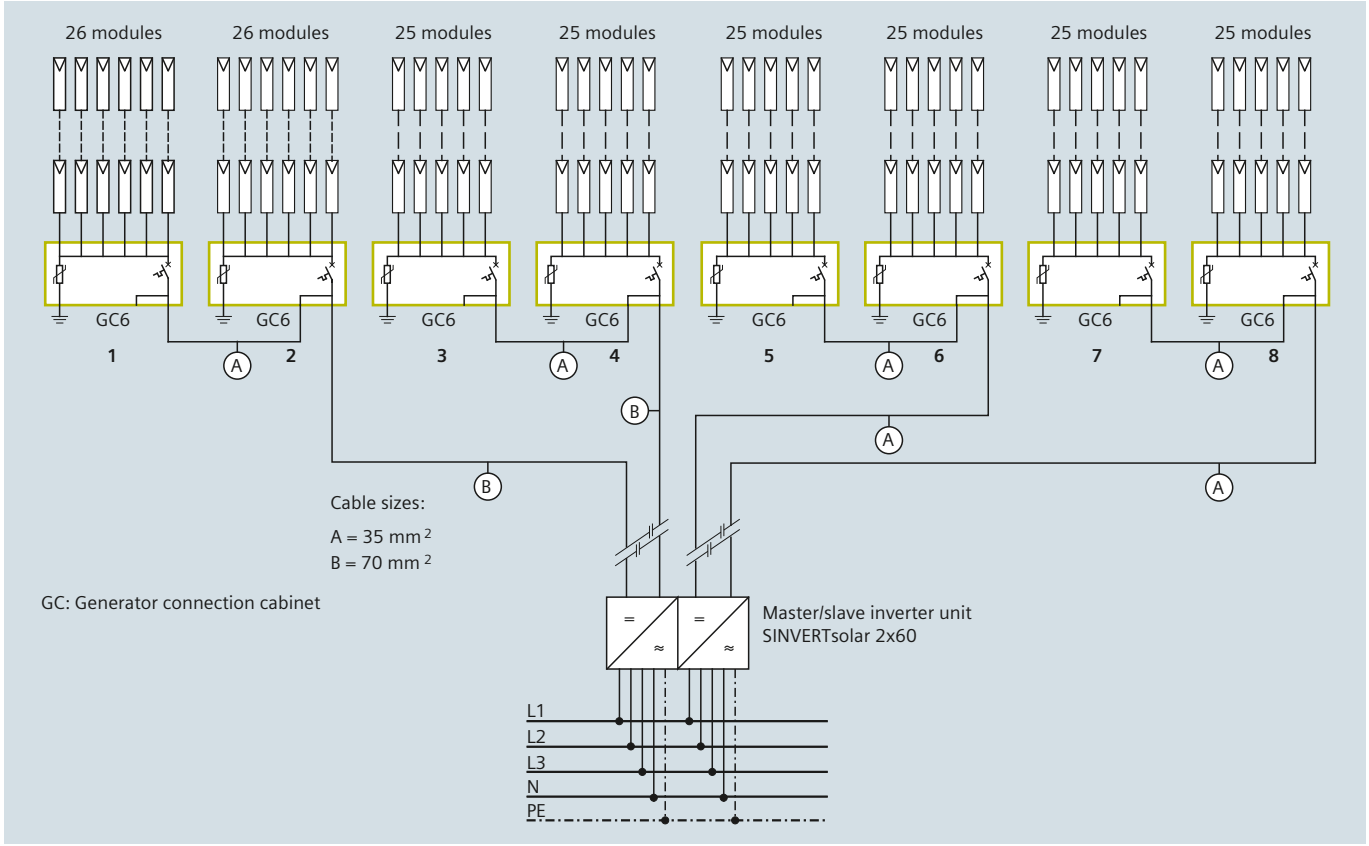

Fig. 2.7- 2: **Schematic diagram of the layout of a grid-linked PV system**

2.8 SIESTORAGE

2.8.1 The Modular Energy Storage System for a Sustainable Energy Supply

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

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

Fig. 2.8-1: **SIESTORAGE offers solutions for distribution systems with a high share of distributed renewable energy sources**

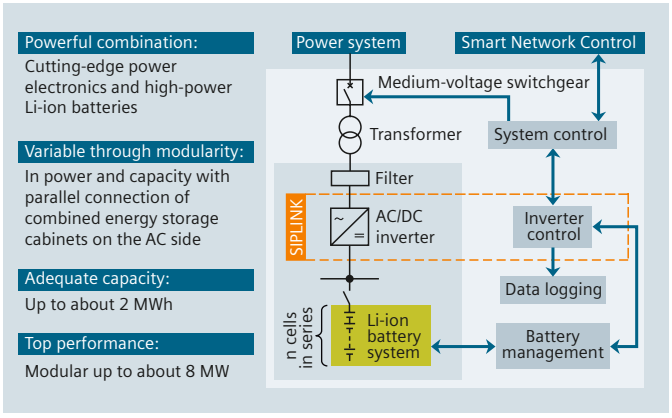

Fig. 2.8-2: **A modular energy storage solution based on proven components**

The advantages at a glance

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

- High degree of availability and reliability thanks to modular design
- Suitable for all requirements due to highest flexibility
- Easy handling of battery modules (safe low voltage) ensures the highest degree of safety for system an persons
- Completely integrated turnkey solution thoughout the entire life cycle
- Parallel connection of energy storage cabinets on AC side ensures the highest flexibility
- Prowen expertence in power electronics for power system applications
- Black start capability for microgrid application
- Emissions-free solution and improvement of CO_2 footprint

Always the right storage solution

Modular design (fig. 2.8-3)

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

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

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

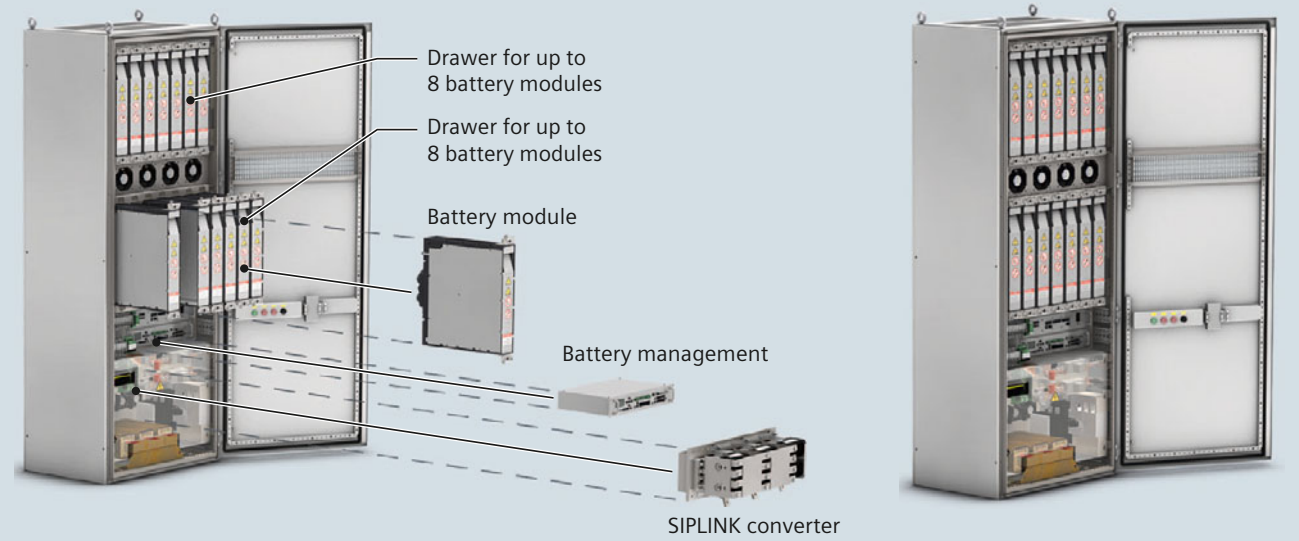

Fig. 2.8-3: **Batteries and control electronics are inserted in cabinets as plug-in units, thus facilitates the exchange of individual units**

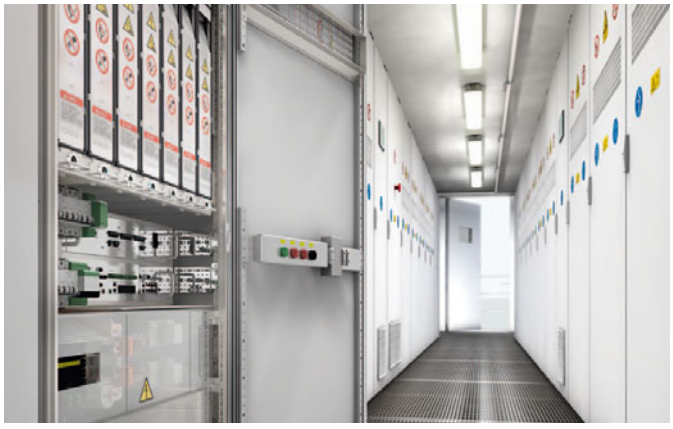

Fig. 2.8-4: **The integration of the energy storage cabinets into a containerized enclosure ensures a particularly easy application**

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

Integrated containerized solution

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

Modular structure: various configurations and storage sizes possible	
	**Usable capacity*** 16 kWh to 24 kWh depending on battery type **Rated power** 32 kW to 96 kW depending on battery type
	**Usable capacity*** 48 kWh to 72 kWh depending on battery type **Rated power** 96 kW to 288 kW depending on battery type
	**Usable capacity*** 80 kWh to 120 kWh depending on battery type **Rated power** 160 kW to 480 kW depending on battery type
	**Usable capacity*** Up to 500 kWh in standard container **Rated power** 1 MVA to 2 MVA depending on battery type
*The usable capacity is guaranteed to the end of the service life	

Tab. 2.8-1: **A modular solution for each application**

2.8.2 Spot-on for a Wide Variety of Applications

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

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

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

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

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

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

Fig. 2.8-5: **SIESTORAGE can be used for performance buffering at electric vehicle charging stations**

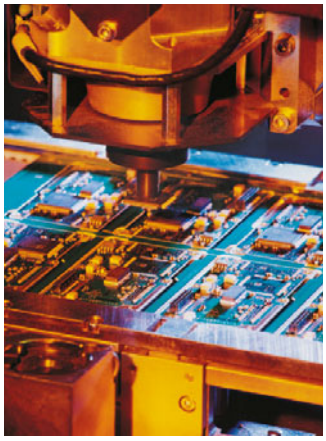

Fig. 2.8-6: **SIESTORAGE ensures high reliability and quality of the energy supply for industrial production processes**

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

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

Fig. 2.8-7: **SIESTORAGE ensures self-sufficient energy supply for microgrids with renewable generation**

2.8.3 The Solution Provider for Energy Storage Solutions

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

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

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

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

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

2.9 SIEHOUSE

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

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

Flexible and reliable power supply solution

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

Advantages of SIEHOUSE compared to classical site-built substations

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

Fig. 2.9-1: **SIEHOUSE ist the optimal approach to install electrical equipment**

Fig. 2.9-2: **SIEHOUSE with several modules enables the optimum use of the available space**

Various types to suit any project and application

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

Fig. 2.9-3: **A fully integrated solution: SIEHOUSE is a fully integrated power distribution system that is completely engineered, manufactured, assembled and tested at the Siemens facilities, and then joined on site**

2.9.2 Spot-on for a Broad Range of Applications

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

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

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

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

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

- Oil and gas
- Metal and mining industry
- Data centers
- Chemical industry
- Automotive and aerospace
- Food and beverage
- Infrastructure
- Utility power plants and substations.

Fig. 2.9-4: **19 SIEHOUSE E-houses to supply power for oil pipelines in Colombia (ECOPETROL)**

Fig. 2.9-5: **3 split modules SIEHOUSE for Pearl GTL in Qatar, jointly developed by QP and Shell**

Fig. 2.9-6: **SIEHOUSE in Lubbock (Texas) to power forced draft fans at the generating power plant**

2

2.9.3 It is All about the Best Design

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

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

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

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

Fig. 2.9-7: **The SIEHOUSE design starts with structural analyses, calculations and 3D-simulations**

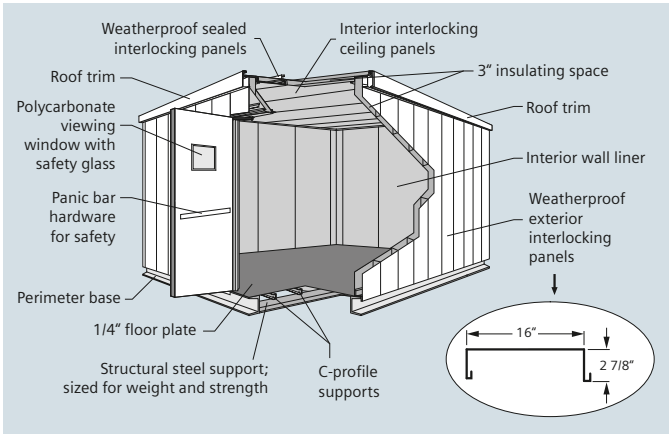

Fig. 2.9-8: **The most widely used design of SIEHOUSE consists in self-framing, interlocking wall and roof panels that are installed on a structural steel support**

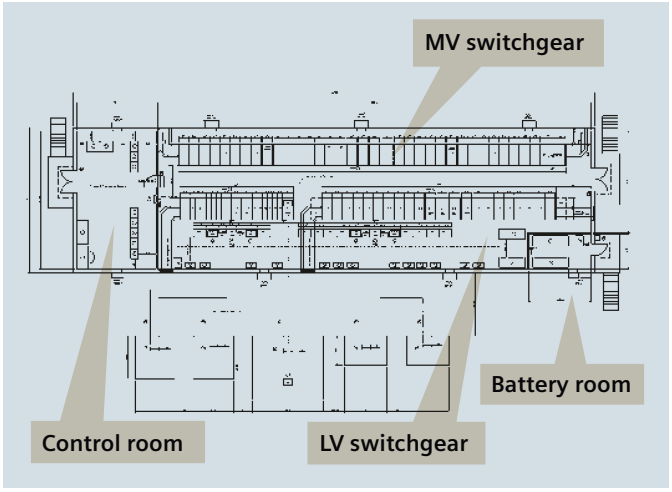

Fig. 2.9-9: **Global SIEHOUSE solution: Our design competence makes the difference**

2.9.4 Completely Integrated Solutions from a Single Source

Turnkey solutions all over the world

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

The benefits of SIEHOUSE solutions

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

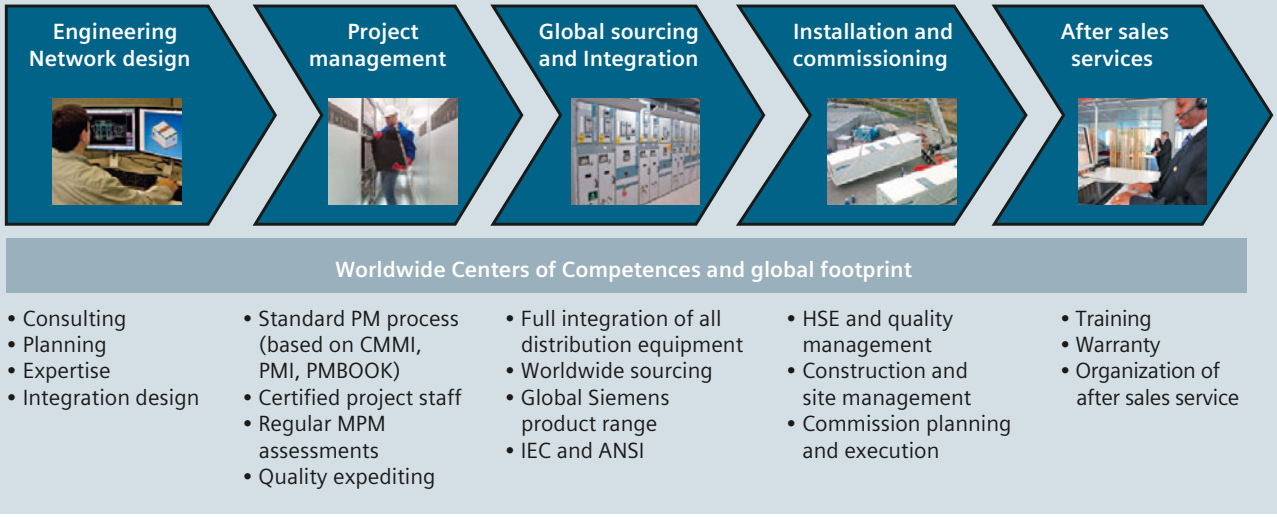

Fig. 2.9-10: **From engineering to after sales service: complete integration from a single source**