High Voltage

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High-Voltage Switchgear for Substations

Introduction

High-voltage substations form an important link in the power transmission chain between generation source and consumer. Two basic designs are possible:

Air-insulated outdoor switchgear of open design (AIS)

AIS are favorably priced high-voltage substations for rated voltages up to 800 kV which are popular wherever space restrictions and environmental circumstances do not have to be considered. The individual electrical and mechanical components of an AIS installation are assembled on site. Air-insulated outdoor substations of open design are not completely safe to touch and are directly exposed to the effects of weather and the environment (Fig. 1).

Fig. 1: Outdoor switchgear

Gas-insulated indoor or outdoor switchgear (GIS)

GIS compact dimensions and design make it possible to install substations up to 550 kV right in the middle of load centers of urban or industrial areas. Each circuit-breaker bay is factory assembled and includes the full complement of isolator switches, grounding switches (regular or make-proof), instrument transformers, control and protection equipment, interlocking and monitoring facilities commonly used for this type of installation. The earthed metal enclosures of GIS assure not only insensitivity to contamination but also safety from electric shock (Fig. 2).

Gas-insulated transmission lines (GIL)

A special application of gas-insulated equipment are gas-insulated transmission lines (GIL). They are used where high-voltage overhead lines are not suitable for any reason. GIL have a high power transmission capability, even when laid underground, low resistive and capacitive losses and low electromagnetic fields.

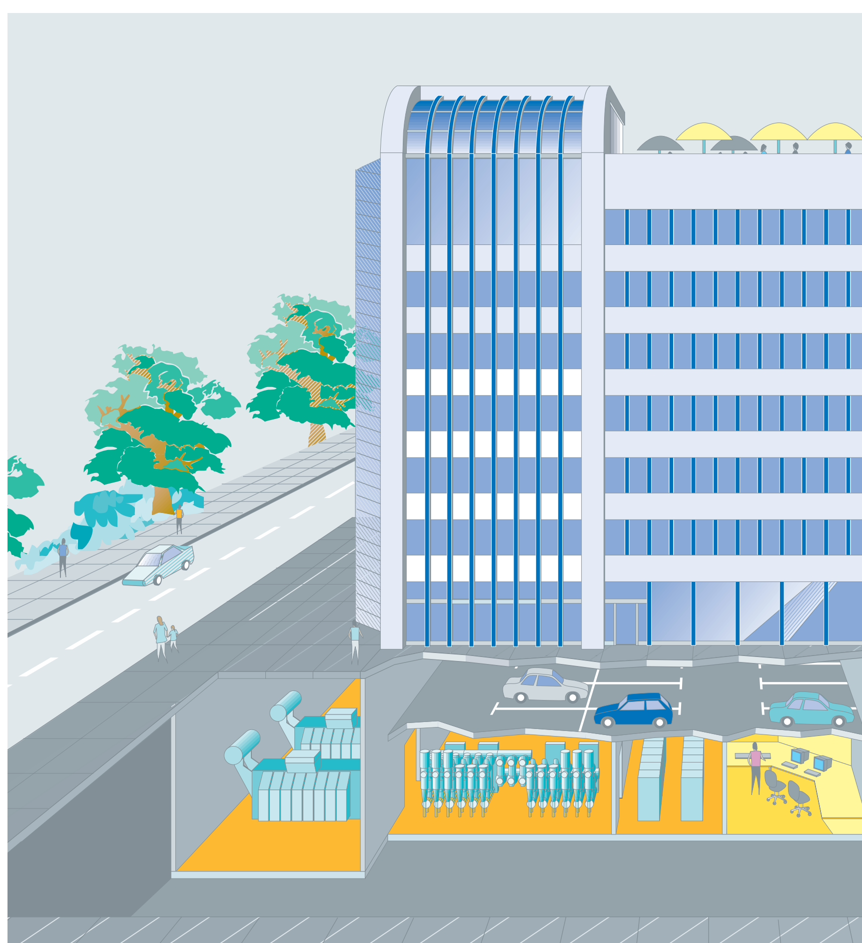

Fig. 2: GIS substations in metropolitan areas

High-Voltage Switchgear for Substations

Turnkey Installations

High-voltage switchgear is normally combined with transformers and other equipment to complete transformer substations in order to

- Step-up from generator voltage level to high-voltage system (MV/HV)
- Transform voltage levels within the high-voltage grid system(HV/HV)
- Step-down to medium-voltage level of distribution system (HV/MV)

The High Voltage Division plans and constructs individual high-voltage switchgear installations or complete transformer substations, comprising high-voltage switchgear, medium-voltage switchgear, major components such as transformers, and all ancillary equipment such as auxiliaries, control systems, protective equipment, etc., on a turnkey basis or even as general contractor.

The spectrum of installations supplied ranges from basic substations with single busbar to regional transformer substations with multiple busbars or 1 $^{1}/_{2}$ circuit-breaker arrangement for rated voltages up to 800 kV, rated currents up to 8000 A and short-circuit currents up to 100 kA, all over the world.

The services offered range from system planning to commissioning and after-sales service, including training of customer personnel.

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

All these high-voltage installations have in common their high-standard of engineering, which covers power systems, steel structures, civil engineering, fire precautions, environmental protection and control systems (Fig. 3).

Every aspect of technology and each work stage is handled by experienced engineers. With the aid of high-performance computer programs, e.g. the finite element method (FEM), installations can be reliably designed even for extreme stresses, such as those encountered in earthquake zones. All planning documentation is produced on modern CAD systems; data exchange with other CAD systems is possible via standardized interfaces.

By virtue of their active involvement in national and international associations and standardization bodies, our engineers are always fully informed of the state of the art, even before a new standard or specification is published.

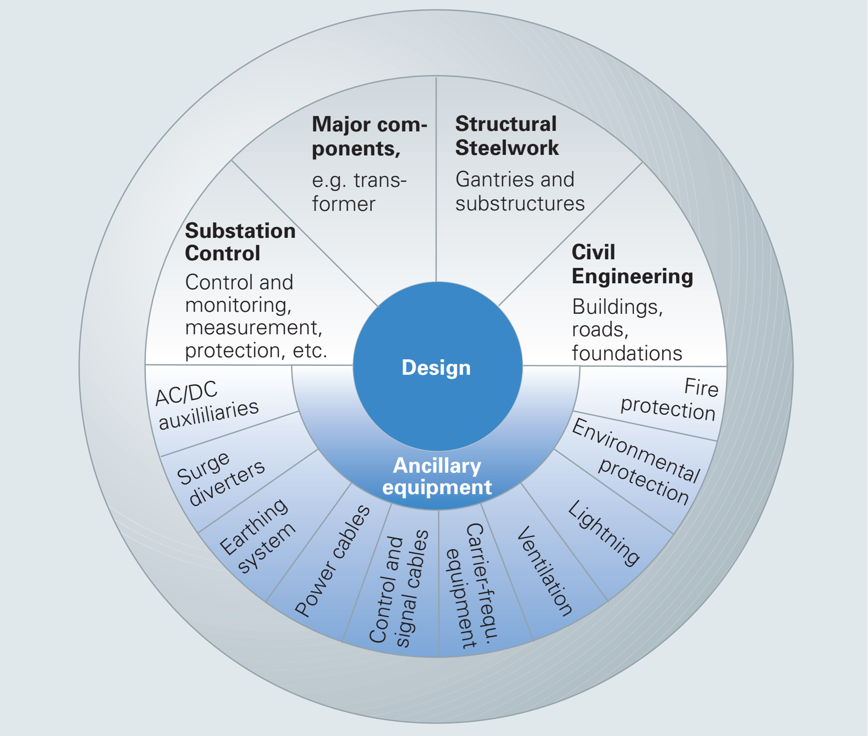

Fig. 3: Engineering of high-voltage switchgear

Quality/Environmental Management

Our own high-performance, internationally accredited test laboratories and a certified QM system testify to the quality of our products and services.

Milestones:

- 1983: Introduction of a quality system on the basis of Canadian standard CSA Z 299 Level 1
- 1989: Certification of the SWH quality system in accordance with DIN EN ISO 9001 by the German Association for Certification of Quality Systems (DQS)
- 1992: Repetition audit and extension of the quality system to the complete EV H Division
- 1992: Accreditation of the test laboratories in accordance with DIN EN 45001 by the German Accreditation Body for Technology (DATech)
- 1994: Certification of the environmental-systems in accordance with DIN EN ISO 14001 by the DQS
- 1995: Mutual QEM Certificate

Know how, experience and worldwide presence

A worldwide network of liaison and sales offices, along with the specialist departments in Germany, support and advise our customers in all matters of switchgear technology.

Siemens has for many years been a leading supplier of high-voltage equipment, regardless of whether AIS, GIS or GIL has been concerned. For example, outdoor substations of longitudinal in-line design are still known in many countries under the Siemens registered tradename “Kiellinie”. Back in 1968, Siemens supplied the world’s first GIS substation using SF_6 as insulating and quenching medium. Gas-insulated transmission lines have featured in the range of products since 1976.

Design of Air-Insulated Outdoor Substations

Standards

Air-insulated outdoor substations of open design must not be touched. Therefore, air-insulated switchgear (AIS) is always set up in the form of a fenced-in electrical operating area, to which only authorized persons have access.

Relevant IEC 60060 specifications apply to outdoor switchgear equipment. Insulation coordination, including minimum phase-to-phase and phase-to-ground clearances, is effected in accordance with IEC 60071.

Outdoor switchgear is directly exposed to the effects of the environment such as the weather. Therefore it has to be designed based on not only electrical but also environmental specifications.

Currently there is no international standard covering the setup of air-insulated outdoor substations of open design. Siemens designs AIS in accordance with DIN/VDE standards, in line with national standards or customer specifications.

The German standard DIN VDE 0101 (erection of power installations with rated voltages above 1 kV) demonstrates typically the protective measures and stresses that have to be taken into consideration for air-insulated switchgear.

Protective measures

Protective measures against direct contact, i. e. protection in the form of covering, obstruction or clearance and appropriately positioned protective devices and minimum heights.

Protective measures against indirect touching by means of relevant grounding measures in accordance with DIN VDE 0141.

Protective measures during work on equipment, i.e. during installation must be planned such that the specifications of DIN EN 50110 (VDE 0105) (e.g. 5 safety rules) are complied with

- Protective measures during operation, e.g. use of switchgear interlock equipment
- Protective measures against voltage surges and lightning strike
- Protective measures against fire, water and, if applicable, noise insulation.

Stresses

- Electrical stresses, e.g. rated current, short-circuit current, adequate creepage distances and clearances
- Mechanical stresses (normal stressing), e.g. weight, static and dynamic loads, ice, wind
- Mechanical stresses (exceptional stresses), e.g. weight and constant loads in simultaneous combination with maximum switching forces or short-circuit forces, etc.
- Special stresses, e.g. caused by installation altitudes of more than 1000 m above sea level, or earthquakes

Variables affecting switchgear installation

Switchgear design is significantly influenced by:

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

The design of a substation determines its accessibility, availability and clarity. The design must therefore be coordinated in close cooperation with the customer. The following basic principles apply:

Accessibility and availability increase with the number of busbars. At the same time, however, clarity decreases. Installations involving single busbars require minimum investment, but they offer only limited flexibility for operation management and maintenance. Designs involving $1\,^1/_2$ and 2 circuit-breaker arrangements assure a high redundancy, but they also entail the highest costs. Systems with auxiliary or bypass busbars have proved to be economical. The circuit-breaker of the coupling feeder for the auxiliary bus allows uninterrupted replacement of each feeder circuit-breaker.

For busbars and feeder lines, mostly wire conductors and aluminum are used. Multiple conductors are required where currents are high. Owing to the additional short-circuit forces between the subconductors (pinch effect), however, multiple conductors cause higher mechanical stressing at the tension points. When wire conductors, particularly multiple conductors, are used higher short-circuit currents cause a rise not only in the aforementioned pinch effect but in further force maxima in the event of swinging and dropping of the conductor bundle (cable pull). This in turn results in higher mechanical stresses on the switchgear components. These effects can be calculated in an FEM (Finite Element Method) simulation (Fig. 4).

Design of Air-Insulated Outdoor Substations

When rated and short-circuit currents are high, aluminum tubes are increasingly used to replace wire conductors for busbars and feeder lines. They can handle rated currents up to 8000 A and short-circuit currents up to 80 kA without difficulty.

Not only the availability of land, but also the lie of the land, the accessibility and location of incoming and outgoing overhead lines together with the number of transformers and voltage levels considerably influence the switchgear design as well. A one or two-line arrangement, and possibly a U arrangement, may be the proper solution. Each outdoor switchgear installation, especially for step-up substations in connection with power stations and large transformer substations in the extra-high-voltage transmission system, is therefore unique, depending on the local conditions. HV/MV transformer substations of the distribution system, with repeatedly used equipment and a scheme of one incoming and one outgoing line as well as two transformers together with medium-voltage switchgear and auxiliary equipment, are more subject to a standardized design from the individual power supply companies.

Preferred designs

The multitude of conceivable designs include certain preferred versions, which are dependent on the type and arrangement of the busbar disconnectors:

H arrangement

The H arrangement (Fig. 5) is preferrably used in applications for feeding industrial consumers. Two overhead lines are connected with two transformers and interlinked by a single-bus coupler. Thus each feeder of the switchgear can be maintained without disturbance of the other feeders. This arrangement assures a high availability.

Special layouts for single busbars up to 145 kV with withdrawable circuit-breaker and modular switchbay arrangement

Further to the H arrangement that is built in many variants, there are also designs with withdrawable circuit-breakers and modular switchbays for this voltage range.

For detailed information see the following pages:

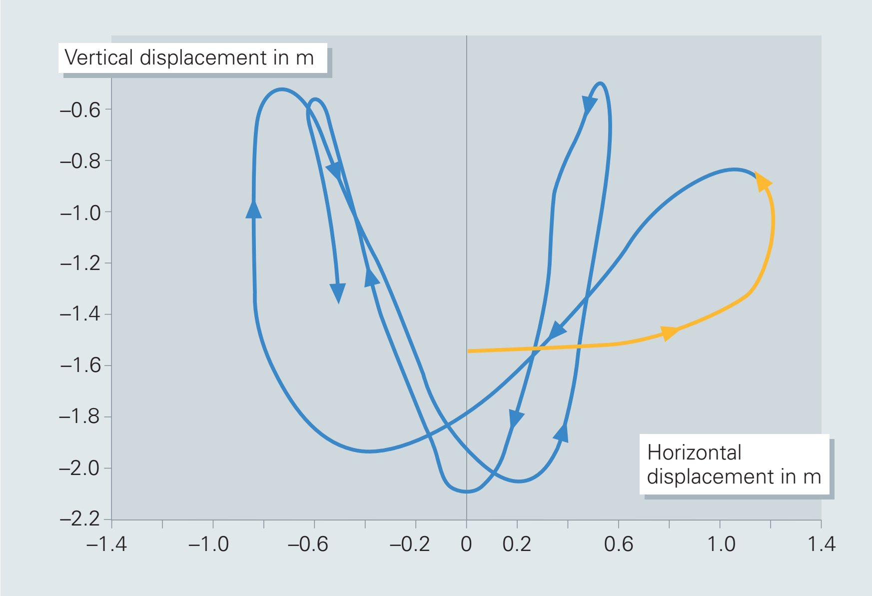

Fig. 4: FEM calculation of deflection of wire conductors in the event of short circuit

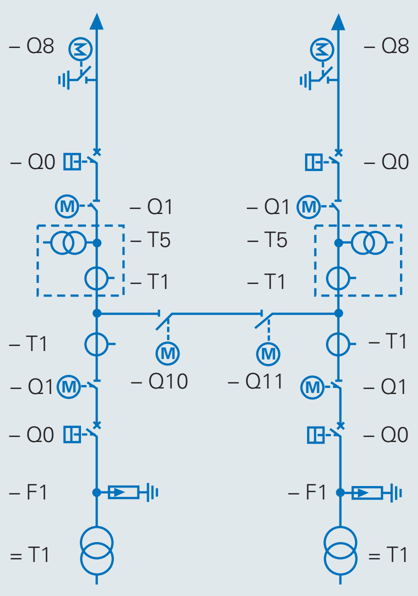

Fig. 5: Module plan view

2

Withdrawable circuit-breaker

General

For 123/145 kV substations with single busbar system a suitable alternative is the withdrawable circuit-breaker. In this kind of switchgear busbar- and outgoing disconnector become inapplicable (switchgear without disconnectors). The isolating distance is reached with the moving of the circuit-breaker along the rails, similar to the well-known withdrawable-unit design technique of medium-voltage switchgear. In disconnected position busbar, circuit-breaker and outgoing circuit are separated from each other by a good visible isolating distance. An electromechanical motive unit ensures the uninterrupted constant moving motion to both end positions. The circuit-breaker can only be operated if one of the end positions has been reached. Movement with switched-on circuit-breaker is impossible. Incorrect movement, which would be equivalent to operating a disconnector under load, is interlocked. In the event of possible malfunction of the position switch, or of interruptions to travel between disconnected position and operating position, the operation of the circuit-breaker is stopped.

The space required for the switchgear is reduced considerably. Due to the arrangement of the instrument transformers on the common steel frame a reduction in the required space up to about 45% in comparison to the conventional switchgear section is achieved.

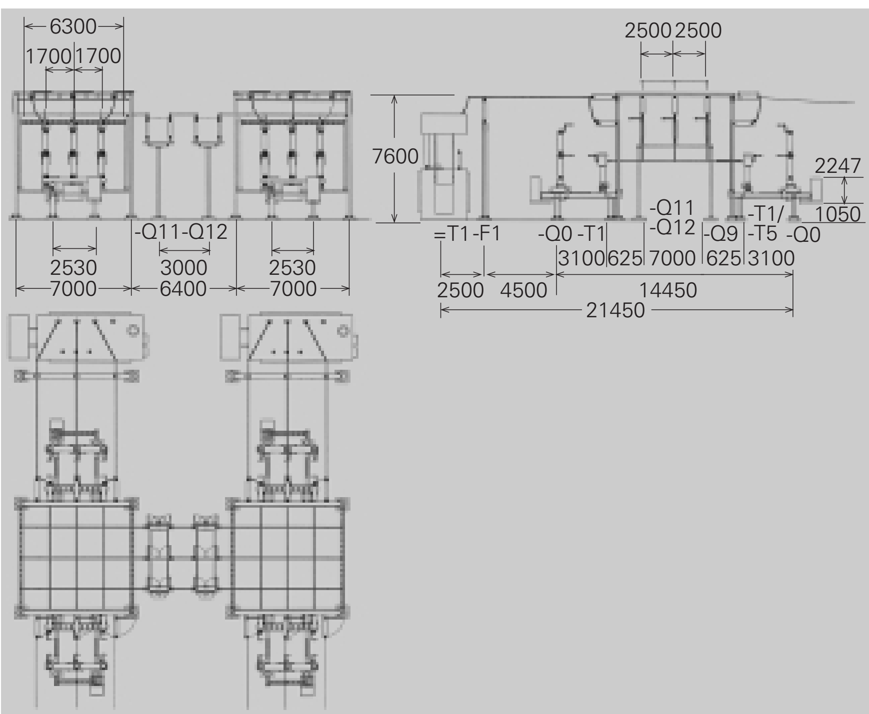

Fig. 6a: H arrangement with withdrawable circuit-breaker, plan view and sections

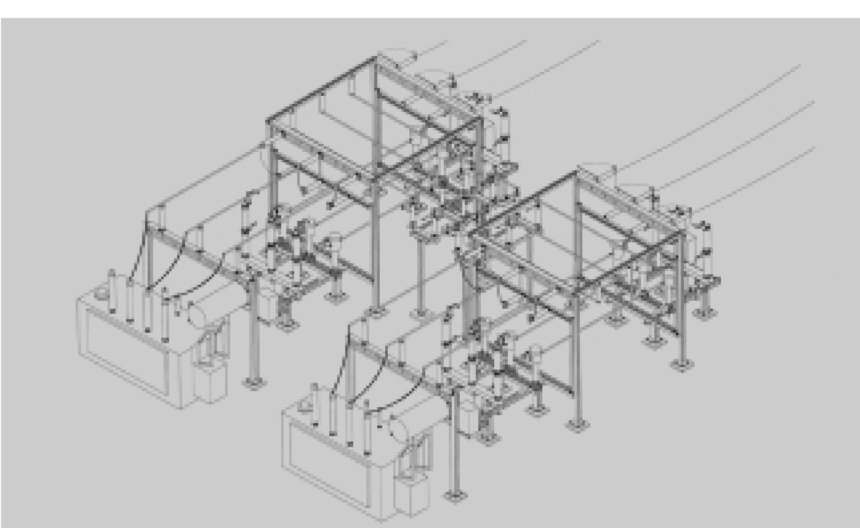

Fig. 6b: H arrangement with withdrawable circuit-breaker, ISO view

Description

A common steel frame forms the base for all components necessary for reliable operation. The withdrawable circuit-breaker contains:

- Circuit-breaker type 3AP1F
- Electromechanical motive unit
- Measuring transformer for protection and measuring purposes
- Local control cubicle

All systems are preassembled as far as possible. Therefore the withdrawable CB can be installed quite easily and efficiently on site.

The advantages at a glance

- Complete system and therefore lower costs for coordination and adaptation.
- A reduction in required space by about 45% compared with conventional switchbays
- Clear wiring and cabling arrangement
- Clear circuit state
- Use as an indoor switchbay is also possible.

Technical data	
Nominal voltage [kV]	123 kV (145 kV)
Nominal current [A]	1250 A (2000 A)
Nominal short time current [kA]	31.5 kA, 1s, (40 kA, 3s)
Auxiliary supply/ motive unit [V]	230/400 V AC
Control voltage [V]	220 V DC

Fig. 7: Technical data

Design of Air-Insulated Outdoor Substations

Modular switchbay

General

As an alternative to conventional substations an air-insulated modular switchbay can often be used for common layouts. In this case the functions of several HV devices are combined with each other. This makes it possible to offer a standardized module.

Appropriate conventional air-insulated switchbays consist of separately mounted HV devices (for example circuit-breaker, disconnector, earthing switches, transformers), which are connected to each other by conductors/tubes. Every device needs its own foundations, steel structures, earthing connections, primary and secondary terminals (secondary cable routes etc.).

Description

A common steel frame forms the base for all components necessary for a reliable operation. The modul contains:

- Circuit-breaker type 3AP1F
- Motor-operated disconnecting device
- Current transformer for protection and measuring purposes
- Local control cubicle

All systems are preassembled as far as possible. Therefore the module can be installed quite easily and efficiently on site.

The advantages at a glance

- Complete system and therefore lower costs for coordination and adaptation.
- Thanks to the integrated control cubicle, upgrading of the control room is scarecely necessary.
- A modular switchbay can be inserted very quickly in case of total breakdown or for temporary use during reconstruction.
- A reduction in required space by about 50% compared with conventional switchbays is achieved by virtue of the compact and tested design of the module (Fig. 8).
- The application as an indoor switchbay is possible.

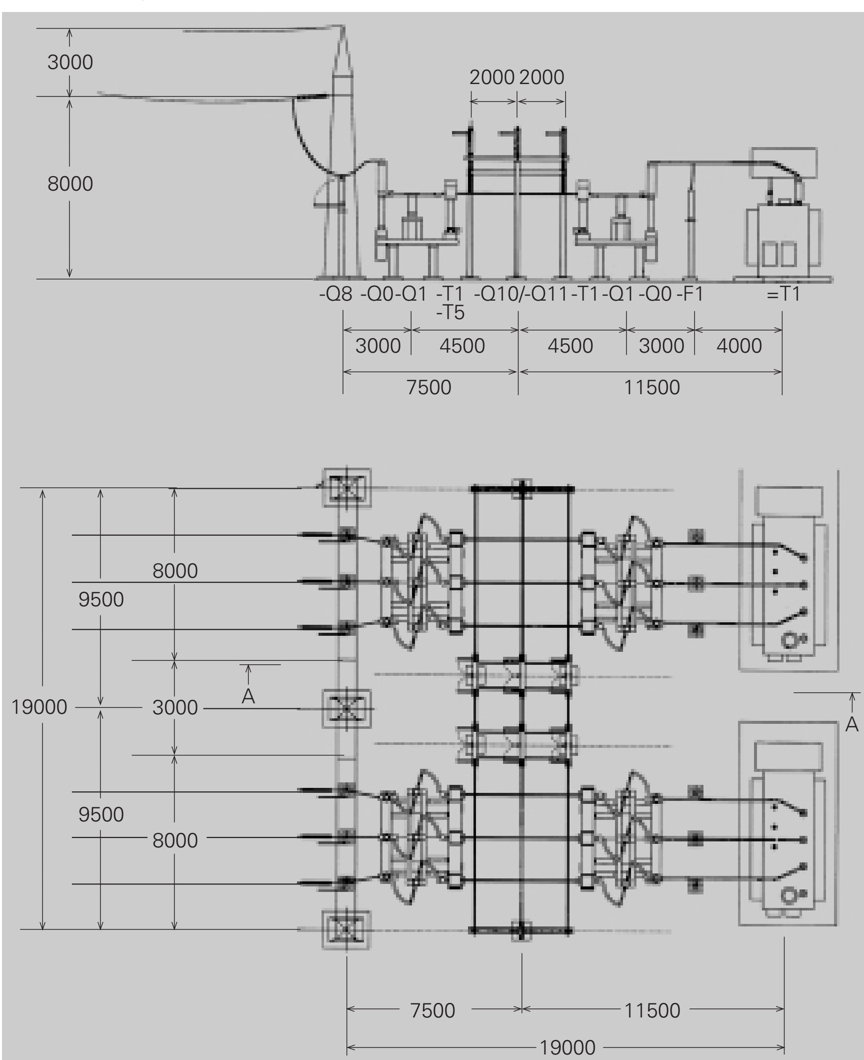

Fig. 8: Plan view and side view of H arrangement with modular switchbays

Technical data	
Nominal voltage	123 kV (145 kV)
Nominal current	1250 A (2000 A)
Nominal short current	31.5 kA, 1s, (40 kA, 3s)
Auxiliary supply	230/400 V AC
Control voltage	220 V DC

Fig. 9: Technical data

Design of Air-Insulated Outdoor Substations

In-line longitudinal layout, with rotary disconnectors, preferable up to 170 kV

The busbar disconnectors are lined up one behind the other and parallel to the longitudinal axis of the busbar. It is preferable to have either wire-type or tubular busbars located at the top of the feeder conductors. Where tubular busbars are used, gantries are required for the outgoing overhead lines only. The system design requires only two conductor levels and is therefore clear. If, in the case of duplicate busbars, the second busbar is arranged in U form relative to the first busbar, it is possible to arrange feeders going out on both sides of the busbar without a third conductor level (Fig. 10).

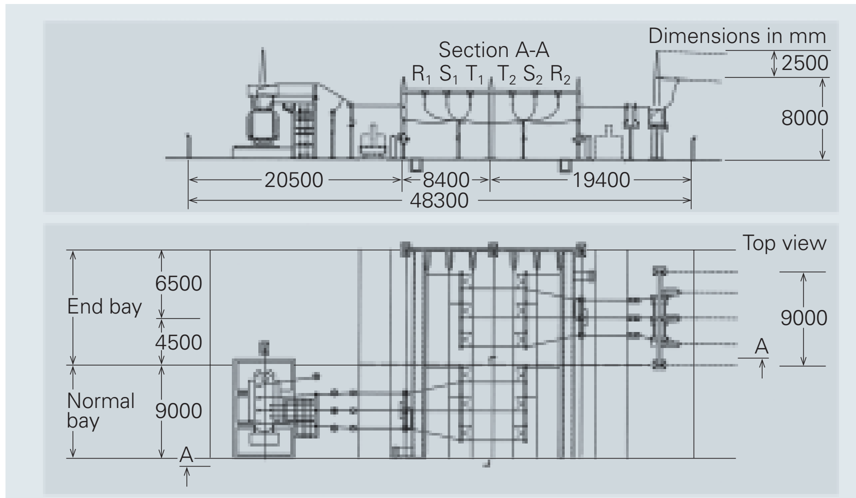

Fig. 10: Substation with rotary disconnector, in-line design

Central tower layout with rotary disconnectors, normally only for 245 kV

The busbar disconnectors are arranged side by side and parallel to the longitudinal axis of the feeder. Wire-type busbars located at the top are commonly used; tubular busbars are also conceivable. This arrangement enables the conductors to be easliy jumpered over the circuit-breakers and the bay width to be made smaller than that of in-line designs. With three conductor levels the system is relatively clear, but the cost of the gantries is high (Fig. 11).

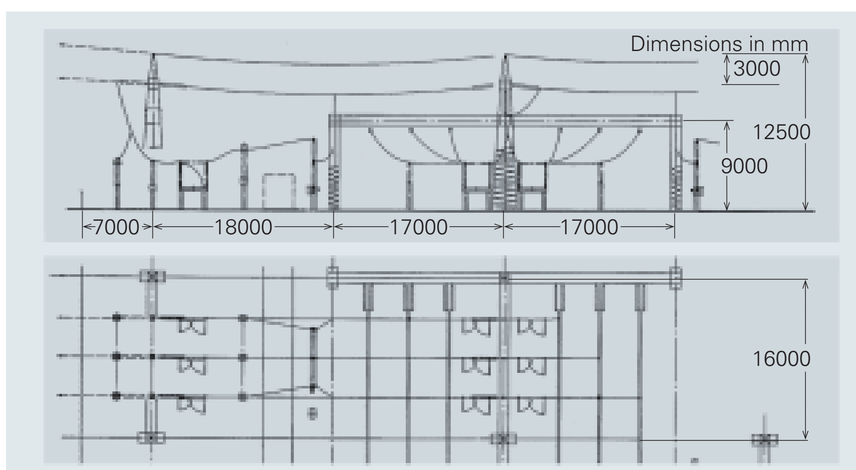

Fig.11: Central tower design

Diagonal layout with pantograph disconnectors, preferable up to 245 kV

The pantograph disconnectors are placed diagonally to the axis of the busbars and feeder. This results in a very clear, space-saving arrangement. Wire and tubular conductors are customary. The busbars can be located above or below the feeder conductors (Fig. 12).

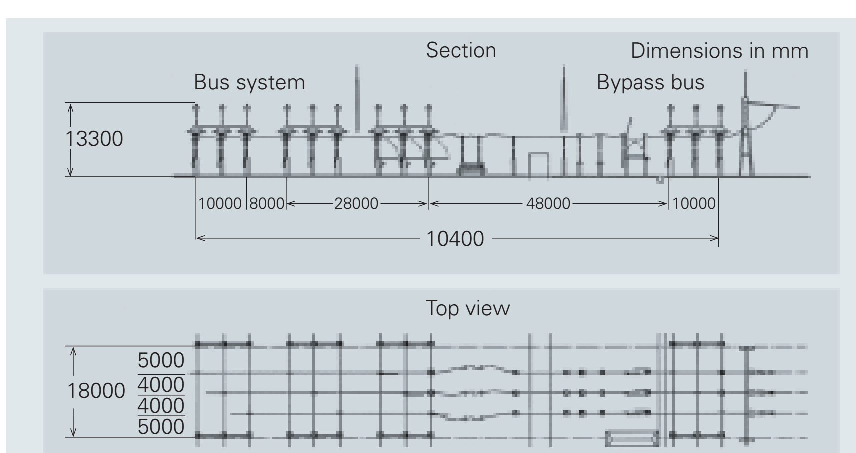

Fig. 12: Busbar area with pantograph disconnector of diagonal design, rated voltage 420 kV

Design of Air-Insulated Outdoor Substations

1 $^1/_2$ circuit-breaker layout, preferable up to 245 kV

The 1 $^1/_2$ circuit-breaker arrangement assures high supply reliability; however, expenditure for equipment is high as well.

The busbar disconnectors are of the pantograph, rotary and vertical-break type. Vertical-break disconnectors are preferred for the feeders. The busbars located at the top can be of wire or tubular type. Of advantage are the equipment connections, which are very short and enable (even in the case of multiple conductors) high short-circuit currents to be mastered. Two arrangements are customary:

- External busbar, feeders in line with three conductor levels
- Internal busbar, feeders in H arrangement with two conductor levels (Fig. 13).

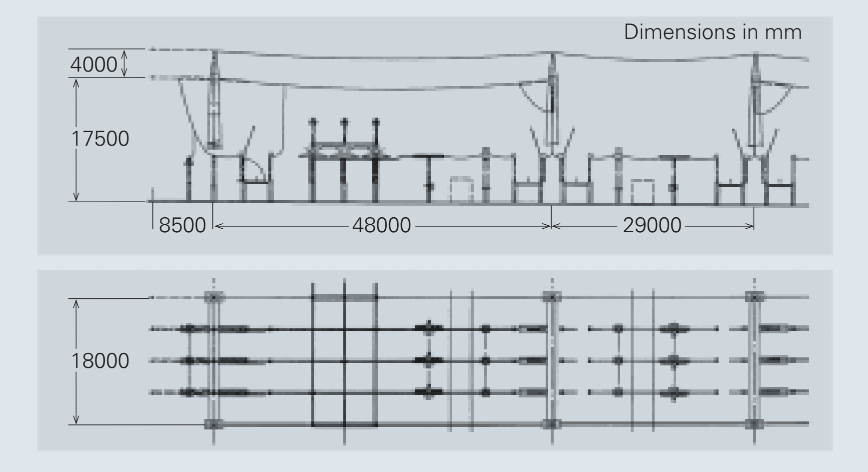

Fig.13 : 1 $^1/_2$ Circuit-breaker design

Planning principles

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

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

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Circuit-Breakers for 72 kV up to 800 kV

General

Circuit-breakers are the main module of both AIS and GIS switchgear. They have to meet high requirements in terms of:

- Reliable opening and closing
- Consistent quenching performance with rated and short-circuit currents even after many switching operations
- High-performance, reliable maintenance-free operating mechanisms.

Technology reflecting the latest state of the art and years of operating experience are put to use in constant further development and optimization of Siemens circuit-breakers. This makes Siemens circuit-breakers able to meet all the demands placed on high-voltage switchgear.

The comprehensive quality system, ISO 9001 certified, covers development, manufacture, sales, installation and after-sales service. Test laboratories are accredited to EN 45001 and PEHLA/STL.

Main construction elements

Each circuit-breaker bay for gas-insulated switchgear includes the full complement of isolator switches, grounding switches (regular or proven), instrument transformers, control and protection equipment, interlocking and monitoring facilities commonly used for this type of installation (See chapter GIS, page **2**/30 and following).

Circuit-breakers for air-insulated switchgear are individual components and are assembled together with all individual electrical and mechanical components of an AIS installation on site.

All Siemens circuit-breaker types, whether air or gas-insulated, are made up of the same range of components, i.e.:

- Interrupter unit
- Operating mechanism
- Sealing system
- Operating rod
- Control elements.

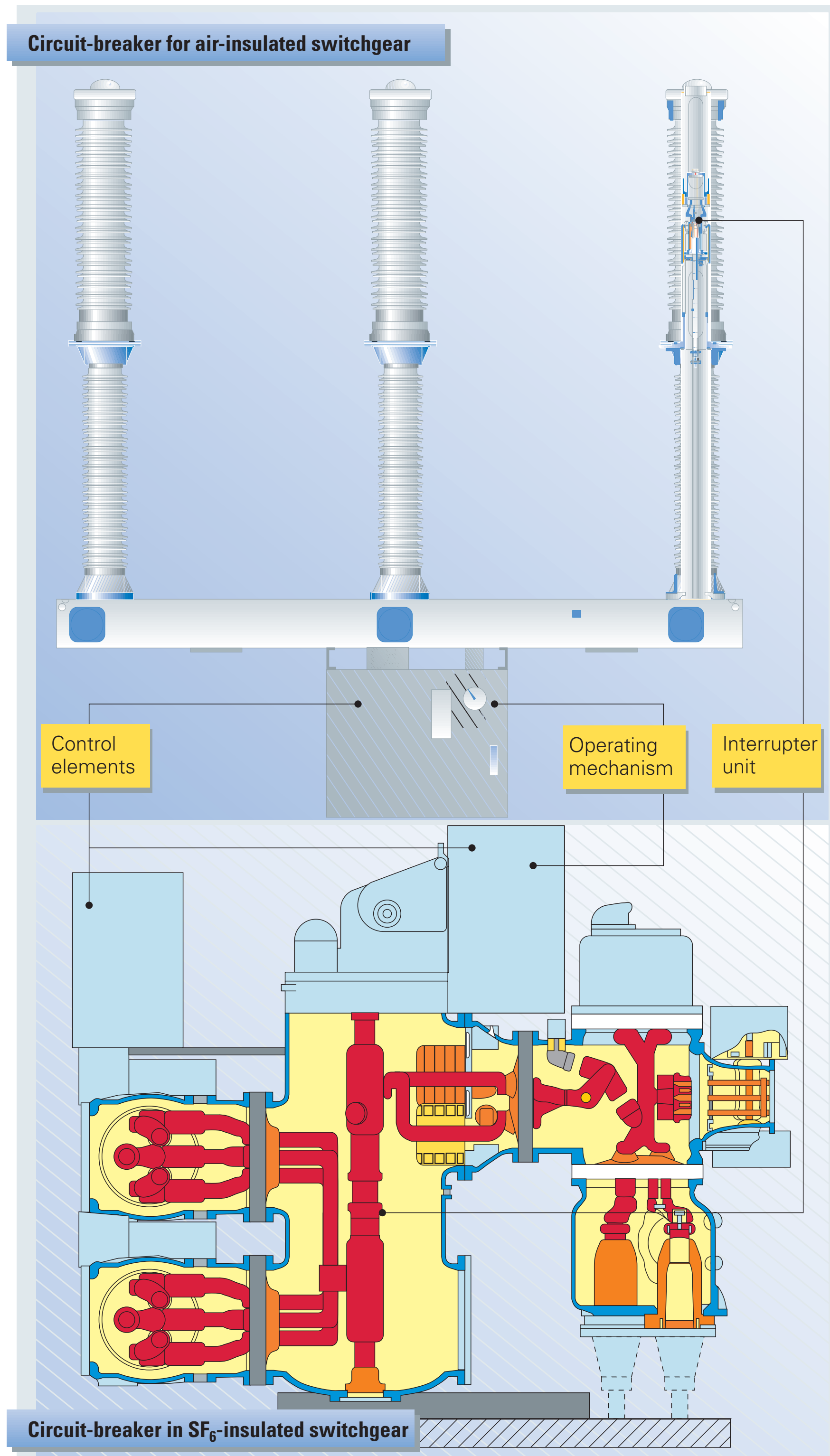


Fig. 14: Circuit-breaker parts

Circuit-Breakers for 72 kV up to 800 kV

Interrupter unit – two arc-quenching principles

The Siemens product range includes high-voltage circuit-breakers with self-compression interrupter chambers and twin-nozzle interrupter chambers – for optimum switching performance under every operating condition for every voltage level.

Self-compression breakers

3AP high-voltage circuit-breakers for the lower voltage range ensure optimum use of the thermal energy of the arc in the contact tube. This is achieved by the self-compression switching unit.
Siemens patented this arc-quenching principle in 1973. Since then, we have continued to develop the technology of the self-compression interrupter chamber. One of the technical innovations is that the arc energy is being increasingly used to quench the arc. In short-circuit breaking operations the actuating energy required is reduced to that needed for mechanical contact movement. That means the operating energy is truly minimized. The result is that the self-compression interrupter chamber allows the use of a compact stored-energy spring mechanism with unrestrictedly high dependability.

Twin-nozzle breakers

On the 3AQ and 3AT switching devices, a contact system with graphite twin-nozzles ensures consistent arc-quenching behavior and constant electric strength, irrespective of pre-stressing, i.e. the number of breaks and the switched current. The graphite twin-nozzles are resistant to burning and thus have a very long service life. As a consequence, the interrupter unit of the twin-nozzle breaker is particularly powerful.

Moreover, this type of interrupter chamber offers other essential advantages. Generally, twin-nozzle interrupter chambers operate with low overpressures during arc-quenching. Minimal actuating energy is adequate in this operating system as well. The resulting arc plasma has a comparatively low conductivity, and the switching capacity is additionally favourably influenced as a result.

The twin-nozzle system has also proven itself in special applications. Its specific properties support switching without restriking of small inductive and capacitive currents. By virtue of its high arc resistance, the twin-nozzle system is particularly suitable for breaking certain types of short circuit (e.g. short circuits close to generator terminals) on account of its high arc resistance.

Operating mechanism – two principles for all specific requirements

The operating mechanism is a central module of the high-voltage circuit-breakers. Two different mechanism types are available for Siemens circuit-breakers:

- Stored-energy spring actuated mechanism,
- Electrohydraulic mechanism,

depending on the area of application and voltage level, thus every time ensuring the best system of actuation. The advantages are trouble-free, economical and reliable circuit-breaker operation for all specific requirements.

Specific use of the stored-energy spring mechanism

The actuation concept of the 3AP high-voltage circuit-breaker is based on the stored-energy spring principle. The use of such an operating mechanism in the lower voltage range became appropriate as a result of development of a self-compression interrupter chamber that requires only minimal actuation energy.

Advantages of the stored-energy spring mechanism at a glance:

- The stored-energy spring mechanism offers the highest degree of operational safety. It is of simple and sturdy design – with few moving parts. Due to the self-compression principle of the interrupter chamber, only low actuating forces are required.
- Stored-energy spring mechanisms are readily available and have a long service life: Minimal stressing of the latch mechanisms and rolling-contact bearings in the operating mechanism ensure reliable and wear-free transmission of forces.
- Stored-energy spring mechanisms are maintenance-free: the spring charging gear is fitted with wear-free spur gears, enabling load-free decoupling.

Specific use of the electrohydraulic mechanism

The actuating energy required for the 3AQ and 3AT high-voltage circuit-breakers at higher voltage levels is provided by proven electrohydraulic mechanisms. The interrupter chambers of these switching devices are based on the graphite twin-nozzle system.

Advantages of the electrohydraulic mechanism at a glance:

- Electrohydraulic mechanisms provide the high actuating energy that makes it possible to have reliable control even over very high switching capacities and to be in full command of very high loads in the shortest switching time.
- The switch positions are held safely even in the event of an auxiliary power failure.
- A number of autoreclosing operations are possible without the need for recharging.
- Energy reserves can be reliably controlled at any time.
- Electrohydraulic mechanisms are maintenance-free, economical and have a long service life.
- They satisfy the most stringent requirements regarding environmental safety. This has been proven by electrohydraulic mechanisms in Siemens high-voltage circuit-breakers over many years of service.

Circuit-Breakers for 72 kV up to 245 kV

Siemens circuit-breakers for the lower voltage levels 72 kV up to 245 kV, whether for air-insulated or gas-insulated switchgear, are equipped with self-compression switching units and spring-stored energy operating mechanisms.

2

The interrupter unit

Self-compression system

The current path

The current path is formed by the terminal plates (1) and (8), the contact support (2), the base (7) and the moving contact cylinder (6). In closed state the operating current flows through the main contact (4). An arcing contact (5) acts parallel to this.

Breaking operating currents

During the opening process, the main contact (4) opens first and the current commutates on the still closed arcing contact. If this contact is subsequently opened, an arc is drawn between the contacts (5). At the same time, the contact cylinder (6) moves into the base (7) and compresses the quenching gas there. The gas then flows in the reverse direction through the contact cylinder (6) towards the arcing contact (5) and quenches the arc there.

Breaking fault currents

In the event of high short-circuit currents, the quenching gas on the arcing contact is heated substantially by the energy of the arc. This leads to a rise in pressure in the contact cylinder. In this case the energy for creation of the required quenching pressure does not have to be produced by the operating mechanism.

Subsequently, the fixed arcing contact releases the outflow through the nozzle (3). The gas flows out of the contact cylinder back into the nozzle and quenches the arc.

Major features:

- Self-compression interrupter chamber
- Use of the thermal energy of the arc
- Minimized energy consumption
- High reliability for a long time

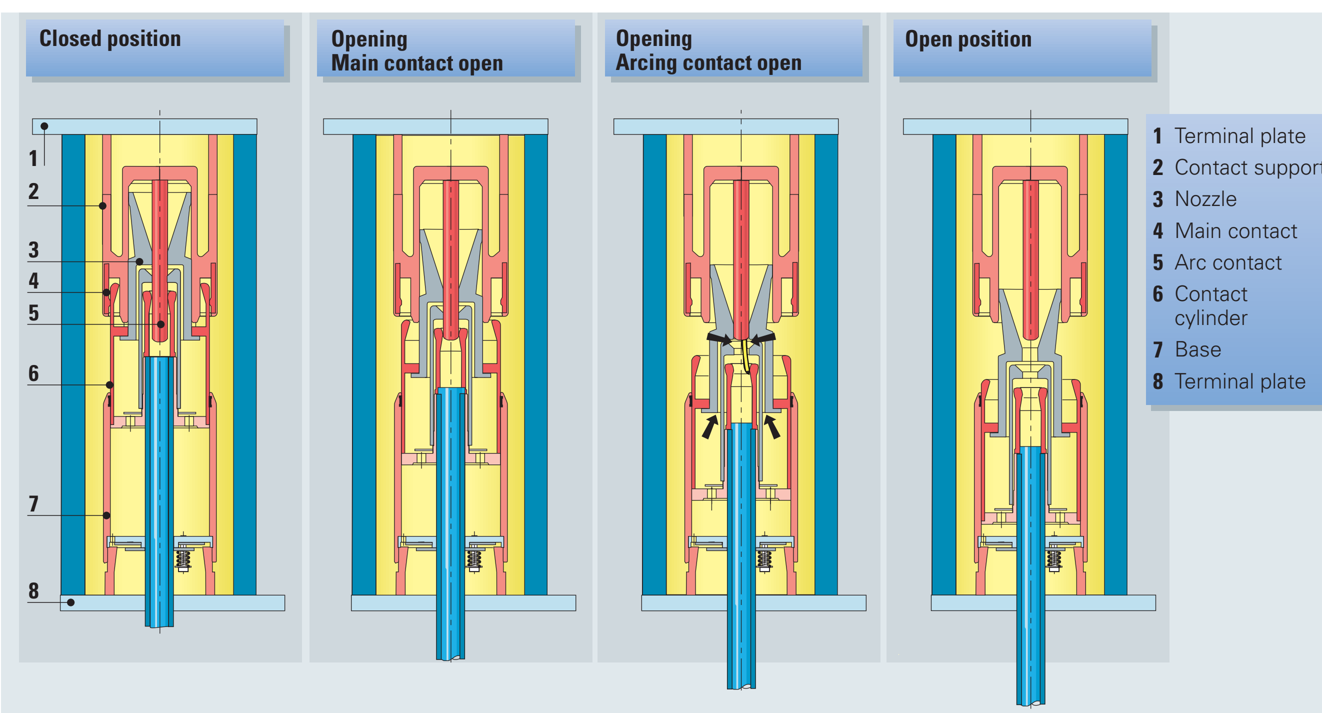


Fig. 15: The interrupter unit

The operating mechanism

Spring-stored energy type

Siemens circuit-breakers for voltages up to 245 kV are equipped with spring-stored energy operating mechanisms. These drives are based on the same principle that has been proving its worth in Siemens low and medium-voltage circuit-breakers for decades. The design is simple and robust with few moving parts and a vibration-isolated latch system of highest reliability. All components of the operating mechanism, the control and monitoring equipment and all terminal blocks are arranged compact and yet clear in one cabinet.

Depending on the design of the operating mechanism, the energy required for switching is provided by individual compression springs (i.e. one per pole) or by springs that function jointly on a triple-pole basis.

The principle of the operating mechanism with charging gear and latching is identical on all types. The differences between mechanism types are in the number, size and arrangement of the opening and closing springs.

Major features at a glance

- Uncomplicated, robust construction with few moving parts
- Maintenance-free
- Vibration-isolated latches
- Load-free uncoupling of charging mechanism
- Ease of access
- 10,000 operating cycles

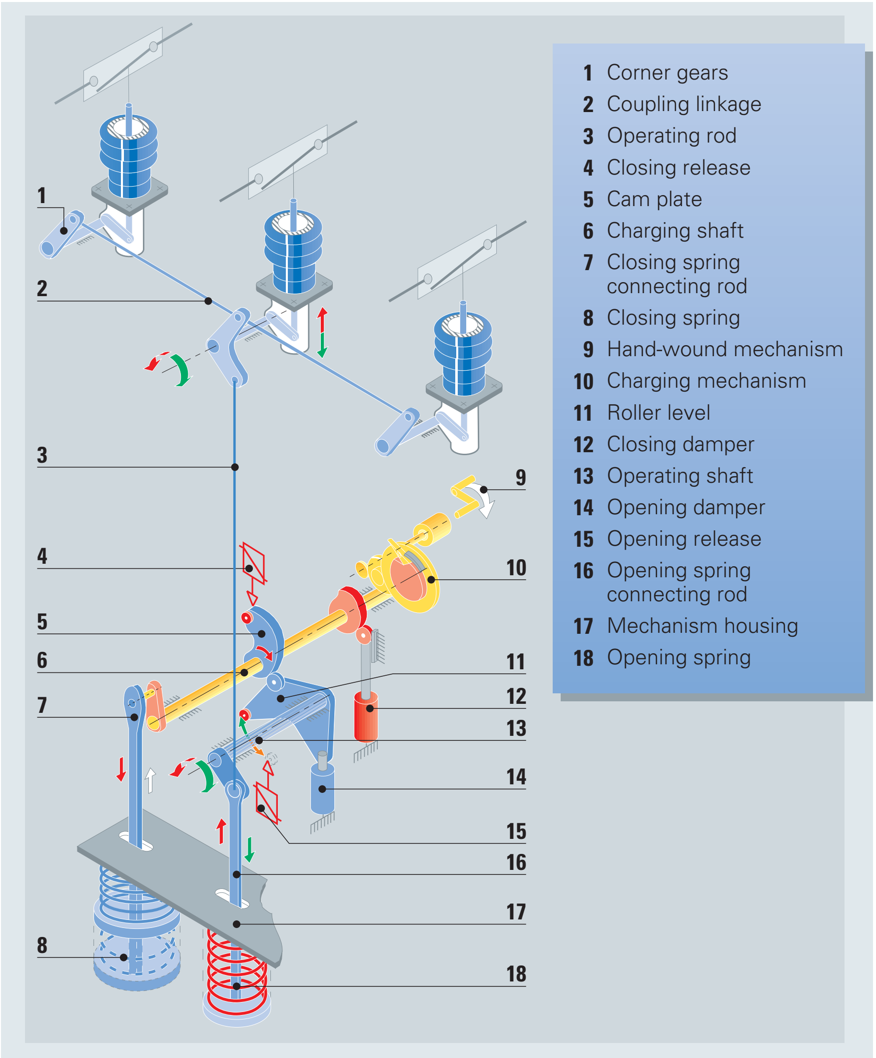


Fig. 16

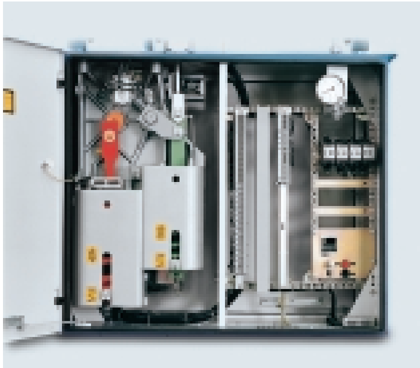


Fig. 17: Combined operating mechanism and monitoring cabinet

Circuit-Breakers for 245 kV up to 800 kV

2

Siemens circuit-breakers for the higher voltage levels 245 kV up to 800 kV, whether for air-insulated or gas-insulated switchgear, are equipped with twin-nozzle interrupter chambers and electrohydraulic operating mechanisms.

The interrupter unit

Twin-nozzle system

Current path assembly

The conducting path is made up of the terminal plates (1 and 7), the fixed tubes (2) and the spring-loaded contact fingers arranged in a ring in the moving contact tube (3).

Arc-quenching assembly

The fixed tubes (2) are connected by the contact tube (3) when the breaker is closed. The contact tube (3) is rigidly coupled to the blast cylinder (4), the two together with a fixed annular piston (5) in between forming the moving part of the break chamber. The moving part is driven by an operating rod (8) to the effect that the SF_6 pressure between the piston (5) and the blast cylinder (4) increases.

When the contacts separate, the moving contact tube (3), which acts as a shutoff valve, releases the SF_6. An arc is drawn between one nozzle (6) and the contact tube (3). It is driven in a matter of milliseconds between the nozzles (6) by the gas jet and its own electrodynamic forces and is safely extinguished.

The blast cylinder (4) encloses the arc-quenching arrangement like a pressure chamber. The compressed SF_6 flows radially into the break by the shortest route and is discharged axially through the nozzles (6). After arc extinction, the contact tube (3) moves into the open position.

In the final position, handling of test voltages in accordance with IEC 60000 and ANSI is fully assured, even after a number of short-circuit switching operations.

Major features

- Erosion-resistant graphite nozzles
- Consistently high dielectric strength
- Consistent quenching capability across the entire performance range
- High number of short-circuit breaking operations
- High levels of availability
- Long maintenance intervals.

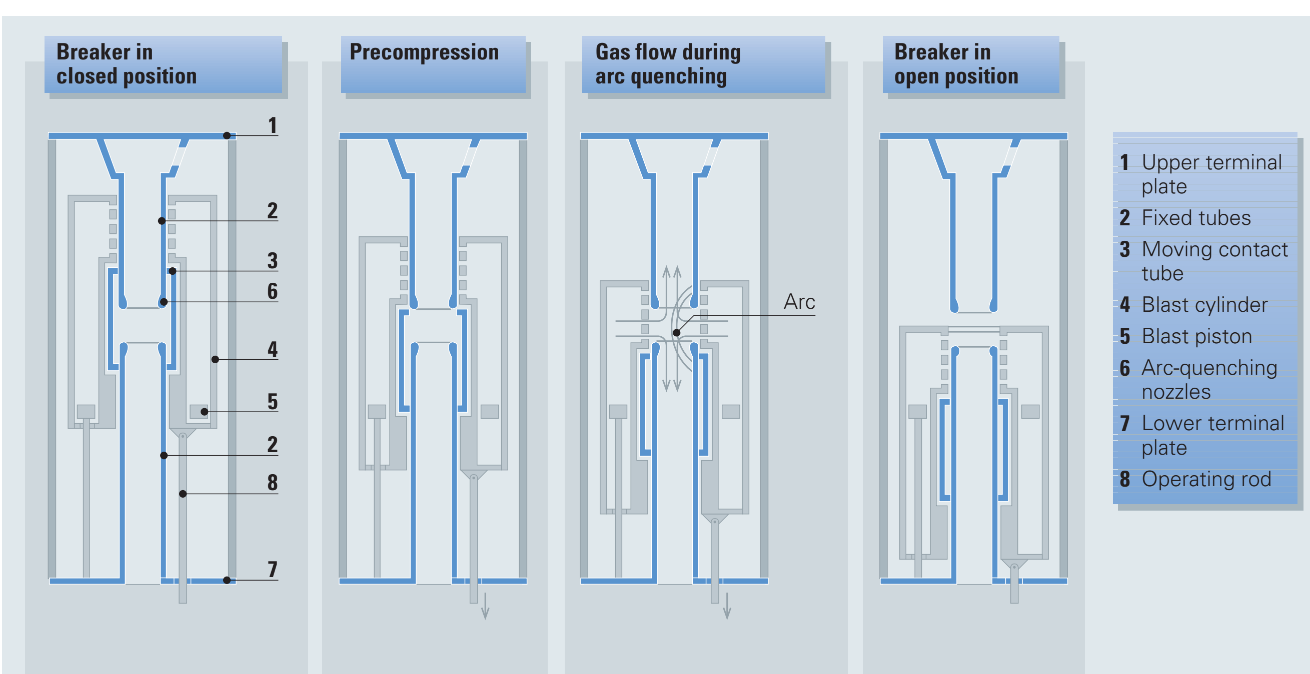


Fig. 18: The interrupter unit

Circuit-Breakers for 245 kV up to 800 kV

The operating mechanism

Electrohydraulic type

All hydraulically operated Siemens circuit-breakers have a uniform operating mechanism concept. Identical operating mechanisms (modules) are used for single or triple-pole switching of outdoor circuit-breakers.

The electrohydraulic operating mechanisms have proved their worth all over the world. The power reserves are ample, the switching speed is high and the storage capacity substantial. The working capacity is indicated by the permanent self-monitoring system.

The force required to move the piston and piston rod is provided by differential oil pressure inside a sealed system. A hydraulic storage cylinder filled with compressed nitrogen provides the necessary energy. Electromagnetic valves control the oil flow between the high and low-pressure side in the form of a closed circuit.

Main features:

- Plenty of operating energy
- Long switching sequences
- Reliable check of energy reserves at any time
- Switching positions are reliably maintained, even when the auxiliary supply fails
- Excessive strong foundations
- Low-noise switching
- No oil leakage and consequently environmentally compatible
- Maintenance-free.

Description of function

- Closing:
  The hydraulic valve is opened by electromagnetic means. Pressure from the hydraulic storage cylinder is thereby applied to the piston with two different surface areas. The breaker is closed via couplers and operating rods moved by the force which acts on the larger surface of the piston. The operating mechanism is designed to ensure that, in the event of a pressure loss, the breaker remains in the particular position.
- Tripping:
  The hydraulic valve is changed over electromagnetically, thus relieving the larger piston surface of pressure and causing the piston to move onto the OFF position. The breaker is ready for instant operation because the smaller piston surface is under constant pressure. Two electrically separate tripping circuits are available for changing the valve over for tripping.

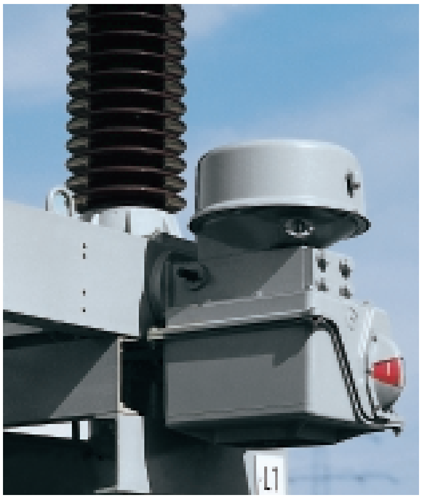


Fig. 19: Operating unit of the Q range AIS circuit breakers

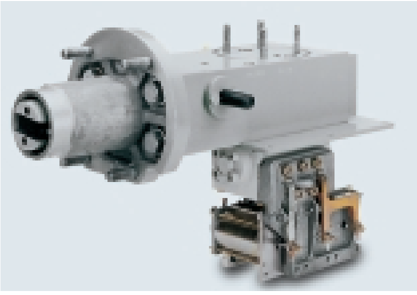


Fig. 20: Operating cylinder with valve block and magnetic releases

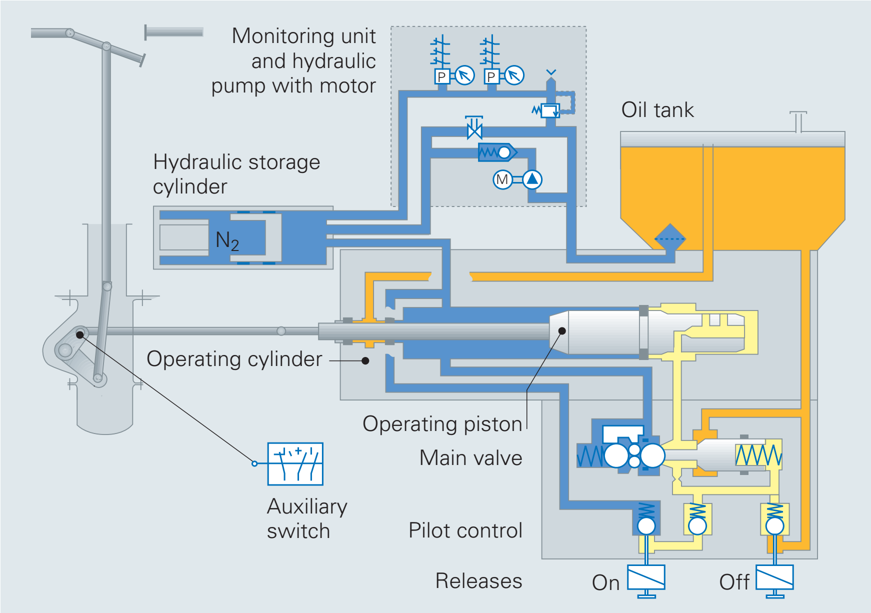


Fig. 21: Schematic diagram of a Q-range operating mechanism

Live-Tank Circuit-Breakers for 72 kV up to 800 kV

Circuit-breakers for air-insulated switchgear Standard live-tank breakers

2

The construction

All live-tank circuit-breakers are of the same general design, as shown in the illustrations. They consist of the following main components:

1) Interrupter unit
2) Closing resistor (if applicable)
3) Operating mechanism
4) Insulator column (AIS)
5) Operating rod
6) Breaker base
7) Control unit

The uncomplicated design of the breakers and the use of many similar components, such as interrupter units, operating rods and control cabinets, ensure high reliability because the experience of many breakers in service has been applied in improvement of the design. The twin nozzle interrupter unit for example has proven its reliability in more than 60,000 units all over the world.

The control unit includes all necessary devices for circuit-breaker control and monitoring, such as:

- Pressure/SF_6 density monitors
- Gauges for SF_6 and hydraulic pressure (if applicable)
- Relays for alarms and lockout
- Antipumping devices
- Operation counters (upon request)
- Local breaker control (upon request)
- Anticondensation heaters.

Transport, installation and commissioning are performed with expertise and efficiency.

The tested circuit-breaker is shipped in the form of a small number of compact units. If desired, Siemens can provide appropriately qualified personnel for installation and commissioning.

Fig. 22: 145 kV circuit-breaker 3AP1FG with triple-pole spring stored-energy operating mechanism

Fig. 23: 800 kV circuit-breaker 3AT5

Fig. 24: 245 kV circuit-breaker 3AQ2

Live-Tank Circuit-Breakers for 72 kV up to 800 kV

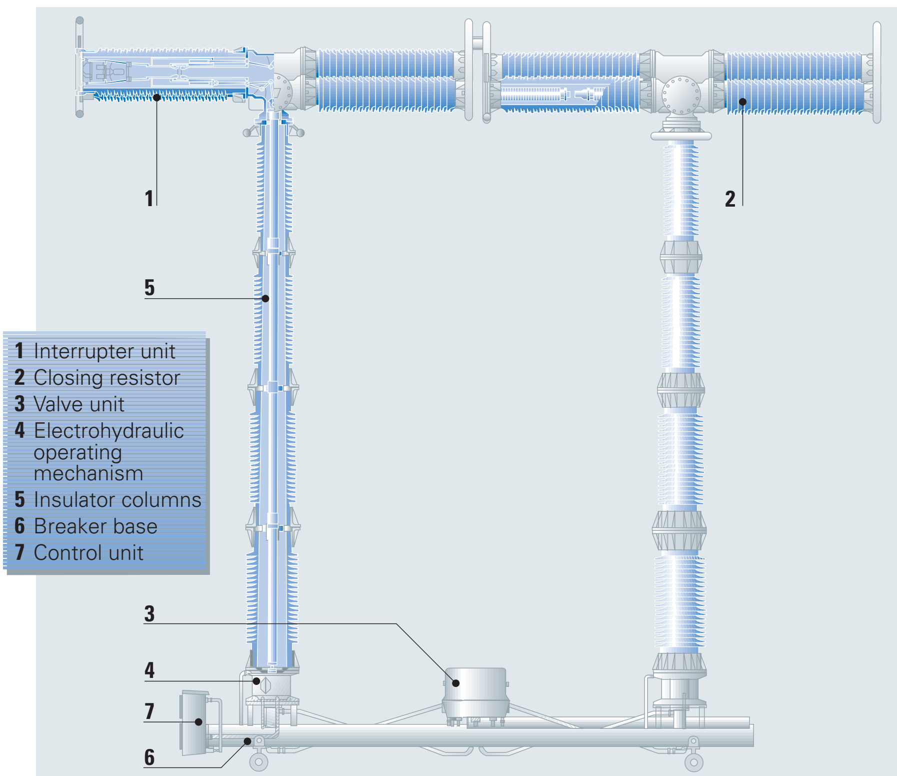


Fig. 25: Type 3AT4/5

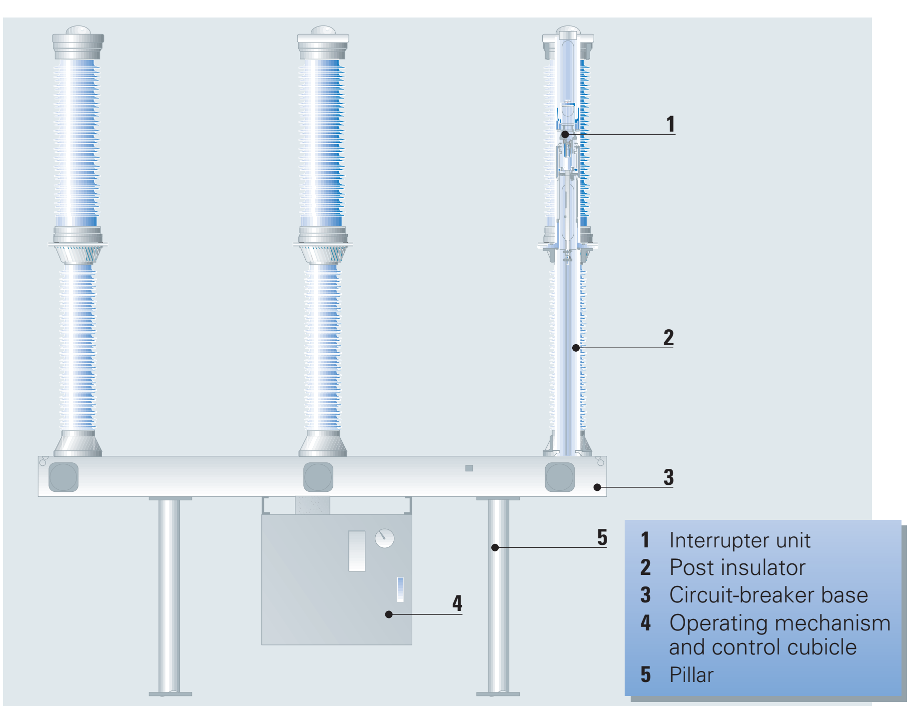


Fig. 26: Type 3AP1FG

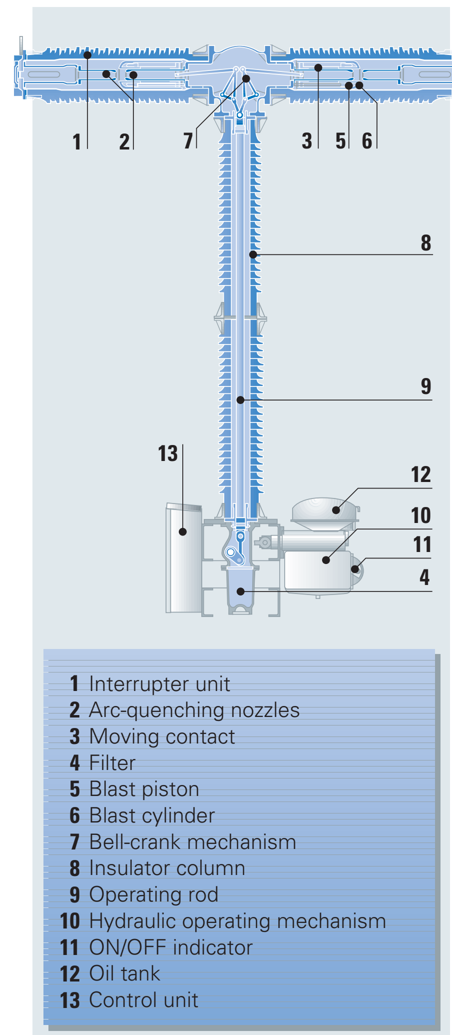
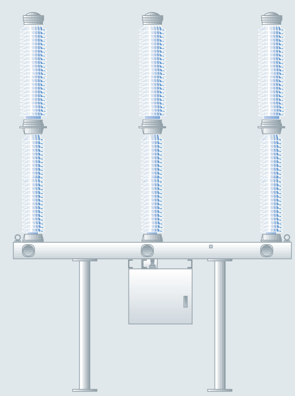
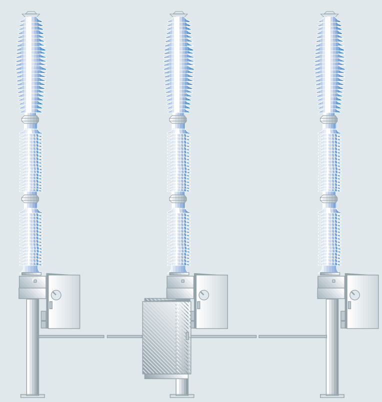


Fig. 27: Type 3AQ2

Live-Tank Circuit-Breakers for 72 kV up to 800 kV

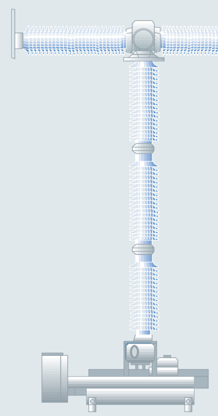
Technical data

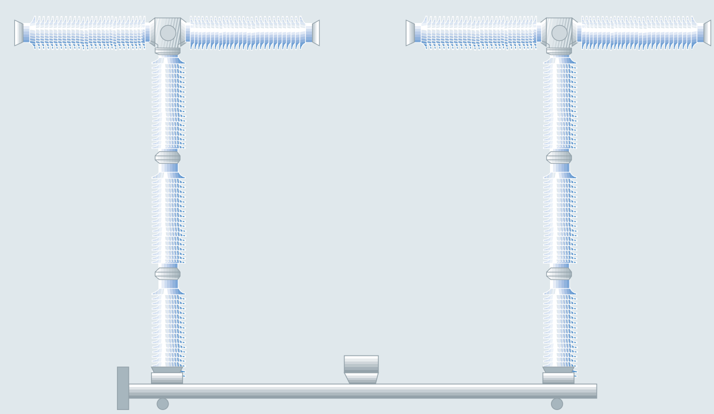




Type	3AP1/3AQ1					3AP2/3AQ2	
Rated voltage [kV]	72.5	123	145	170	245/300	362	420
Number of interrupter units per pole	1	1	1	1	1	2	2
Rated power-frequency withstand voltage 1 min. [kV]	140	230	275	325	460	520	610
Rated lightning impulse withstand voltage 1.2 / 50 µs [kV]	325	550	650	750	1050	1175	1425
Rated switching impulse withstand voltage [kV]	–	–	–	–	–/850	950	1050
Rated current up to [A]	4000	4000	4000	4000	4000	4000	4000
Rated short-time current (3 s) up to [kA]	40	40	40	40/50	50	63	63
Rated peak withstand current up to [kA]	108	108	108	135	135	170	170
Rated short-circuit-breaking current up to [kA]	40	40	40	40/50	50	63	63
Rated short-circuit making current up to [kA]	108	108	108	135	135	170	170
Rated duty cycle	O - 0.3 s - CO - 3 min - CO or CO - 15 s - CO						
Break time [cycles]	3	3	3	3	3	3	3
Frequency [Hz]	50/60	50/60	50/60	50/60	50/60	50/60	50/60
Operating mechanism type	Spring-stored energy mechanism/Electrohydraulic mechanism						
Control voltage [V, DC]	60…250						
Motor voltage [V, DC]	60…250						
[V, DC]	120…240, 50/60 Hz						
Design data of the basic version:							
Clearance in air – Phase/earth [mm]	700	1250	1250	1500	2200	2750	3400
Clearance in air – across the contact gap [mm]	1200	1200	1200	1400	1900/2200	2700	3200
Minimum creepage distance – Phase/earth [mm]	2248	3625	3625	4250	6150/7626	7875	10375
Minimum creepage distance – across the contact gap [mm]	3625	3625	3625	4250	6125/7500	9050	10500
Dimensions							
Height [mm]	2750	3300	3300	4030	5220/5520	4150	4800
Width [mm]	3200	3900	3900	4200	6600/7000	8800	9400
Depth [mm]	660	660	660	660	800	3500	4100
Distance between pole centers [mm]	1350	1700	1700	1850	2800/3000	3800	4100
Weight of circuit-breaker [kg]	1350	1500	1500	1600	3000	4700	5000
Inspection after	25 years						

Fig. 28a





3AT2/3AT3*					3AT4/3AT5*			
245	300	362	420	550	362	420	550	800
2	2	2	2	2	4	4	4	4
460	460	520	610	800	520	610	800	1150
1050	1050	1175	1425	1550	1175	1425	1550	2100
–	850	950	1050	1175	950	1050	1175	1425
4000	4000	4000	4000	4000	4000	4000	4000	4000
80	63	63	63	63	80	80	63	63
216	170	170	170	170	200	200	160	160
80	63	63	63	63	80	80	63	63
216	170	170	170	170	200	200	160	160
				O - 0.3 s - CO - 3 min - CO or CO - 15 s - CO				
2	2	2	2	2	2	2	2	2
50/60	50/60	50/60	50/60	50/60	50/60	50/60	50/60	50/60
				Electrohydraulic mechanism				
				48…250 48…250 or 208/120…500/289 50/60 Hz				
2200 2000	2200 2400	2700 2700	3300 3200	3800 3800	2700 4000	3300 4000	3800 4800	5000 6400
6050 6070	6050 8568	7165 9360	9075 11390	13750 13750	7165 12140	9075 12140	10190 17136	13860 22780
4490 7340 4060 3000	4490 8010 4025 3400	6000 9300 4280 3900	6000 10100 4280 4300	6700 13690 5135 5100	4990 10600 6830 4350	6000 11400 6830 4750	6550 16600 7505 7200	8400 22200 9060 10000
5980	6430	9090	8600	12500	14400	14700	19200	23400
				25 years				

Fig. 28b

* with closing resistor

Dead-Tank Circuit-Breakers for 72 kV up to 245 kV

Circuit-breakers in dead-tank design

For certain substation designs, dead-tank circuit-breakers might be required instead of the standard live-tank breakers. For these purposes Siemens can offer the dead-tank circuit breaker types.

Main features at a glance

Reliable opening and closing

- Proven contact and arc-quenching system
- Consistent quenching performance with rated and short-circuit currents even after many switching operations
- Similar uncomplicated design for all voltages

High-performance, reliable operating mechanisms

- Easy-to-actuate spring operating mechanisms
- Hydraulic operating mechanisms with on-line monitoring

Economy

- Perfect finish
- Simplified, quick installation process
- Long maintenance intervals
- High number of operating cycles
- Long service life

Individual service

- Close proximity to the customer
- Order specific documentation
- Solutions tailored to specific problems
- After-sales service available promptly worldwide

The right qualifications

- Expertise in all power supply matters
- 30 years of experience with SF_6-insulated circuit breakers
- A quality system certified to ISO 9001, covering development, manufacture, sales, installation and after-sales service
- Test laboratories accredited to EN 45001 and PEHLA/STL

Fig. 29a: SPS-2 circuit-breaker 72.5 kV

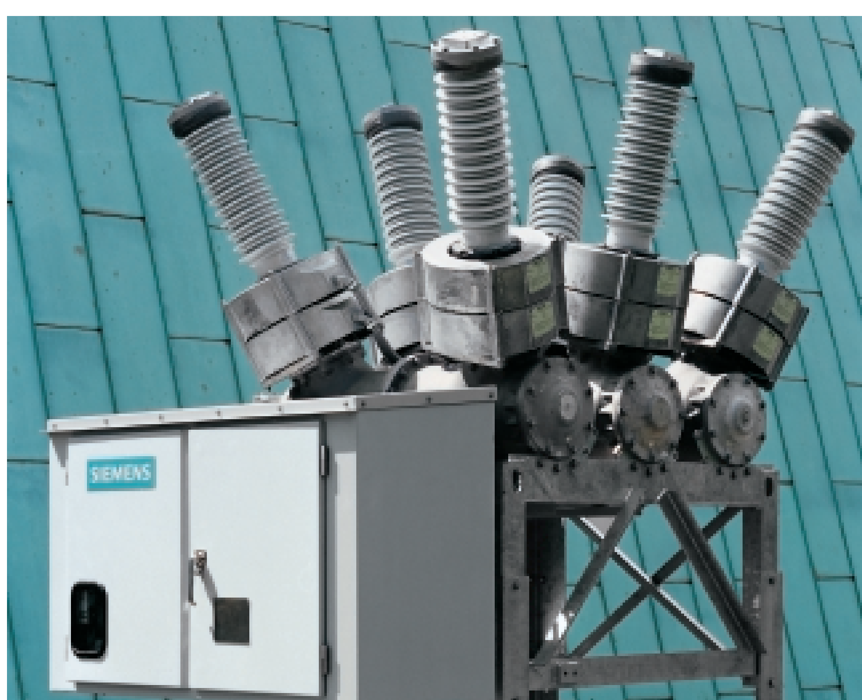


Fig. 29b: SPS-2 circuit-breaker 170 kV

Dead-Tank Circuit-Breakers for 72 kV up to 245 kV

Subtransmission breaker Type SPS-2 and 3AP1-DT

Type SPS-2 power circuit-breakers (Fig. 29a/b) are designed as general, definite-purpose breakers for use at maximum rated voltages of 72.5 and 245 kV.

The construction

The type SPS-2 breaker consists of three identical pole units mounted on a common support frame. The opening and closing force of the FA2/4 spring operating mechanism is transferred to the moving contacts of the interrupter through a system of connecting rods and a rotating seal at the side of each phase.

The tanks and the porcelain bushings are charged with SF_6 gas at a nominal pressure of 6.0 bar. The SF_6 serves as both insulation and arc-quenching medium.

A control cabinet mounted at one end of the breaker houses the spring operating mechanism and breaker control components.

Interrupters are located in the aluminum housings of each pole unit. The interrupters use the latest Siemens puffer arc-quenching system.

The spring operating mechanism is the same design as used with the Siemens 3AP breakers. This design has been in service for years, and has a well documented reliability record.

Customers can specify up to four (in some cases, up to six) bushing-type current transformers (CT) per phase. These CTs, mounted externally on the aluminum housings, can be removed without disturbing the bushings.

Operating mechanism

The type FA2/4 mechanically and electrically trip-free spring mechanism is used on type SPS-2 breakers. The type FA2/4 closing and opening springs hold a charge for storing "open-close-open" operations

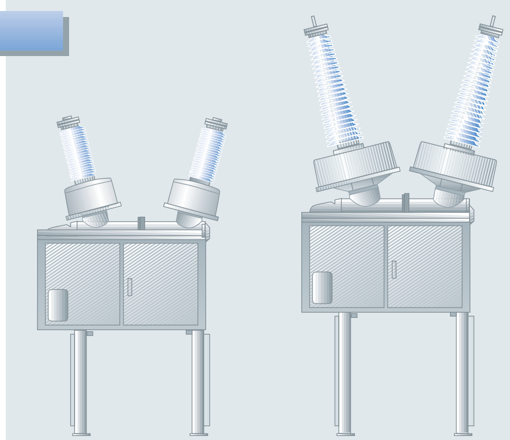
A weatherproof control cabinet has a large door, sealed with rubber gaskets, for easy access during inspection and maintenance. Condensation is prevented by units offering continuous inside/outside temperature differential and by ventilation.

Included in the control cabinet are necessary auxiliary switches, cutoff switch, latch check switch, alarm switch and operation counter. The control relays and three control knife switches (one each for the control, heater and motor) are mounted on a control panel. Terminal blocks on the side and rear of the housing are available for control and transformer wiring.

For non US markets the control cabinet is also available similar to the 3AP cabinet (3AP1-DT).

2

Technical data



Type		SPS-2/3AP1-DT						
Rated voltage	**[kV]**	38	48.3	72.5	121	145	169	242
Rated power-frequency withstand voltage	**[kV]**	80	105	160	260	310	365	425
Rated lighting impulse withstand voltage	**[kV]**	200	250	350	550	650	750	900/1050
Rated switching impulse withstand voltage	**[kV]**	–	–	–	–	–	–	–/850
Rated nominal current up to	**[A]**	4000	4000	4000	4000	4000	4000	4000
Rated breaking current up to	**[kA]**	40	40	40	63	63	63	63
Operating mechanism type		Spring-stored-energy mechanism						

Fig. 30

Dead-Tank Circuit-Breakers for 550 kV

Circuit-breaker Type 3AT2/3-DT

Composite insulators

The 3AT2/3-DT is available with bushings made from composite insulators – this has many practical advantages.

The SIMOTEC® composite insulators manufactured by Siemens consist of a basic body made of epoxy resin reinforced glass fibre tubes. The external tube surface is coated with vulcanized silicon. As is the case with porcelain insulators, the external shape of the insulator has a multished profile. Field grading is implemented by means of a specially shaped screening electrode in the lower part of the composite insulator.

The bushings and the metal tank of the circuit-breaker surround a common gas volume. The composite insulator used on the bushing of the 3AT2/3-DT is a one-piece insulating unit. Compared with conventional housings, composite insulators offer a wide range of advantages in terms of economy, efficiency and safety.

Interrupter unit

The 3AT2/3-DT pole consists of two breaking units in series impressive in the sheer simplicity of their design. The proven Siemens contact system with double graphite nozzles assures faultless operation, consistently high arc-quenching capacity and a long operating life, even at high switching frequencies. Thanks to constant further development, optimization and consistent quality assurance, Siemens arc-quencing systems meet all the requirements placed on modern high-voltage technology.

Hydraulic drive

The operating energy required for the 3AT2/3-DT interrupters is provided by the hydraulic drive, which is manufactured in-house by Siemens. The functional principle of the hydraulic drive constitutes a technically clear solution which offers certain fundamental advantages.

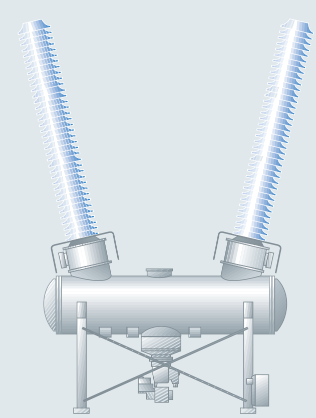
Hydraulic drives provide high amounts of energy economically and reliably. In this way, even the most demanding switching requirements can be mastered in short opening times.

Siemens hydraulic drives are maintenance-free and have a particulary long operating life. They meet the strictest criteria for enviromental acceptability. In this respect, too, Siemens hydraulic drives have proven themselves throughout years of operation.

For further information please contact:

Fax: ++49-30386-25867

Technical data



Type		3AT 2/3-DT
Rated voltage	[kV]	550
Rated power-frequency withstand voltage	[kV]	860
Rated lighting impulse withstand voltage	[kV]	1800
Rated switching impulse withstand voltage	[kV]	1300
Rated nominal current up to	[A]	4000
Rated breaking current up to	[kA]	50/63
Operating mechanism type		Electrohydraulic mechanism

Fig. 31

Dead-Tank Circuit-Breakers for 550 kV

Fig. 32: The 3AT2/3-DT circuit-breaker with SIMOTEC composite insulator bushings

Surge Arresters

Introduction

The main task of an arrester is to protect equipment from the effects of overvoltages. During normal operation, it should have no negative effect on the power system. Moreover, the arrester must be able to withstand typical surges without incurring any damage. Nonlinear resistors with the following properties fulfill these requirements:

- Low resistance during surges so that overvoltages are limited
- High resistance during normal operation, so as to avoid negative effects on the power system and
- Sufficient energy absorption capability for stable operation

With this kind of nonlinear resistor, there is only a small flow of current when continuous operating voltage is being applied. When there are surges, however, excess energy can be quickly removed from the power system by a high discharge current.

Nonlinear resistors

Nonlinear resistors, comprising metal oxide (MO), have proved especially suitable for this.

The nonlinearity of MO resistors is considerably high. For this reason, MO arresters, as the arresters with MO resistors are known today, do not need series gaps.

Siemens has many years of experience with arresters – with the previous gapped SiC-arresters and the new gapless MO arresters – in low-voltage systems, distribution systems and transmission systems. They are usually used for protecting transformers, generators, motors, capacitors, traction vehicles, cables and substations. There are special applications such as the protection of

- Equipment in areas subject to earthquakes or heavy pollution
- Surge-sensitive motors and dry-type transformers
- Generators in power stations with arresters which posses a high degree of short-circuit current strength
- Gas-insulated high-voltage metal-enclosed switchgear (GIS)
- Thyristors in HVDC transmission installations
- Static compensators
- Airport lighting systems
- Electric smelting furnaces in the glass and metals industries
- High-voltage cable sheaths
- Test laboratory apparatus.

MO arresters are used in medium, high and extra-high-voltage power systems. Here, the very low protection level and the high energy absorption capability provided during switching surges are especially important. For high voltage levels, the simple construction of MO arresters is always an advantage.

Another very important advantage of MO arresters is their high degree of reliability when used in areas with a problematic climate, for example in coastal and desert areas, or regions affected by heavy industrial air pollution. Furthermore, some special applications have become possible only with the introduction of MO arresters. One instance is the protection of capacitor banks in series reactive-power compensation equipment which requires extremly high energy absorption capabilities.

Arresters with polymer housings

Fig. 34 shows two Siemens MO arresters with different types of housing. In addition to what has been usual up to now – the porcelain housing – Siemens offers also the latest generation of high-voltage surge arresters with polymer housing.

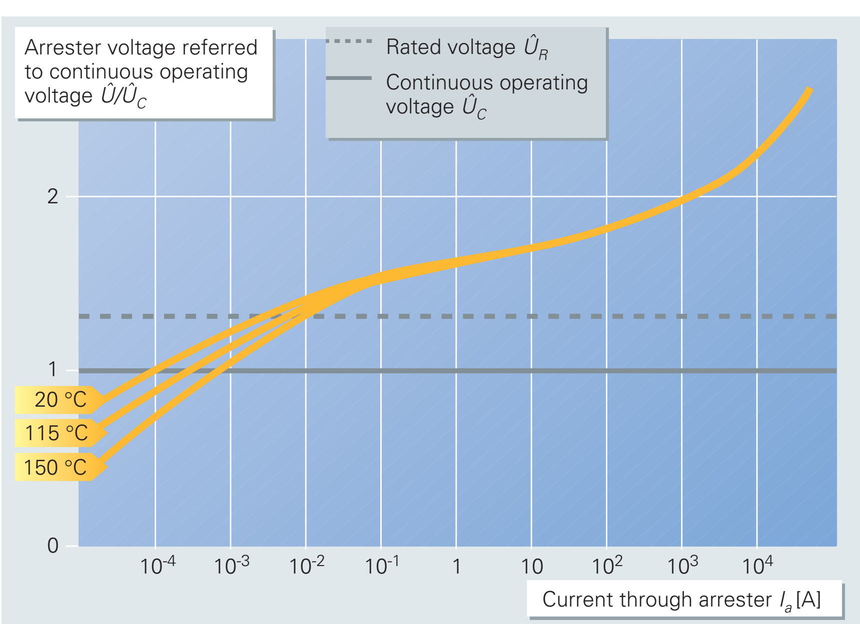


Fig. 33: Current/voltage characteristics of a non-linear MO arrester

Fig. 34: Measurement of residual voltage on porcelain-housed (foreground) and polymer-housed (background) arresters

Fig. 35 shows the sectional view of such an arrester. The housing consists of a fiber-glass-reinforced plastic tube with insulating sheds made of silicon rubber. The advantages of this design which has the same pressure relief device as an arrester with porcelain housing are absolutely safe and reliable pressure relief characteristics, high mechanical strength even after pressure relief and excellent pollution-resistant properties. The very good mechanical features mean that Siemens arresters with polymer housing (type 3EQ/R) can serve as post insulators as well. The pollution-resistant properties are the result of the water-repellent effect (hydrophobicity) of the silicon rubber, which even transfers its effects to pollution.

The polymer-housed high-voltage arrester design chosen by Siemens and the high-quality materials used by Siemens provide a whole series of advantages including long life and suitability for outdoor use, high mechanical stability and ease of disposal.

Another important design shown in Fig. 36 are the gas-insulated metal-enclosed surge arresters (GIS arresters) which have been made by Siemens for more then 25 years. There are two reasons why, when GIS arresters are used with gas-insulated switchgear, they usually offer a higher protective safety margin than when outdoor-type arresters are used (see also IEC 60099-5, 1996-02, Section 4.3.2.2.): Firstly, they can be installed closer to the item to be protected so that traveling wave effects can be limited more effectively. Secondly, compared with the outdoor type, inductance of the installation is lower (both that of the connecting conductors and that of the arrester itself). This means that the protection offered by GIS arresters is much better than by any other method, especially in the case of surges with a very steep rate of rise or high frequency, to which gas-insulated switchgear is exceptionally sensitive.

Please find an overview of the complete range of Siemens arresters in Figs. 37 and 38, pages 26 and 27.

For further information please contact:

Fax: ++49-3 03 86-2 67 21

e-mail: arrester@siemens.de

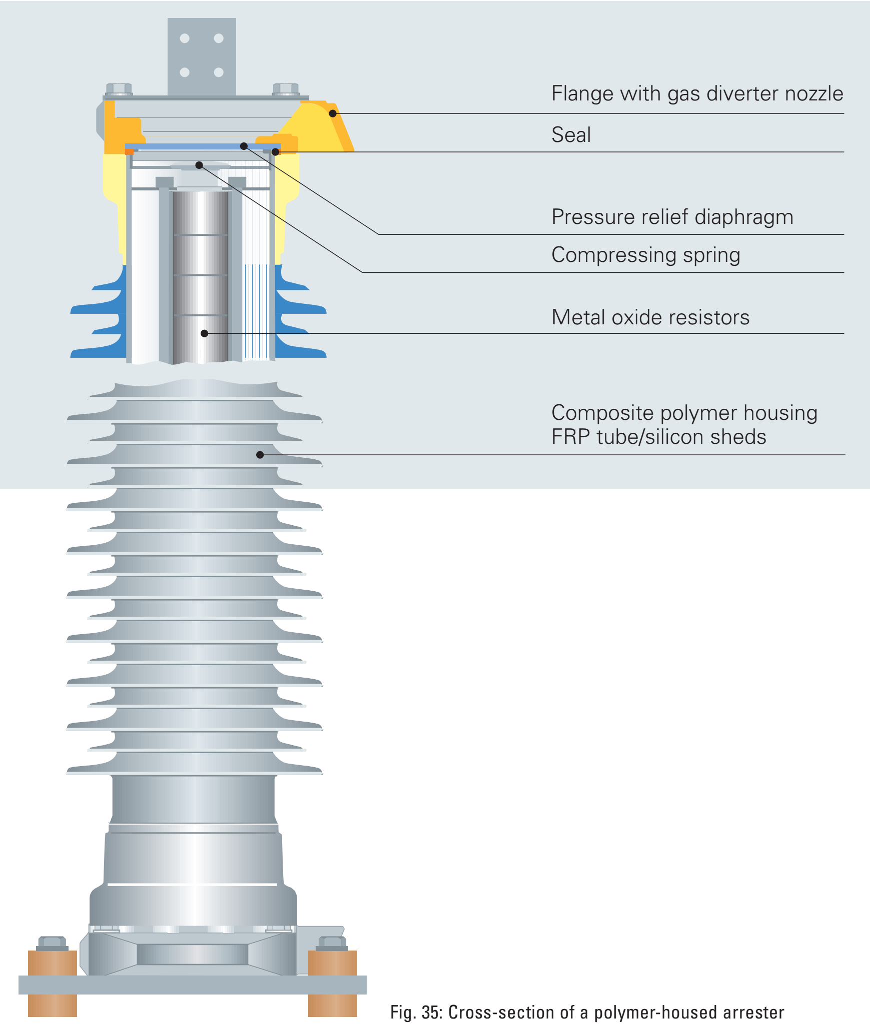


Fig. 35: Cross-section of a polymer-housed arrester

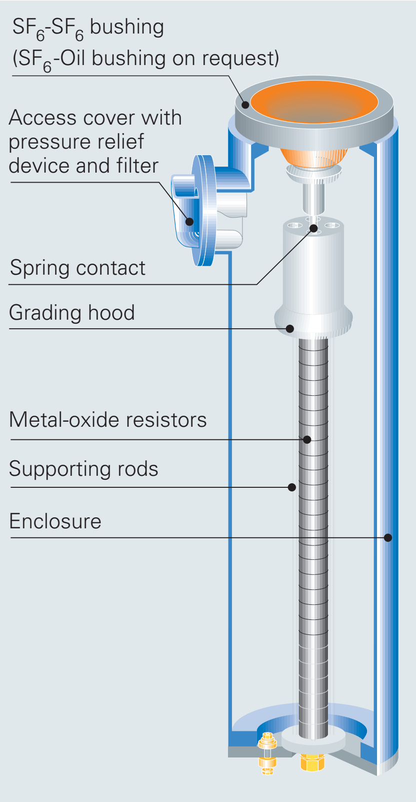


Fig. 36: Gas-insulated metal-enclosed arrester (GIS arrester)

Low-Voltage and Medium-Voltage Arresters and Limiters (230/400 V to 52 kV)

Type	**Low-voltage arresters and limiters**		**Medium-voltage arresters**						
	3EA2	**3EF1** **3EF2** **3EF3** **3EF4** **3EF5**	**3EC3**	**3EE2**	**3EH2**	**3EG5**	**3EK5**	**3EK7**	**3EQ1-B**
Applications	Low-voltage over-head line sys-tems	Motors, dry-type transformers, airfield light-ing systems, sheath voltage limiters, protection of converters for drives	DC sys-tems (loco-motives, overhead contact lines)	Gene-rators, motors, melting furnaces, 6-arrester connec-tions, power plants	Distri-bution systems metal-enclosed gas-in-sulated switch-gear with plug-in connec-tion	Distri-bution systems and medium-voltage switch-gear	Distri-bution systems and medium-voltage switch-gear	Distri-bution systems and medium-voltage switch-gear	AC and DC locomotives, overhead contact lines
Nom. syst. voltage (max.) [kV]	1	10	3	30	45	30	60	30	25
Highest voltage for equipment (max.) [kV]		12	4	36	52	36	72.5	36	30
Maximum rated voltage [kV]	1	15	4	45	52	45	75	45	37 (AC) 4 (DC)
Nominal discharge current [kA]	5	1	10	10	10	10	10	10	10
Maximum energy absorbing capability (at thermal stability) [kJ/kV]	–	3EF1/2 0.8 3EF3 9 3EF4 12.5 3EF5 8	10	10	1.3	3	5	3	10
Maximum long duration current impulse, 2 ms [A]	1 x 380 20 x 250	3EF4 1500 3EF5 1200	1200	1200	200	300	500	300	1200
Maximum short-circuit rating [kA]	Line dis-connec-tion	40	40	300	16	20	20	20	40
Housing material	Polymer	Polymer	Porcelain	Porcelain	Metal	Porcelain	Porcelain	Polymer	Polymer

Fig. 37: Low and medium-voltage arresters

High-Voltage Arresters (72.5 to 800 kV)

Type	Metal-oxide surge arresters									
	3EP1	**3EP4**	**3EP2**	**3EP3**	**3EQ1**	**3EQ4**	**3EQ3 3ER3**	**3EP2-K**	**3EP2-K3**	**3EP3-K**
Applications	Medium- and high-voltage systems, outdoor instal-lations	Medium- and high-voltage systems, outdoor instal-lations	High-voltage systems, outdoor instal-lations	High-voltage systems, outdoor instal-lations, HVDC, SC & SVC appli-cations	Medium- and high-voltage systems, outdoor instal-lations	High-voltage systems, outdoor instal-lations	High-voltage systems, outdoor instal-lations, HVDC, SC & SVC appli-cations	High-voltage systems, metal-enclosed gas-insulated switch-gear	High-voltage systems, metal-enclosed gas-insulated switch-gear	High-voltage systems, metal-enclosed gas-insulated switch-gear
Nom. syst. voltage (max.) [kV]	60	150	500	765	275	500	765	150	150	500
Highest voltage for equip. (max.) [kV]	72.5	170	550	800	300	550	800	170	170	550
Maximum rated voltage [kV]	84	147	468	612	240	468	612	180	180	444
Nominal discharge current [kA]	10	10	10/20	10/20	10	10/20	20	10/20	10/20	20
Maximum line discharge class	2	3	5	5	3	5	5	4	4	5
Maximum energy absorbing capability (at thermal stability) [kJ/kV]	5	8	12.5	20	8	12.5	20	10	10	12.5
Maximum long duration current impulse, 2 ms [A]	500	850	1500	3900	850	1500	3900	1200	1200	1500
Maximum short-circuit rating [kA]	40	65	65	100	50	65	80	–	–	–
Minimum breaking moment [kNm][2]	2.1[2]	4.5[2]	12.5[2]	34[2]						
Maximum permissible service load [MPSL]					6[3]	21[3]	72[3]	–	–	–
Housing material	Porcelain	Porcelain	Porcelain	Porcelain	Polymer[1]	Polymer[1]	Polymer[1]	Metal	Metal	Metal

[1] Silicon rubber sheds [2] Acc. to DIN 48113 [3] Acc. to IEC TC 37 WG5 03.99; > 50% of this value are maintained after pressure relief

Fig. 38: High-voltage arresters

Gas-Insulated Switchgear for Substations

2

Introduction

Common characteristic features of switchgear installation

Because of its small size and outstanding compatibility with the environment, SF_6-insulated switchgear (GIS) is gaining constantly on other types. Siemens has been a leader in this sector from the very start.

The concept of SF_6-insulated metal-enclosed high-voltage switchgear has proved itself in more than 70,000 bay operating years in over 6,000 installations in all parts of the world. It offers the following outstanding advantages.

Minimal space requirements

The availability and price of land play an important part in selecting the type of switchgear to be used. Siting problems arise in

- Large towns
- Industrial conurbations
- Mountainous regions with narrow valleys
- Underground power stations

In cases such as these, SF_6-insulated switchgear is replacing conventional switchgear because of its very small space requirements.

Full protection against contact with live parts

The all-round metal enclosure affords maximum safety for personnel under all operating and fault conditions.

Protection against pollution

Its metal enclosure fully protects the switchgear interior against environmental effects such as salt deposits in coastal regions, industrial vapors and precipitates, as well as sandstorms. The compact switchgear can be installed in buildings of uncomplicated design in order to minimize the cost of cleaning and inspection and to make necessary repairs independent of weather conditions.

Free choice of installation site

The small site area required for SF_6-insulated switchgear saves expensive grading and foundation work, e.g. in permafrost zones. Other advantages are the short erection times and the fact that switchgear installed indoors can be serviced regardless of the climate or the weather.

Protection of the environment

The necessity to protect the environment often makes it difficult to erect outdoor switchgear of conventional design, whereas buildings containing compact SF_6-insulated switchgear can almost always be designed so that they blend well with the surroundings.

SF_6-insulated metal-enclosed switchgear is, due to the modular system, very flexible and can meet all requirements of configuration given by network design and operating conditions.

Each circuit-breaker bay includes the full complement of disconnecting and grounding switches (regular or make-proof), instrument transformers, control and protection equipment, interlocking and monitoring facilities commonly used for this type of installation (Fig. 39).

Beside the conventional circuit-breaker bay, other arrangements can be supplied such as single-bus, ring cable with load-break switches and circuit-breakers, single-bus arrangement with bypass-bus, coupler and bay for triplicate bus. Combined circuit-breaker and load-break switch feeder, ring cable with load-break switches, etc. are furthermore available for the 145 kV level.

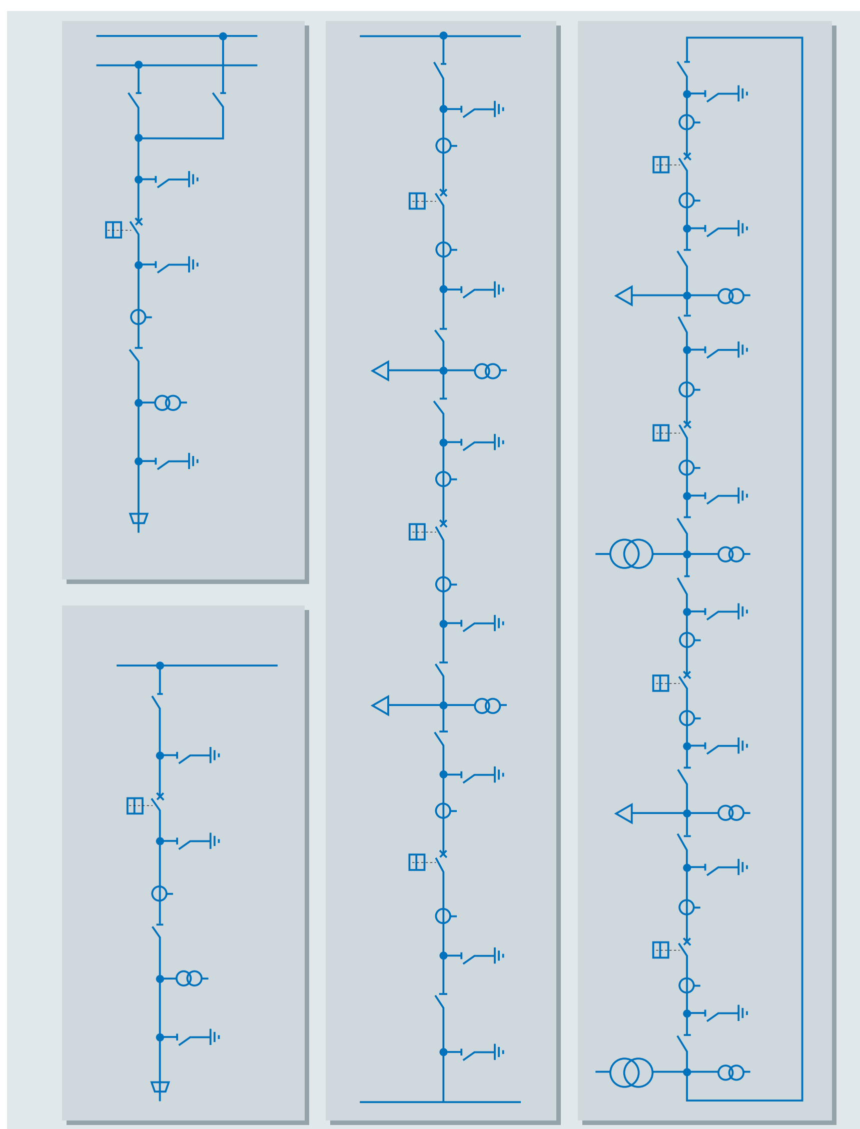


Fig. 39: Typical circuit arrangements of SF_6-switchgear

Main product range of GIS for substations

SF_6 switchgear up to 550 kV (the total product range covers GIS from 66 up to 800 kV rated voltage): Fig. 40.

The development of the switchgear is always based on an overall production concept, which assures the achievement of the high technical standards required of the HV switchgear whilst providing the maximum customer benefit.

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

Siemens GIS switchgear meets all the performance, quality and reliability demands such as:

Compact space-saving design

means uncomplicated foundations, a wide range of options in the utilization of space, less space taken up by the switchgear.

Minimal-weight construction

through the use of aluminum alloy and the exploitation of innovations in development such as computer-aided design tools.

Safe encapsulation

means an outstanding level of safety based on new manufacturing methods and optimized shape of enclosures.

Environmental compatibility

means no restrictions on choice of location through minimal space requirement, extremely low noise emission and effective gas sealing system (leakage < 1% per year per gas compartment).

Economical transport

means simplified and fast transport and reduced costs because of maximum possible size of shipping units.

Minimal operating costs

means the switchgear is practically maintenance-free, e.g. contacts of circuit-breakers and disconnectors designed for extremely long endurance, motor-operated mechanisms self-lubricating for life, corrosion-free enclosure. This ensures that the first inspection will not be necessary until after 25 years of operation.

Reliability

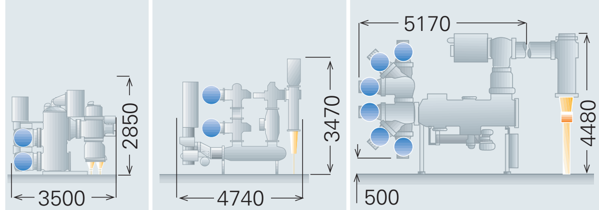
means our overall product concept which includes, but is not limited to, the use of finite elements method (FEM), three-dimensional design programs, stereolithography, and electrical field development programs assuring the high standard of quality.

Smooth and efficient installation and commissioning

transport units are fully assembled and tested at the factory and filled with SF_6 gas at reduced pressure. Plug connection of all switches, all of which are motorized, further improves the speediness of site installation and substantially reduces field wiring errors.

Routine tests

All measurements are automatically documented and stored in the EDP information system, which enables quick access to measured data even if years have passed.



Switchgear type	8DN8	8DN9	8DQ1
Details on page	2/30	2/31	2/32
Rated voltage [kV]	up to 145	up to 245	up to 550
Rated power-frequency withstand voltage [kV]	up to 275	up to 460	up to 740
Rated lightning impulse withstand voltage [kV]	up to 650	up to 1050	up to 1800
Rated switching impulse withstand voltage [kV]	–	up to 850	up to 1250
Rated (normal) current busbar [A]	up to 3150	up to 3150	up to 6300
Rated (normal) current feeder [A]	up to 2500	up to 3150	up to 4000
Rated breaking current [kA]	up to 40	up to 50	up to 63
Rated short-time withstand current [kA]	up to 40	up to 50	up to 63
Rated peak withstand current [kA]	up to 108	up to 135	up to 170
Inspection [Years]	> 25	> 25	> 25
Bay width [mm]	800	1200/1500	3600

All dimensions in mm

Fig. 40: Main product range

For further information please contact:

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Gas-Insulated Switchgear for Substations

SF_6-insulated switchgear up to 145 kV, type 8DN8

Three-phase enclosures are used for type 8DN8 switchgear in order to achieve extremely low component dimensions. The low bay weight ensures minimal floorloading and eliminates the need for complex foundations. Its compact dimensions and low weight enable it to be installed almost anywhere. This means that capital costs can be reduced by using smaller buildings, or by making use of existing ones, for instance when medium voltage switchgear is replaced by 145 kV GIS.
The bay ist based on a circuit-breaker mounted on a supporting frame (Fig. 41). A special multifunctional cross-coupling module combines the functions of the disconnector and earthing switch in a three-position switching device. It can be used as

- an active busbar with integrated disconnector and work-in-progress earthing switch (Fig. 41/Pos. 3 and 4),
- outgoing feeder module with integrated disconnector and work-in-progress earthing switch (Fig. 41/Pos. 5),
- busbar sectionalizer with busbar earthing.

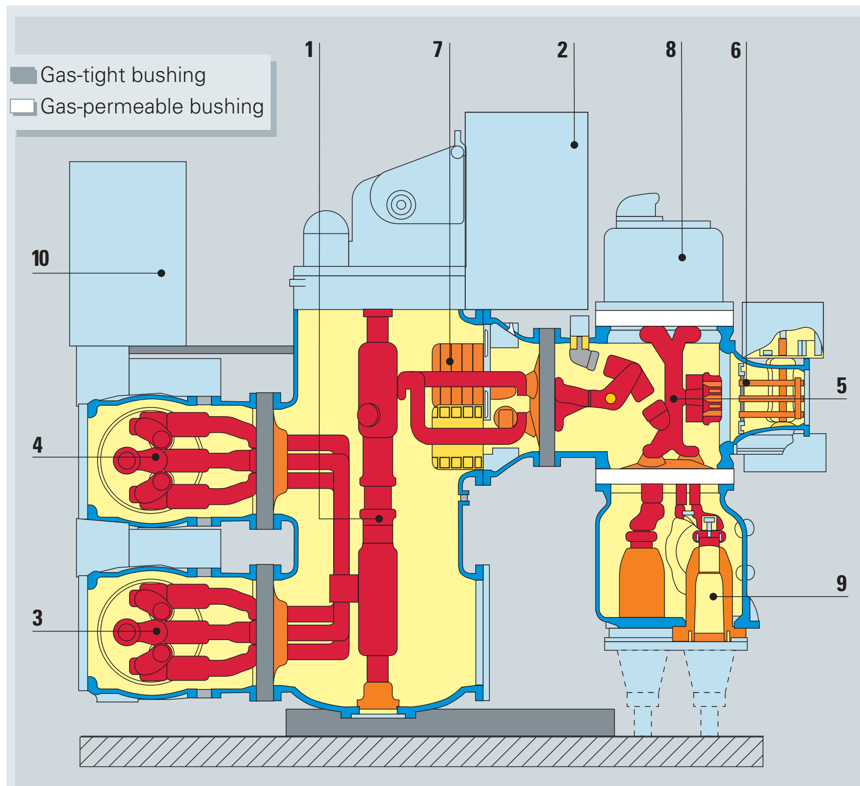
For cable termination, a cable termination module can be equipped with either conventional sealing ends or the latest plug-in connectors (Fig. 41/Pos. 9). Flexible single-pole modules are used to connect overhead lines and transformers by using a splitting module which links the 3-phase encapsulated switchgear to the single pole connections.

Thanks to the compact design, up to three completely assembled and works-tested bays can be shipped as one transport unit. Fast erection and commissioning on site ensure the highest possible quality.

The feeder control and protection can be located in a bay-integrated local control cubicle, mounted in the front of each bay (Fig. 42). It goes without saying that we supply our gas-insulated switchgear with all types of currently available bay control systems – ranging from contactor circuit controls to digital processor bus-capable bay control systems, for example the modern SICAM HV system based on serial bus communication. This system offers

- Online diagnosis and trend analysis enabling early warning, fault recognition and condition monitoring.
- Individual parameterization, ensuring the best possible incorporation of customized control facilities.
- Use of modern current and voltage sensors.

This results in a longer service life and lower operating costs, in turn attaining a considerable reduction in life cycle costs.



1 Interrupter unit of the circuit-breaker
2 Spring-stored energy mechanism with circuit-breaker control unit
3 Busbar I with disconnector and earthing system
4 Busbar II with disconnector and earthing system
5 Outgoing feeder module with disconnector and earthing switch
6 Make-proof earthing switch (high-speed)
7 Current transformer
8 Voltage transformer
9 Cable sealing end
10 Integrated local control cubicle

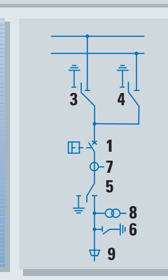


Fig. 41: Switchgear bay 8DN8 up to 145 kV

Fig. 42: 8DN8 switchgear for rated voltage 145 kV

Fig. 43

SF_6-insulated switchgear up to 245 kV, type 8DN9

The clear bay configuration of the light-weight and compact 8DN9 switchgear is evident at first sight. Control and monitoring facilities are easily accessible in spite of the compact design of the switchgear.

The horizontally arranged circuit-breaker forms the basis of every bay configuration. The operating mechanism is easily accessible from the operator area. The other bay modules – of single-phase encapsulated design like the circuit-breaker module – are located on top of the circuit-breaker. The three-phase encapsulated passive busbar is partitioned off from the active equipment.

Thanks to "single-function" assemblies (assignment of just one task to each module) and the versatile modular structure, even unconventional arrangements can be set up out of a pool of only 20 different modules.

The modules are connected to each other by a standard interface which allows an extensive range of bay structures. The switchgear design with standardized modules and the scope of services mean that all kinds of bay structures can be set up in a minimal area.

The compact design permits the supply of double bays fully assembled, tested in the factory and filled with SF_6 gas at reduced pressure, which assures smooth and efficient installation and commissioning.

The following major feeder control level functions are performed in the local control cubicle for each bay, which is integrated in the operating front of the 8DN9 switchgear:

- Fully interlocked local operation and state-indication of all switching devices managed reliably by the Siemens digital switchgear interlock system
- Practical dialog between the digital feeder protection system and central processor of the feeder control system
- Visual display of all signals required for operation and monitoring, together with measured values for current, voltage and power
- Protection of all auxiliary current and voltage transformer circuits
- Transmission of all feeder information to the substation control and protection system

Factory assembly and tests are significant parts of the overall production concept mentioned above. Two bays at a time undergo mechanical and electrical testing with the aid of computer-controlled stands.

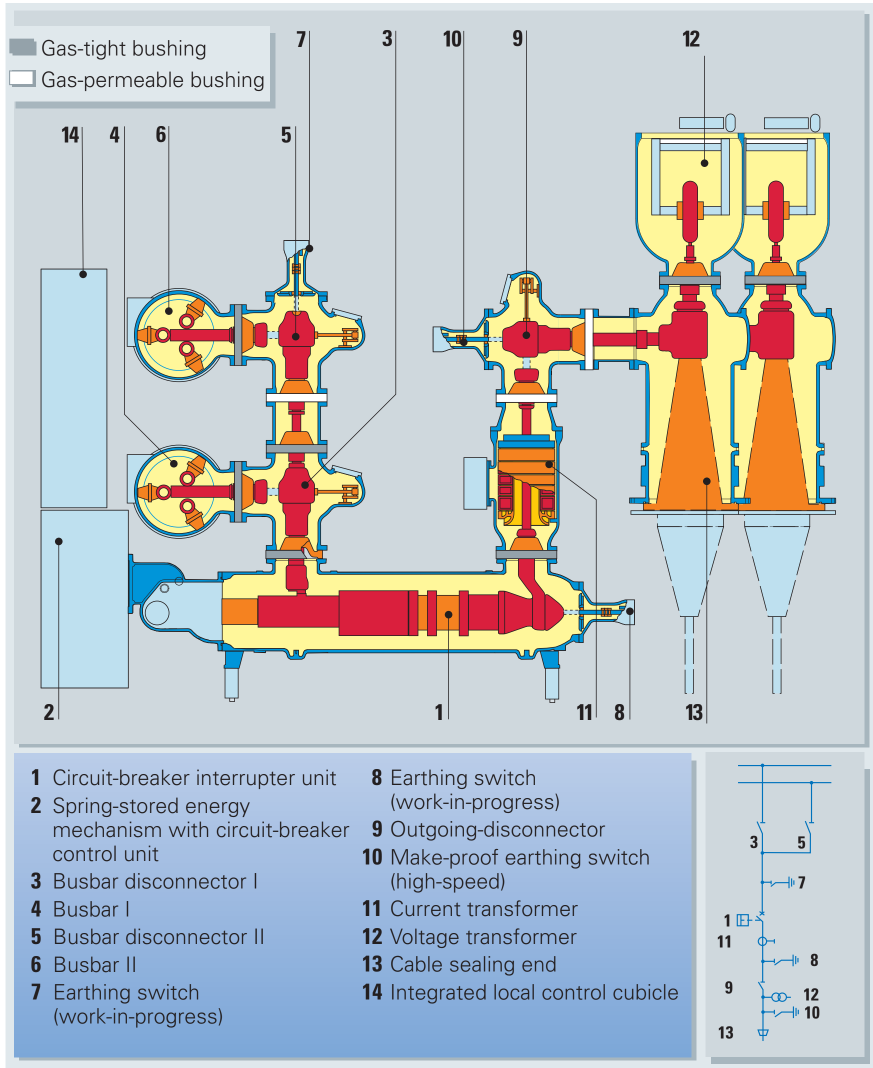


Fig. 44: Switchgear bay 8DN9 up to 245 kV

Fig. 45: 8DN9 switchgear for rated voltage 245 kV

SF_6-insulated switchgear up to 550 kV, type 8DQ1

The GIS type 8DQ1 is a modular switchgear system for high power switching stations with individual enclosure of all modules for the three-phase system.
The base unit for the switchgear forms a horizontally arranged circuit-breaker on top of which are mounted the housings containing disconnectors, grounding switches, current transformers, etc. The busbar modules are also single-phase encapsulated and partitioned off from the active equipment.
As a matter of course the busbar modules of this switchgear system are passive elements, too.

Additional main characteristic features of the switchgear installation are:

- Circuit-breakers with two interrupter units up to operating voltages of 550 kV and breaking currents of 63 kA (from 63 kA to 100 kA, circuit-breakers with four interrupter units have to be considered)
- Low switchgear center of gravity by means of circuit-breaker arranged horizontally in the lower portion
- Utilization of the circuit-breaker transport frame as supporting device for the entire bay
- The use of only a few modules and combinations of equipment in one enclosure reduces the length of sealing faces and consequently lowers the risk of leakage

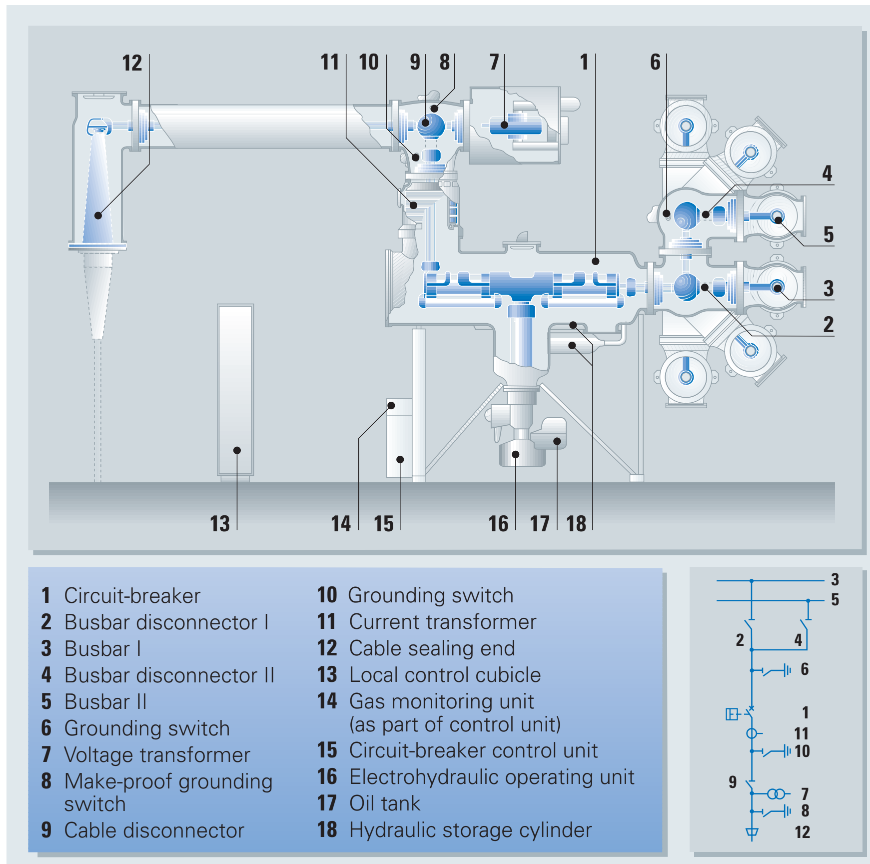


Fig. 46: Switchgear bay 8DQ1 up to 550 kV

Fig. 47: 8DQ1 switchgear for rated voltage 420 kV

Gas-Insulated Switchgear for Substations

Some examples for special arrangement

Gas-insulated switchgear – usually accommodated in buildings (as shown in a tower-type substation) – is expedient whenever the floor area is very expensive or restricted or whenever ambient conditions necessitate their use (Fig. 50, page **2**/34).

For smaller switching stations, or in cases of expansion when there is no advantage in constructing a building, a favorable solution is to install the substation in a container (Fig. 49).

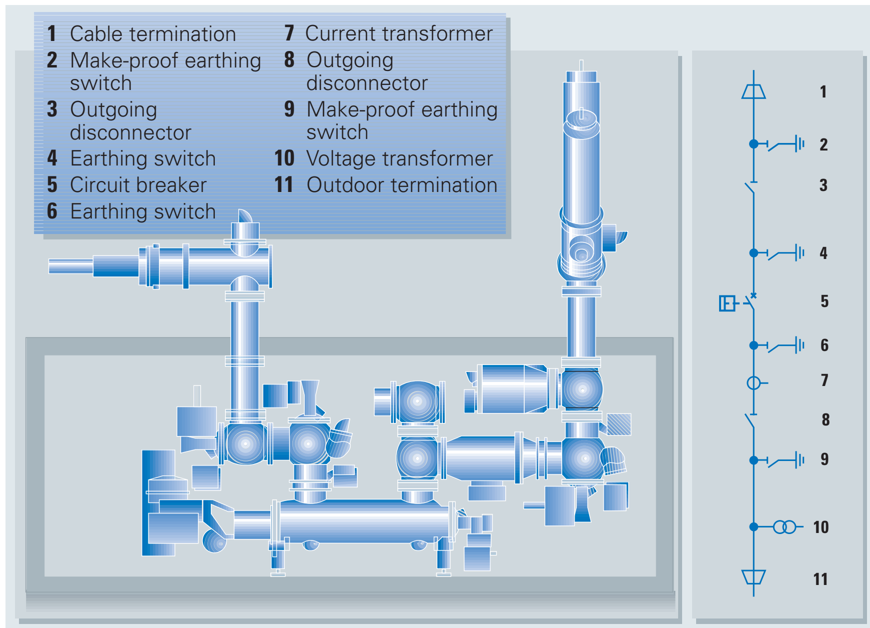


Fig. 48: Containerized 8DN9 switchgear with stub feed in this example

Mobile containerized switchgear – even for high voltage

At medium-voltage levels, mobile containerized switchgear is the state of the art. But even high-voltage switching stations can be built in this way and economically operated in many applications.

The heart is the metal-enclosed SF_6-insulated switchgear, installed either in a sheet-steel container or in a block house made of prefabricated concrete elements. In contrast to conventional stationary switchgear, there is no need for complicated constructions; mobile switching stations have their own "building".

Fig. 49: 8DN9 switchgear bay in a container

Mobile containerized switching stations can be of single or multi-bay design using a large number of different circuits and arrangements. All the usual connection components can be employed, such as outdoor bushings, cable adapter boxes and SF_6 tubular connections. If necessary, all the equipment for control and protection and for the local supply can be accommodated in the container. This allows extensively independent operation of the installation on site. Containerized switchgear is preassembled in the factory and ready for operation. On site, it is merely necessary to set up the containers, fit the exterior system parts and make the external connections. Shifting the switchgear assembly work to the factory enhances the quality and operational reliability. Mobile containerized switchgear requires little space and usually fits in well with the environment. Rapid availability and short commissioning times are additional, significant advantages for the operators. Considerable cost reductions are achieved in the planning, construction work and assembly.

Building authority approvals are either not required or only in a simple form. The installation can be operated at various locations in succession, and adaptation to local circumstances is not a problem. These are the possible applications for containerized stations:

- Intermediate solutions for the modernization of switching stations
- Low-cost transitional solutions when tedious formalities are involved in the new construction of transformer substations, such as in the procurement of land or establishing cable routes
- Quick erection as an emergency station in the event of malfunctions in existing switchgear
- Switching stations for movable, geothermal power plants

GIS up to 245 kV in a standard container

The dimensions of the 8DN9 switchgear made it possible to accommodate all active components of the switchgear (circuit-breaker, disconnector, grounding switch) and the local control cabinet in a standard container.

The floor area of 20 ft x 8 ft complies with the ISO 668 standard. Although the container is higher than the standard dimension of 8 ft, this will not cause any problems during transportation as proven by previously supplied equipment.

German Lloyd, an approval authority, has already issued a test certificate for an even higher container construction.

The standard dimensions and ISO corner fittings will facilitate handling during transport in the 20 ft frame of a container ship and on a low-loader truck.

Operating staff can enter the container through two access doors.

Rent a GIS

Containerized gas-insulated high voltage substations for hire are now available. In this way, we can step into every breach, instantly and in a remarkably cost-effective manner.
Whether for a few weeks, months or even 2 to 3 years, a fair rent makes our Instant Power Service unbeatably economical.

Gas-Insulated Switchgear for Substations

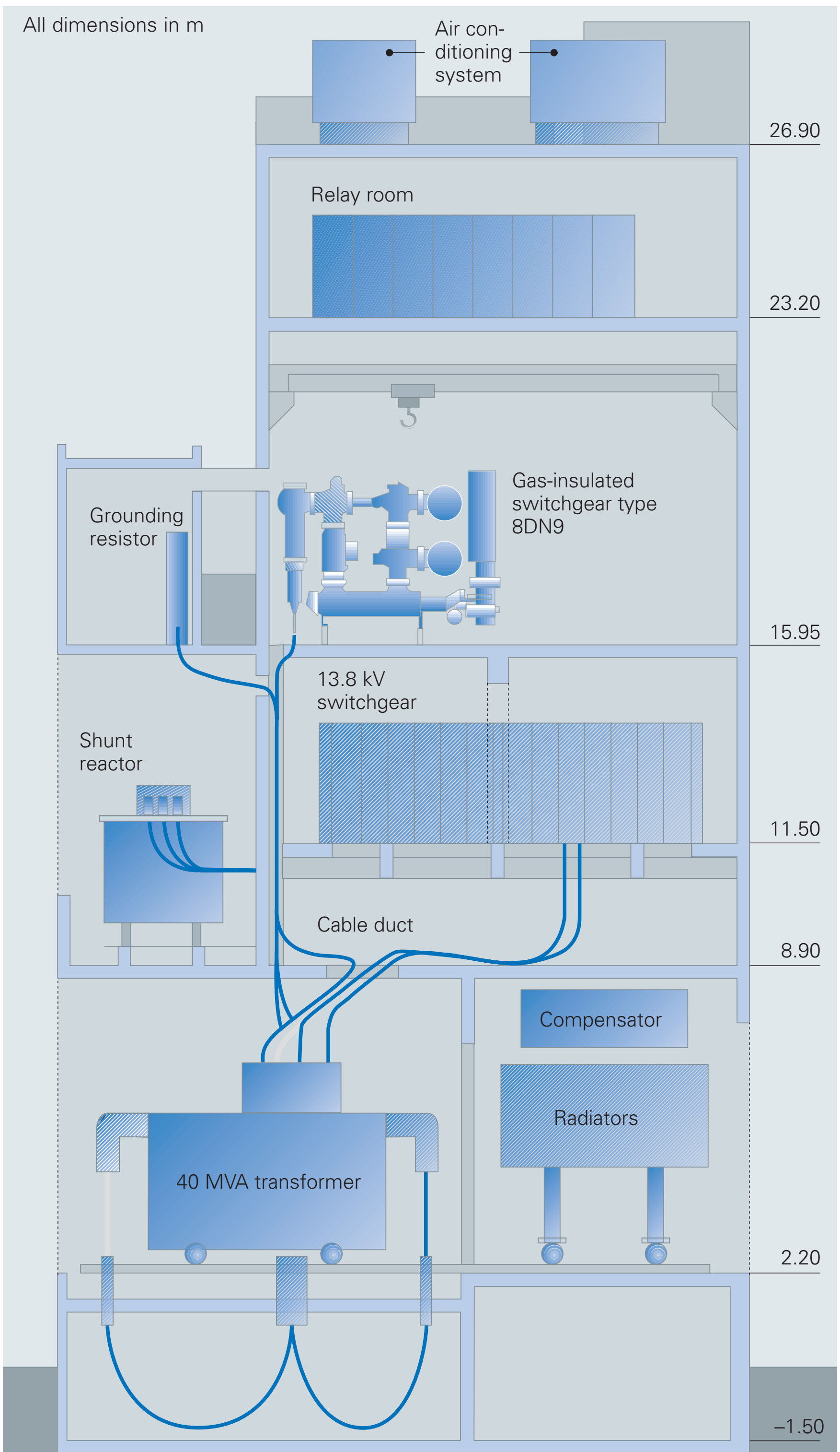


Fig. 50: Special arrangement for limited space. Sectional view of a building showing the compact nature of gas-insulated substations

Specification guide for metal-enclosed SF_6-insulated switchgear

The points below are not considered to be comprehensive, but are a selection of the important ones.

General

These specifications cover the technical data applicable to metal-enclosed SF_6 gas-insulated switchgear for switching and distribution of power in cable and/or overhead line systems and at transformers. Key technical data are contained in the data sheet and the single-line diagram attached to the inquiry.

A general "Single-line diagram" and a sketch showing the general arrangement of the substation and the transmission line exist and shall form part of a proposal.

The switchgear quoted shall be complete to form a functional, safe and reliable system after installation, even if certain parts required to this end are not specifically called for.

Applicable standards

All equipment shall be designed, built, tested and installed to the latest revisions of the applicable IEC 60 standards (IEC Publ. 60517 "High-voltage metal-enclosed switchgear for rated voltages of 72.5 kV and above", IEC Publ. 60129 "Alternating current disconnectors (isolators) and grounding switches", IEC Publ. 60056 "High-voltage alternating-current circuit-breakers"), and IEC Publ. 60044 for instrument transformers.

Local conditions

The equipment described herein will be installed indoors. Suitable lightweight, prefabricated buildings shall be quoted if available from the supplier.

Only a flat concrete floor will be provided by the buyer with possible cutouts in case of cable installation. The switchgear shall be equipped with adjustable supports (feet). If steel support structures are required for the switchgear, these shall be provided by the supplier.

For design purposes indoor temperatures of –5 °C to +40 °C and outdoor temperatures of –25 °C to +40 °C shall be considered.

For parts to be installed outdoors (overhead line connections) the applicable conditions in IEC Publication 60517 shall also be observed.

Gas-Insulated Switchgear for Substations

Work, material and design

Aluminium or aluminium alloys shall be used preferabely for the enclosures.

Maximum reliability through minimum amount of erection work on site is required. Subassemblies must be erected and tested in the factory to the maximum extent. The size of the subassemblies shall be limited only by the transport conditions.

The material and thickness of the enclosure shall be selected to withstand an internal arc and to prevent a burn-through or puncturing of the housing within the first stage of protection, referred to a short-circuit current of 40 kA.

Normally exterior surfaces of the switchgear shall not require painting. If done for aesthetic reasons, surfaces shall be appropriately prepared before painting, i.e. all enclosures are free of grease and blasted. Thereafter the housings shall be painted with no particular thickness required but to visually cover the surface for decorative reasons only. The interior color shall be light (white or light grey).

All joints shall be machined and all castings spotfaced for bolt heads, nuts and washers.

Assemblies shall have reliable provisions to absorb thermal expansion and contractions created by temperature cycling. For this purpose metal bellows-type compensators shall be installed. They must be provided with adjustable tensioners.

All solid post insulators shall be provided with ribs (skirts).

For supervision of the gas within the enclosures, density monitors with electrical contacts for at least two pressure levels shall be installed. The circuit-breakers, however, might be monitored by density gauges fitted in circuit-breaker control units.

The manufacturer assures that the pressure loss within each individual gas compartment – and not referred to the total switchgear installation only – will be not more than 1% per year per gas compartment.

Each gas-filled compartment shall be equipped with static filters of a capacity to absorb any water vapor penetrating into the switchgear installation over a period of at least 25 years.

Long intervals between the necessary inspections shall keep the maintenance cost to a minimum. A minor inspection shall only become necessary after ten years and a major inspection preferably after a period exceeding 25 years of operation, unless the permissible number of operations is met at an earlier date.

Arrangement and modules

Arrangement

The arrangement shall be single-phase or three-phase enclosed.

The assembly shall consist of completely separate pressurized sections designed to minimize the risk of damage to personnel or adjacent sections in the event of a failure occurring within the equipment. Rupture diaphragms shall be provided to prevent the enclosures from uncontrolled bursting and suitable deflectors provide protection for the operating personnel. In order to achieve maximum operating reliability, no internal relief devices may be installed because adjacent compartments would be affected. Modular design, complete segregation, arc-proof bushings and "plug-in" connection pieces shall allow ready removal of any section and replacement with minimum disturbance of the remaining pressurized switchgear.

Busbars

All busbars shall be three-phase or single-phase enclosed and be plug-connected from bay to bay.

Circuit-breakers

The circuit-breaker shall be of the single pressure (puffer) type with one interrupter per phase*. Heaters for the SF_6 gas are not permitted.

The arc chambers and contacts of the circuit-breaker shall be freely accessible. The circuit-breaker shall be designed to minimize switching overvoltages and also to be suitable for out-of-phase switching.

The specified arc interruption performance must be consistent over the entire operating range, from line-charging currents to full short-circuit currents.

The circuit breaker shall be designed to withstand at least 18–20 operations (depending on the voltage level) at full short-circuit rating without the necessity to open the circuit-breaker for service or maintenance.

The maximum tolerance for phase disagreement shall be 3 ms, i.e. until the last pole has been closed or opened respectively after the first.

A standard station battery required for control and tripping may also be used for recharging the operating mechanism.

The energy storage system (hydraulic or spring operating system) will hold sufficient energy for all standard IEC close-open duty cycles.
The control system shall provide alarm signals and internal interlocks, but inhibit tripping or closing of the circuit-breaker when there is insufficient energy capacity in the energy storage system, or the SF_6 density within the circuit-breaker has dropped below a minimum permissible level.

Disconnectors

All isolating switches shall be of the single-break type. DC motor operation (110, 125, 220 or 250 V), completely suitable for remote operation, and a manual emergency drive mechanism is required.

Each motor-drive shall be self-contained and equipped with auxiliary switches in addition to the mechanical indicators. Life lubrication of the bearings is required.

Grounding switches

Work-in-progress grounding switches shall generally be provided on either side of the circuit-breaker. Additional grounding switches may be used for the grounding of bus sections or other groups of the assembly.

DC motor operation (110, 125, 220 or 250 V), completely suitable for remote operation, and a manual emergency drive mechanism is required.

Each motor drive shall be self-contained and equipped with auxiliary position switches in addition to the mechanical indicators. Life lubrication of the bearings is required.

* two interrupters for voltages exceeding 245 kV

2

Make-proof high-speed grounding switches shall generally be installed at cable and overhead-line terminals. DC motor operation (110, 125, 220 or 250 V), completely suitable for remote operation, and a manual emergency drive mechanism is required.

Each motor drive shall be self-contained and equipped with auxiliary position switches in addition to the mechanical indicators. Life lubrication of the bearings is required.
These switches shall be equipped with a rapid closing mechanism to provide fault-making capability.

Instrument transformers

Current transformers (CTs) shall be of the dry-type design not using epoxy resin as insulation material. Cores shall be provided with the accuracies and burdens as shown on the SLD. Voltage transformers shall be of the inductive type, with ratings up to 200 VA. They shall be foil-gas-insulated.

Cable terminations

Single or three-phase, SF_6 gas-insulated, metal-enclosed cable-end housings shall be provided. The stress cone and suitable sealings to prevent oil or gas from leaking into the SF_6 switchgear are part of the cable manufacturer's supply. A mating connection piece, which has to be fitted to the cable end, shall be made available by the switchgear supplier.

The cable end housing shall be suitable for oil-type, gas-pressure-type and plastic-insulated (PE, PVC, etc.) cables as specified on the SLD, or the data sheets.

Facilities to safely isolate a feeder cable and to connect a high-voltage test cable to the switchgear or the cable shall be provided.

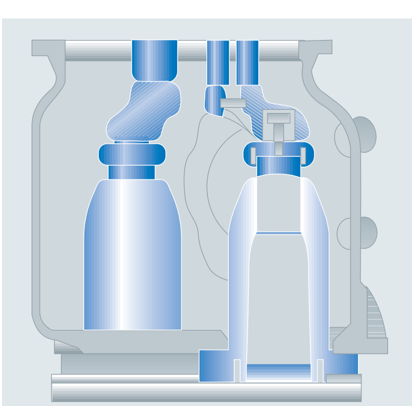


Fig. 51: Three phase cable termination module. Example for plug-in type cables.

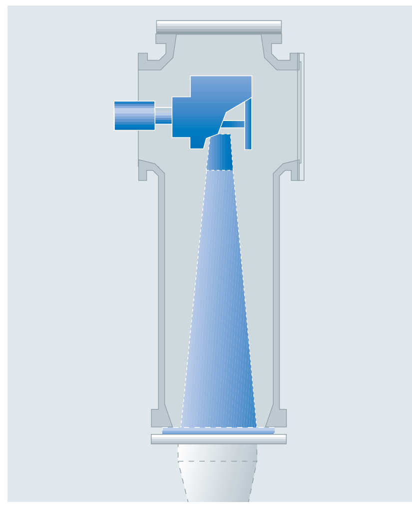


Fig. 52: Cable termination module – Cable termination modules conforming to IEC are available for connecting the switchgear to high-voltage cables. The standardized construction of these modules allows connection of various cross-sections and insulation types. Parallel cable connections for higher rated currents are also possible using the same module.

Overhead line terminations

Terminations for the connection of overhead lines shall be supplied complete with SF_6-to-air bushings, but without line clamps.

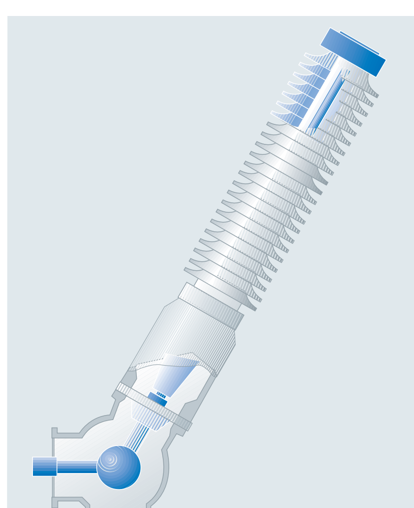


Fig. 53: Outdoor termination module – High-voltage bushings are used for transition from SF_6-to-air as insulating medium. The bushings can be matched to the particular requirements with regard to arcing and creepage distances. The connection with the switchgear is made by means of variable-design angular-type modules.

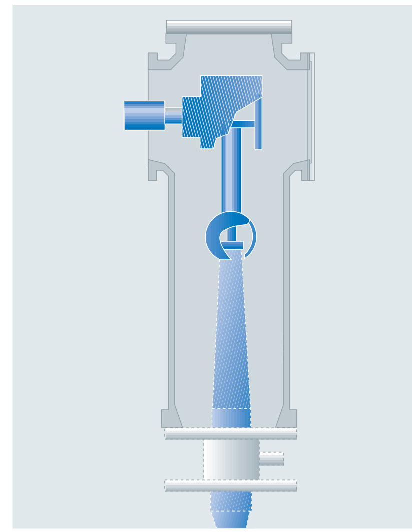


Fig. 54: Transformer/reactor termination module – These termination modules form the direct connection between the GIS and oil-insulated transformers or reactance coils. They can be matched economically to various transformer dimensions by way of standardized modules.

Fig. 55: Transformer termination modules

Control

An electromechanical or solid-state interlocking control board shall be supplied as a standard for each switchgear bay. This fail-safe interlock system will positively prevent maloperations. Mimic diagrams and position indicators shall give clear demonstration of the operation to the operating personnel.

Provisions for remote control shall be supplied.

Tests required

Partial discharge tests

All solid insulators fitted into the switchgear shall be subjected to a routine partial discharge test prior to being installed. No measurable partial discharge is allowed at 1.1 line-to-line voltage (approx. twice the phase-to-ground voltage). This test ensures maximum safety against insulator failure, good long-term performance and thus a very high degree of reliability.

Pressure tests

Each cast aluminium enclosure of the switchgear shall be pressure-tested to at least double the service pressure.

Leakage tests

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

Power frequency tests

Each assembly shall be subjected to power-frequency withstand tests to verify the correct installation of the conductors and also the fact that the insulator surfaces are clean and the switchgear as a whole is not polluted inside.

Additional technical data

The supplier shall point out all dimensions, weights and other applicable data of the switchgear that may affect the local conditions and handling of the equipment. Drawings showing the assembly of the switchgear shall be part of the quotation.

Instructions

Detailed instruction manuals about installation, operation and maintenance of the equipment shall be supplied by the contractor in case of an order.

Fig. 56: The modular system of the 8DQ1 switchgear enables all conceivable customer requirements to be met with just a small number of components

Scope of supply

For all types of GIS Siemens supplies the following items and observes these interface points:

- Switchgear bay with circuit-breaker interrupters, disconnectors and grounding switches, instrument transformers, and busbar housings as specified. For the different feeder types, the following limits apply:
  - Overhead line feeder: the connecting stud at the SF_6-to-air bushing without the line clamp.
  - Cable feeder: according to IEC 60859 the termination housing, conductor coupling, and connecting plate are part of the GIS delivery, while the cable stress cone with matching flange is part of the cable supply (see Fig. 52 on page **2**/36).
  - Transformer feeder: connecting flange at switchgear bay and connecting bus ducts to transformer including any expansion joint are delivered by Siemens. The SF_6-to-oil bushings plus terminal enclosures are part of the transformer delivery, unless agreed otherwise (see Fig. 54 on page **2**/36)*.
- Each feeder bay is equipped with grounding pads. The local grounding network and the connections to the switchgear are in the delivery scope of the installation contractor.
- Initial SF_6-gas filling for the entire switchgear as supplied by Siemens is included. All gas interconnections from the switchgear bay to the integral gas service and monitoring panel are supplied by Siemens as well.
- Hydraulic oil for all circuit-breaker operating mechanisms is supplied with the equipment.
- Terminals and circuit protection for auxiliary drive and control power are provided with the equipment. Feeder circuits and cables, and installation material for them are part of the installation contractor's supply.
- Local control, monitoring, and interlocking panels are supplied for each circuit-breaker bay to form completely operational systems. Terminals for remote monitoring and control are provided.
- Mechanical support structures above ground are supplied by Siemens; embedded steel and foundation work is part of the installation contractor's scope.

* Note: this interface point should always be closely coordinated between switchgear manufacturer and transformer supplier.

Gas-Insulated Transmission Lines (GIL)

Introduction

For high-power transmission systems where overhead lines are not suitable, alternatives are gas-insulated transmission lines (GIL).

The GIL exhibits the following differences in comparison with cables:

- High power ratings (transmission capacity up to 3000 MVA per System)
- High overload capability
- Suitable for long distances (100 km and more without compensation of reactive power)
- High short-circuit withstand capability (including internal arc faults)
- Possibility of direct connection to gas-insulated switchgear (GIS) and gas-insulated arresters without cable entrance fitting
- Multiple earthing points possible
- Non-flammable, no fire risk in case of failures

The innovations in the latest Siemens GIL development are the considerable reduction of costs and the introduction of buried laying technique for GIL for long-distance power transmission.
SF_6 has been replaced by a gas mixture of SF_6 and N_2 as insulating medium.

Siemens experience

Back in the 1960s with the introduction of sulphur hexafluoride (SF_6) as an insulating and switching gas, the basis was found for the development of gas-insulated switchgear (GIS).

On the basis of GIS experience, Siemens developed SF_6 gas-insulated lines to transmit electrical energy too. In the early 1970s initial projects were planned and implemented. Such gas-insulated lines were usually used within substations as busbars or bus ducts to connect gas-insulated switchgear with overhead lines, the aim being to reduce clearances in comparison to air-insulated overhead lines.
Implemented projects include GIL laying in tunnels, in sloping galleries, in vertical shafts and in open air installation.
Flanging as well as welding has been applied as jointing technique.

The gas-insulated transmission line technique is a highly reliable system in terms of mechanical and electrical failures. Once a system is commissioned and in service, it runs reliably without any dielectrical or mechanical failures as experience over the course of 20 years shows. For example, one particular Siemens GIL will not undergo its scheduled inspection after 20 years of service, as there has been no indication of any weak point.
Fig. 57 shows the arrangement of six phases in a tunnel.

Basic design

In order to meet mechanical stability criteria, gas-insulated lines need minimum cross-sections of enclosure and conductor. With these minimum cross-sections, high power transmission ratings are given.
Due to the gas as insulating medium, low capacitive loads are given so that compensation of reactive power is not needed, even for long distances of 100 km and more.

Fig. 57: GIL arrangement in the tunnel of the Wehr pumped storage station
(4000 m length, in service since 1975)

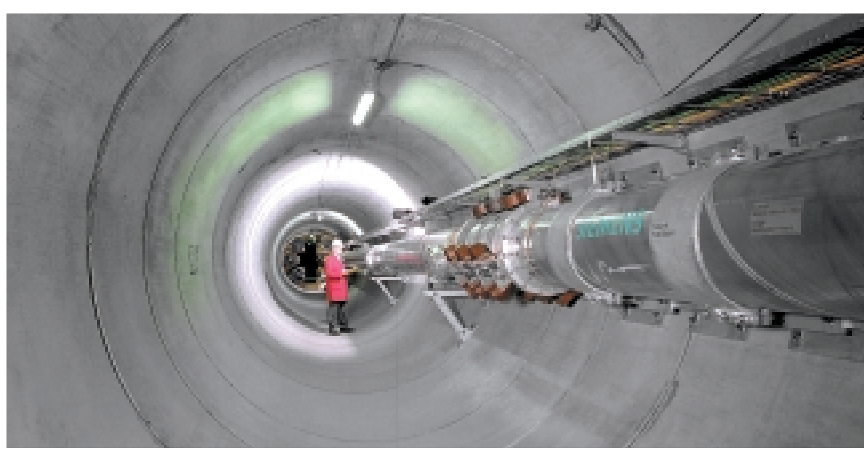


Fig. 58: Long-term test set-up at the IPH, Berlin

Reduction of SF_6 content

Several tests have been carried out in Siemens facilities as well as in other test laboratories world-wide since many years.

Results of these investigations show that the bulk of the insulating gas for industrial projects involving a considerable amount of gas should be nitrogen, a nontoxic natural gas.

However, another insulating gas should be added to nitrogen in order to improve the insulating capability and to minimize size and pressure. A N_2/SF_6 gas mixture with high nitrogen content (and sulphur hexafluoride portion as low as possible) was finally chosen as insulating medium.

The characteristics of N_2/SF_6 gas mixtures show that with an SF_6 content of only 15–25% and a slightly higher pressure, the insulating capability of pure SF_6 can be attained. Besides, the arcing behavior is improved through this mixture. Tests have proven that there would be no external damage or fire caused by an internal failure.

The technical data of the GIL are shown in Fig. 59.

Gas-Insulated Transmission Lines (GIL)

Technical data	
Rated voltage	up to 550 kV
Rated current I_r	2000 – 4600 A
Transmission capacity	1500 – 3000 MVA
Capacitance	≈ 60 nF/km
Typical length	1–100 km
Gas mixture SF_6/N_2 ranging from	10%/90% up to 35%/65%
Laying	directly buried
	in tunnels/ sloping galleries/ vertical shafts
	open air installation

Fig. 59: GIL technical data

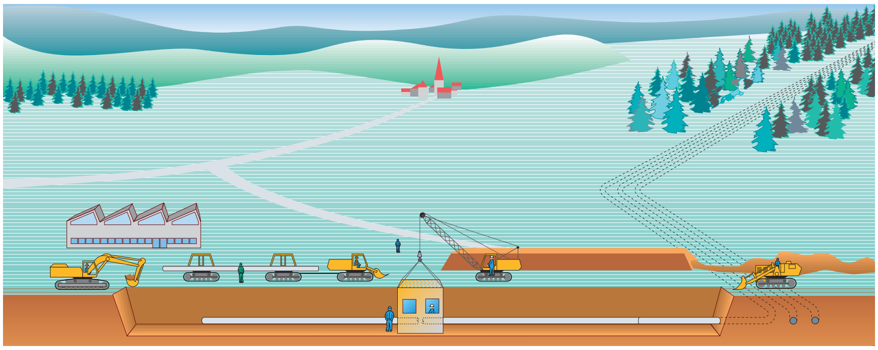


Fig. 60: GIL laying technique

Jointing technique

In order to improve the gas-tightness and to facilitate laying, flanges have been avoided as jointing technique. Instead, welding has been chosen to join the various GIL construction units.

The welding process is highly automated, with the use of an orbital welding machine to ensure high quality of the joints. This orbital welding machine contributes to high productivity in the welding process and therefore speeds up laying. The reliability of the welding process is controlled by an integrated computerized quality assurance system.

Laying

The most recently developed Siemens GILs are scheduled for directly buried laying.
The laying technique must be as compatible as possible with the landscape and must take account of the sequence of seasons. The laying techniques for pipelines have been improved over many years and they are applicable for GIL as a "pipeline for electrical current" too. However, the GIL needs slightly different treatment where the pipeline technique has to be adapted. The laying process is illustrated in Fig. 60.

The assembly area needs to be protected against dust, particles, humidity and other environmental factors that might disturb the dielectric system. Clean assembly therefore plays an important role in setting up cross-country GILs under normal environmental conditions. The combination of clean assembly and productivity is enhanced by a high level of automation of the overall process.

Anti-corrosion protection

Directly buried gas-insulated transmission lines will be safeguarded by a passive and active corrosion protection system. The passive corrosion protection system comprises a PE or PP coating and assures at least 40 years of protection. The active corrosion protection system provides protection potential in relation to the aluminum sheath. An important requirement taken into account is the situation of an earth fault with a high current of up to 63 kA to earth.

Testing

The GIL is already tested according to the report IEC 61640 (1998) "Rigid high-voltage, gas-insulated transmission lines for voltages of 72.5 kV and above."

Long-term performances

Besides nearly 25 years of field experience with GIL installations world wide, the long-term performance of the GIL for long-distance installations has been proven by the independent test laboratory IPH, Berlin, Germany and the Berlin power utility BEWAG according to 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 assembly and repair procedures under realistic site conditions were examined too. The Siemens GIL is the first one in the world that has passed these tests, without any objection. Fig. 58 shows the test setup arranged in a tunnel of 3 m diameter, corresponding to the tunnel used in Berlin for installing a 420 kV transmission link through the city.

References

Siemens has gathered experience with gas-insulated transmission lines at rated voltages of up to 550 kV and with system lengths totalling more than 30 km.
The first GIL stretch built by Siemens was the connection of the turbine generator/ pumping motor of a pumped storage station with the switchyard. The 420 kV GIL is laid in a tunnel through a mountain and has a length of 4000 m (Fig. 57). This connection was commissioned in 1975 at the Wehr pumped storage station in the Black Forest in Southern Germany.

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Fig. 61: Siemens lab prototype for dielectric tests

Overhead Power Lines

Introduction

Since the very beginning of electric power, overhead lines have constituted the most important component for transmission and distribution. Their portion of overall length of electric circuits 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 sector. In other parts of the world, for example in North America, overhead lines are often used also for distribution purposes within cities. Siemens has planned, designed and erected overhead power lines on all important voltage levels in many parts of the world.

Selection of line voltage

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

- The low-voltage level up to 1 kV
- The medium-voltage level between 1 kV and 36 kV and
- The high-voltage level up to 800 kV.

For DC transmission the voltages vary from the mentioned data.

Low-voltage lines serve households and small business consumers. Lines on the medium-voltage level supply small settlements, individual industrial plants and larger consumers, the electric power being 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 high-voltage level network is often adopted 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).

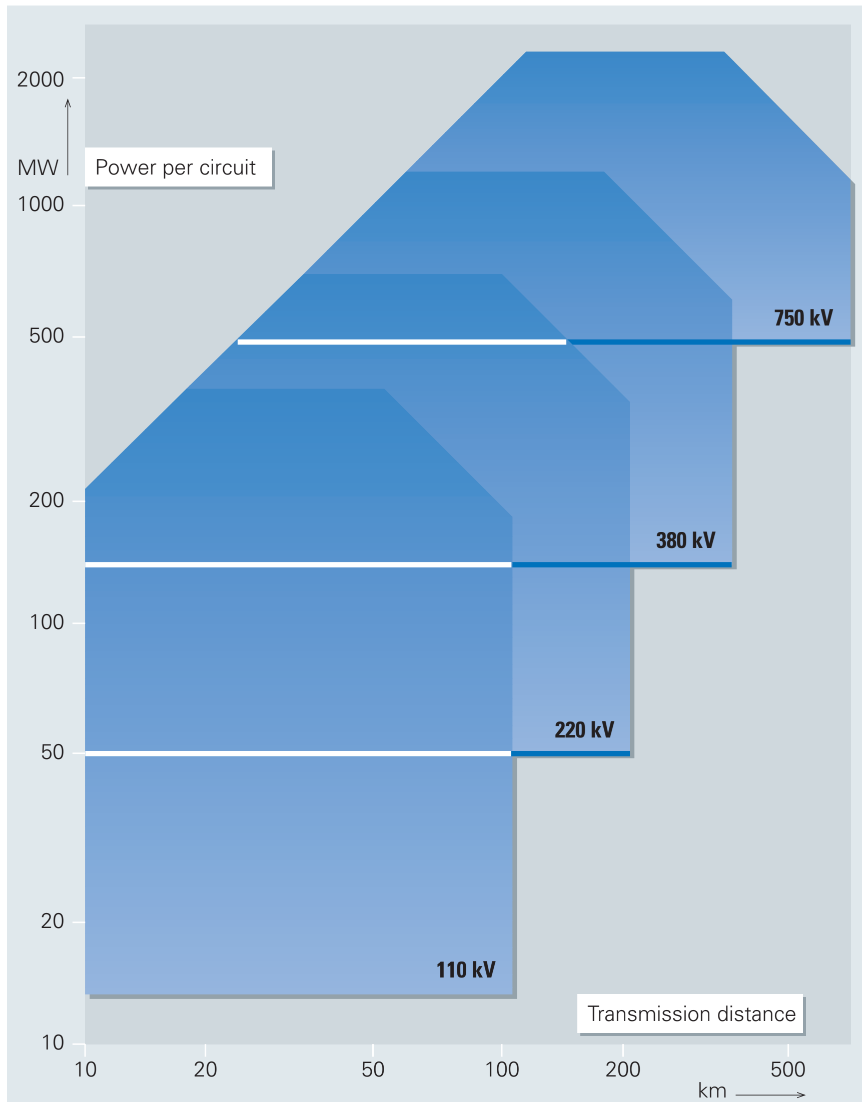


Fig. 62: Selection of rated voltage for power transmission

245 kV lines were used in Central Europe for interconnection of utility networks before the changeover to the 420 kV level for this purpose. Long-distance transmission, for example between the hydro power plants in the Alps and the consumers, was performed out by 245 kV lines.
Nowadays, the importance of 245 kV lines is decreasing due to the application of 420 kV.

The 420 kV level represents the highest voltage used for AC transmission in Central Europe with the task of interconnecting the utility networks and of transmitting the energy over long distances. Some 420 kV lines connect the national grids of the individual European countries enabling Europewide interconnected network operation. Large power plants, such as nuclear stations, feed directly into the 420 kV network. The thermal capacity of the 420 kV circuits may reach 2000 MVA with a surge impedance load of approximately 600 MVA and a transmission capacity up to 1200 MVA.

Rated voltage [kV]	20		110		220		380		750
Highest system voltage [kV]	24		123		245		420		800
Nominal cross-section [mm²]	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	1290	2580	2080	4160
Thermal capacity [MVA]	7	14	90	140	340	490	1700	1370	5400
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 ground [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	2320
Ground-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	2170

Fig. 63: Electric characteristics of AC overhead power lines (Data refer to one circuit of a double-circuit line)

Overhead power lines with voltages higher than 420 kV are needed to economically transmit bulk electric power over long distances, a task typically arising when utilizing hydro energy potentials far away from consumer centers. Fig. 62 depicts schematically the range of application for the individual voltage levels depending on the distance of transmission and the power rating.

The voltage level has to be selected based on the duty of the line within the network or on results of network planning. Siemens has carried out such studies for utilities all over the world.

Selection of conductors and ground wires

Conductors represent the most important components of an overhead power line since 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.
The conductors are prone to corrosion. Aluminum, in principle, is a very corrosive metal. However, a dense oxide layer is formed which stops further corrosive attacks. Therefore, aluminum conductors are well-suited also for corrosive areas, 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 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, the strength of which is twice that of pure aluminum.
All-aluminum and aluminum alloy conductors have shown susceptibility against eolian vibrations. Compound conductors with a steel core, so-called aluminum cables, steel reinforced (ACSR), avoid this disadvantage. The ratio between aluminum and steel ranges from 4.3:1 to 11:1. Experience has demonstrated that ACSR has a long life, too.

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 such that the permissible temperatures will not be exceeded during normal operation as well as under short circuit. With increasing cross-section the line costs increase, while the costs for losses decrease. Depending on the duty of a line and its power, a cross-section can be determined which results in lowest transmission costs. This cross-section should be aimed for. 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 has proven to be an economical solution.

High voltage results in correspondingly high-voltage gradients at the conductors and in corona-related effects such as visible discharges, radio interference, audible noise and energy losses. When selecting the conductors, the voltage gradient has to be limited to values between 15 and 17 kV/cm. This aspect is important for lines with voltages of 245 kV and above. Therefore, bundle conductors are adopted for extra-high-voltage lines. Fig. 63 shows typical conductor configurations.

From the 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 ultimate tensile stress can be adopted, resulting in a limited risk of conductor damage.

Ground wires can protect a line against direct lightning strokes and improve the system behavior in case of short circuits; therefore, lines with single-phase voltages of 110 kV and above are usually equipped with ground wires. Ground wires made of ACSR with a sufficiently high aluminum cross-section satisfy both requirements.

Selection of insulators

Overhead line insulators are subject to electrical and mechanical stress since they have to insulate the conductors from potential to ground 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 power frequency voltage
- Temporary overvoltages at power frequency and
- Switching and lightning overvoltages.

Various insulator designs are in use, depending on the requirements and the experience with certain insulator types. Cap and pin-type insulators (Fig. 64) are made of porcelain or glass. The individual units are connected by fittings of malleable cast iron. The insulating bodies are not puncture-proof which is the reason for relatively numerous insulator failures.

In Central Europe long-rod insulators (Fig. 65) are most frequently adopted. These insulators are puncture-proof. Failures under operation are extremely rare. Long-rod insulators show a superior behavior especially under pollution. The tensile loading of the porcelain body forms a disadvantage, which requires relatively large cross-sections. Composite insulators are made of a core with fiberglass-reinforced resin and sheds of differing plastic materials. They offer light weight and high tensile strength and will gain increasing importance for high-voltage lines.

Insulator sets must provide a creepage path long enough for the expected pollution level, which is classified according to IEC 60815 from light with 16 mm/kV up to very heavy with 31 mm/kV.

To cope with switching and lightning overvoltages, the insulator sets have to be designed with respect to insulation coordination according to IEC 60071-1. These design aspects determine the gap between the grounded fittings and the live parts.

Suspension insulator sets carry the conductor weight and are arranged more or less vertically. There are I-shaped (Fig. 66a) and V-shaped sets in use. Single, double or triple sets cope with the mechanical loadings and the design requirements. Tension insulator sets (Fig. 66b, c) 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.

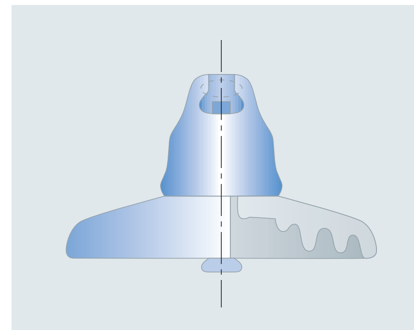


Fig. 64: Cap and pin-type insulator

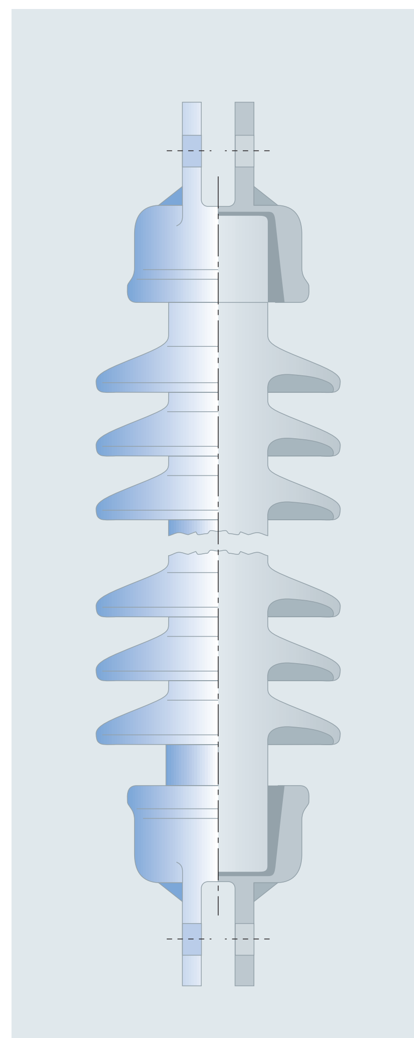


Fig. 65: Long-rod insulator with clevis and tongue connection

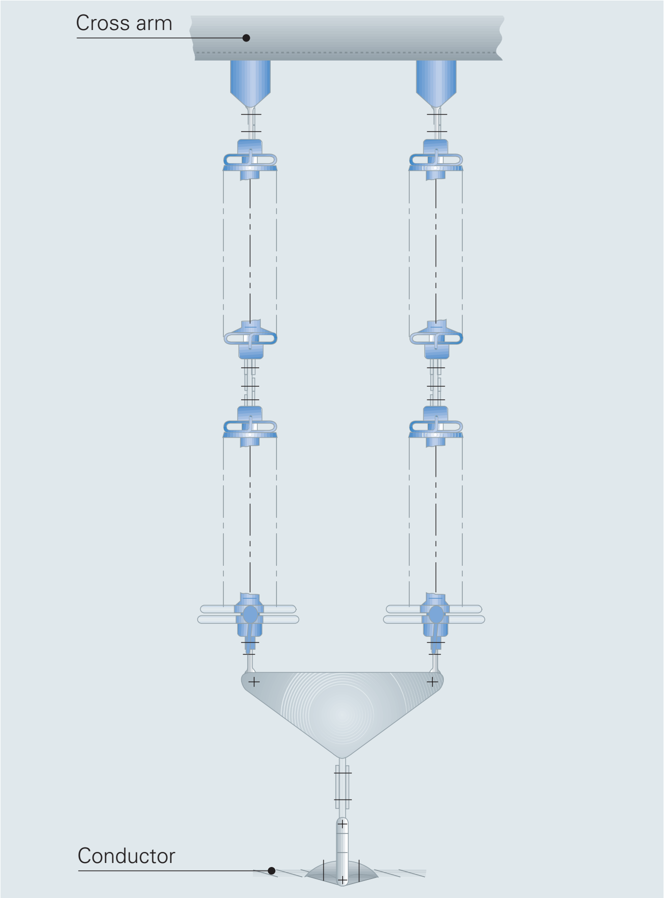


Fig. 66a: I-shaped suspension insulator set for 245 kV

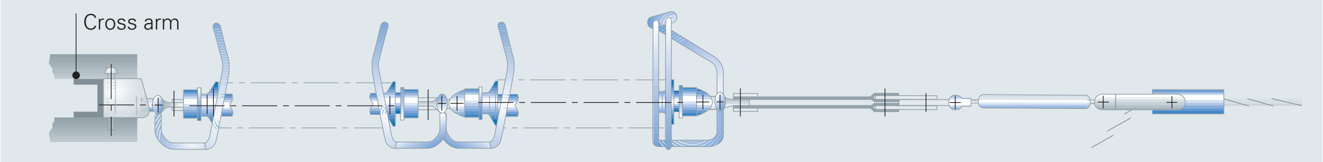


Fig. 66b: Double tension insulator set for 245 kV (elevation)

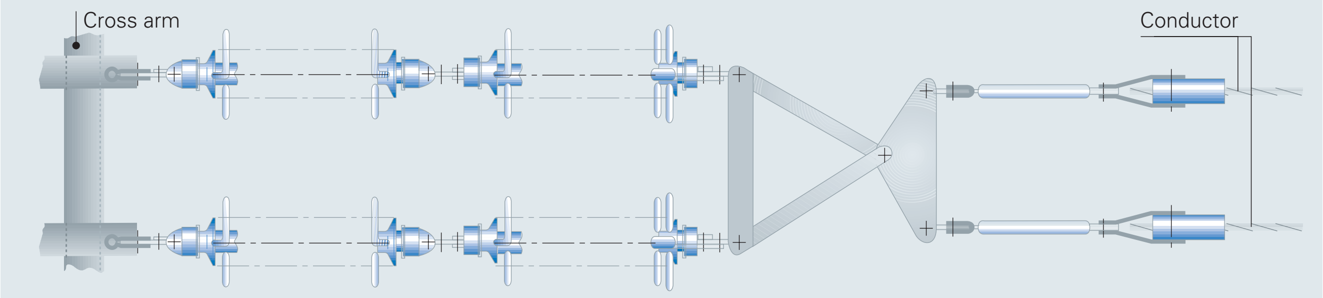


Fig. 66c: Double tension insulator set for 245 kV (plan)

Overhead Power Lines

Selection and design of supports

Together with the line voltage, number of circuits and type of conductors the configuration of the circuits determines the design of overhead power lines. Additionally, lightning protection by ground 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 and the transmission capacity of the line. Very often there are contradicting requirements, such as a tower height as low as possible and a narrow right-of-way, which can only be met partly by compromises.

The mutual 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- and medium-voltage lines horizontal conductor configurations prevail which feature line post insulators as well as suspension insulators. Preferably poles made of wood, concrete or steel are used. Fig. 67 shows some typical line configurations. Ground wires are omitted at this voltage level.

For high and extra-high-voltage power lines a large variety of configurations are available which depend on the number of circuits and on local conditions. Due to the very limited right-of-way, more or less all high-voltage lines in Central Europe comprise at least two circuits. Fig. 68 shows a series of typical tower configurations. Arrangement e) is called the "Danube" configuration and is most often adopted. It represents a fair compromise with respect to width of right-of-way, tower height and line costs.

For 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. 68g).

The arrangement of insulators depends on the task of a support within the line. Suspension towers support the conductors in straight-line sections and at small bends. This tower type results in the lowest costs; special attention should therefore be paid to using this tower type as often as possible.

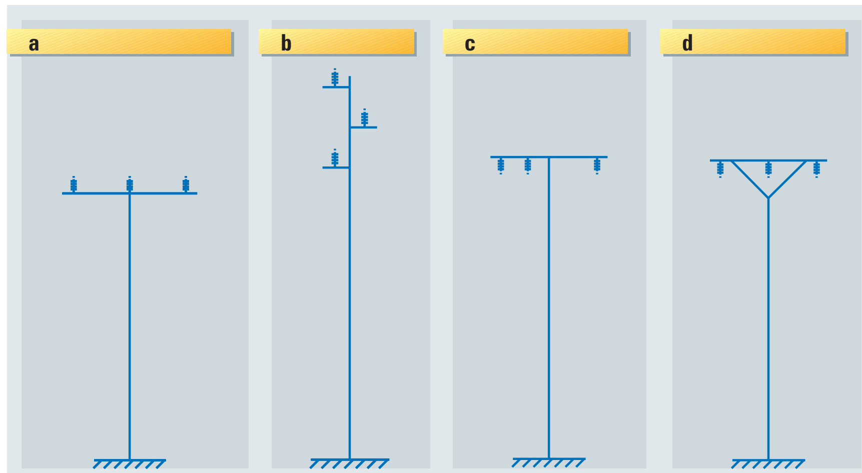


Fig. 67: Configurations of medium-voltage supports

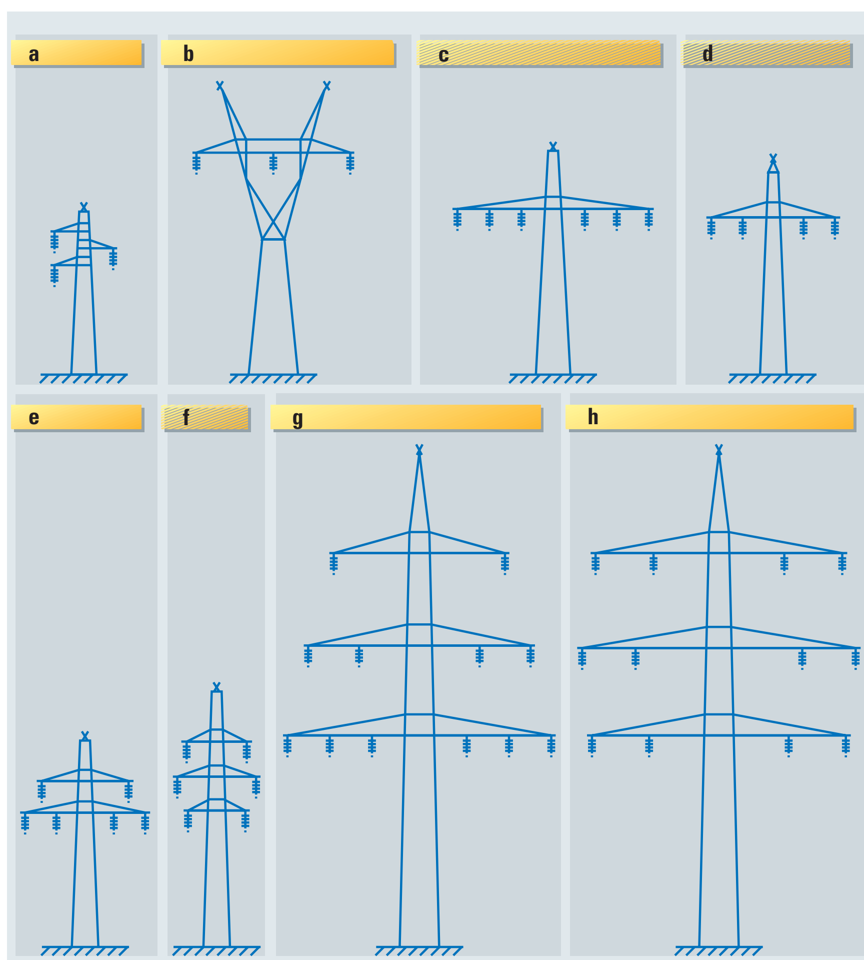


Fig. 68: Tower configurations for high-voltage lines

Angle towers have to carry the conductor tensile forces at angle points of the line. The tension insulator sets permanently exert high forces on the supports. Various loading conditions have to be met when designing angle towers. The climatic conditions are a determining factor as well.

Finally, dead-end towers are used at the ends of a transmission line. They carry the total conductor tensile forces of the connection to the substations.

Depending on the size of the supports and the acting forces, differing designs and materials are adopted. Poles made of wood, concrete or steel are very often used for low and medium-voltage lines. Towers with lattice steel design, however, prevail at voltage levels of 110 kV and above (Fig. 69). 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 conductor tensile forces can result in torsional loading. Additionally, special loading conditions are adopted for the purpose of failure containment, i.e. to limit the extent of damage. Finally, provisions have to be made for construction and maintenance conditions.

Siemens adopts modern computer programs for tower design in order to optimize the structures, select components and joints and determine foundation loadings.

The stability of the support poles and towers needs also accordingly designed foundations. The type of towers and poles, the loads, the soil conditions as well as the accessibility to the line route and the availability of machinery determine the selection and design of foundation.

Concrete blocks or concrete piers are in use for poles which exert bending moments on the foundation. For towers with four legs a foundation is provided for each individual leg (Fig. 70). Pad-and-chimney and concrete block foundations require good bearing soil conditions without ground water. Driven or augured piles and piers are adopted for low bearing soil, for sites with bearing soil in a greater depth and for high ground water level.
In this case the soil conditions must permit pile driving. Concrete slabs can be used for good bearing soil, when subsoil and ground water level prohibit pad and chimney foundations as well as piles. Siemens can design all types of foundation and has the necessary equipment, such as pile drivers, grouting devices, soil and rock drills, at its command to build all types of power line foundations.

Fig. 69: Lattice steel towers of a high-voltage line

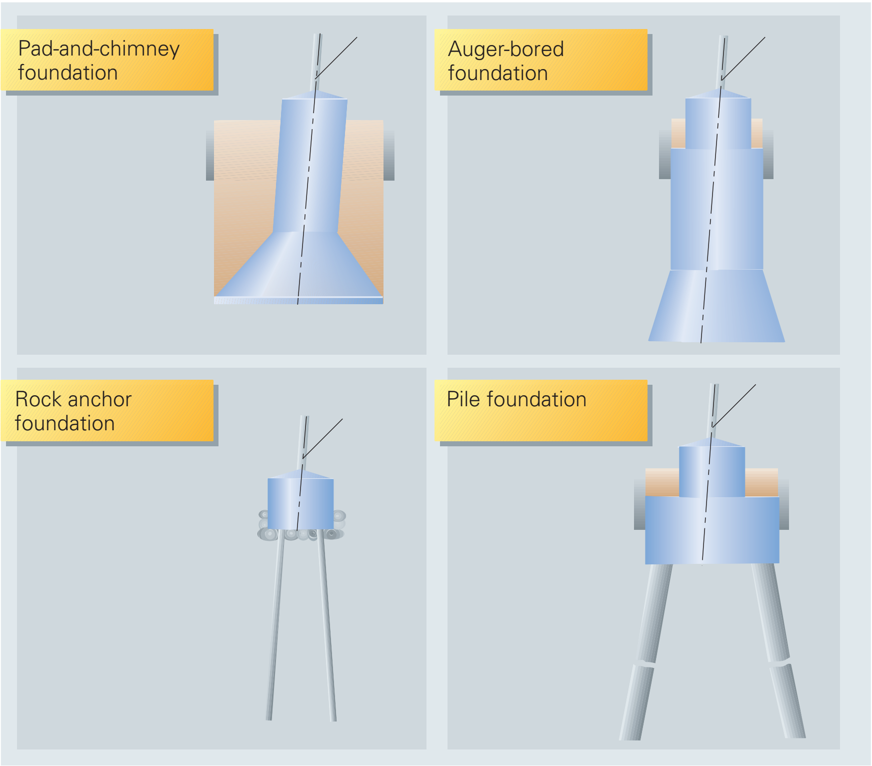


Fig. 70: Foundations for four-legged towers

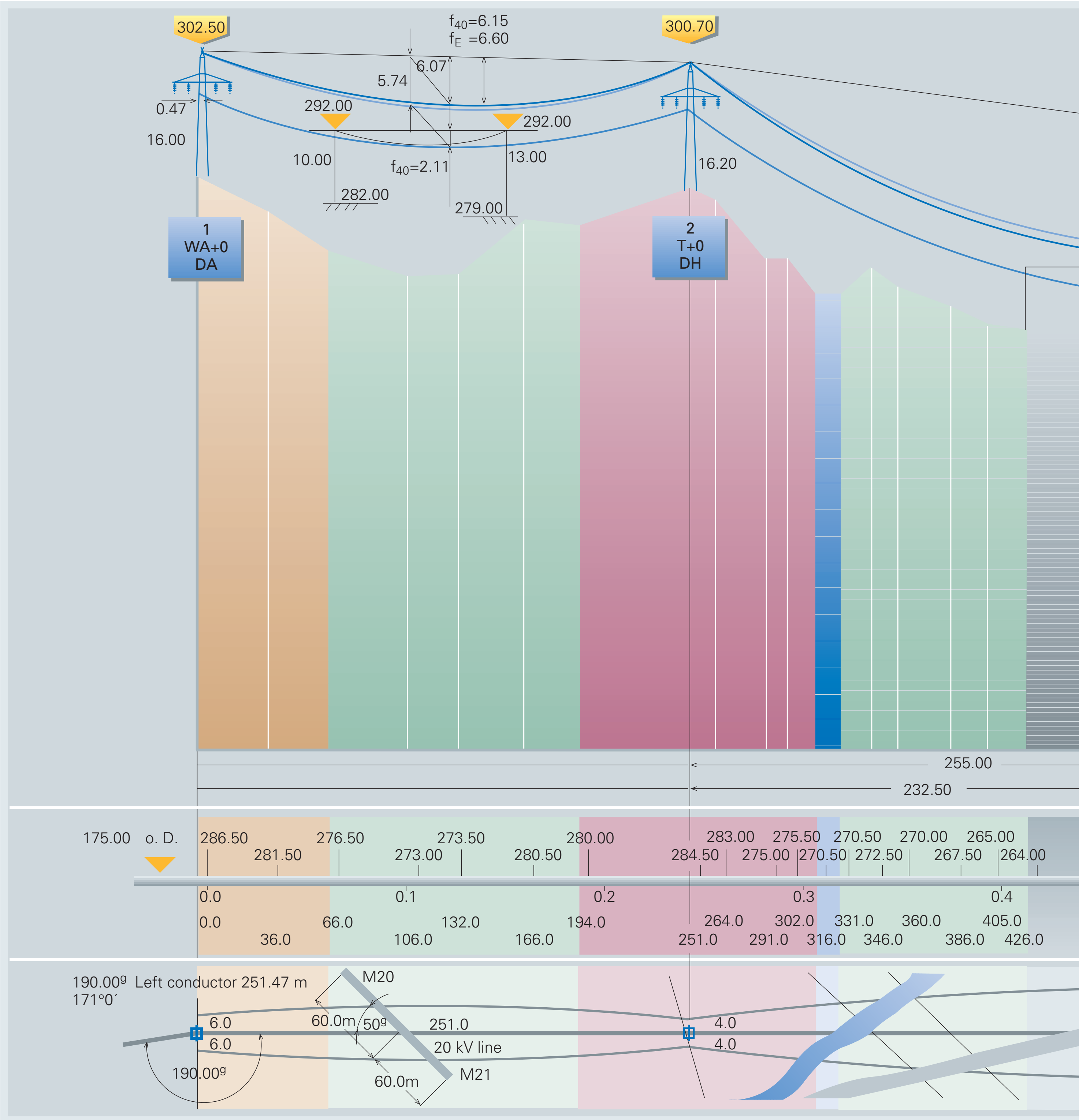
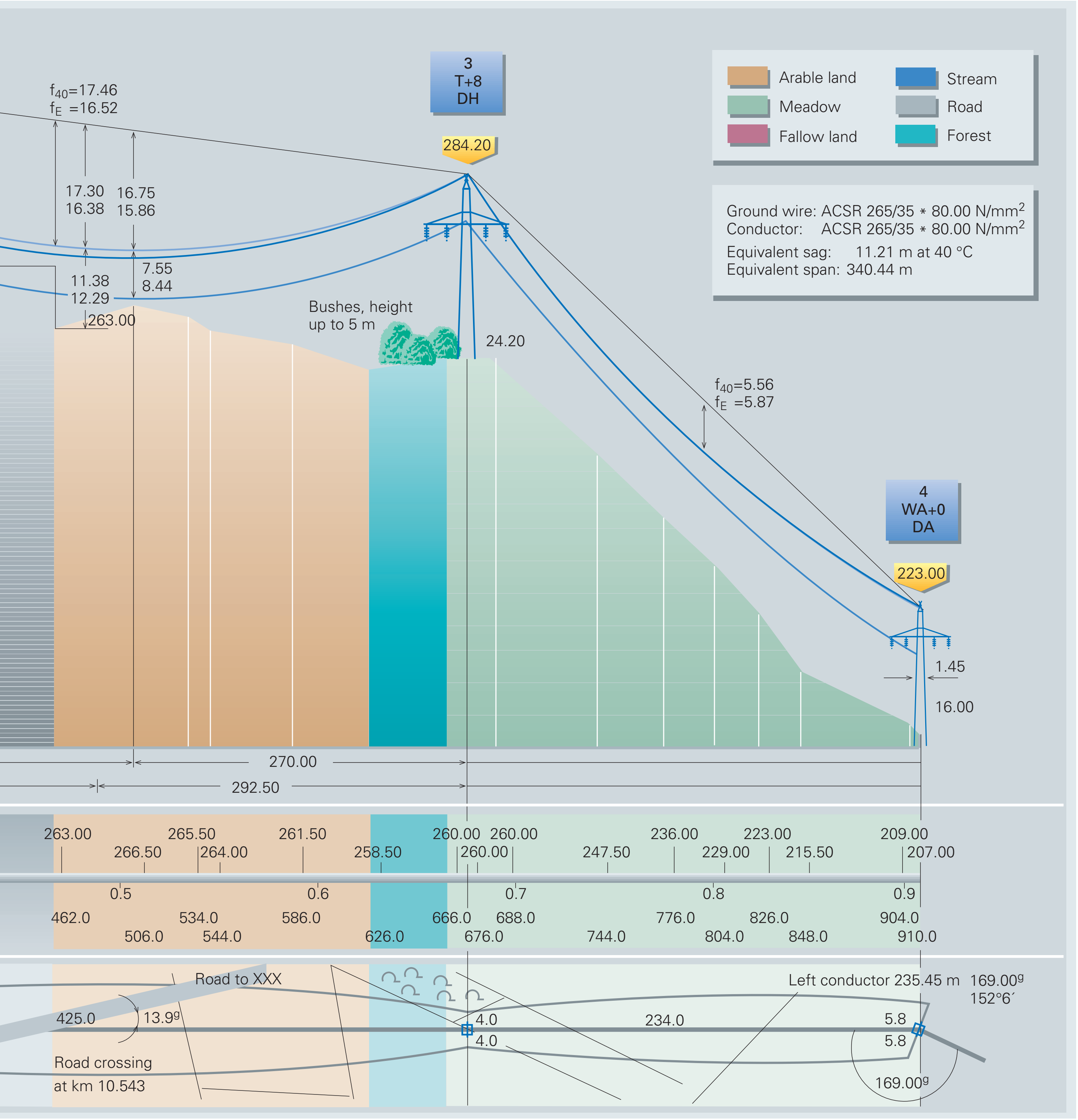


Fig. 71: Line profile established by computer


3
T+8
DH
284.20
Arable land
Meadow
Fallow land
Stream
Road
Forest
f40=17.46
fE =16.52
17.30 16.75
16.38 15.86
11.38
12.29
7.55
8.44
263.00
Bushes, height
up to 5 m
24.20
Ground 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=5.56
fE =5.87
4
WA+0
DA
223.00
1.45
16.00
270.00
292.50
263.00 265.50 261.50 260.00 260.00 236.00 223.00 209.00
266.50 264.00 258.50 260.00 247.50 229.00 215.50 207.00
0.5 0.6 0.7 0.8 0.9
462.0 534.0 586.0 666.0 688.0 776.0 826.0 904.0
506.0 544.0 626.0 676.0 744.0 804.0 848.0 910.0
Road to XXX
425.0
13.9g
Road crossing
at km 10.543
4.0
4.0
234.0
Left conductor 235.45 m
169.00g
152°6´
5.8
5.8
169.00g

Overhead Power Lines

Route selection and tower spotting

Route selection and planning represent increasingly difficult tasks since 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 and always involve iterative studies carried out in the office and surveys in the terrain which consider and evaluate a great variety of alternatives. After definition of the route the longitudinal profile has to be surveyed, identifying all crossings over roads, rivers, railways, buildings and other overhead power lines. The results are evaluated with computer programs to calculate and plot the line profile. The towers are spotted by means of computer programs as well, which take into account the conductor sags under different conditions, the ground clearances, objects crossed by the line, technical data of the available tower range, tower and foundation costs and costs for compensation of landowners. The result is an economical design of a line, which accounts for all the technical and environmental conditions. Line planning forms the basis for material acquisition and line erection. Fig. 71 shows a line profile established by computer.

Siemens' 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 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. The 420 kV transmission lines across the Elbe river in Germany comprising four circuits and requiring 235 m tall towers as well as the 420 kV line across the Bosphorus in Turkey with a span of approximately 1800 m (Fig. 72) are worthy of special mention.

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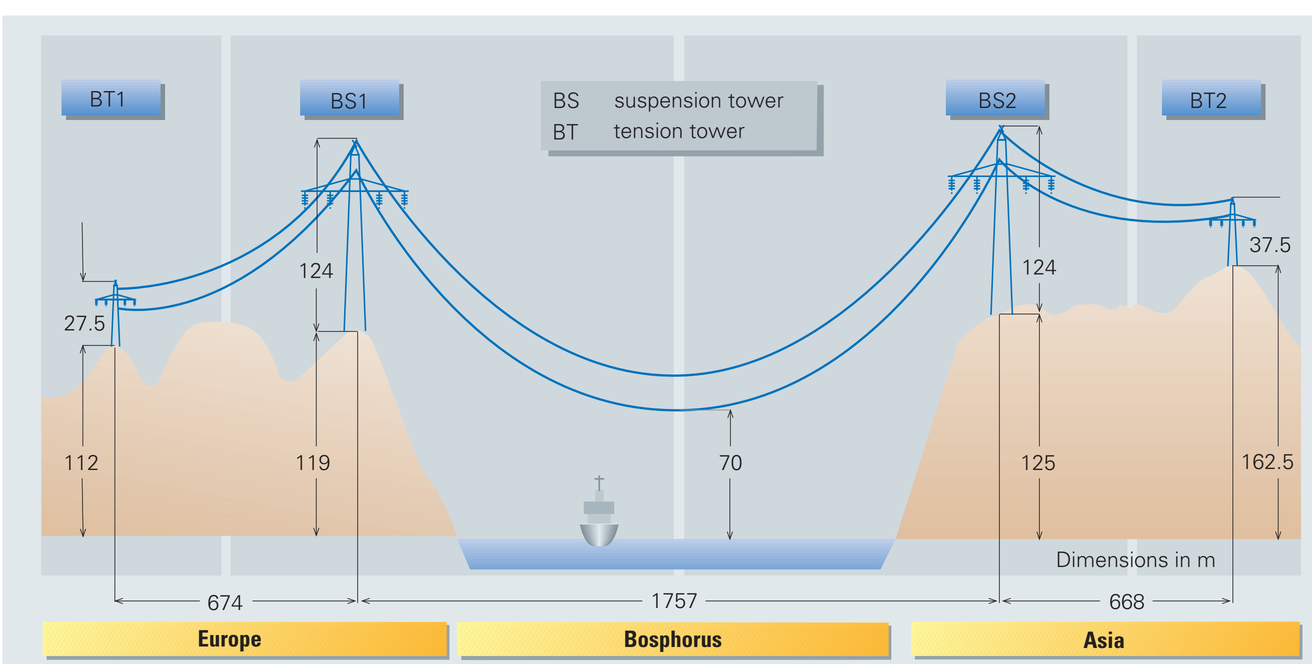

Fig. 72: 420 kV line across the Bosphorus, longitudinal profile

High-Voltage Direct Current Transmission

HVDC

When technical and/or economical feasibility of conventional high voltage AC transmission technology reach their limits, high voltage DC can offer the solution, namely

- For economical transmission of bulk power over long distances
- For interconnection of asynchronous power grids
- For power transmission across the sea, when a cable length is long
- For interconnection of synchronous but weak power grids, adding to their stability
- For additional exchange of active power with other grids without having to increase the short-circuit power of the system
- For increasing the transmission capacity of existing rights-of-way by changing from AC to DC transmission system

Siemens offers HVDC systems as

- Back-to-Back (B/B) stations to interconnect asynchronous networks, without any DC transmission line in between
- Power transmission via Dc submarine cables
- Power transmission via long-distance DC overhead lines

Back-to-Back (B/B):

To connect asynchronous high voltage power systems or systems with different frequencies.
To stabilize weak AC links or to supply even more active power, where the AC system reaches the limit of short-circuit capability.

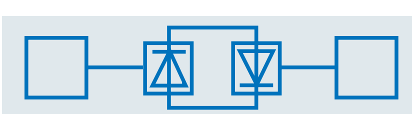

Fig. 73: Back-to-back link between asynchronous grids

Cable transmission (CT):

To transmit power across the sea with cables to supply islands/offshore platforms from the mainland and vice-versa.

Fig. 74: Submarine cable transmission

Long-distance transmission (LD):

For transmission of bulk power over long distances (beyond approx. 600 km, considered as the break-even distance).

Fig. 76: Earthquake-proof, fire-retardant thyristor valves in Sylmar East, Los Angeles

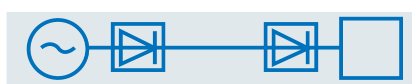

Fig. 75: Long-distance transmission

Special features

Valve technology

- Simple, easy-to-maintain mechanical design
- Use of fire-retardant, self-extinguishing material
- Minimized number of electrical connections
- Minimized number of components
- Avoidance of potential sources of failure
- "Parallel" cooling for the valve levels
- Oxygen-saturated cooling water.

After more than 20 years of operation, thyristor valves based on this technology have demonstrated their excellent reliability.

- The recent introduction of direct light-triggered thyristors with integrated overvoltage protection further simplifies the valve and reduces maintenance requirements.

Control system

In our HVDC control system, high-performance components with proven records in many other standard fields of application have been integrated, thus adding to the overall reliability of the system.
Use of "state-of-the-art" microprocessor systems for all functions.
Redundant design for fault-tolerant systems.

Filter technology

Single, double and triple-tuned as well as high-pass passive filters, or any combination thereof, can be installed.
Active filters, mainly for the DC circuit, are available.
Wherever possible, identical filters are selected so that the performance does not significantly change when one filter has to be switched off.

Turnkey service

Our experienced staff are prepared to design, install and commission the whole HVDC system on a turnkey basis.

Project financing

We are in a position to assist our customers in finding proper project financing, too.

General services

- Extended support to customers 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 on:
  - HVDC systems basic design
  - System dynamic response
  - Load flow and reactive power balance
  - Harmonic voltage distortion
  - Insulation coordination
  - Interference of radio and PLC
  - Special studies, if any

Typical ratings

Some typical ratings for HVDC schemes are given below for orientation purposes only:

B/B: 100 ... 600 MW

CT: 100 ... 800 MW

LD: 300 ... 3000 MW (bipolar),

whereby the lower rating is mainly determined by economic aspects and the higher one limited by the constraints of the interconnected networks.

Innovations

In recent years, the following innovative technologies and equipment have for example been successfully implemented by Siemens in diverse HVDC projects worldwide:

- Direct light-triggered thyristors (already mentioned above)
- Hybrid-optical DC measuring system (Fig. 77)
- Active harmonic filters
- Advanced eletrode line monitoring of bipolar HVDC systems
- An SF_6 HVDC circuit-breaker for use as Metallic Return Transfer Breaker, developed from a standard AC high-voltage breaker.

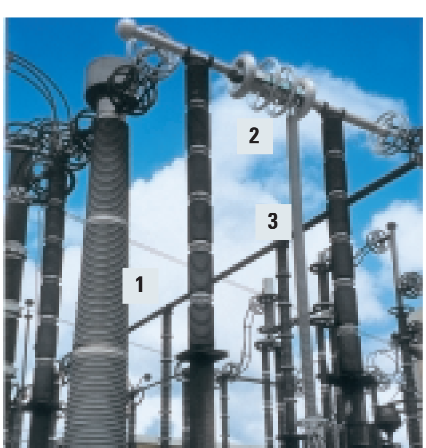

Fig. 77: Conventional DC measuring device (1) vs. the new hybrid-optical device (2) with composite insulator (3) shows the reduced space requirement for the new system (installed at HVDC converter station Sylmar, USA)

Fig. 78: HVDC outdoor valves, 533 kV (Cahora Bassa Rehabilitation, Southern Africa)

Rehabilitation and modernization of existing HVDC stations (Fig. 78)

The integration of state-of-the-art microprocessor systems or thyristors allows the owner better utilization of his investment, e.g.

- Higher availability
- Fewer outages
- Lower losses
- Better performance values
- Less maintenance.

Higher availability means more operating hours, better utilization and higher profits for the owner.

The new Human-Machine Interface (HMI) system enhances the user-friendliness and increases the reliability considerably due to the operator guidance. This rules out maloperation by the operator, because an incorrect command will be ignored by the HMI.

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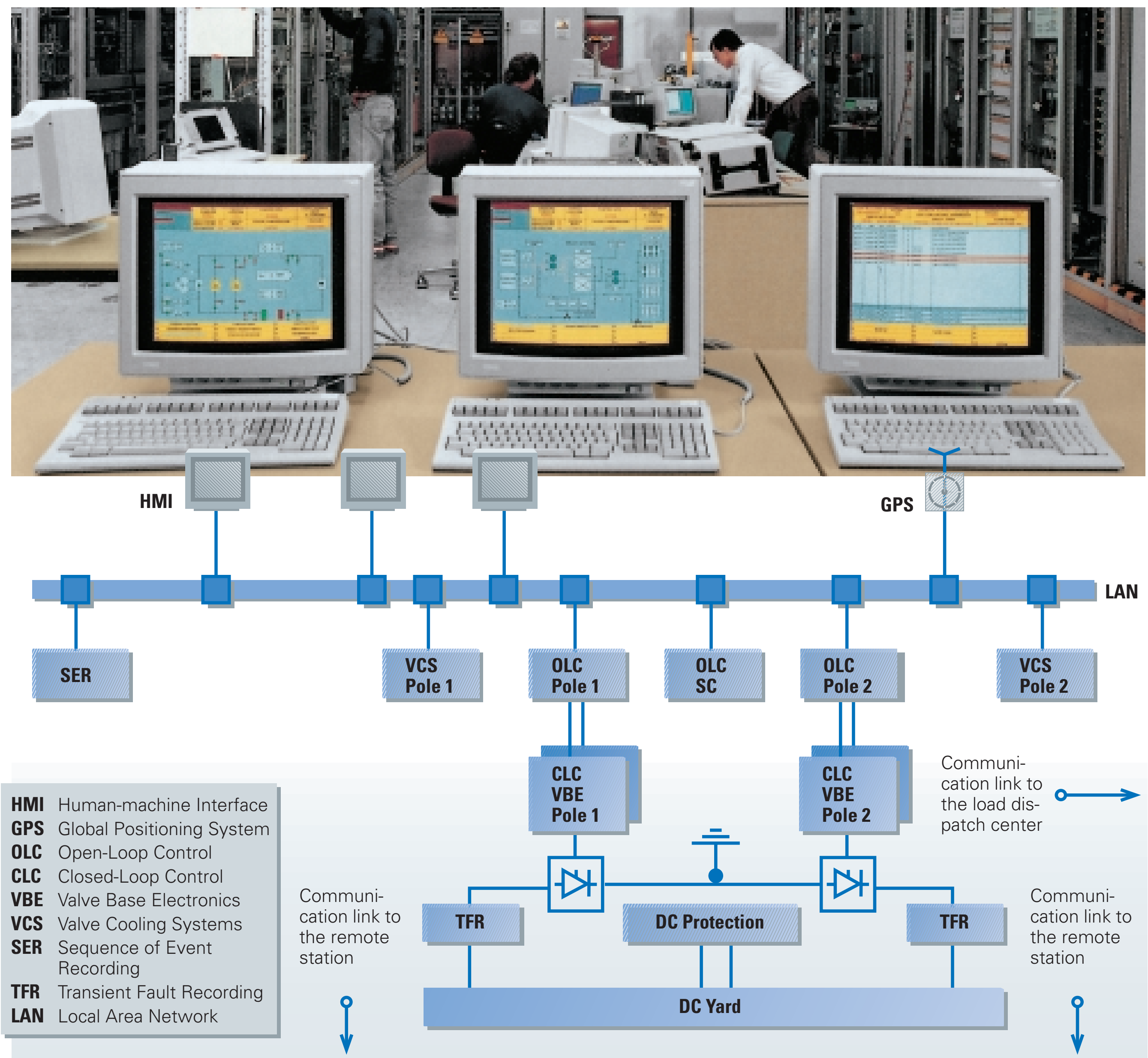

Fig. 79: Human-Machine Interface with structure of HVDC control system

Power Compensation in Transmission Systems

Introduction

In many countries increasing power consumption leads to growing and more interconnected AC power systems. These complex systems consist of all types of electrical equipment, such as power plants, transmission lines, switchgear transformers, cables etc., and the consumers.

Since power is often generated in those areas of a country with little demand, the transmission and distribution system has to provide the link between power generation and load centers.

Wherever power is to be transported, the same basic requirements apply:

- Power transmission must be economical
- The risk of power system failure must be low
- The quality of the power supply must be high

However, transmission systems do not behave in an ideal manner. The systems react dynamically to changes in active and reactive power, influencing the magnitude and profile of the power systems voltage.

Examples:

- A load rejection at the end of a long-distance transmission line will cause high overvoltages at the line end. However, a high load flow across the same line will decrease the voltage at its end.
- The transport of reactive power through a grid system produces additional losses and limits the transmission of active power via overhead lines or cables.
- Load-flow distribution on parallel lines is often a problem. One line could be loaded up to its limit, while another only carries half or less of the rated current. Such operating conditions limit the actual transmittable amount of active power.
- In some systems load switching and/or load rejection can lead to power swings which, if not instantaneously damped, can destabilize the complete grid system and then result in a "Black Out".

Reactive power compensation helps to avoid these and some other problems.
In order to find the best solution for a grid system problem, studies have to be carried out simulating the behavior of the system during normal and continuous operating conditions, and also for transient events. Study facilities which cover digital simulations via computer as well as analog ones in a transient network analyzer laboratory are available at Siemens.

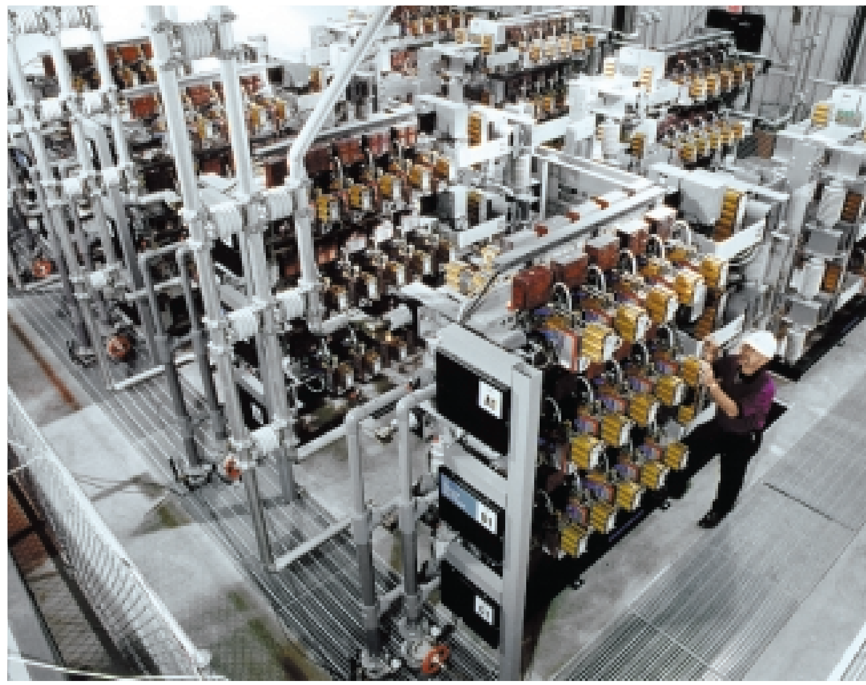

Fig. 80: STATCOM inverter hall

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Power Compensation in Transmission Systems

Types of reactive power compensation

Parallel compensation

Parallel compensation is defined as any type of reactive power compensation employing either switched or controlled units, which are connected parallel to the transmission network at a power system node. In many cases switched compensation (reactors, capacitor banks or filters) can provide an economical solution for reactive power compensation using conventional switchgear.

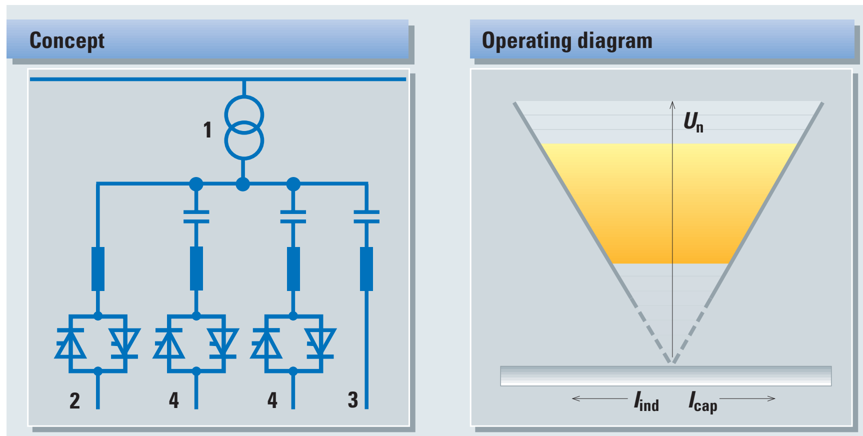
Static VAr compensator (SVC)

In comparison to mechanically-switched reactive power compensation, controlled compensation (SVC, Fig. 81) offers the advantage that rapid dynamic control of the reactive power is possible within narrow limits, thus maintaining reactive power balance.
Fig. 82 is a general outline of the problem-solving applications of SVCs in high-voltage systems.

STATCOM

The availability of high power gate-turn-off (GTO) thyristors has led to the development of a Static Synchronous Compensator (STATCOM), Fig. 80, page **2**/52.

The STATCOM is an "electronic generator" of dynamic reactive power, which is connected in shunt with the transmission line (Fig. 83) and designed to provide smooth, continuous voltage regulation, to prevent voltage collapse, to improve transmission stability and to dampen power oscillations. The STATCOM supports subcycle speed of response (transition between full capacitive and full inductive rating) and superior performance during system disturbances to reduce system harmonics and resonances. Particular advantages of the equipment are the compact and modular construction that enables ease of siting and relocation, as well as flexibility in future rating upgrades (as grid requirements change) and the generation of reactive current irrespective of network voltage.



1 Transformer
2 Thyristor-controlled reactor (TCR)
3 Fixed connected capacitor/filter bank
4 Thyristor-switched capacitor bank (TSC)

Fig. 81: Static VAr compensator (SVC)

- Voltage control
- Reactive power control
- Overvoltage limitation at load rejection
- Improvement of AC system stability
- Damping of power oscillations
- Reactive power flow control
- Increase of transmission capability
- Load reduction by voltage reduction
- Subsynchronous oscillation damping

Fig. 82: Duties of SVCs

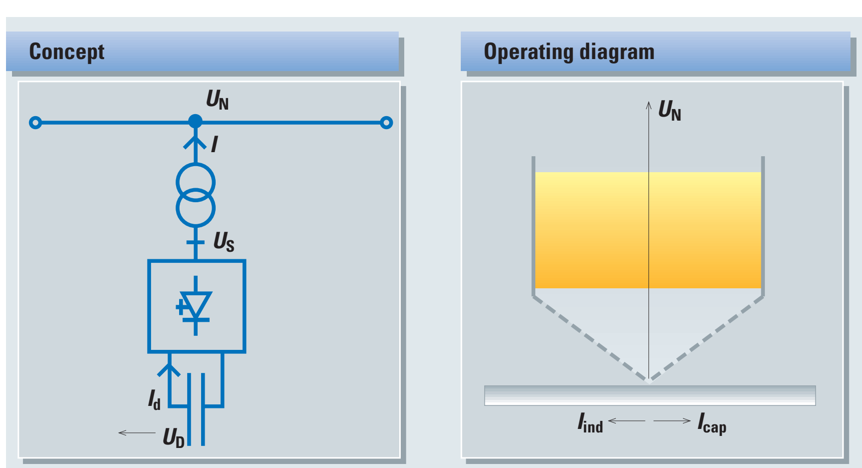


Fig. 83: STATCOM

Power Compensation in Transmission Systems

2

Series compensation

Series compensation is defined as insertion of reactive power elements into transmission lines. The most common application is the series capacitor.

Thyristor-Controlled Series Compensation (TCSC)

By providing continuous control of transmission line impendance, the Thyristor Controlled Series Compensation (TCSC, Fig. 84) offers several advantages over conventional fixed series capacitor installations. These advantages include:

- Continuous control of desired compensation level
- Direct smooth control of power flow within the network
- Improved capacitor bank protection
- Local mitigation of subsynchronous oscillations (SSR). This permits higher levels of compensation in networks where interactions with turbine-generator torsional vibrations or with other control or measuring systems are of concern.
- Damping of electromechanical (0.5–2 Hz) power oscillations which often arise between areas in a large interconnected power network. These oscillations are due to the dynamics of interarea power transfer and often exhibit poor damping when the aggregate power transfer over a corridor is high relative to the transmission strength.

Synchronous Series Compensation (SSSC)

The Static Synchronous Series Compensator (SSSC) is a solid-state voltage generator connected in series with the transmission line through an insertion transformer (Fig. 85). The generation of a boost voltage advancing or lagging behind the line current by 90° affects the voltage drop caused at the line reactance and can be used to dampen transient oscillations and control real power flow independent of the magnitude of the line current.

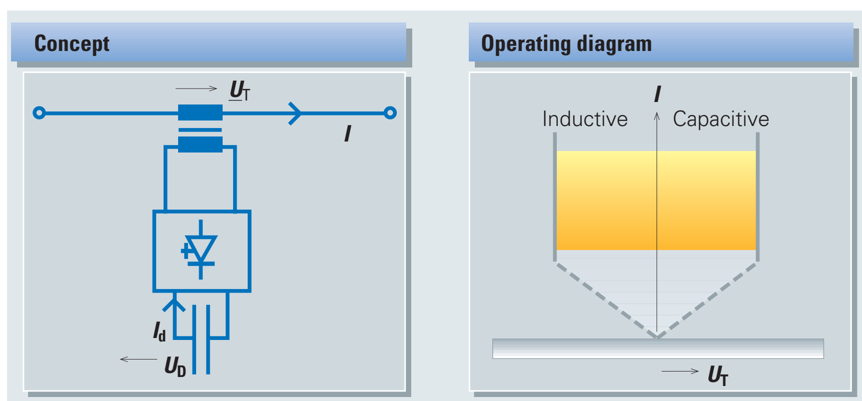


Fig. 85: Static Synchronous Series Compensator (SSSC)

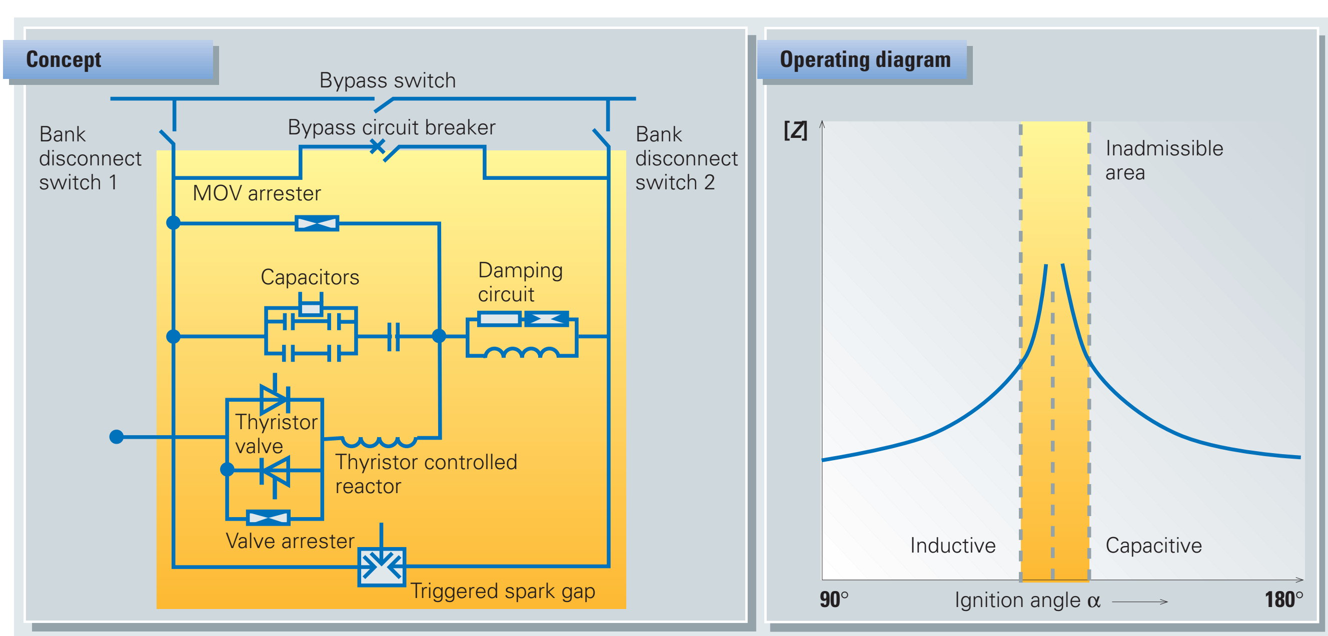


Fig. 84: Thyristor controlled Series Compensation (TCSC). Example: Single line diagram TCSC S. da Mesa

Unified Power Flow Controller (UPFC)

The Unified Power Flow Controller (UPFC) is the fastest and most versatile FACTS controller (Fig. 86). The UPFC constitutes a combination of the STATCOM and the SSSC. It can provide simultaneously and independently real time control of all basic power system parameters (transmission voltage, impedance and phase angle), determinig the transmitted real and reactive power flow to optimize line utilization and system capability. The UPFC can enhance transmission stability and dampen system oscillations.

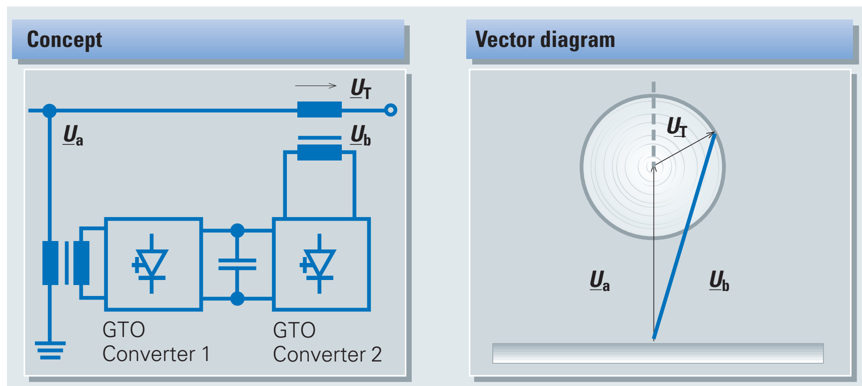


Fig. 86: Unified power-flow controller (UPFC)

Comparison of reactive power compensation facilities

The following tables show the characteristics and application areas of UPFC (Fig. 87a), parallel compensation and series compensation (Fig. 87b, page **2**/56) and the influence on various parameters such as short-circuit rating, transmission phase angle and voltage behavior at this load.

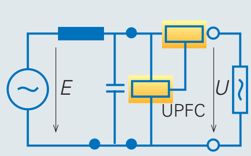
	Compensation element	Location	Behavior of compensation element: Short-circuit level	Behavior of compensation element: Voltage influence	Behavior of compensation element: Transmission phase angle	Behavior of compensation element: Voltage after load rejection	Applications
UPFC (Parallel and/or series compensation)							
1	UPFC		Reduced	Controlled	Controlled	Limited by control	Real and reactive power flow control, enhancing transmission stability and dampening system oscillations

Fig. 87a: Components for reactive power compensation, UPFC

Power Compensation in Transmission Systems

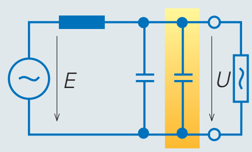
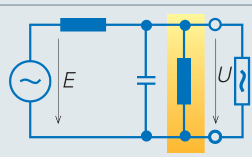
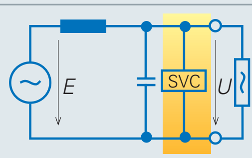
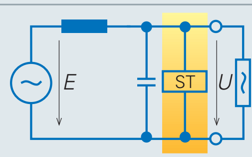
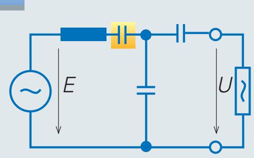
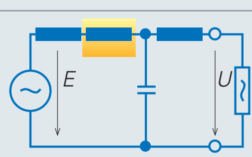
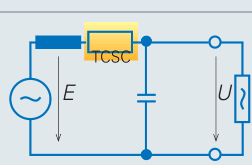
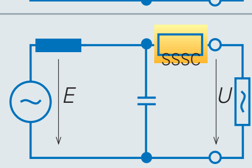
	Compen-sation element	Location	Behavior of compensation element: Short-circuit level	Voltage influence	Transmis-sion phase angle	Voltage after load rejection	Applications
Parallel compensation							
2	Shunt capacitor		Little influence	Voltage rise	Little influence	High	Voltage stabilization at high load
3	Shunt reactor		Little influence	Voltage drop	Little influence	Low	Reactive power compensation at low load; limitation of temporary overvoltage
4	Static VAr com-pensator (SVC)		Little influence	Controlled	Little influence	Limited by control	Reactive power and voltage control, damping of power swings to improve system stability
5	STATCOM		No influence	Controlled	Little influence	Limited by control	Reactive power and voltage control, damping of power swings
Series compensation							
6	Series capacitor		Increased	Very good	Much smaller	(Very) low	Long transmission lines with high transmission power rating
7	Series reactor		Reduced	(Very) slight	(Much) larger	(Very) high	Short lines, limitation of SC power
8	Thyristor Controlled SeriesCom-pensation (TCSC)		Variable	Very good	Much smaller	(Very) low	Long transmission lines, power flow distribution between parallel lines and SSR damping
9	SSSC		Reduced	Controlled	Controlled	Limited by control	Real power flow control, damping of transient oscillations

Fig. 87b: Components of reactive power compensation, parallel compensation/series compensation