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High Voltage Circuit Breakers: Trends and Recent Developments

Answers for energy.

Dear Reader,

The availability of electric energy is vital for the development of an economy and for the quality of life. One of the necessary conditions for a reliable electric power supply is a well functioning transmission system. As a world market leader in high voltage circuit breakers, Siemens takes the responsibility to provide switchgear which meets the environmental, technological and economic conditions which result from the situations in the various countries.

We are pleased to present you the brochure in hand based on recent publications and reports. We would like to inform you about the complementation and supplementation of our product portfolio, e.g. at voltage levels of 550 kV and above as well as special solutions for DC applications and a new compact designed product, based on Dead Tank circuit breakers for 145 kV and 245 kV. Further reports focus on the Quality Management treating the product life cycle from the development to the operation at our customers' locations, covering, among other things, service and customer training. Our engineers have constantly converted good ideas into successful products. Our daily work is to continue this.

We are looking forward to your feedback, to questions arising from the content and to your remarks. Please do not hesitate to contact us at circuit-breaker@siemens.com.

Enjoy the study.

Yours truly,

Dr. Harald Fien
Chief Executive Officer

Siemens AG
Energy Sector
Power Transmission
High Voltage Products
Circuit Breakers and Disconnectors

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Trends in High Voltage Circuit Breaker Technology

Introduction

The availability of electric energy is vital for the development of an economy and for the quality of life. Therefore, the consumption of electric power is steadily increasing and will continue to do so in the coming decades. While the rate of increase is in the order of 2 % p.a. in countries with an established industry a higher percentage can be observed in developing or newly industrialising countries, e.g. in India with an average of 7 % increase p.a. up to 2030 [1].

One of the necessary conditions for a reliable electric power supply is a well functioning transmission system. Consequently, countries with an expanding economy are taking severe efforts to improve the capability of their national high voltage networks. As high voltage circuit breakers are the ultimate safety devices in the transmission and distribution systems new technical requirements, economic considerations and political conditions provide strong impulses for further developments of high voltage switchgear technology.

As a world market leader in high voltage circuit breakers Siemens takes the responsibility to provide switchgear which meet the environmental, technological and economic conditions which result from the situations in the various countries. This paper is intended to show the Siemens' competence in this field and to give an overview of their today's respective technology and developments.

Further developments of high voltage transmission systems



Figure 1: High voltage test of an 800 kV pole for dc voltage



Figure 2: 800 kV live tank circuit breaker

To supply electric energy to the large urban and industrial centres in the East, China has started to install a 1100 kV a. c. and a 800 kV dc system. Figure 1 shows a pole of an 800 kV dc bypass circuit breaker at high voltage tests. For the next decade India is planning a 1200 kV ac network and numerous dc connections. Other existing 800 kV ac connections are enlarged and new ones will be built to supply the megacities in Asia and Latin America with power. Figure 2 shows an 800 kV ac live tank circuit breaker of the newest technology with spring operating mechanism. This circuit breaker copes with 63 kA short circuit breaking currents. In the industrial areas in the eastern United States new 800 kV lines are in the planning stage. Figure 3 gives an overview of the worldwide extra high voltage (EHV) networks.



Figure 3: Worldwide EHV networks

In many regions, particularly in the USA and in Europe, the short circuit current levels are rising, in some places up to 80 kA. A 550 kV dead tank circuit breaker for 63 kA short circuit interruption is shown in Figure 4.



Figure 4: 500 kV Dead tank circuit breaker for 63 kA

All these developments require high voltage switchgear of corresponding ratings. Siemens has accepted this challenge and is ready to contribute to the improvements of the electric energy supply in the respective countries.

Ac networks of high power, especially if not closely meshed, tend to be more sensitive to stability problems and switching overvoltages. Therefore requirements are increasing regarding the breaking time of 2 cycles instead of 3 cycles. The solutions provided by Siemens are shorter total breaking times and controlled switching with a phase synchronizing device (Figure 5), minimizing electro-dynamic and dielectric stresses of operational equipment in high voltage systems.

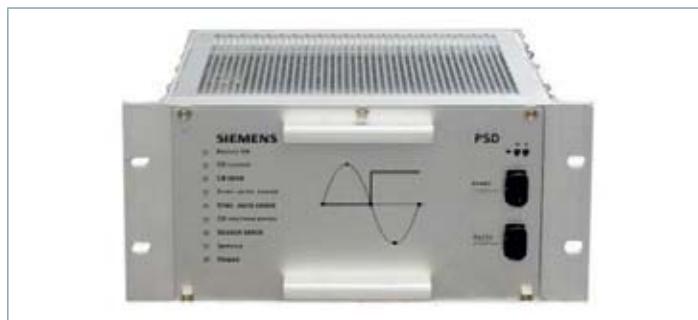


Figure 5: A phase synchronizing device for controlled switching

Meeting of environmental requirements

High voltage switchgear for present and future transmission systems are using SF₆ as an insulating gas and arc extinguishing medium. Although it does not contribute to ozon depletion SF₆ is considered to be one of the most potent greenhouse gases. If the gas is used solely for insulation it can be mixed with nitrogen. An SF₆/N₂ mixture of 20/80 % has still 70–80 % of the insulation properties of pure SF₆ [3]. However, to extinguish the electric arc in high voltage circuit breakers during current interruption SF₆ has proved to be unique. As a consequence intensive research and systematic investigations, carried out world-wide, came to the conclusion that there is no substitute for SF₆ [4]. Manufacturers and users of equipment containing SF₆ have agreed to avoid as far as possible the emission of SF₆ into the atmosphere. They provide on a voluntary basis a documentation on how SF₆ is used [5, 6]. An essential contribution comes from the development and design of gas tight housings with a leakage rate well below 0.5 % p.a. Figure 6 shows a test system for cumulative leakage measurements on aluminium cast housings which is routinely used in the manufacturing process.



Figure 6: Test system for cumulative leakage measurements

Reliability and economy

High voltage switchgear supplied by Siemens today has an expected lifetime of up to 50 years and maintenance intervals in the order of 20 to 25 years. The mean-time-between-major-failures (MTBF) is in the range of several thousand years (Figure 7). This high reliability must be considered as an important contribution to high quality power supply.

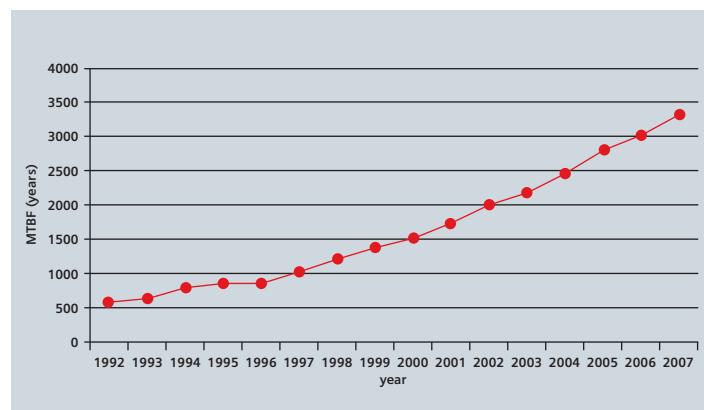


Figure 7: Meantime between failures of Siemens high voltage circuit breakers

Basically the background for these figures can be summarized as follows: As, according to world-wide surveys carried out by CIGRÉ and to our own statistics, the highest percentage of failures is of mechanical nature an important aim of our high voltage circuit breaker development was to reduce the number of active parts (a part which is not there cannot fail) and the mechanical stress these parts are exposed to. New interrupters were developed which require less operating energy and can be driven by simple spring drive mechanisms – up to the highest voltage and breaking current ratings (Figure 8). The technical solutions are based on an improved understanding of the physics of electric arc extinction [7, 8, 9].

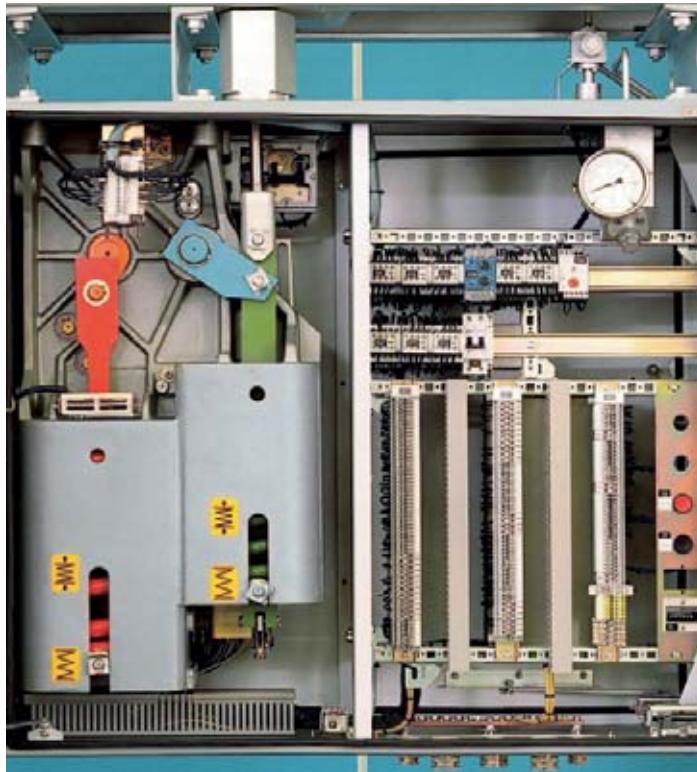


Figure 8: Spring drive mechanism of high voltage circuit breakers

A major contribution to the high reliability and lifetime of our high voltage circuit breakers comes from the production quality and the expertise of the personnel in the factory who fully identify themselves with the products they are manufacturing. Low operating costs result from high quality, extended lifetime and long maintenance intervals. Further savings will be achieved by the transition from time based maintenance, which is the standard procedure today, to condition based maintenance. Manufacturers and users of high voltage switchgear are cooperating to establish the basis for the necessary data evaluation systems to detect developing faults at an early stage and to predict the approaching end of life of a piece of equipment.

New technical solutions

Finally, some examples shall be mentioned to show the wide scope of development activities carried out at Siemens for high voltage circuit breakers.

550 kV SF₆ open air circuit breakers have been supplied in large numbers to areas in central Asia where the outside temperature may drop even below -55°C. Solutions have been found to keep these circuit breakers fully operative throughout the whole winter months. Figure 9 shows a 245 kV dead tank circuit breaker with heating blankets for low temperature applications at the routine testing.



Figure 9: 245 kV dead tank circuit breaker for low temperature applications

The reduction of the number of interrupters per circuit breaker pole, while maintaining the same contact speed, contributes to further improvements in reliability, in the sense mentioned above. This has been proven by statistics over many years. In addition, such circuit breakers require less space in the substation. An even more significant space reduction in outdoor substations comes from the installation of switchgear with integrated functions, like disconnectors, earthing switches and measuring transformers [10]. Very often they are the solution for a needed extension within an existing substation. A dead tank based compact switchgear for 145 kV is shown in Figure 10.



Figure 10: 145 kV dead tank based compact switchgear

Circuit breakers with combined functions will also contribute to further improvements of the reliability of the total substation. A typical example is the high voltage circuit breaker with a disconnector function. For reasons of safety, line and cable disconnectors have to have a higher voltage withstand across the open break than circuit breakers. The application of circuit breakers with combined functions fulfills these requirements. Thus, it does not mean a sacrifice in operational safety but has economic benefits and give a higher overall reliability due to the lower number of elements which could potentially fail. Figure 11 shows a disconnecting circuit breaker pole for 420 kV with composite insulators and without grading capacitors in the high voltage test laboratory.



Figure 11: 420 kV disconnecting circuit breaker pole

Composite insulators with their hydrophobic properties have been used with very good results on overhead lines, for bushings, on surge arrestors and measuring transformers. For various reasons they have not been incorporated comprehensively in high voltage circuit breakers and disconnectors, so far. Improvements in their design and materials are opening possibilities to make use of their advantages over porcelain insulators on high voltage switchgear in the near future.

Conclusion

When a new product is introduced into the market it shall from the start meet fully the customers' expectations with regard to technology and reliability. This necessitates a high quality of the whole development process. Siemens' engineers have at their disposal the most modern and progressive laboratory and test facilities to ensure this quality at every development stage.

Moreover, Siemens' engineers are active in international scientific and standardization bodies, like CIGRÉ and IEC. There, they get a first hand impression of the situation in the high voltage systems world-wide and contribute their expertise to the understanding of system and switchgear behaviour as well as to the adaptation of standards to actual network conditions.

As already mentioned, high voltage circuit breakers and disconnectors are the ultimate safety device in the transmission systems. This places a high responsibility on those who develop and manufacture such equipment. Siemens is well aware of this responsibility and has always taken the position to be a partner of the utilities

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Peter Stenzel

Dead Tank Based Compact Switchgear

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Summary

Compact switchgear assemblies for high voltage substations fill the gap between Air Insulated Switchgear (AIS) and Gas Insulated Switchgear (GIS) [1]. The Dead Tank Compact (DTC) for rated voltages 123 kV to 245 kV is a compact solution based on dead tank circuit breakers. It is a combination of circuit breaker, disconnectors, earthing switches and several other elements of high voltage switchgear. Both standard and customised versions of switchgear assemblies are available thanks to the high degree of flexibility achieved by combining different elements. The DTC concept is characterized by high reliability and notable cost saving.

Keywords

High voltage substation, compact switchgear assembly

Introduction

Due to increasing power demands in quickly developing areas and cost pressure, power transmission is a vital issue for the energy industry. Fundamental parts of energy transmission systems include high voltage substations containing the key elements circuit breakers, disconnectors, earthing switches, current transformers, etc. Standard design layouts for equipment in high voltage substation are Air Insulated Switchgear (AIS; mainly outdoor application) and Gas Insulated Switchgear (GIS; primarily indoor application).

Compact Switchgear assembly joins the advantages of both technologies and fills the gap between them (figure 1).

Dead Tank Compact (DTC) combines various devices with different functions into high voltage switchgear. It is designed, tested and supplied for use as a single unit.

DTC is a switchgear assembly which is comprised of our well established Dead Tank Circuit breaker and several GIS components. It is mostly used in outdoor substations. The advantages are compact set up, higher reliability due to increased grade of encapsulation, shorter erection and installation time, as well as less maintenance.

The Compact switchgear assembly, DTC, is applicable for new substations as well as for retrofits. It is preferably installed in medium developed areas and areas with severe environmental conditions, such as extreme pollution and low temperatures. The DTC is also beneficial for urban areas and mobile substations because of its space saving design.

Far fewer external insulators are needed than with traditional AIS. Thanks to the use of SF₆ encapsulated disconnectors, all well known issues with air-insulated devices (e.g. uncovered contacts in polluted areas or in cold regions and high maintenance effort) have been solved. Excellent earthquake withstand capability is a result of the compact design.

The space-saving setup of the DTC solution reduces land requirements for the site by up to 70 % in comparison to conventional AIS equipped with live tank circuit breakers and other AIS equipment. The application of AIS busbars provides even further cost reductions than SF₆ encapsulated busbars.

One main target for the concept of the new compact switchgear assembly was to create a new platform-based product family from 123 kV to 245 kV (figure 2). The design principles of the modules are the same for both voltage ratings.

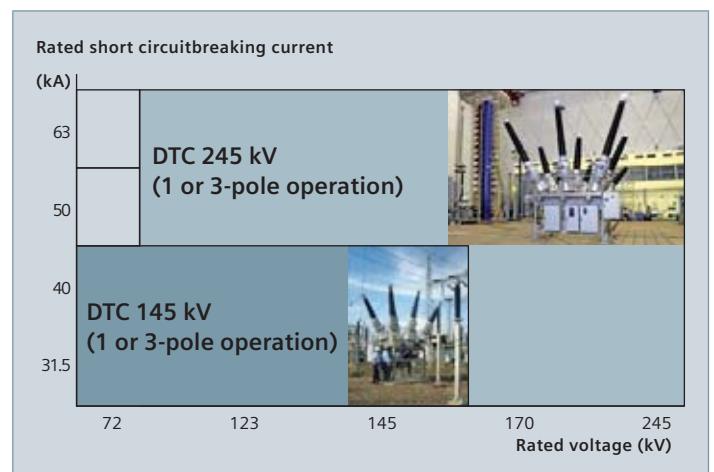


Figure 2: Product portfolio DTC 123 kV to DTC 245 kV

Elements of DTC switchgear assembly

Components of DTC are the Dead Tank circuit breaker (figure 3) and GIS components: disconnectors and earthing switches (figure 4). All assemblies are based on products from our existing product portfolio and have been recognized as well established products for many years.

Dead tank circuit breakers include the self compression interrupter unit and spring drive mechanism. These components are well established throughout the circuit breaker family [2].

A single pole operation with a suitable drive mechanism is also available as a three pole operation.

Current transformers are part of the Dead Tank breaker and consist of ring type cores.

These cores surround the CT housing and provide space for a variety of cores for different ratings.

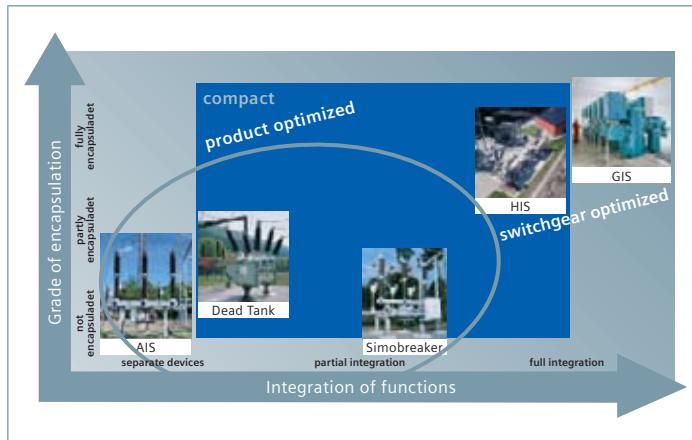


Figure 1: Grade of encapsulation and the integration of functions of different switchgear solutions. DTC is located between AIS and GIS

SF₆ insulated Bushings are the most economical solution for connecting the circuit breaker to the lines of the substation. Only a few parts (a conductor and a shield electrode) are mounted inside the insulator. The insulator is available in either porcelain or composite materials, the latter consisting of epoxy impregnated fiberglass tube with silicon rubber sheds.



Figure 3: One pole of a dead tank circuit breaker

The three position disconnector earthing switch (figure 4) has the same design and parts (e.g. current path and drive mechanism) of the respective GIS component. The reliability of these components has been proved over years.

An optimised design of the disconnector earthing switch offers high variability for this component. We also provide a single disconnector, a three position disconnector / earthing switch, as well as an additional earthing switch, with the same overall dimensions.

The contact path is fixed by epoxy resin supports. If a separation of gas compartments is requested, an epoxy resin bushing can easily be added to the disconnector switch.



Figure 4: Disconnector/earthing switch

The DTC is equipped with conventional ring type current transformers (CTs). A CT positioned between the circuit breaker and disconnector is the standard arrangement for most substations. For this arrangement, a return current has to be avoided if there is an internal failure. This is guaranteed by an insulating clearance between two flanges of the DTC housing (figure 5). An arrangement of CTs positioned directly to the line is also possible.

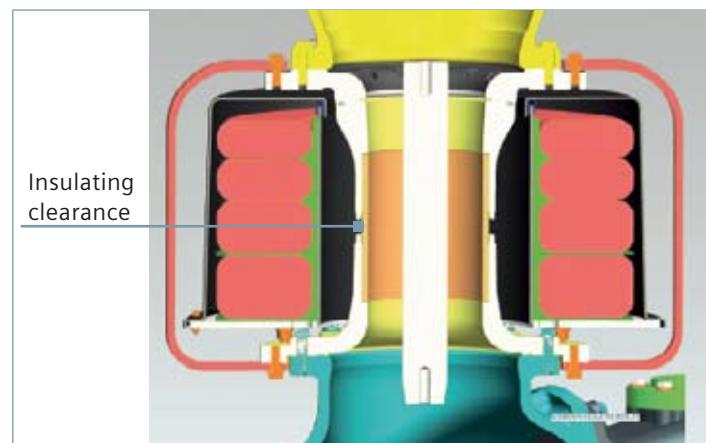


Figure 5: Current transformer housing with current transformers
Insulating clearance to prevent a current return path over the CT housing

The control cabinets for the circuit breaker and disconnector/earthing switch offer sufficient space for different wiring schemes. With a standard scheme, each single device is wired directly to implement the connection on the bay level. This also includes the voltage and current transformer terminals. Control cabinets are easy accessible (human-machine-interface). Interlocking functions are also available.

A cable connection module is also part of the DTC portfolio. Cable cones are the preferred choice to meet the requirements for compact switchgear design (cable connector IEC 62271-209). SF₆-insulated voltage transformers complete the available components for DTC.

The DTC concept allows for the choice between one common gas-compartment for all assemblies or separated gas-compartments (e.g. for circuit breaker and disconnector). All configurations resulting from technical or service requirements can be implemented.



Figure 6: Modular design

Modular design

Generally, two classes of DTC setups are available. A number of standard assemblies to satisfy the requirements of common substation layouts are feasible. The configuration of customized DTCs is also possible because of the modular design of the components. All elements of high voltage substation are available for the DTC (figure 6). Standardized connection between the elements of the DTC (e.g. circuit breaker to disconnector) offers high flexibility and leads to different numbers of possible combination of compact switchgear assemblies.

Standard assemblies

Standardization of assembly types yields reduced time in the concept phase of planning a new substation or extending or retrofitting an exiting substation. This can be realized with less effort than with single elements for AIS. The production process for DTC is comparable with that of a single device.

Compact solutions also reduce on site erection time and the effort required for installation when compared to a conventional air insulated substation. Standardized base frame dimensions (footprint) allow for precast foundation and makes replacing the DTC quite simple.

This is an important advantage, especially for the extension of existing AIS substations with limited space and when the demand for a short outage time is taken into account.

As a result, the use of standardized modules reduces the overall lead time.

Standard setups of DTC are In-Out and Double busbar assemblies, for example.

The In-/Out-Variant (figure 7) represents the basic module of the DTC: A dead tank circuit breaker with current transformer on the incoming side and a disconnector/earthing switch combination (figure 4) on the outgoing side. For defined applications (e.g. earthing of overhead lines and of the DTC itself), a special high speed earthing switch is not necessary. Compared to portable grounding rods or freestanding air insulated grounding switches, the integrated earthing switch shown here offers several advantages with respect to safety, reliability and handling.

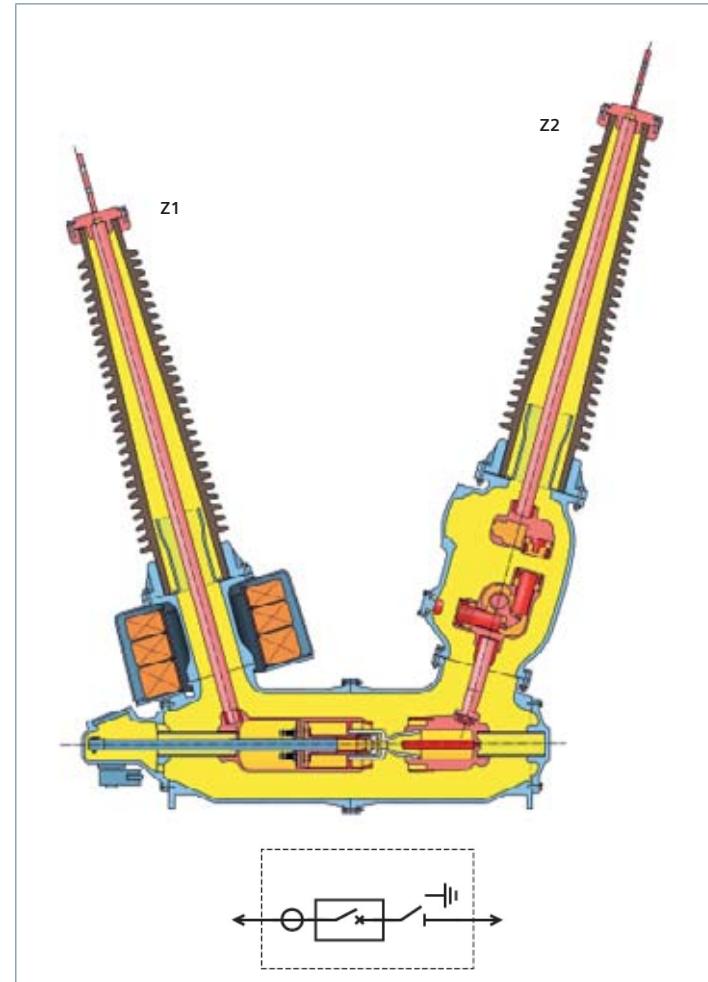


Figure 7: In-Out modules

The DTC can also be used as a double busbar variant (figure 8). One side of the circuit breaker is equipped with a disconnector/earthing switch component and with current transformers. The other side of the circuit breaker provides two "exits" which can be connected to a double busbar system. By two disconnector modules (one for each exit) the connection/disconnection of the two busbars is possible. Gastight insulating bushings are available. They divide each device into functionally separated gas compartments, i.e. a separation between the gas compartments of the circuit breaker and of the disconnector is possible. This arrangement takes the fundamental idea of a double busbar concept into account: In the unlikely event of a failure in one busbar or inside of one disconnector, further operation with the second busbar is still possible. The gas compartments are constantly being monitored by means of density monitors with an integrated indicator.

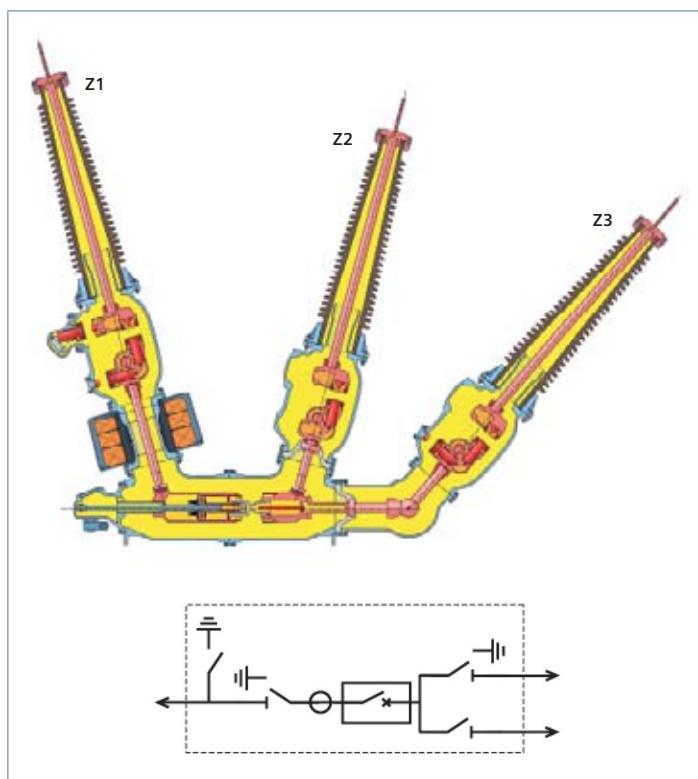


Figure 8: Double busbar assembly

Customised assemblies

Due to its modular design and standardized connections of flanges and contacts the DTC's versatility provides solutions for the various substation layouts. Nearly every switchgear layout can be achieved with this flexible concept.

For example, switchgear applications with cable connection and voltage transformer (VT) can be realized (figure 9).

This device consist of a Dead Tank circuit breaker as a foundation for the compact switching assembly. The disconnector/Earthing switch is located on the incoming side and cable connection with voltage transformer on the outgoing side.



Figure 9: Assembly with cable connection and VT

For special applications and for H-layouts, a double breaker module (figure 10) is available with all the advantages of a single breaker module in respect to factory testing, transport and commissioning. Both or one of the circuit breakers can be equipped with single pole drive or common drive for three poles. The double breaker application itself also offers a high variability of solutions. The number and position of CTs and disconnectors can be varied. Different switchgear layouts can be realized.

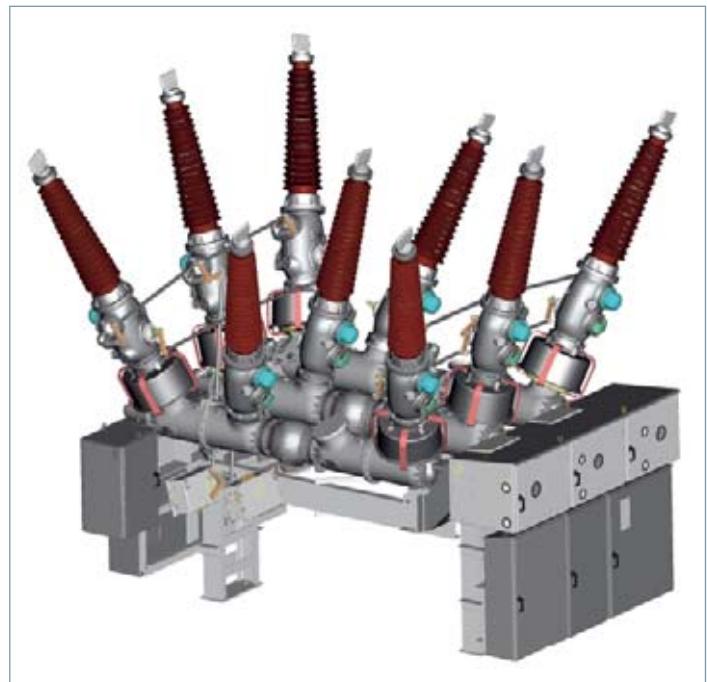


Figure 10: Double breaker assembly

In general, all variations of compact switchgear assembly can be combined with several other AIS-components in a substation if required. In this case DTC is one element of the substation.

Development process

Based on specifications, the product development process includes the following steps: design, calculation, simulation, realization and tests of prototypes, and type tests.

The objective for the DTC design concept was to create a compact, reliable and flexible product platform. The whole design process was supported by the use of modern 3D design tools.

The combination of our extensive experience with the technology in high voltage SF₆ insulated equipment and use of modern methods of numeric design engineering has resulted in an optimized design.

Mechanical stress in high voltage equipment during service (terminal loads, design pressure, wind loads) were also calculated as loads resulting from earthquake. The so called kinematic chains of high voltage equipment were analysed.

Forces due to electro-dynamic loads as a result of short circuit were evaluated. The electrical field strength was calculated in all main components.

All calculated results were verified by development tests and type tests.

Mechanical tests have been carried out on the circuit breakers, disconnectors and earthing switches with more operating cycles than required in the standards. Climatic tests in the temperature

range of -55 °C and +50 °C were part of the development procedure. The handling resistance has been proven on shipped units.

Tests have been successfully performed on the DTC with assemblies designed as single gas compartments to prove that no negative interaction will occur during life cycle. One such test was a combined cycle of high power test, mechanical endurance test and a final dielectric test. The positive results of this dielectric test has proven that there is no negative interaction between the elements of DTC

Type tests and routine tests

A new standard especially for compact switchgear assemblies was issued at the beginning of 2008.

According to this standard, IEC 62271-205 [3], all type test have to be performed on the components of the switchgear assemblies in accordance with the relevant standards. In addition, it has been confirmed that there is no negative interaction between these components. All type tests on DTC have been passed successfully.

Routine tests on fully mounted switchgear assemblies is a standard procedure in our factory. These tests include all mechanical and dielectric tests according to the latest IEC standards.

Commissioning

DTC modules prefilled with SF₆ fit into a container or on standard trucks. This guarantees affordable transport. Only a few hours are required for on site erection of the DTC. Commissioning tests are comparable to those of single circuit breaker. Compact switchgear assemblies reduce commissioning time and guarantee competitive installation costs.

Future prospects

Economical switchgear layout, low engineering work for substation layout and low commissioning costs for the DTC guarantees competitive investment costs. Reduced maintenance costs resulting from high reliability ensures low operating costs.

With the characteristics of compact design, high grade of standardization, increased reliability and low maintenance costs, the DTC is an ideal solution for future application in high voltage substation.

The application of compact switchgear assemblies in AIS is expected to increase (figure 11).

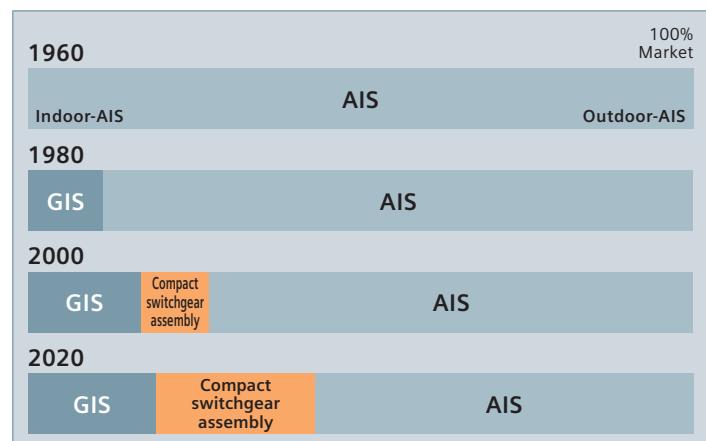


Figure 11: Market development

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Bypass Circuit-Breaker for 800 kV DC

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1 Background

The growth of the power demand throughout the world, in particular in the Asian region, necessitates the transmission of large energies over large distances. For this purpose the high-voltage direct current (HVDC) technology with transmission voltages of up to ± 600 kV has been established as particularly efficient and ecologically compatible procedure. During the past years the requirements by the market for transmission of more than 4000 MW on a single system over increasing distances have intensified. The availability of a ± 800 kV ultra high-voltage direct current (UHVDC) technology allows for the transmission of up to 6000 MW over more than 2000 km from now. A first UHVDC system will be installed in China from 2008 and taken into operation not later than 2010.

2 Application of DC bypass circuit breakers

The ± 800 kV UHVDC system is designed in a bipolar mode. Each pole consists of two 12-pulse valve groups connected in series. The simplified circuit of one pole is shown in figure 1.

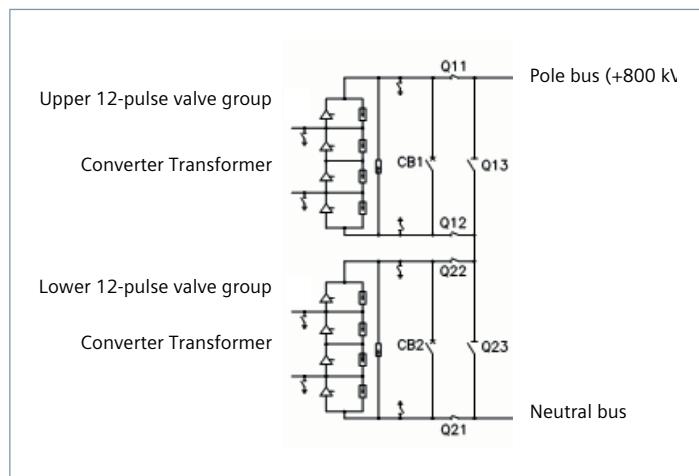


Figure 1: Simplified circuit

The switching elements presented in figure 1 – bypass circuit-breakers CB1 and CB2, the disconnectors Q11 through Q23 and the earthing switches – are required for switching on and off of the respective 12-pulse valve group. In terms of voltages and currents the ratings are based on a bipolar HVDC system with two 12-pulse groups in series:

- Nominal DC transmission voltage ± 800 kV
- Nominal DC voltage per 12 p-group ± 400 kV
- Nominal DC current of the system 4000 A

For the utilities running the power plants and operating the transmission systems the highest reliability and the undisturbed availability of the UHVDC system are of decisive importance. In order to maintain power transmission in case of outages or maintenance work on the system – at least on a reduced level, each of the two valve groups can be short-circuited by a bypass circuit-breaker (CB1 and CB2, see figure 1). In this operating

status the energy can be transmitted on a reduced voltage level by the valve groups which remain in service. After the outage or the completion of the maintenance work the current is commutated again into the valve group by the use of the bypass circuit-breaker.

3 Special requirements

The basis for the development of the new bypass circuit-breaker was the well approved technology of the double nozzle interrupter unit used in the circuit-breaker type 3AQ2 with two interrupter units and with an electro-hydraulic operating mechanism. For the application in the ± 800 kV UHVDC system the bypass circuit-breaker has to fulfill very specific requirements. The stipulations as to the creepage distance and the insulation levels necessitate utilising composite insulators with extremely long clearances for both, the interrupter units (2600 mm each) and the pole column (8200 mm). In case of porcelain insulators the specified length of the insulators would have been even longer (approximately 30 %).

Parameter	Unit	max. values for 12-pulse valve group
Rated voltage		
terminal-ground	kV DC	800
between terminals	kV DC	400
Rated DC withstand voltage (wet)	kV DC	1200
Specified creepage distance		
Composite-Insulator	mm/kV	43
Ceramic-Insulator	mm/kV	57
Lightning Impulse Withstand Level		
HV terminal-ground	kV	1950 (2210)
between terminals	kV	1175 (1330)
Switching Impulse Withstand Level		
HV terminal-ground	kV	1600 (1770)
between terminals	kV	950 (1061)
Values in brackets with altitude correction (2000 m)		

Table1: Special requirements

Due to the high specified test voltages, which are substantially higher than for comparable AC applications, some of the field grading electrodes had to be modified. Special grading elements to control the voltage distribution across the interrupter units for DC application have been developed. As the circuit-breaker is permanently exposed to DC voltage, the design of the interrupter units had to be accommodated. For the two different requirements with respect of the voltage level to ground (800 kV and 400 kV) two different pole versions of the circuit-breaker have been developed: the 3AQ2 ES DC – 800 kV with a long and the 3AQ2 ES – 400 kV with a short pole column (see figure 2).

4 Tests

As far as applicable standards are existent, the circuit-breaker has been type tested to the relevant IEC standards. In other cases testing procedures and parameters have been defined based on the client's specifications and instructions taking also into account standards for similar equipment. The tests were especially focussed on getting test evidence regarding the dielectric and mechanical behaviour of the bypass circuit-breaker.



Figure 2: 2 versions of the bypass circuit breaker
left: 800 kV, connected to the pole bus (CB1,upper 12-pulse valve group),
right: 400 kV, connected to the neutral bus (CB2, lower 12-pulse valve group)

4.1 High voltage tests

Due to the high testing values for lightning impulse, switching impulse and DC voltage tests, some of the existent testing facilities had to be extended (figures 3 and 4) and even some new installations had to be set up.

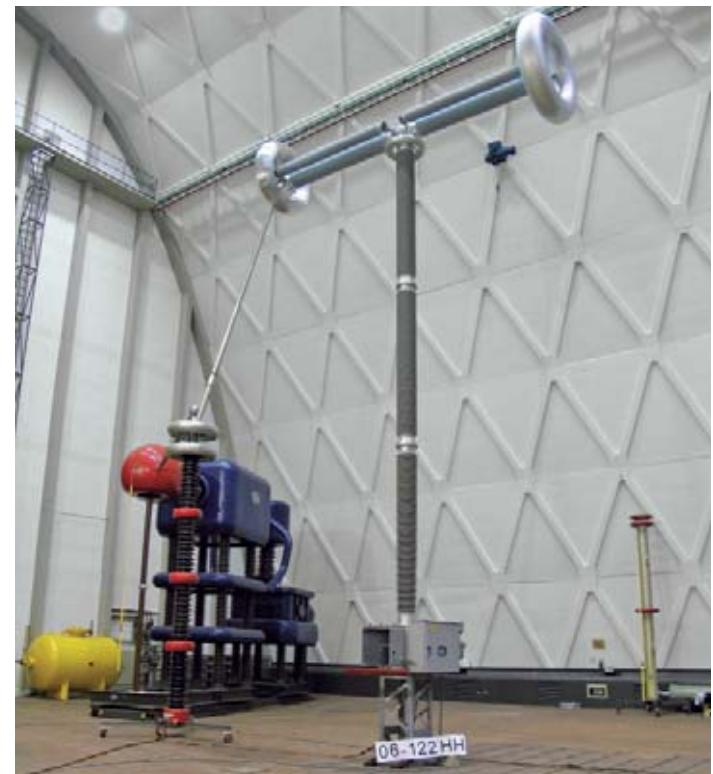


Figure 3: High voltage test of an 800 kV Pole



Figure 4: High voltage test of a 400 kV Pole

Type tests specified for the 800 kV pole:

- DC voltage withstand test, dry
 - between terminals, 600 kV,
60 min positive polarity
 - terminal to ground, 1200 kV,
60 min positive polarity
- Partial Discharge (PD) test, accompanying PD test during the DC voltage withstand test (dry)
- DC voltage withstand test, wet
 - between terminals 600 kV,
60 min positive polarity,
60 min negative polarity
 - terminal to ground 1200 kV,
60 min positive polarity,
60 min negative polarity
- Radio interference voltage (RIV) measurement at a test voltage of up to 1040 kV (DC), max. acceptable RIV level 2500 μ V.

Type tests specified for the 400 kV pole:

- DC voltage withstand test, dry
 - terminal to ground 600 kV,
60 min positive polarity
- Partial Discharge (PD) test, parallel to the DC voltage withstand test (dry)
- DC voltage withstand test, wet
 - terminal to ground 600 kV,
60 min positive polarity,
60 min negative polarity
- Radio interference voltage (RIV) measurement at a test voltage of 520 kV (DC), max. acceptable RIV level 2500 μ V.

All lightning and switching impulse tests have successfully been performed in the high-voltage laboratories of Siemens AG in Berlin. Also all DC voltage tests at voltages up to 600 kV could be performed here, all with positive results, too.

Additional investigations for DC voltages of up to 1200 kV have been carried out. The DC type tests including the requested PD and RIV measurements will be carried out at full voltage in the new laboratory of Hochspannungsgeräte Porz GmbH (HSP) at the end of 2007.

During the whole development additional tests have been carried out to prove availability and reliability for the expected life time of the circuit-breaker, e.g. influence of dust and metallic particles on its dielectric strength.

In service the voltage stress on a single interrupter unit will be 200 kV DC. Applying this voltage level, no signs of external or internal discharges could be found along the insulators and any insulating material in the interrupter units. Even better results could be achieved: In every case one voltage level higher than the service voltage has been withstood for a period of several days.



Figure 5: Dielectric tests with graphite dust as an example
for an extreme pollution

To investigate the dielectric behaviour of the interrupter unit – even with an extreme pollution – dielectric tests have been performed with conductive pollution (graphite dust, figure 5) and metallic particles (metallic cuttings). Under clean conditions as well as with graphite dust in the interrupter unit 1.5 times the system voltage was withstood for several days. After this long term stress no indications of discharges could be found on the insulating materials. With metallic particles in the interrupter unit a level of 1.5 times the system voltage could not be withstood, however, even under these extreme conditions, which are not at all characteristic for normal service, the system voltage was withstood for several days without any problems.

4.2 Mechanical tests

According to the specification the following type tests are requested:

- Mechanical endurance test with 2000 close-open cycles
- Temperature rise test at the rated direct current of 4000 A
- Verification of the seismic withstand capability.

For the bypass circuit-breaker with its very long pole column and operating rod it was necessary to adapt the operating mechanism and the travel characteristic of the system consisting of drive, operating rod and interrupter units. Especially because of the very long operating rod (9200 mm) the damping characteristic of the electro-hydraulic operating mechanism had to be optimised. The mechanical development tests and the endurance tests have been carried out in the laboratories of Siemens AG in Berlin. The preparation of the test object is shown in figures 6, 7 and 8.

Taking into account the application of the bypass circuit-breaker the temperature rise tests had to be performed applying direct current. To get a clear result – also with respect to possible limits – the tests have been performed in two steps, with a DC current of 3150 A and 4000 A. It is known that the use of composite insulators normally causes the reduction of the current carrying capability by one IEC current step. Independent from that the specified capability for 4000 A DC could be reached without any objections. The test results are presented in the diagram of figure 9.



Figure 6, 7: Assembling of the pole column
and the double-break interrupter unit

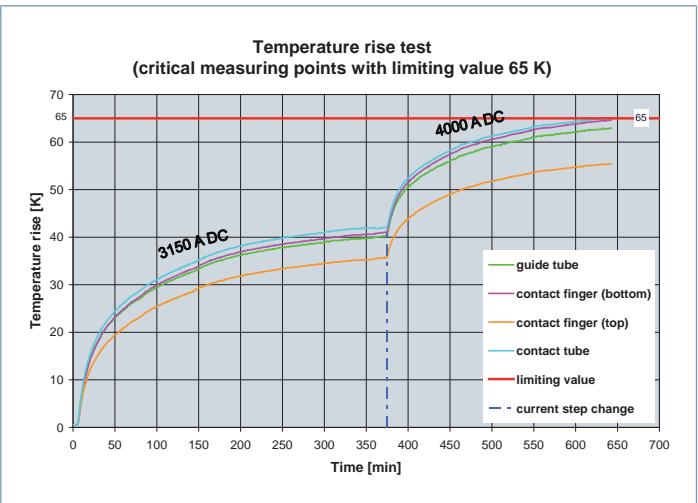


Figure 9: Results of the Temperature rise test and the double-break interrupter unit



Figure 8: Set-up for mechanical operation tests

The verification of the seismic withstand capability of the bypass circuit-breaker according to IEC 62271-300 (CDV) was performed by the use of a computational simulation tool. This tool utilises the well known commercial ANSYS software. The specified seismic withstand capability of ZPA = 0,3 g is proved.



Figure 10: Geometry of FEM-Model (left) and calculated mechanical stresses (right)

For the calculation of the mechanical stresses the geometry of the bypass circuit-breaker was modelled by the use of shell and rod elements, the mechanical tensions have been determined by the use of an FEM software tool (figure 10).

4.3 High power tests

As a result of system simulations the worst case conditions – the bypass circuit-breaker is exposed to during switching and commutating operations with respect to the voltage and current stresses – have been determined. Based on these values the test parameters for a half-pole test (test on a single interrupter unit using the corresponding test values) on the 3AQ2 ES DC – 400/800 kV have been defined. For reasons of the available testing technique the voltage after the specified interruption of 4 kA was applied in two parts. This method is comparable with a test procedure referred to as two-part test in IEC 62271-100, where the transient recovery voltage and the recovery voltage withstand capability of a circuit-breaker is tested in two subsequent steps. In the first part of the test the dielectric recovery capability immediately after current zero is proved (di/dt with following du/dt). The second part of the test is focussing on the crest value of the recovery voltage across the bypass circuit-breaker (u_C) after current interrupting.

In figures 11 and 12 the test parameters for a full-pole test on two interrupter units of the 3AQ2 ES DC – 400/800 kV are shown; the specified and the tested values are compared in the diagrams.

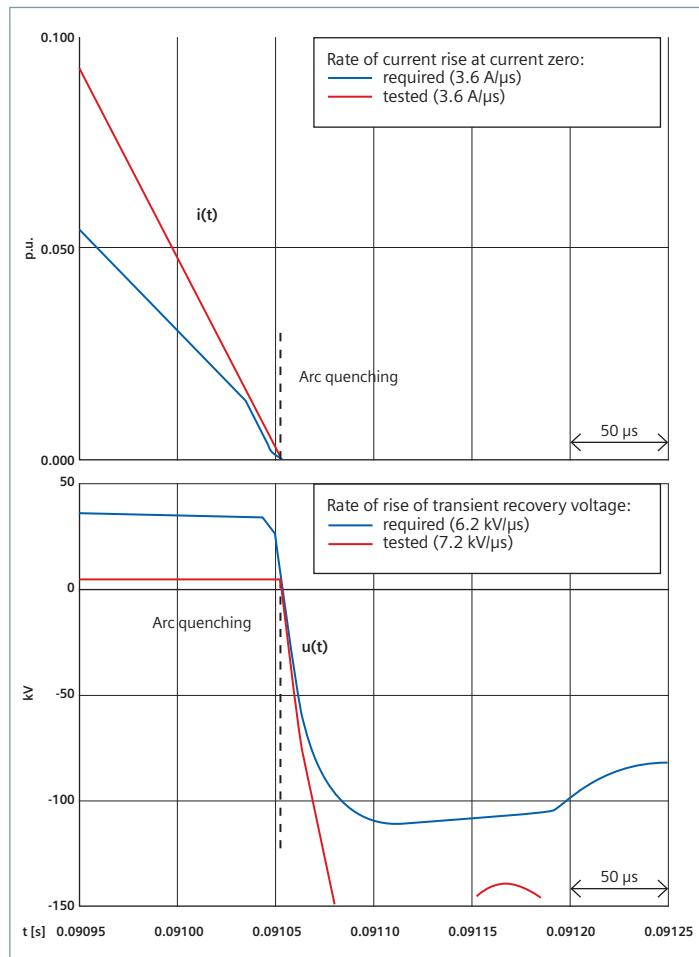


Figure 11: First part of the breaking test:
Arc quenching capability (du/dt , di/dt)

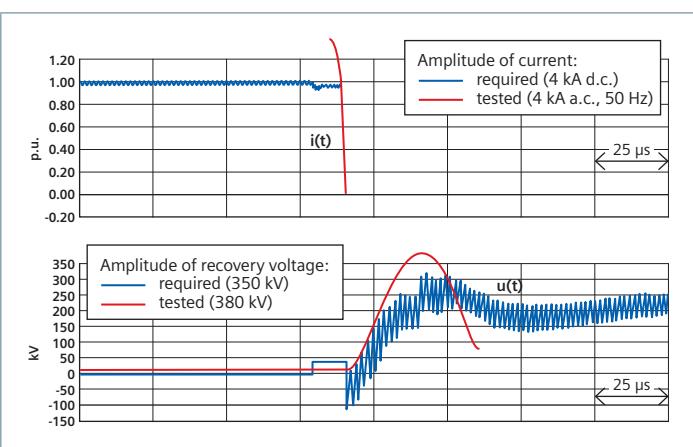


Figure 12: Second part of the breaking test:
Amplitude of recovery voltage (u_C)

As the bypass circuit-breaker has to cope with a DC application, there are no repeatedly occurring current zeros where the current can be interrupted as it is the case in AC applications. If the bypass circuit-breaker would fail to interrupt in the only current zero shown in the breaking process no further interrupting chance would occur. Therefore, the control system of the UHVDC trips the bypass circuit-breaker in an optimised way to interrupt in the current zero.

To monitor the quenching behaviour of the bypass circuit-breaker during the optimised arcing window the output signal of an adapted reference contact is evaluated. The reference contact is directly connected to the cinematic chain of the bypass circuit-breaker (figure 13).



Figure 13: Reference contact at the corner gear

5 Additional basic investigations

The development project has also been supported by the Technical University of Munich (TUM). At the university several basic subjects have been completed in parallel to the design work and the investigations carried out in the facilities of Siemens in Berlin. As examples some of the subjects are given in the following:

- Long term voltage withstand capability of an interrupter unit stressed by DC voltage and partial discharge measurements (figure 14);
- Voltage distribution between the two interrupter units of a double break circuit-breaker in case of DC voltage;
- Material characteristics of insulating material with regard to the creation and degradation of charge carriers.



Figure 14: Tests at the Technical University of Munich – measurement of partial discharges under AC voltage

6 Outlook

From March 2008 an UHVDC system will be put up on behalf of China Southern Power Grid Company connecting Guadong and the province of Yunnan. In this system the bypass circuit-breakers described in this publication will be used the first time. Having a transmission power of 5000 MW and a service voltage of ± 800 kV this system will be one of the powerful and most advanced DC long distance connections in the world. The system will be put into service in 2010.

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1200 kV AC substations: Full-scale products and integrated solutions

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Summary

Growing population, urbanization and industrialization in combination with very remote energy generation, especially for renewable energy sources, increases the need for bulk transmission of electricity over large distances. Depending on the location of energy generation and load centres, the distances in between and the network structure, either AC or DC transmission is the more efficient solution.

AC systems up to 1100 kV have been realized, but operating voltage levels are, due to various reasons, yet lower. Those systems come close to limits of physics, material and product design. In order to realize the full performance and advantages of UHV transmission lines stable operation is needed. The system reliability depends on the structure of the system and the reliability of its elements. – this means adequate system arrangements and reliable high voltage products.

Based on the experience of the development, production, testing, erection and operation of 800 kV DC and 800 kV/1100 kV AC products and systems, this paper describes 1200 kV AC substation arrangements and the products Surge Arresters, Disconnectors, Circuit Breakers, Current and Voltage Transformers.

The realization of 1200 kV AC transmission systems is one of the most challenging tasks in Power Transmission. The probability of its successful realization and operation rises with the close cooperation between transmission companies and suppliers and the total integration of all its products and components.

Keywords

UHV, 1200 kV AC, 800 kV DC, Surge Arresters, Disconnectors, Circuit Breakers, Dead Tank, Current Transformers, Instrument Transformers

1. Basic requirements and substation arrangement

The design of 1200 kV AC substations is a very ambitious task. Working along the known borderline of physics leads to new phenomena; international UHV standards do not exist. All installed UHV switchgear systems are tailored to customers needs and it is not possible to adapt them to 1200 kV requirements by copying or simple scaling of dimensions or parameters [1] [2]. This is the reason why the experience of the development, production, testing, erection and operation of systems up to 1100 kV are necessary together with requirements of the customers.

UHV substations have are important node-points in the power supply and distribution with a need of high security and high availability. Considering also the functional requirement in the network, the following circuit configurations are possible:

- Double busbar configuration
- 1,5 Circuit Breaker configuration
- 2 Circuit Breaker configuration

The electrical requirements from the network together with the minimum clearances are the parameters which are basics for the substation equipment and arrangement.

Electrical requirements	
Rated voltage	1200 kV
Rated current, feeder	5000 A
Rated frequency	50 Hz
Short-circuit current	50 kA/1 s
Rated lightning impulse withstand voltage	2400 kV
Rated switching impulse withstand voltage	1800 kV
Creepage distance	25 mm/kV

Table 1: Electrical data

Minimum clearances	
Phase to earth [1]	8300 mm
Phase to phase [1]	11600 mm
Height of lowest live part	18000 mm
Working clearance	18000 mm

Table 2: Clearances

Considering the available product portfolio for the 1200 kV equipment and the space availability at site as well as the environmental condition, a switchgear arrangement can be designed.

The substation design of the current 1200 kV UHV transmission project for Power Grid Company of India Ltd (PGCIL) is generally based on the experience made for the already built 800 kV substation Seoni in India.



Figure 1: 800 kV, India

Beside the standard installation materials like steelwork, civil work and cabling, the electrical connection on the 1200 kV level is another specific topic to have a detailed look on. The electrical field at conductor surface together with the high current requirements lines with 6 or 8 stranded conductors are considered. For the equipment connection level a tubular conductor is preferred to avoid pinch forces out of short-circuit current failure. For optimal fulfilment of these requirements Siemens compared different technologies and products and proposes an arrangement with dead tank circuit breakers, double-break disconnectors, compact surge arresters, free-standing gas-insulated or ring-core current transformers and capacitive voltage transformers. All designs are extraordinary robust and reliable. Figure 2 shows the example of a 2 circuit breaker arrangement with those products.

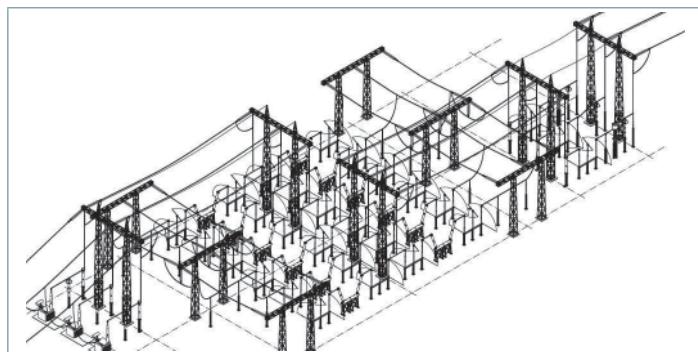


Figure 2: 1200 kV switchgear, 2 Circuit breaker arrangement

Following table 3 gives an overview about the 2 circuit breaker switchgear arrangement dimensions.

Dimensions	
Phase to phase distance	20 m
Bay width	62 m
Height of lower conductor level	18 m
Height of busbar	36 m
Height of outgoing gantry	55 m

Table 3: Dimensions

2 Surge arresters

The equipment used in electric power systems as transformers, instrument transformers or circuit breakers are exposed to overvoltages of different origin. Without countermeasures, occurrence of these overvoltages in the system can lead to failure of the equipment. In order to protect the equipment from overvoltages, surge arresters are used. The purpose is to always limit the voltage across the terminals of the equipment to be protected below its insulation withstand voltage.

Overvoltages can have their origin in atmospheric discharges (lightning overvoltages) or when the conditions in the power system change by volitional switching actions or failures like earth faults (switching overvoltages and temporary overvoltages). For UHV system voltages the rated switching impulse withstand voltage of the equipment is limited by its dimensions, since too large dimensions will cause mechanical problems. Reduced switching impulse withstand voltages require reduced switching impulse protection levels in combination with lower safety margins.

Requirements on surge arresters for the 1200 kV power system of Power Grid Company of India Ltd (PGCIL) are shown in table 4.

Rated voltage	850 kV
Continuous operating voltage	723 kV
Nominal discharge current	20 kA
Lightning impulse protection level	1700 kV
Switching impulse protection level	1500 kV
Energy discharge capability	55 MJ
Specific creepage distance	25 mm / kV

Table 4: Surge arrester requirements

Metal oxide surge arresters must fulfil two basic requirements: the equipment installed in the system has to be protected in a proper way and the surge arrester must remain stable even under the most severe operating conditions [3] including a sufficient energy discharge capability and withstand against temporary overvoltages of certain magnitudes and durations.

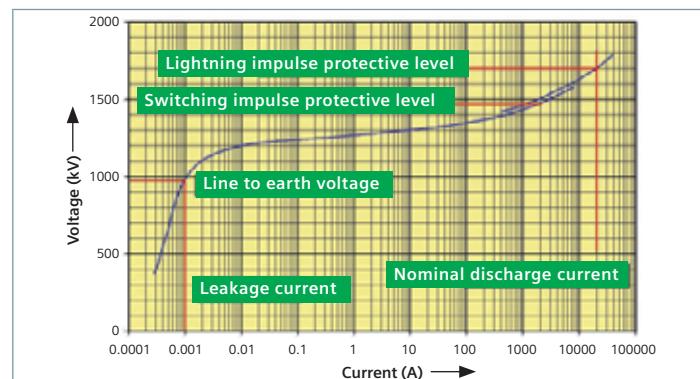


Figure 3: Voltage-current characteristic of a MO surge arrester for 1200 kV AC power system

The dimensioning of UHV surge arresters must be done more strictly than for surge arresters used in power systems of lower system voltage. This is because these surge arresters must have extremely low protection levels. The operation of a surge arrester is given by its voltage current characteristic which is shown in Figure 3 for the 1200 kV PGCIL application.

Low protection levels and a high continuous operating voltage are contradictory requirements which only can be fulfilled using metal oxide resistors with a high steepness of the voltage current characteristic. Further improvement of the protection level can be obtained using multi column arrangements. The surge arrester with the voltage current characteristic of Figure 3 is assembled with four columns in parallel.

Due to the very low protection level surge arresters for 1200 kV UHV applications are very sensitive to temporary overvoltages. These temporary overvoltages determine the energy discharge capability.

The housing of air insulated surge arresters can be made of porcelain or polymeric material. As surge arresters for UHV systems do have an overall height of more than 10 m there are extreme requirements concerning the mechanical properties of the surge arrester housing. These requirements only can be fulfilled by a composite housing with their very low weight and high mechanical strength [4]. The composite housing of the 1200 kV surge arrester with a height of 12 m and a bending moment of 150 kNm was developed for the DC line arrester of the first 800 kV HVDC in China (Figure 4).

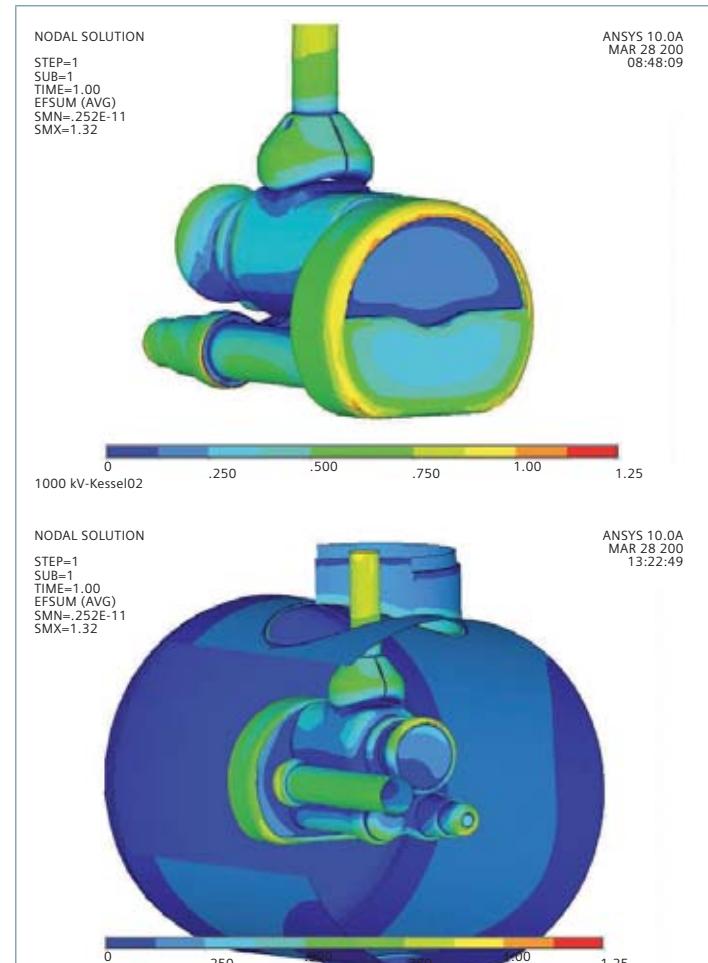


Figure 4: DC line surge arrester for 800 HVDC applications

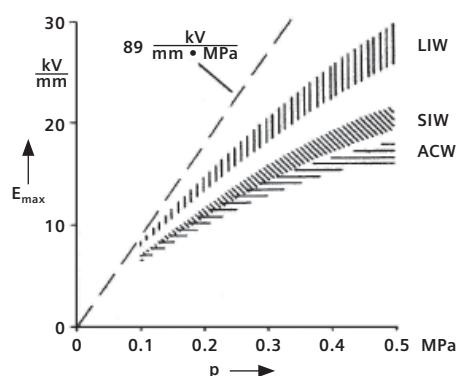
3 Circuit breakers

AC Transmission systems with rated voltage of 550 kV are common in the bigger countries of the world. Some of these countries have also successfully established the voltage level of 800 kV and expanded their transmission capability. Therefore suitable circuit-breakers for these voltage levels have been available for years, whereas the numbers of necessary interrupter units have been reduced during this time. So circuit-breakers with two interrupter units like the 3AP2FI were established for the rated voltage of 550 kV. Based on this reliable interrupter unit design Siemens developed UHV metal enclosed circuit-breakers with four interrupter units for use in DT or GIS installations. Using a metal enclosed design alleviates the need for long support insulators, which easily reach lengths close to ten meters and have to carry not only the interrupter units but also the pre-insertion resistors, normally required in UHV applications. This advantage becomes highly visible in seismic adverse areas. Also the dielectric performance of the circuit-breaker in highly polluted regions is positively affected by having exclusively an external creepage path direct to ground. As well metal enclosed design offers additional advantages during service and maintenance, because all active parts are relatively close to ground and thus easier to handle.

Disregarding the dielectric requirements and the switching performance, pre-insertion resistors and their thermal capability obtain a higher influence to the design of a circuit-breaker. To integrate pre-insertion resistors to existing interrupter units and in a suitable vessel design is a demand to the experience of the engineers. During the development of a new circuit-breaker the engineers were endorsed by several computer based tools, like motion analysis, mechanical stress, thermal effect or dielectric field calculations (Figure 5)



Insulation Co-ordination Related to Internal Insulation of Gas Insulated System 09/2007 WG C4.302



Ranges of maximum electric fields for withstand voltages of industrial GIS units at factory tests. The broken line corresponds to the theoretical breakdown field E_{max} : maximum electric field, P: SF₆ gas pressure, LIW: LI withstand voltage, SIW: SI withstand voltage, ACW: AC withstand voltage (crest value).

Figure 5: Results of dielectric field calculations supported by empirical knowledge

Tests on models are helpful in proving the validity of these calculations but many tests on the complete circuit-breaker are indispensable. Therefore also the testing stations have had to improve their capabilities to ensure tests in accordance with the requirements of the utilities and being close enough to the

standards, which do not currently cover the UHV segment. In the beginning of 2008 KEMA (Arnhem, The Netherlands) performed as the first testing station world wide several full pole tests on a Siemens metal enclosed circuit-breaker 8DQ1-P5-1100 kV for 50 kA with TRV peak values up to 2062 kV [5][6].



Figure 6 Test setup of cb type 8DQ1-P5-1100 kV – 50 kA during power test at KEMA

In summer of the same year FGH (Mannheim, Germany) finished the refurbishment of their testing facilities with the successful dielectric test of the same circuit-breaker.



Figure 7: Test setup Siemens 8DQ1-P5-1100 kV – 50 kA during dielectric test at FGH

The successfully performed tests show the capability of the new Siemens metal enclosed circuit-breaker family to fulfil the requirements of the UHV markets.

Full pole test T100

D.C. time constant	120 ms
First pole to clear factor	1,3 p. u.
TRV peak value	1600 kV
Minimum arcing time	10,3 ms

Full pole test T10

First pole to clear factor	1,5 p. u.
TRV peak value	2062 kV
Minimum arcing time	5,1 ms

Power-frequency withstand voltage

to earth	1100 kV
across open CB	1180 kV
(against power-frequency)	320 kV

Lightning impulse withstand voltage

to earth	2400 kV
across open CB	2400 kV
(against power-frequency)	630 kV

Switching impulse withstand voltage

to earth	1800 kV
across open CB	1675 kV
(against power-frequency)	900 kV

4 Disconnectors

Disconnectors with a clearly visible isolating distance will remain an important requirement of many substation customers. Different technologies were developed, because of the different requirements and production technologies worldwide. Below shown are the most common designs, with their usually used voltage level applications:

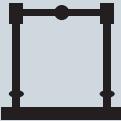
				
Centre Break Disconnectors 72.5 ... 550 kV	Pantograph Disconnectors 123 ... 550 kV	Knee-Type Disconnectors 123 kV 550 kV	Vertical Break Disconnectors 123 ... 550 kV	Double Side Break Disconnectors 36 ... 800 kV

Figure 8: Product portfolio of AC disconnectors

For new ambitious requirements of a 1200 kV AC disconnectors, Siemens recommends, based on their various operational experience on 800 kV AC and DC applications a double side break design. This design is in operation in the Ukraine and China.

The advantages are:

- High reliability due to the reduced number of moving parts in the kinematic chain and the current path
- Well proven turn and twist design in the current path
- Space savings in the vertical dimension due to the current path movement only in the horizontal direction



ZBF 515 kV DC, Project Gui Guang, China, DoubleSideBreak

ZBF 824 kV DC, Project Yun Guang, China, DoubleSideBreak

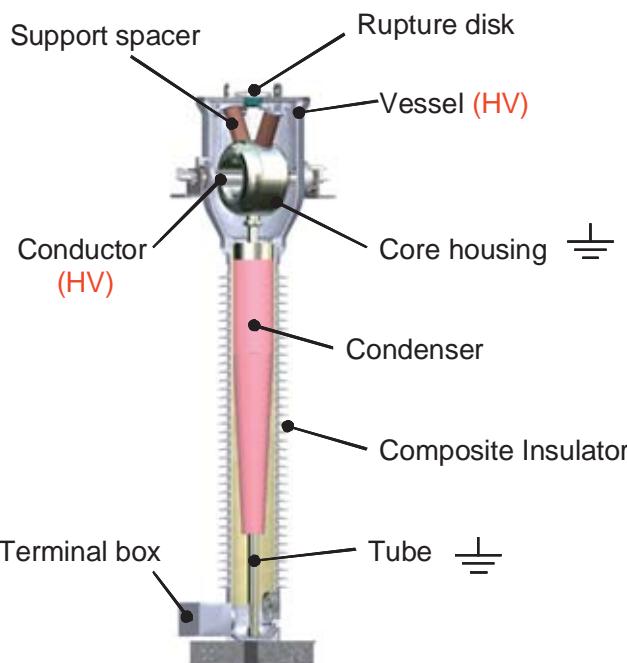
Figure 9: Examples of double side breaker applications

5 Current transformer and voltage transformers

Instrument Transformers are the link between the primary equipment on the high voltage side and the secondary equipment on the low voltage side. For protection, measurement and control purposes they have to provide a true image of the primary voltage and primary current at their secondary output. Their accuracy has to be stable over the entire life time of the Instrument Transformers. Current and voltage transformers are available today in different technologies well proven in the voltage ranges up to 800 kV. Beside that some types have been produced also for the UHV range up to 1200 kV.

For the application in 1200 kV AC systems we recommend capacitive voltage transformers and gas insulated free standing current transformers [7]. In case of dead tank breakers ring core current transformers can also be integrated in the bushings of the breaker.

For the insulation of current transformers for Air Insulated Switchgear two technologies are used: oil-paper insulation or gas insulation with SF₆ gas. For voltages above 500 kV the gas insulation technology has some advantages in costs and manufacturing time. Therefore gas insulation is recommended for UHV applications. The cores for measuring the primary current are located in a head housing at high voltage potential and the secondary wires are led through a bushing to the terminal box at the bottom of the unit. The bushing is equipped with a condenser grading to avoid high electrical field stress in the insulation. For the external insulation composite insulators are used with this technology. For the application in 1200 kV substations the main data are shown in Table 5. The principle design is shown in a cross section in Figure 10a.



a.: cross section of a gas insulated current transformer



b.: ring core current transformer on the bushings of a dead tank breaker

Figure 10: Current Transformer principles for UHV application

All types of core requirements can be realised with the gas insulated current transformer including TPY cores for transient behaviour.

	Proposed values	PGCIL requirements
Rated voltage	1200 kV	1200 kV
Rated current	5000 A	5000 A
BIL	2400 kV	2400 kV
SIL	1800 kV	1800 kV
1 min AC test	1215 kV	1200 kV
Insulator	Composite	
Overall height	11.3 m	
Weight	4250 kg	

Table 5: Main characteristic data for free standing current transformers for 1200 kV

In case of dead tank breakers, the current transformer cores can be integrated in the bushings of the breaker as shown in Figure 10b. For that solution also all types of core requirements can be realised. The insulation effort compared to the free standing current transformer is not needed and this gives a solution with low costs. For the application in 1200 kV substation no separate development has to be done.

The recommended technology for the voltage measurement in 1200 kV substations is the capacitive voltage transformer (CVT). A capacitive divider inside the insulator is dividing the high voltage to an intermediate value of approximate 5 to 12 kV. The output signal at the terminals of the CVT is provided by an inductive intermediate transformer which is placed together with a serial compensation coil in a metallic base box. Due to the technology and material used for the capacitor this design has excellent stability of the accuracy. An internal ferroresonance control unit avoids resonances between the capacitance in the divider and the reactance of the compensation coil and the intermediate transformer.

This technology is today well known in systems up to 800 kV. The design has been upgraded to 1100 kV systems. This unit with small modifications could also be used in 1200 kV systems. Five capacitive units have been placed in series to form the capacitive divider of that CVT. The main data are listed in Table 6. This capacitive voltage transformer for UHV has been type tested at Wuhan test lab in China and is running since one year in a test set up in Wuhan (Figure 11).



Figure 11: Capacitive voltage transformer in an 1100 test setup at Wuhan/China

	Proposed values	PGCIL requirements
Rated voltage	1200 kV	1200 kV
BIL	2400 kV	2400 kV
SIL	1800 kV	1800 kV
1 min ac test	1200 kV	1200 kV
Capacitance	2000 pF	2000 pF
Overall height	11.6 m	
Weight	2450 kg	

Table 6: Main characteristic data for capacitive voltage transformers for 1200 kV

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Development of SF₆ Current Transformers and Capacitive Voltage Transformers for High Voltage Levels with regard to Design, Installation and Service Life of Instrument Transformers,
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Circuit-Breaker Platform for 550 kV

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1 Introduction

Circuit-breakers have a protective function in a high-voltage transmission and distribution system. High reliability and continuous availability are basic requirements for the service. Based on long-term service experience with high-voltage circuit-breakers the existing product portfolio has been completed with a circuit-breaker platform for 550 kV [1-7]. This platform supersedes the previous products for this voltage rating, which were representatives of the successful type family of double nozzle circuit-breakers with electro-hydraulic operating mechanisms [8-14]. Now all circuit-breakers in the product portfolio from 72 kV up to 800 kV use the same principle of arc assist interrupter units and a stored-energy spring-spring operating mechanism. The operating experiences for this product family are adding up to more than 450 000 circuit-breaker bay-years. The platform includes live tank and dead tank circuit-breakers for air-insulated outdoor switchgear and circuit-breakers for gas-insulated switchgear and highly integrated switchgear as well.

2 Circuit-Breaker platform, a modular design concept

Very often modern circuit-breakers for one and the same set of ratings are offered in various configurations corresponding to the respective application: e. g. live tank (LT) and dead tank (DT) circuit-breakers, circuit-breakers for gas-insulated (GIS) or highly integrated switchgear (HIS) or circuit-breakers for so-called hybrid or compact switchgear. If the development responsibility for the different types of constructions lies in a single hand, then advantages for both, the user and the manufacturer, can be gained by creating a modular design concept (platform) with standardised modules and assembly groups from a common kit.

Where a product platform is developed instead of three or four different products, the manufacturer can concentrate his entire development force on one subject. The development process can be optimised and shortened without impact on the product quality; on the contrary, the quality of the final products will be improved as the development efforts have not to be split.

The parts used for the individual modules of the products are manufactured in higher numbers. Therefore, more efficient manufacturing processes can be utilised, resulting in reduced effort for the production and harmonised assembly procedures. This leads to optimised and stable processes and at the end to an increased product quality.

As the manufacturer can focus his development work on a single subject, the product platform, he is able to acquire more knowledge on the materials used and a better understanding of the behaviour of the new products. The feedback from operation is based on a bigger population as the number of nearly identical samples in operation is considerably higher than in the case of individual products. The operational experiences gained during service are basically applicable for all platform products.

Every component and module being part of the common kit is designed for easy combination. Therefore, circuit-breakers for special applications or further extensions of the product portfolio can easily be constructed using existing elements of the kit.

As the number of different spare parts is reduced due to the more or less identical design of the different products, the delivery time of spare parts is shorter and spare part management is easier resulting in lower life-cycle costs.

Another advantage is the usage of identical components in circuit-breakers with different ratings and for different service applications. As the highest ratings must be reached, circuit-breakers not exposed to the maximum stresses the platform is designed for offer larger margins than circuit-breakers which are developed for a certain rating and a limited range of applications.

3 Circuit-breaker platform 3AP2/3 – 550 kV/63 kA

After the completion of the development the new SF₆ circuit-breaker platform was introduced in 2006. The basic ratings of the standard product are presented in table 1. The following main configurations are offered:

- 3AP2FI – 550 kV Live tank circuit-breaker
- 3AP2DT – 550 kV Dead tank circuit-breaker
- 8DQ1 – 550 kV GIS applications
- 8DQ1 – 550 kV HIS applications

Rated voltage	550 kV
Rated frequency	50 / 60 Hz
Rated normal current	4000 / 5000 A
Ambient temperature range	-30 to +55 °C
Short-circuit making current	170 kA
Short-circuit breaking current	63 kA
First-pole-to-clear factor	1.3 and 1.5
Break time	2 cycles
Capacitive voltage factor	1.4 p.u.
Capacitive current switching	Class C2
Mechanical endurance	Class M2
Electrical endurance	Class E2
Type of gas	SF ₆
Filling pressure at 20°C	0.66 / 0.7 MPa

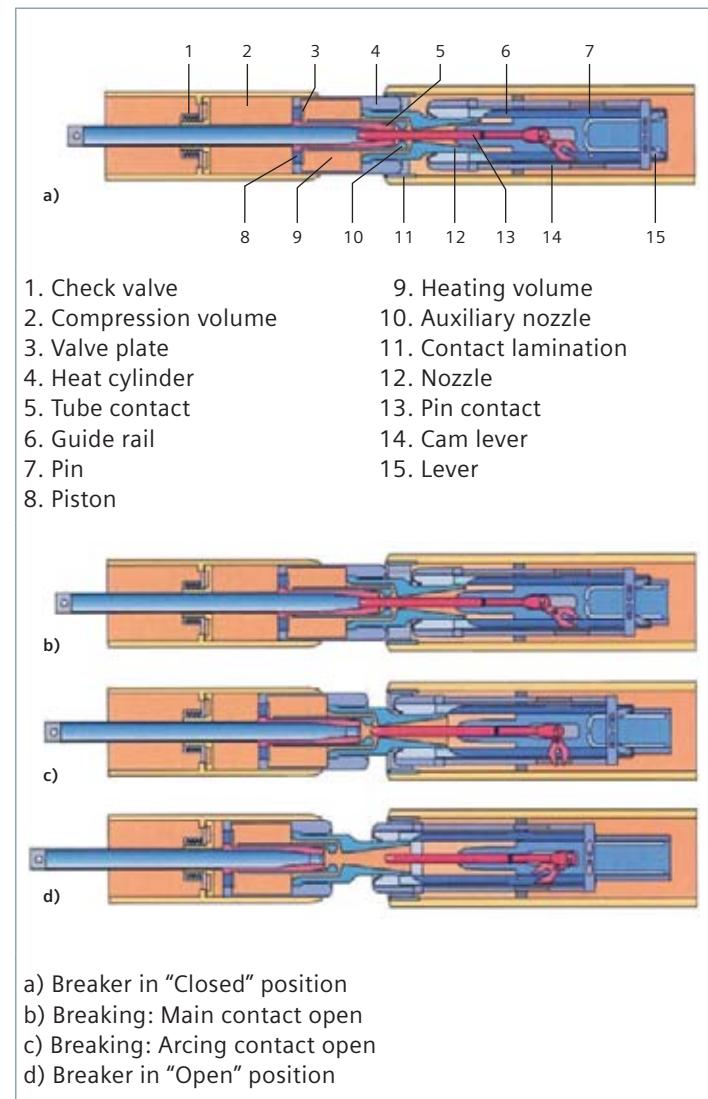
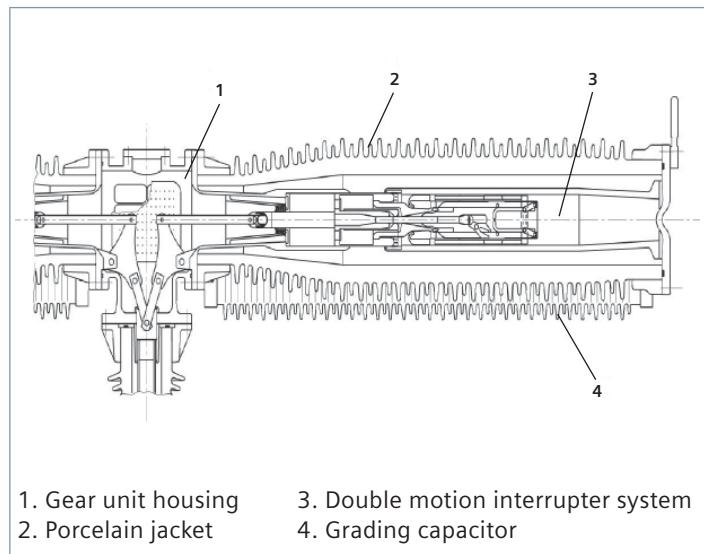
Table 1: Common main ratings of the type 3AP2 platform circuit-breakers rated 550 kV

In every configuration the following identical basic modules as the essential sub-assemblies of a circuit-breaker are used:

- The arc assist self compression interrupter system with insulating nozzle and
- the stored energy spring-spring operating mechanism.

3.1 Interrupter unit

A schematic diagram of the arc assist self compression interrupter system is given in figure 1, its functional principle is shown in figure 2. By the use of this switching principle significantly improvements of the circuit-breaker performance during short-circuit making and breaking and in its capacitive current switching capabilities are obtained. A wide contact gap of the arcing contacts in open position ensures the high dielectric stability. The high speed of the arcing contacts and the design of the interrupter unit carefully improved and optimised by means of various simulation tools have reduced the minimum arcing time, so that all 550 kV circuit-breaker types fulfil the condition for 2 cycles for 50 Hz and for 60 Hz as well according to IEC and IEEE standard rules. Furthermore, due to these measures an excellent capacitive current switching capability for 50 Hz and 60 Hz could be achieved. Some special applications are presented later in this paper.

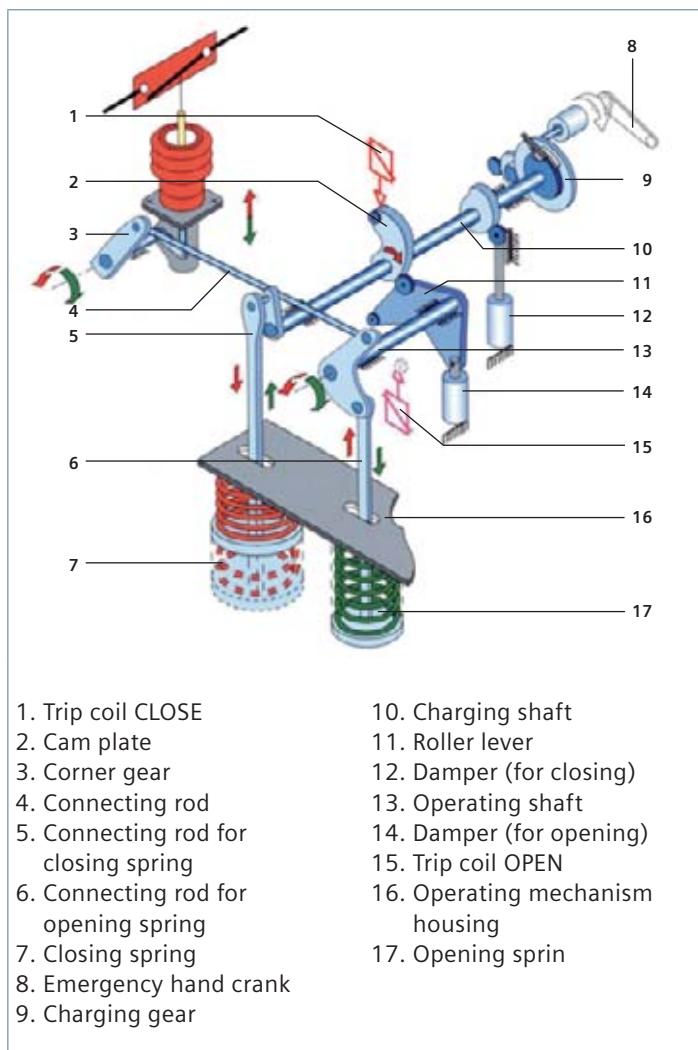


3.2 Operating mechanism

The stored-energy spring-spring operating mechanism (see figure 3) is – with respect to energy, contact speed and moving characteristic – designed for a true 2 cycles break time for 50 and 60 Hz according to IEC and IEEE standards. The operating mechanism is assembled in a compact and corrosion-free aluminium housing. Both, the closing and the opening spring are arranged in the same mechanism housing. The status, charged or not charged, of both springs are visible from outside of the mechanism cabinet. The entire operating system is completely isolated from the SF₆ gas compartments. Anti-friction bearings and a maintenance-free operating mechanism ensure more than two decades of reliable operations. The charging time of the springs is short enough to allow for all normal duty cycles like 0 – 0.3 sec – CO – 3 min – CO or CO – 15 sec – CO. All parts of the cinematic chain are tested for a series of at least 10,000 operations, during the development those test series have been applied repeatedly to make sure that every sample has an appropriate safety margin for its entire operational life.

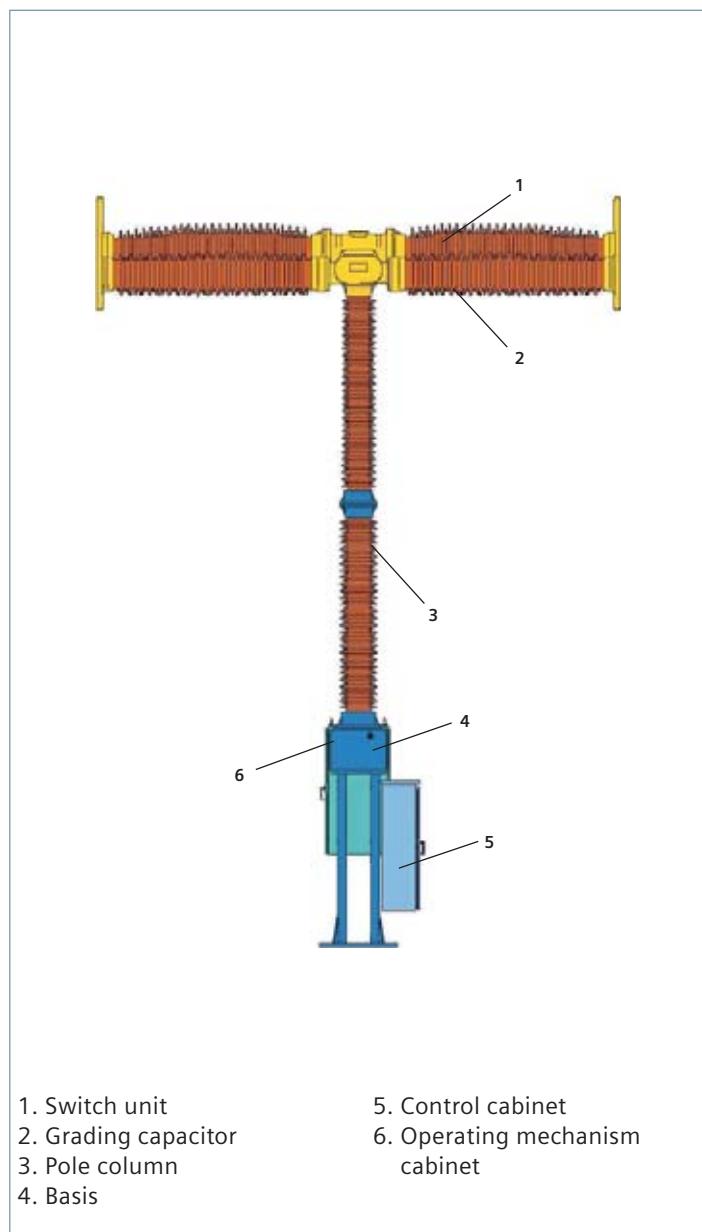
3.3 Live tank circuit-breaker

The live tank circuit-breaker type 3AP2FI – 550 kV is shown in figure 4. It is established with a double interrupter head, based on the interrupter unit presented in 3.1, and the operating mechanism, shown in 3.2, one drive for each pole. Different versions with regard to the clearances of the pole column and the interrupter units are available. By appropriate choice of the insulator lengths every requirement given in the relevant standards for light up to very heavy pollution can be fulfilled. An adaptation can be easily made at a later date if the operational conditions change. Furthermore, by the choice of the insulator lengths the circuit-breaker can be strengthened to cope e.g. with an application on higher altitude or with extreme dielectric requirements. If the user prefers composite insulators, this type of insulators can be used instead of porcelains.



Where closing or pre-insertion resistors are requested, they can be attached to the gear housing on top of the column. The standard value of the resistors is 450Ω per pole; the insertion time is approximately 12 ms, covering the majority of specifications. Other values are available on demand.

For applications at extremely low temperatures a gas mixture of SF₆ and CF₄ can be used instead of pure SF₆. Another option, which can be applied depending on the minimum ambient temperature, is the use of pure SF₆ at reduced gas pressure.



3.4 Dead tank circuit-breaker

The same sub-assemblies are used for the dead tank version of the 550 kV circuit-breaker. The housing of the switch unit is made of cast-aluminium, the compartments are more or less the same as used for the GIS and HIS circuit-breakers (see also 3.5). To cope with non-standard requirements as to pollution level, increased voltage withstand capability or higher service altitudes different bushing lengths can be supplied. Porcelain or composite bushings are available. A large variety of current transformers can be assembled on both sides of the circuit-breaker to meet the specified ratings.

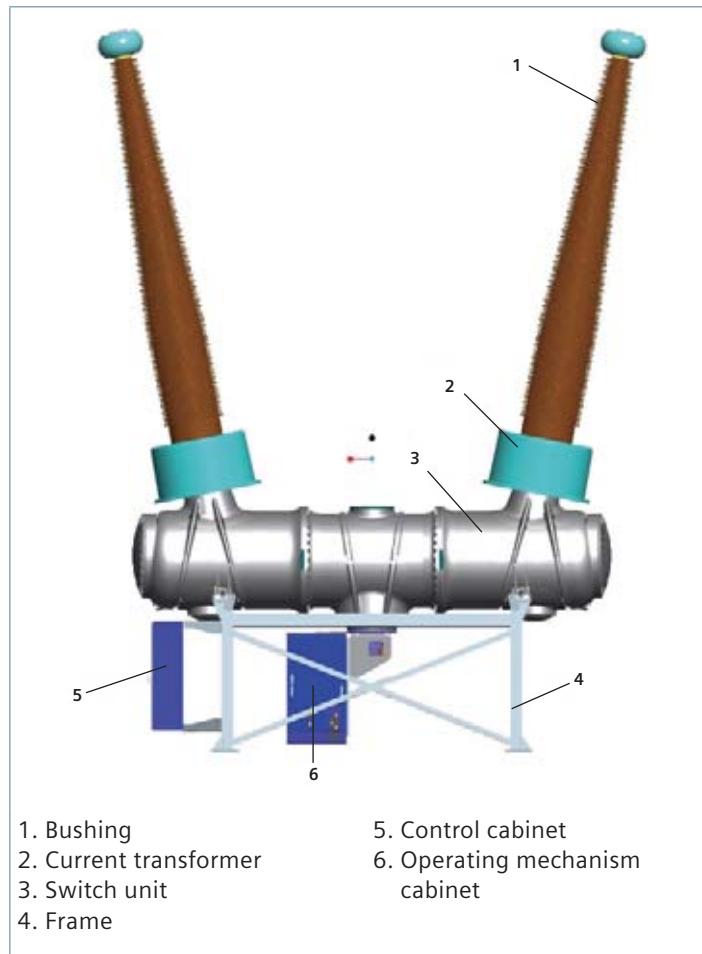


Figure 5: Dead tank circuit-breaker 3AP2FI – 550 kV

For applications at ambient temperature of less than -30°C three different options are available depending on the operational conditions:

- Pure SF₆ at reduced filling pressure
- Mixture of SF₆ and CF₄
- Heating blankets around the switch unit

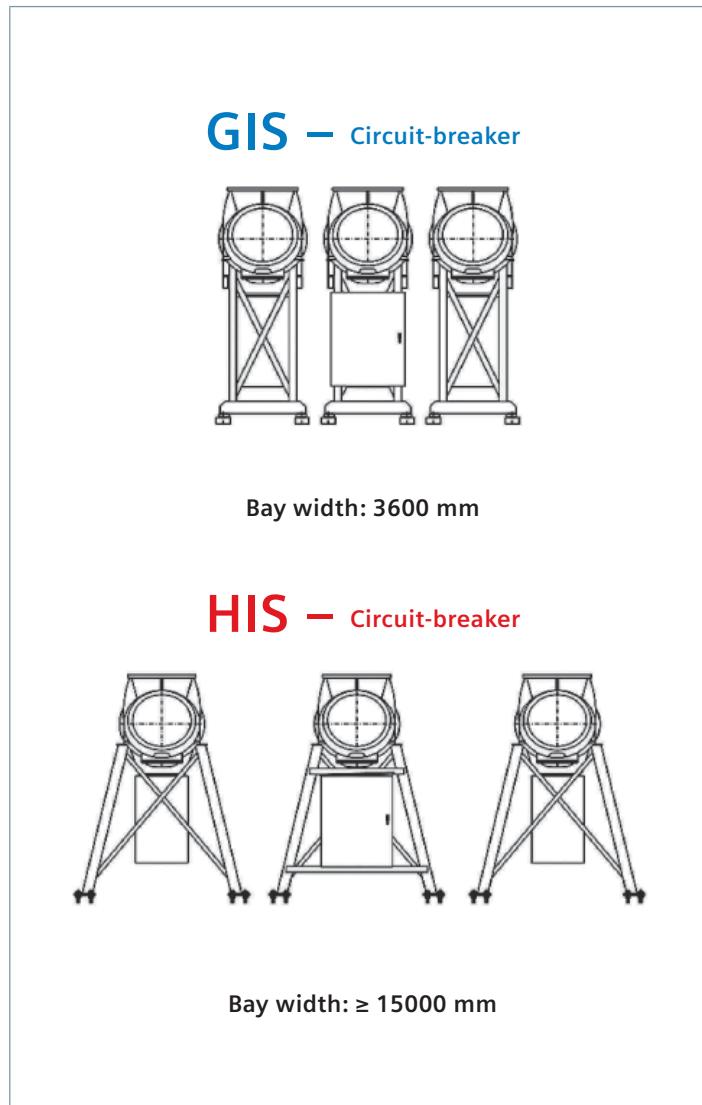


Figure 6: GIS and HIS arrangements

3.5 Circuit-breaker for gis and his

The interrupter unit and the operating mechanism presented in 3.1 and 3.2 respectively are also used in the gas-insulated switchgear 8DQ1 – 550 kV. The 8DQ1 type has a single-phase encapsulated design which keeps dielectric and dynamic stresses to a minimum. The outline is shown in figure 7. The same circuit-breaker is supplied with different frames for indoor application (GIS) and outdoor application (HIS) as shown in figure 6.

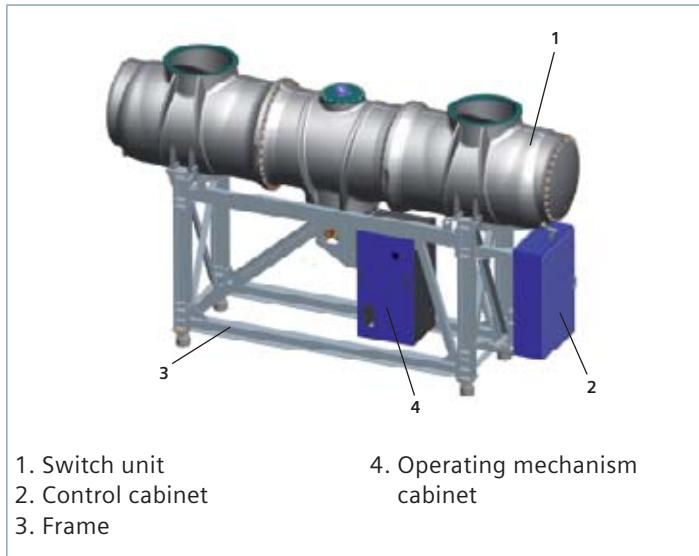


Figure 7: Circuit-breaker for GIS and HIS application

With only 4 different cast-aluminium housing components it is possible to realise all configurations for every GIS, HIS and dead tank design, as shown in figure 8. The conductor connections of the 8DQ1 GIS circuit-breaker can be applied horizontally and vertically. In figure 9 three typical arrangements are shown.

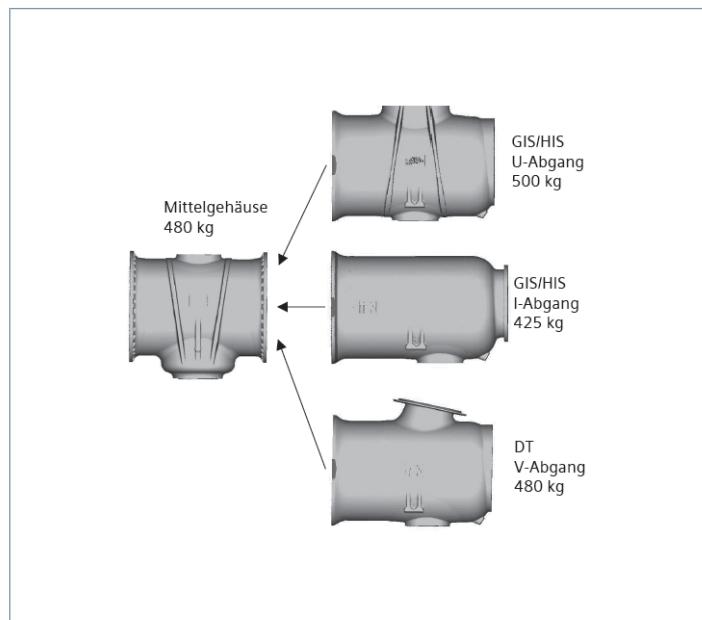


Figure 8: Cast-aluminium housing components for the HIS, GIS and DT versions of the platform circuit-breaker

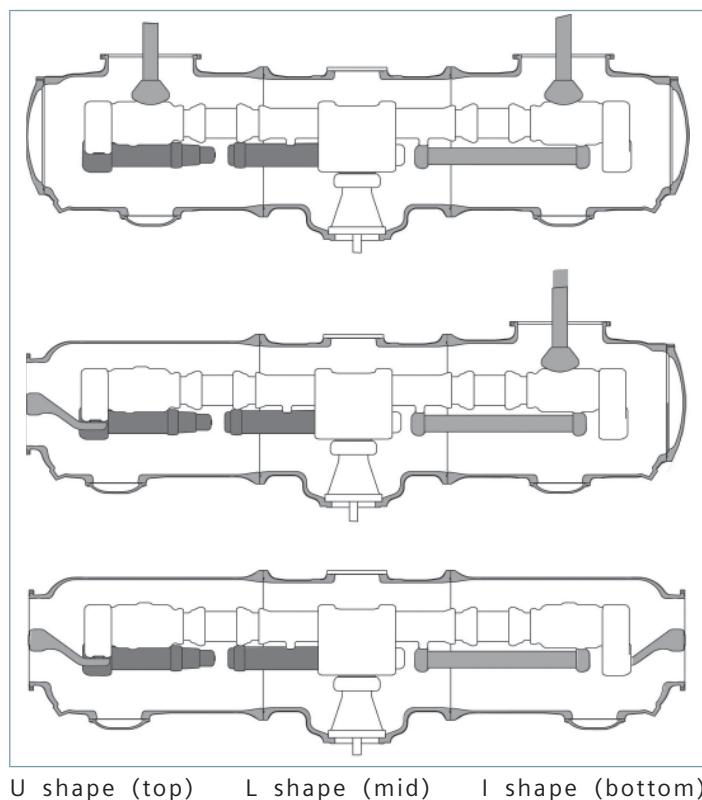


Figure 9: Presentation of typical GIS circuit-breaker arrangements:

4 Type tests

All different versions of circuit-breakers representing the 550 kV circuit-breaker platform have been completely type tested according to the latest editions of IEC 62271-1, IEC 62271-100 and IEC 62271-101 as well as the C37 series of IEEE. Where drafts of updated standards were available, not contradicting present standards, those have been applied as well. In total approximately 150 type test reports are available, each of them issued by a third party laboratory, as there are e. g. CESI, KEMA and PEHLA.

The tests are covering 50 Hz and 60 Hz applications for 63 kA. For short-line faults no additional capacitances are needed. The tests for terminal faults have been carried out for the first-pole-to-clear factor of 1.3 and 1.5, thus, covering also special requirements of some US utilities even for the high voltage ratings. Out-of-phase tests have been performed successfully for voltage factors of 2.0 p. u. and 2.5 p. u. as well.

Capacitive current switching tests cover 50 Hz and 60 Hz applications for line, cable, capacitor banks and back-to-back capacitor bank switching. All types of circuit-breakers of the 550 kV platform are capable of switching capacitive currents in the presence of the voltage factor of 1.4 p. u. Without any exception the tests have been carried out fulfilling the class C2 requirements in accordance with the relevant IEC and IEEE standards.

Although there are no type tests prescribed with regard to the electrical endurance for circuit-breakers of this rated voltage and to the switching capability of small inductive currents, those tests have been carried out, too. The results of the small inductive current switching tests proved the suitability of this circuit-breaker for switching of small inductive currents (e. g. shunt reactors) even where smaller currents than specified in IEC 62271-107 are applied. The switching overvoltages created are distinctly lower than 2.0 p. u. Where the occurrence of harmless re-ignitions is not wanted, the use of the synchronous relay PSD03 is recommended [15]. This relay can also be applied for switching of lines, even compensated lines, or any capacitive load to substitute closing resistors without loosing operational reliability.

The electrical endurance tests have been carried out for the more severe case of 60 Hz related to a short-circuit breaking current of 63 kA according to the present edition of IEC 62271-310. The behaviour of the circuit-breaker during these tests gave prove of the excellent switching, making and breaking capability throughout the entire life time of this circuit-breaker type (class E2).

Each configuration passed the complete dielectric type test to both, IEC and IEEE; to fulfil the IEEE requirements also chopped wave tests have been carried out where needed. As in some places test voltages beyond the standards are specified by some clients, also test evidence for those extreme testing parameters is given. The dielectric tests on the control equipment have been passed as well.

Depending on the operating conditions and the configuration of the circuit-breaker at both 50 Hz and 60 Hz a rated current of 5000 A is available. Where, for example, an ambient temperature as high as 55°C is specified a limitation to 4000 A may be necessary in some rare cases.

The mechanical operating tests provided evidence of the class M2 capability. Type tests have been performed for each configuration. The earth quake withstand capability has been proven by both, tests on the shaking table in the laboratory and by means of computational simulation.

Table 2 gives a summary of the type tests performed on the different versions of the 550 kV platform circuit-breaker.

Power tests for 50/60 Hz

- Terminal faults
- Short-line faults
- Capacitive current switching – line- and cable charging
- Capacitive current switching – back to back
- Short-time withstand and peak withstand current test
- Single-phase shunt reactor current
- Electrical endurance test
- Out-of-phase making test, with max. pre-arc between the contacts of the closing resistor

Dielectric Tests

- Rated power-frequency voltage test
- Rated lightning impulse withstand voltage test
- Lightning impulse voltage against power frequency voltage
- Rated switching impulse withstand voltage tests
- Switching impulse voltage against power-frequency voltage
- Chopped wave lightning impulse withstand voltage
- Dielectric tests on auxiliary and control circuits
- Electromagnetic compatibility on secondary systems

Mechanical tests for 50/60 Hz

- Mechanical life test – 10.000 operations
- Temperature rise test – 4000/5000 A
- Temperature rise test on auxiliary and control circuits
- Low and high temperature test -30°C to 55°C
- Degree of protection IP55 for operating mechanism and control cabinet
- Sound pressure level measurement

Table 2: Conclusion of the main type tests
(according to IEC and IEEE standards)

5 Features beyond or in addition to the type tests

As part of development or acceptance tests some features beyond the relevant standards or in addition to them have been tested on either circuit-breaker configuration. The results of these tests give an idea of the margins incorporated in the presented circuit-breaker design.

Following a regional standard capacitive current switching tests at a frequency of 66 Hz and for a capacitive voltage factor of 1.4 p.u. have been tested successfully. The conditions of class C2 have been fulfilled.

To check the capability to cope with short-circuit breaking currents higher than 63 kA terminal and short-line fault tests at 80 kA have been carried out with good results. For 90 % short-line fault at 60 Hz an additional capacitance in the range of 15 nF was used on the line side.

For special applications, e. g. in filter bank circuits of HVDC systems, capacitive voltage factors higher than 1.4 p.u. are requested. Therefore, a capacitive current switching test using a voltage factor of 1.64 p.u. has been carried out at a power frequency of 50 Hz. No restrike occurred during the test, the interrupter unit was found in proper conditions after the test. A series of fundamental tests has supported that the circuit-breaker can be used without grading capacitors at least for rated voltages of 420 kV and below. A complete type test program will be carried out in the near future to cover such applications.

6 Summary

The new circuit-breaker platform for 550 kV includes live tank and dead tank circuit-breakers for air-insulated outdoor switchgear and circuit-breakers for gas-insulated switchgear and highly integrated switchgear. Long time experience with the state of the art arc assist self compression interrupter system and stored-energy spring operating mechanism are incorporated in the design of this circuit-breaker platform.

The platform concept for 550 kV using the same modules and assembly groups from a common kit provides several benefits for the manufacturer as well as for the user.

The manufacturer can focus his development work on a single subject, the product platform. More efficient manufacturing processes can be utilised, resulting in reduced effort for the production and harmonised assembly procedures. This leads to optimised and stable processes and at the end to an increased product quality. The operational experiences gained during service are basically applicable for all platform products.

As the number of different spare parts is reduced due to the more or less identical design of the different products, the delivery time of spare parts is shorter and spare part management is easier resulting in lower life-cycle costs.

The platform for 550 kV was proven to meet the requirements of IEC and IEEE and even beyond these standards. The wide experiences from development and type tests with the excellent results are a basis for further developments for higher voltage levels and power ratings.

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Siemens High-Voltage Circuit-Breakers for Use at Low Temperatures

High-voltage circuit-breakers are a key component in electrical transmission networks. Apart from the pure switching function, the circuit-breakers provide a protective function in the transfer of electrical energy by preventing unnecessary loads in the event of breakdowns caused by short-circuit currents and thus ensuring the networks operate safely.

Siemens high-voltage circuit-breakers are in use all over the world, not least in extreme environmental conditions. In some cases, they are used in ambient temperatures that drop to -60°C. Standard circuit-breakers have been designed for use in temperature areas ranging from -30 to +55°C. By providing technical options for extended temperature ranges, Siemens has the perfect solution for every application. The following report features these solutions taking the various design forms into consideration.

Siemens high-voltage circuit-breakers are single-pressure apparatuses. The devices currently supplied are usually equipped with an arc supported self-compression interrupter unit and a spring drive mechanism. Pure SF₆ gas or SF₆ gas mixtures are used as arc-quenching and insulating media. The switching capacity and insulation performance depend on the density of the gas or gas mixture, with a falling gas density reducing both the switching capacity and insulation performance. For standard version Siemens high-voltage circuit-breakers, there is a minimum operating temperature of -30°C corresponding with the minimum gas density required for operation.

1. Designs for Low-Temperature Circuit-Breakers

1.1 Usage of Pure SF₆

If the ambient temperature drops for a circuit-breaker with a specified nominal operating pressure, the pressure will reduce, as depicted in Figure 1, initially along a line of constant density, i.e. the performance of the circuit-breaker remains unchanged. The gas will partially liquefy only once the liquefying limit is reached and the density will reduce. The switching capacity and the insulation properties reduce when the gas density drops. The minimum operating temperature specified for pure SF₆ and the associated filling and lockout pressures are listed in Table 1.

Here, there are three variants available:

- Minimum operating temperature of -30°C:
Standard design with full performance data.
- Minimum operating temperature of -35°C or -40°C:
The circuit-breaker is filled with the standard gas density and has a density monitor with "knee-point characteristic". Full performance data are reached at temperatures down to -30°C. In the range between the lower limit temperature for the standard-design circuit-breaker (-30°C) and the reduced minimum operating temperature (-35°C or -40°C), a minimum reduction in performance due to the fractional liquefaction of SF₆ is accepted.
- Minimum operating temperature of -40°C:
With this variant the circuit-breaker in the standard design is filled with reduced density appropriate for the minimum operating temperature without gas liquefaction. Due to the reduced density the insulation properties and the switching capability are limited due to the reduced filling density.

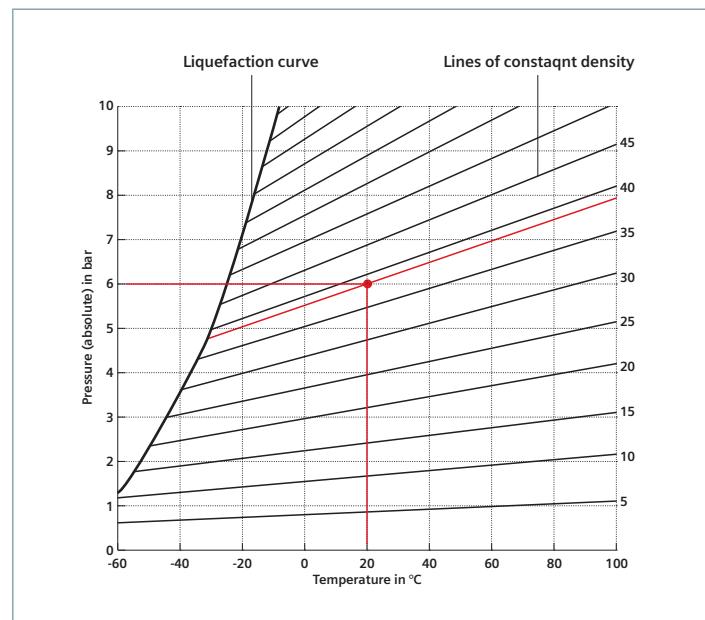


Figure 1: Vapour pressure curve and lines of constant density for pure SF₆

Minimum operating temperature [°C]	SF ₆ – Rated filling pressure, absolute value at 20 °C [bar]	SF ₆ function lockout pressure, absolute value at 20 °C [bar]
-30	7,0	6,0
-35/-40 ¹	7,0	6,0
-40	5,5	4,5

1) Using a density monitor with a knee-point characteristic

Table 1: Values of minimum operating temperatures and pressures when using pure SF₆

1.2 Usage of Tank Heaters

If a reduction of the circuit-breaker's performance is to be avoided when using pure SF₆ at a reduced minimum operating temperature, a tank heater can be used to counteract a reduction of the gas density caused by the liquefaction of SF₆. When the surface of the circuit-breaker is covered by an external insulation, the heating power required can be considerably reduced. The use of tank heaters and additional insulation is only common with dead-tank circuit-breakers and dead-tank compact circuit-breakers (hybrid circuit-breakers). Figure 2 shows a dead-tank circuit-breaker rated 245 kV with tank heaters, whereas in figure 3 a 550 kV circuit-breaker is shown using both, tank heaters and insulation.

Normally, in the case of dead-tank circuit-breakers the tank and the installed bushings form a common gas compartment. This means the heat from the gas compartment can dissipate via the surfaces of the porcelain or composite bushings. The tank heater power must be increased to compensate for this heat dissipation. Another negative effect on the switching capacity and insulation performance is caused by the fact that the gas in the bushings is colder than in the circuit-breaker tank thus reducing the gas density in the interrupter unit at the same pressure in the common circuit-breaker volume.

This can be prevented by using foam-filled bushings. With this make of bushings, the volume of the installed insulator is not filled with gas but with polyurethane foam expanded with SF₆. A cast resin bushing is used for the separation to the gas compartment. Apart from the thermal insulation effect, the SF₆ volume is reduced too. Compared to a separated gas bushing, there is the benefit that a reduced volume of gas and fewer tanks must be monitored. The effect explained above of the "displacement" of the gas density into the bushings is eliminated by the use of these foam-filled bushings.

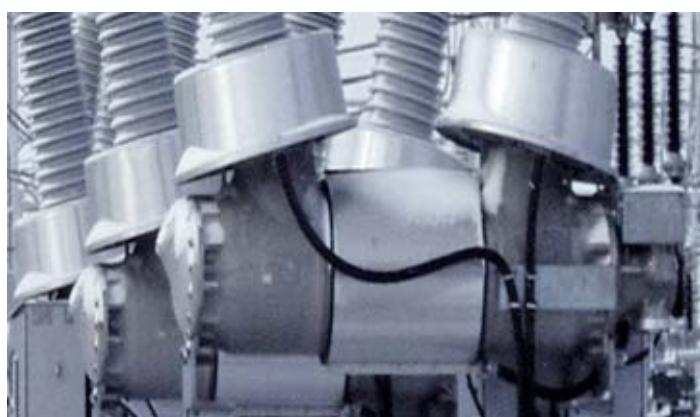


Figure 2: Use of a tank heater on a dead-tank circuit-breaker,
type 3AP1DT - 245 kV



Figure 3: Use of tank heaters and insulation on a dead-tank breaker,
type 3AP2DT - 550 kV

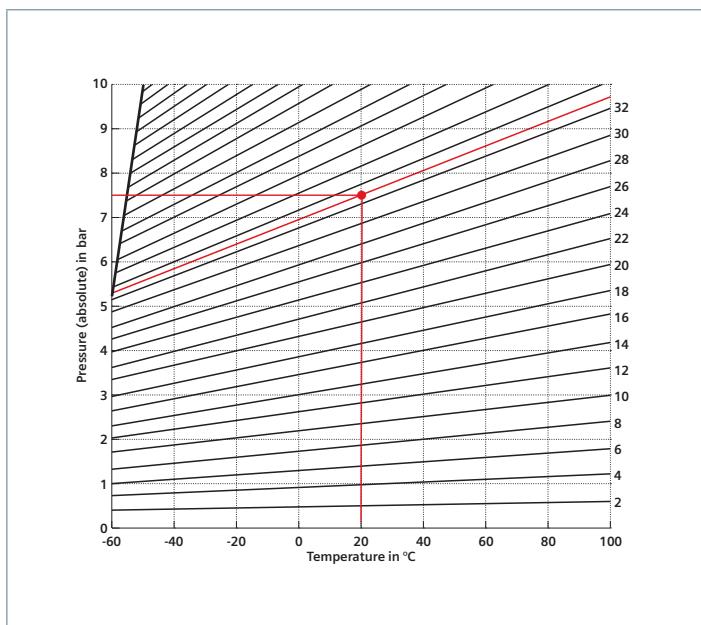
1.3 Use of Gas Mixtures Containing SF₆ with N₂ or CF₄

Adding N₂ or CF₄ can lower the minimum operating temperature down to -60 °C. Both gases liquefy at considerably lower temperatures and are thus gaseous at all ambient temperatures relevant to the circuit-breaker. When using SF₆ gas mixtures containing N₂ or CF₄, the SF₆ fraction only liquefies if the partial pressure of the SF₆ reaches the liquefaction limit. The lower the partial pressure of the SF₆, the lower is the minimum operating temperature of the circuit-breaker at the same filling pressure.

It is not necessary to heat the gas compartment when using gas mixtures even at low temperatures. Figure 4 shows the temperature behaviour of an SF₆/CF₄ gas mixture. Table 2 specifies the minimum operating temperatures and partial pressures for the gas ratios of mixed gas circuit-breakers. Irrespective of the type of mixed gas and minimum operating temperature, mixed-gas circuit-breakers are operated at a rated filling pressure of 8.5 bar or a lockout pressure of 7.5 bar (both absolute values).

Minimum operating temperature [°C]	SF_6		CF_4 or N_2	
	Ratio [%]	Partial pressure with rated filling pressure, absolute value at 20°C [bar]	Ratio [%]	Partial pressure with rated filling pressure, absolute value at 20°C [bar]
-40	60	5,1	40	3,4
-45	51	4,3	49	4,2
-50	43	3,7	57	4,8
-55	35	3,0	65	5,5
-60	25	2,1	75	6,4

Table 2: Composition of gas mixture for various minimum operating temperatures

Figure 4: Vapour pressure curve and lines of constant density for a SF_6/CF_4 mixture Example for a mixture ratio of 75% CF_4 and 25% SF_6

1.4 Gas Density Monitoring

The density of the SF_6 gas or SF_6 gas mixture in the circuit-breaker is monitored by a density monitor. The density monitor used in Siemens high-voltage circuit-breakers works using a reference volume surrounded by a bellows system as a differential pressure sensor. The density monitor with its reference volume is exposed to the same atmospheric conditions as the circuit-breaker. This ensures that the pressure sensor works without being dependent on the temperature. For this reason, the density monitor only reacts to a leak in the circuit-breaker compartment and not to the ambient temperature dropping below a specific value. The SF_6 or the SF_6 gas mixture in the density monitor's reference volume always corresponds to the gas composition in the circuit-breaker. The reference volume is filled with a density corresponding to the "Loss of SF_6 " warning level. When reaching this level the functionality of the circuit-breaker is not restricted. Only when the density caused by falling temperature is dropping further, thus liquefying more SF_6 , and the residual density in the breaker drops below the density value corresponding to the "General lockout" level, the performance of the circuit-breaker will drop impermissibly. Figure 5 illustrates the principle and the individual operating conditions of the density monitors and Figure 6 shows the operating values.

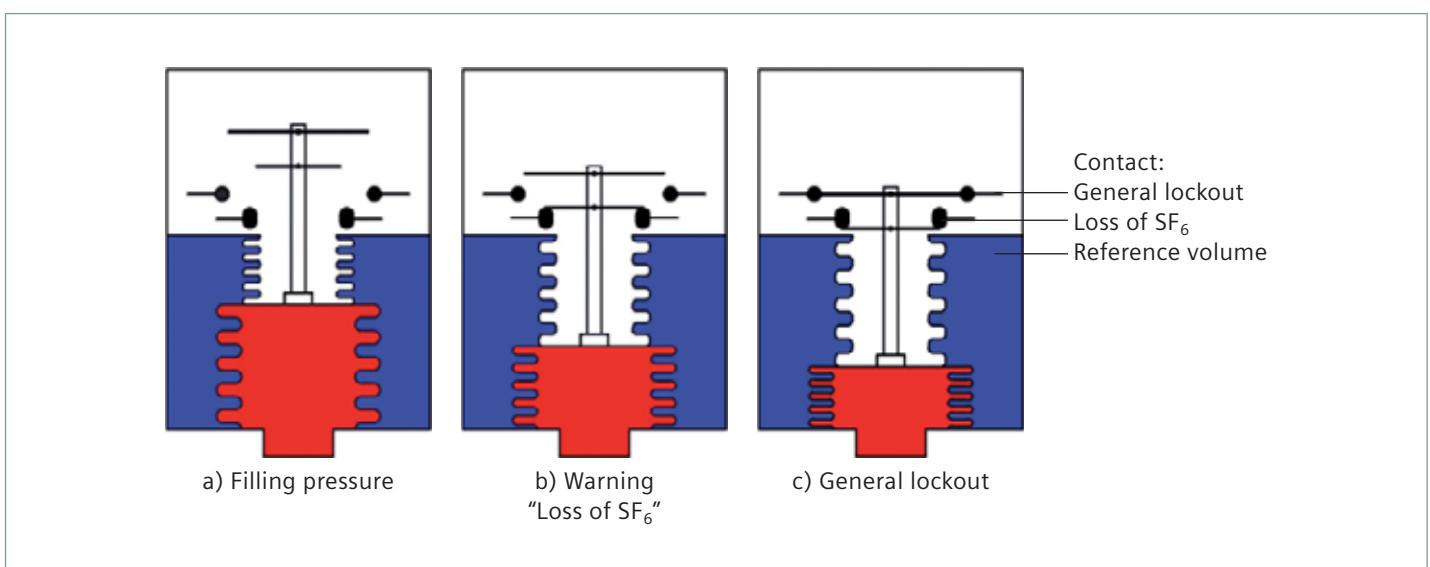
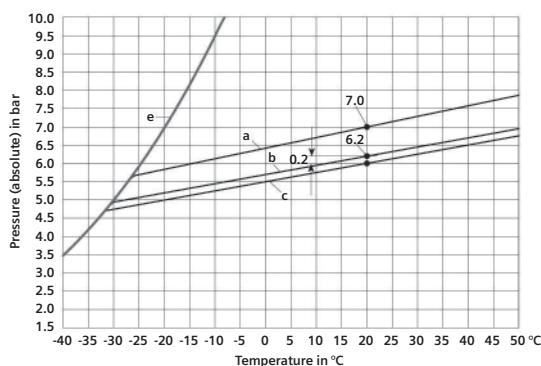


Figure 5: Operating conditions for the density monitor

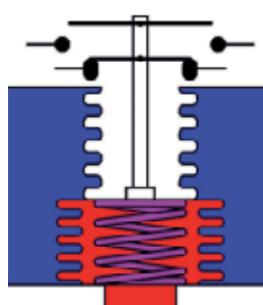


- a) SF₆ rated filling pressure,
- b) pressure for "Loss of SF₆" signal,
- c) pressure for general lockout SF₆,
- e) Liquefaction curve

Figure 6: Operating values for a density monitor,
example for a minimum operating temperature of -30°C

1.5 Density Monitor with "knee-point characteristic"

If the circuit-breaker should operate at full capacity down to the standard minimum operating temperature of -30°C and be used at an ambient temperature down to -40°C, a minimal reduction in the performance data and a partial liquefaction of the SF₆ is permissible. This particular type of density monitor functions correctly even in this application case. This assumes a differential pressure between the circuit-breaker and the reference volume even when liquefaction has already occurred. The reference volume of the density monitor is filled with a higher density than the density value for the loss of SF₆ signal. A compensation spring on the circuit-breaker side counteracts the greater force from the reference volume on the bellows system. Figure 7 shows the density monitor with "knee-point characteristic"

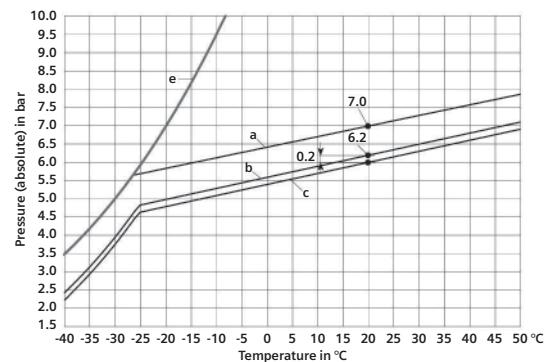


Operating state
"Loss of SF₆" warning

Figure 7: Density monitor with compensation spring for application
with "knee-point characteristic"

Thanks to this design, the reference volume density line for the temperature range, in which liquefaction also occurs in the circuit-breaker, is below the reference line of the circuit-breaker volume to be monitored. The arrangement of the density monitor contacts and the filling of the circuit-breaker are subject to the same rules as for a standard density monitor, Figure 8.

The advantage of this technical solution compared to a circuit-breaker with reduced filling pressure is that the circuit-breaker retains its full switching capacity and insulation properties down to temperatures where gas liquefaction occurs. Only when the temperature falls below this reference temperature, the switching and insulation capacity does reduce with falling temperature. If this behaviour is compared with that of a circuit-breaker with reduced filling pressure appropriate to the minimum operating temperature, the latter will constantly exhibit the minimum performance of a circuit-breaker with the density monitor with the knee point characteristic curve. As temperatures of below -30°C only occur for short periods of time even in the cold climate regions, this projected across the whole year, such that the circuit-breaker's high level of performance is retained for the majority of the year thanks to the use of this special density monitor and only a minimal reduction of the performance must possibly be tolerated for a few cold nighttimes hours. This can increase the operating safety of the circuit-breaker considerably.



- a) SF₆ rated filling pressure,
- b) pressure for "Loss of SF₆" signal,
- c) pressure for general lockout SF₆,
- e) Liquefaction curve

Figure 8: Operating values for a density monitor
with "knee-point characteristic"

1.6 Gas Mixtures – Handling and their Behaviour

There are four different established processes for filling mixed-gas circuit-breakers:

- The gas mixture is obtained as a finished product from the manufacturer and is used to fill the circuit-breaker unit. The pressure of the gas mixture in the gas containers must be specified such that a partial liquefaction of the SF₆ does not occur due to the temperature dropping during the complete handling process including the transport and filling procedure. The liquefaction could even lead to partial separation and thus the falsification of the mixture ratio (reduction of the SF₆ component); this would lead to a reduction in the circuit breaker's performance.
- The circuit-breaker can be filled sequentially from separate gas containers, each of which contains a component of the gas mixture. During this process, the SF₆ is poured in with the corresponding partial pressure. The other gas component is then added, N₂ or CF₄, until the specified filling pressure is reached. The accuracy of this filling method is dependant on the precision of the record of the temperature of the gas being added. In order to mix the different gas components no-load switching operations are carried out. In addition, diffusion and thermal processes create the final mixture; usually the mixture is sufficiently mixed after approximately 24 hours. Experience has proven that the mixture remains adequately mixed even if the circuit-breaker is not activated for longer periods of time. The SF₆ concentration is measured by an SF₆ ratio measuring instrument. It is advisable to check the mixture ratios several days after being filled to prevent the circuit-breaker performance being impaired.
- In commercially available mixing equipment, the flow rate for the gas components is controlled during the filling process, such that the final gas mixture for the circuit-breaker satisfies the target density relation (see also Table 2). This filling process is very accurate; control measurements are not necessary.
- Another method is to fill the gas components in the required ratios into the circuit-breaker using weighing machines. Subsequent control measurements are not necessary if precise scales are used, however their usage under extreme site conditions could be problematic. Similar to the method given under b), this filling method also achieves an adequately mixed gas mixture with the help of no-load switching operations and by waiting 24 hours.

In the event of a gas leakage while the circuit-breaker is in operation, the mixture ratio of the gases remaining in the circuit-breaker may change as particularly small points of leakage can vary in terms of permeability for the gases in the mixture. In this instance, the composition of the mixed gas can also be measured by an SF₆ ratio measuring instrument; during the topping up process, the individual components can be added as required.

2. SF₆ and SF₆ Gas Mixtures as Insulating and Arc-Quenching Media

For SF₆ circuit-breakers, the switching capacity and insulation performance are dependent on the density of the gas contents as well as the quality of the gas used (pure SF₆ or mixed gas). If the density drops or the pressure drops while the temperature remains constant, the performance of a monitored circuit-breaker reduces, this applies irrespective of the design of the unit. Similarly, the performance reduces in mixed-gas breakers should the SF₆ ratio drop while the temperature and overall pressure remain constant. To reduce this negative impact on the performance of mixed-gas circuit-breakers, these are frequently supplied with a higher rated filling pressure than a corresponding circuit-breaker with pure SF₆.

2.1 SF₆ and SF₆ Gas Mixtures as Insulating Media

Verification tests for the dielectric strength specified in relevant national and international standards are carried out in the form of type tests for every circuit-breaker variant at the respective general lockout pressure. Using pure SF₆ reduces the dielectric strength of a breaker for a minimum operating temperature of -40°C (the absolute value of the filling pressure at 20°C is 5.5 bar) by 15 to 20 % compared to a standard-design circuit-breaker for -30°C.

However, if a mixed-gas circuit-breaker is considered for a minimum operating temperature of -50°C with an SF₆ ratio of 43 % and an absolute filling pressure value of 8.5 bar at 20°C, a reduction of 5 % to 15 % can be expected; compared to a standard circuit-breaker with pure SF₆ for a minimum operating temperature of -30°C. The reduction amount depends on the voltage rating regarded, the geometry of the insulating section and the gas used for the mixture, N₂ or CF₄.

2.2 SF₆ and SF₆ Gas Mixtures as Arc Quenching Media

For the arc-quenching and switching capacity of circuit-breakers, there is a differentiation made between the thermal and dielectric arc-quenching capacity. Both aspects deteriorate in the event of falling gas density, this applies to both, the short-circuit switching capacity and the capacitive current switching capability. Compared to a circuit-breaker for a minimum operating temperature of -30°C, the switching capacity of a -40°C circuit-breaker drops equivalent to a rating level of the rated short-circuit current in accordance with IEC. The characteristics become more beneficial only when switching small inductive currents while the gas density drops.

When compared to standard circuit-breakers for a minimum operating temperature of -30°C, there is also a reduction in arc-quenching and switching capacity for low-temperature circuit-breakers filled with mixed-gas. When using N₂ as the second gas component in a mixed-gas circuit-breaker for a minimum operating temperature of -50°C, there is a reduction of approximately one rating level of the rated short-circuit current in accordance with IEC; if, however, CF₄ is used the drop can be anticipated as only being maximum 0.5 of a current level. If the full short-circuit current levels are to be retained, the rated voltage level must be reduced by one rating level according to IEC.

Just like standard circuit-breakers filled with pure SF₆, low-temperature circuit-breakers undergo short-circuit and load-current tests to determine the switching capacity. As the switching capacity and insulation performance depend on the density of the gas/gas mixture used and not on their pressure or ambient temperature, only the gas density is of importance for the dielectric tests and switching capacity tests. This is why these tests can be carried out without distorted test results for the ambient temperatures prevailing in the test laboratories, as long as the filling density is set in accordance with Figure 1 or the layout of the circuit-breaker is set up as shown in Figure 4 for example. It is only due to these interrelations that low-temperature circuit-breakers can be tested for the complete range of their application temperatures in switching capacity and dielectric test laboratories at ambient temperatures, as there is not a test laboratory in the world where high-voltage and extra-high-voltage breakers can be loaded with the necessary electrical test values at lowered temperatures.

3. Design of low temperature circuit-breakers

3.1 Auxiliary heaters for the operating mechanism and the control components

The spring drive mechanism and control components are housed in a cubicle. Each cubicle contains a condensation heater and ventilation system. The condensation heater is constantly active to stimulate ventilation. For ambient temperatures of -40°C and lower, an auxiliary heater is connected, which is controlled via thermostat. This prevents a higher degree of liquid viscosity in the dampers of the spring drive mechanism.

3.2 Special materials

Steels that do not embrittle at low temperatures are used for the circuit-breakers' support structure, e.g. circuit-breaker frame, circuit-breaker base and pillars. Notched bar impact work is at least 27 J.

Gaskets made of rubber materials that retain sufficient elasticity at low temperatures are used to seal the gas compartment and in the corner gear. All bearings in the spring drive mechanism, the kinematic chain and the corner gear are lubricated with grease that can be used in temperatures ranging from -60 to 130°C. The interrupter unit is identical to the one used in the standard design.

4. Type tests

All low-temperature circuit-breakers undergo a complete type test, just the same as every other Siemens high-voltage circuit-breaker. This type test comprises dielectric tests specified in the relevant standard, short-circuit current breaking tests and load-current switching tests. Mechanical life cycle tests for the classes M1 or M2 in accordance with IEC are carried out as required. A focal point of the testing is the so-called climate test, in which the mechanical switching behaviour is checked in temperature cycles at both the lowest and highest operating temperature. An important criterion during this test is the circuit-breaker's gas leak tightness at the limit temperatures. In addition, a record of the orderly function of the gas monitoring and heating systems must be kept. Finally, it must be shown that the circuit-breaker under test retains its functionality even in the event of the heaters being used failing for two hours. The circuit-breakers for various temperature levels and with various gas contents of SF₆ or SF₆ gas mixtures undergo these type tests. Figure 9 shows a dead-tank compact circuit-breaker during a climate test.

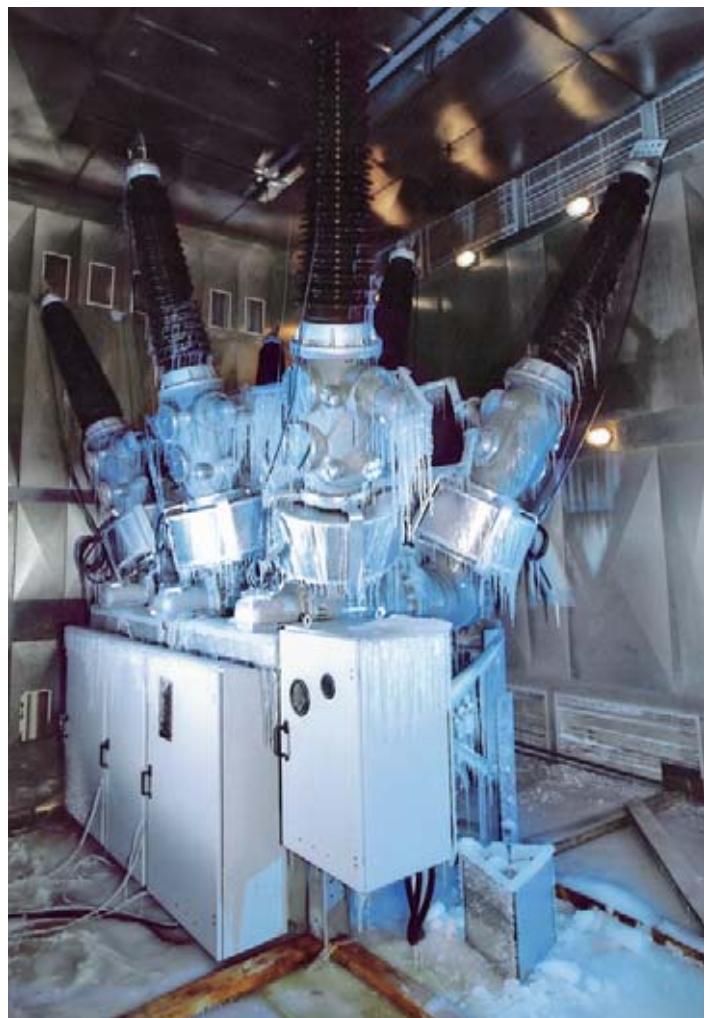


Figure 9: Type test in a climate chamber for a dead-tank compact circuit-breaker DTC - 145 kV

5. Target markets

Many utilities cover a diversity of temperature zones with the regions they supply. This is why many customers require not only standard circuit-breakers for minimum operating temperatures of -30°C but also low-temperature circuit-breakers for the temperature range down to -60°C (e.g. in Siberia). When selecting the temperature level required, reference is made to the long-term temperature records kept by climate and meteorological services.

Target markets include all regions with low temperatures such as:

- Scandinavia: -40°C, pure SF₆ or SF₆/N₂ mixed gas preferred
- Russia: -45 to -60°C
- China: -40°C
- Kazakhstan: -52°C
- USA, Canada: -40 to -50°C

6. Solutions from Siemens

Siemens supplies the following solutions for using high-voltage circuit-breakers in regions with low temperatures:

- Live-tank circuit-breakers of 3AP series from 72.5 to 800 kV:
 - For -40°C with pure SF₆ and lowered pressure or alternatively with pure SF₆ at standard filling pressure and density monitor with "knee-point characteristic" or alternatively with mixed gas
 - Down to -60°C with an SF₆/CF₄ mixed gas
- Dead-tank circuit-breakers of 3AP series from 72.5 to 550 kV:
 - For -40 °C with pure SF₆ and lowered pressure or alternatively at standard filling pressure with tank heater and additional insulation or alternatively with pure SF₆ at standard filling pressure and density monitor with "knee-point characteristic"
 - Down to -60 °C with an SF₆/CF₄ mixed gas or alternatively with pure SF₆ at standard filling pressure with tank heater
- Dead-tank compact circuit-breakers of 3AP1DTC series, 72.5 to 245 kV
 - For -40°C with pure SF₆ and lowered pressure or alternatively with pure SF₆ at standard filling pressure and density monitor with "knee-point characteristic"
 - Down to -60°C with a SF₆/CF₄ mixed gas.

7. Summary

High-voltage circuit-breakers from Siemens for the complete voltage range from 72.5 to 800 kV are mainly supplied with the state-of-the-art arc-supported self-compression quenching system and spring drive mechanisms. Siemens has been supplying circuit-breakers with this technology since 1996 and there are now 50.000 such circuit-breakers in operation across the world. The standard range has been expanded to include the low-temperature circuit-breaker to exploit the advantages of this technology in regions of the world with ambient temperatures as low as -60°C. The circuit-breaker comprises approved and tested components that have been enhanced with other sealing materials, lubricant, additional heaters and, if required, by the use of gas mixtures. This means there is a perfect solution for every application.

Thomas Chyla

3AP4/5 High-Voltage Circuit-Breaker for 800 kV

Transmission of electrical energy at the highest voltages is constantly gaining in importance across the globe.

The technical demands on high-voltage circuit-breakers have continued to increase in recent years. A high level of reliability under extreme climatic conditions and during earthquakes are essential prerequisites, as well as the ability to cope with high voltage loads, high breaking currents and fast break times.

By completing the development of the 3AP4/5 800 kV circuit-breaker, Siemens's product range includes the 3AP series with self-compression system and spring drive mechanisms for a voltage range of 72.5 kV to 800 kV and a short-circuit breaking current of up to 63 kA. Figure 1 shows the circuit-breaker at the Siemens high-voltage testing facility. The product range for the live tank breaker is shown in Figure 2.



Figure 1: Breaker pole on the new 800 kV outdoor circuit-breaker

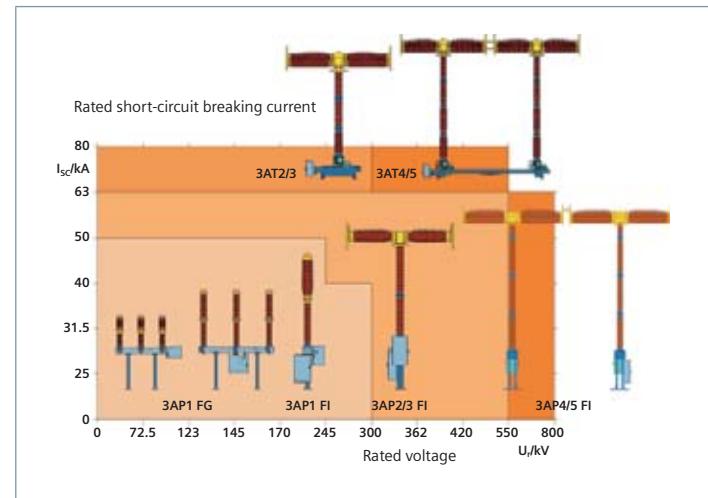


Figure 2: 3AP circuit-breaker product range

The New 800 kV Circuit-Breaker

The 800 kV high-voltage circuit-breaker is an extension of the modular system of the 3AP2/3 420 kV and 550 kV live tank breakers with two interrupter units, closing resistors and spring drive mechanisms. [1]

The existing pole column of the 550 kV circuit-breaker was extended to the required flashover distance using an additional insulator porcelain, the base was enhanced due to higher degrees of force and the creepage path requirements of 31 mm/kV are met in accordance with the latest standard. An overview of the technical data is shown in the table in Figure 4.

The durability of the elastic power connection (see Figure 3) between the two double break assemblies was verified in accordance with IEEE and Transselec standards via 10,000 mechanical operating cycles, a surge current test and during an earthquake test on the 3AP3 550 kV circuit-breaker with closing resistors.

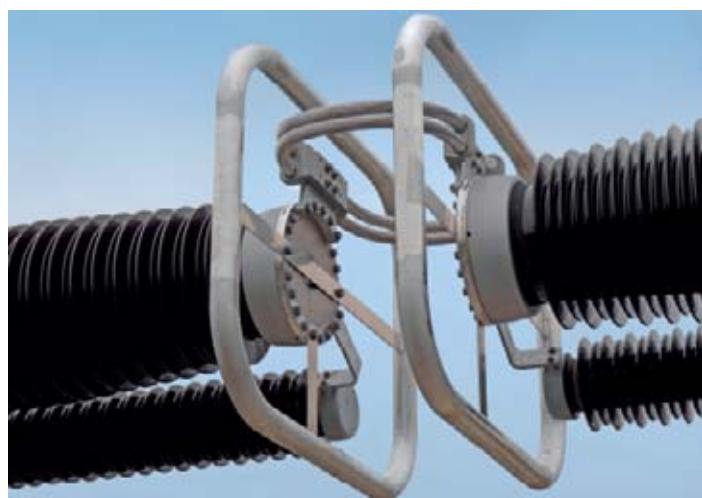


Figure 3: Elastic power connection between the two double break assemblies

Technical Data 3AP4/5 FI

Rated voltage	800 kV
Rated lightning impulse withstand voltage	2100 kV
Rated switching impulse withstand voltage	1425 kV
Rated power frequency withstand voltage	830 kV
Rated normal current	4000 A/500 A
Rated short circuit current	63 kA
Rated frequency	50 Hz
Break time	2-cycle
First-pole-to-clear factor	1.5
Ambient temperature range	-30 °C ... +55 °C
Standard	IEC/ANSI

Figure 4: Technical Data

Functional Components

The layout of an 800 kV circuit-breaker pole is shown in Figure 5. The interrupter units with the self-compression system with support for arc power – which has been tried and tested for many years – have been designed in accordance with the highest technical specifications. Switching a short-circuit current from 63 kA with a pole factor of 1.5 can be guaranteed in the same way as capacitive switching with a voltage factor of 1.4 p.u. All Siemens 3AP hi0gh-voltage circuit-breakers from 72.5 kV to 800 kV have the same switching principle with self-compression system and spring drive mechanism [2, 3]. The switching principle is shown in Figure 6.

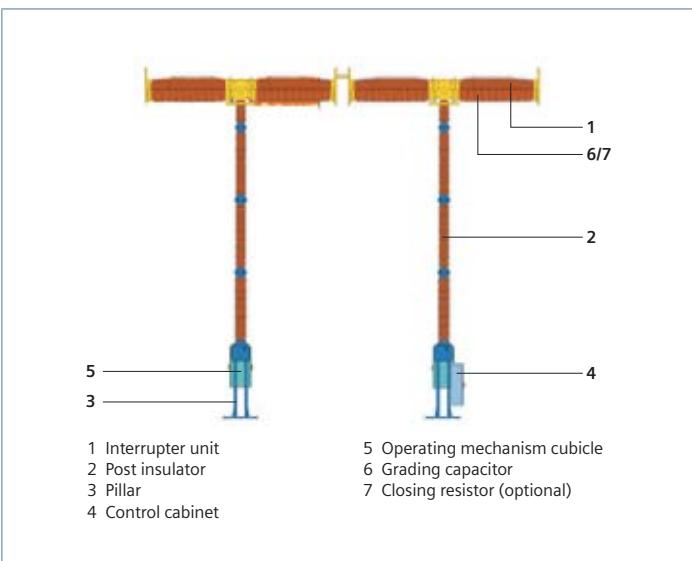


Figure 5: Layout of a pole for the 800 kV circuit-breaker with four contact gabs

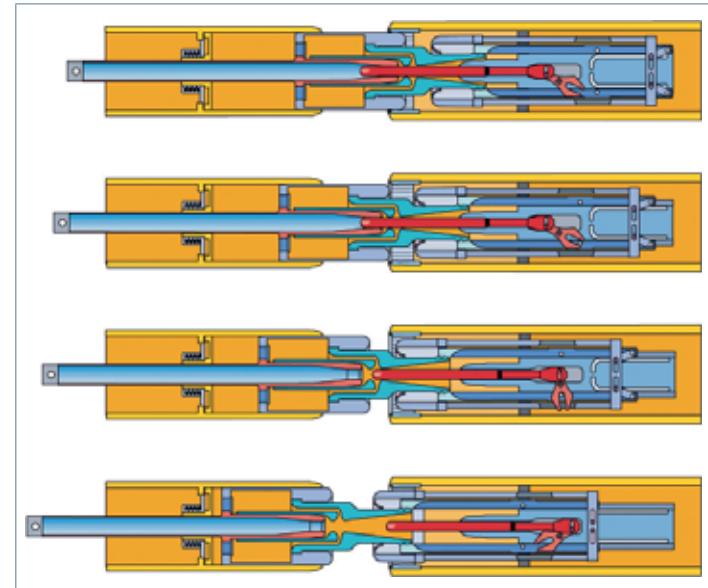


Figure 6: Switching principle of the interrupter unit with self-compressions system

The self-compression system requires a low level of operating energy. The resulting lower forces on the kinematic chain allow the 800 kV high-voltage circuit-breaker to have a light construction. Over 70,000 spring drive mechanisms are used worldwide and work according to the same operating principle as that shown in Figure 7. On 800 kV high-voltage circuit-breakers, each column of one phase has a spring drive mechanism. Using a simple controller that has been proven successful over several years, the spring drive mechanisms of a phase are coupled together electrically. The controller and the spring drive mechanisms are designed in such a way that switching a phase within two periods can be guaranteed. Each column of a phase has its own gas compartment monitoring with density monitor.

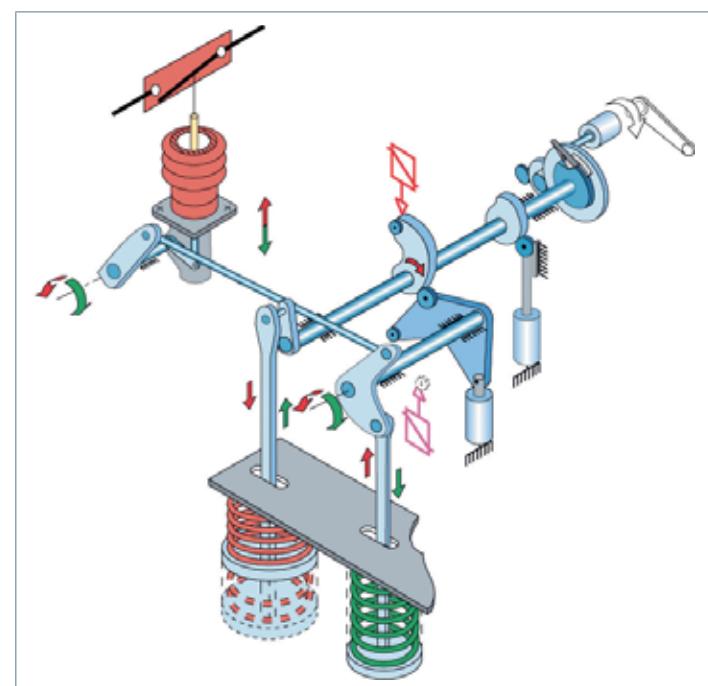


Figure 7: Schematic layout of the spring drive mechanism

The 800 kV high-voltage circuit-breaker is available with or without closing resistors. Depending on the switching surges in the power networks, the closing resistors can be adapted to the customer's requirements to have different closing times and resistance values. The closing resistors are operated in accordance with the approved operating principle via direct coupling without latching with the driving rods of the interrupter units. The operating principle for the closing resistors is shown in Figures 8 and 9. The PSD controller can also be used in place of the closing resistors.

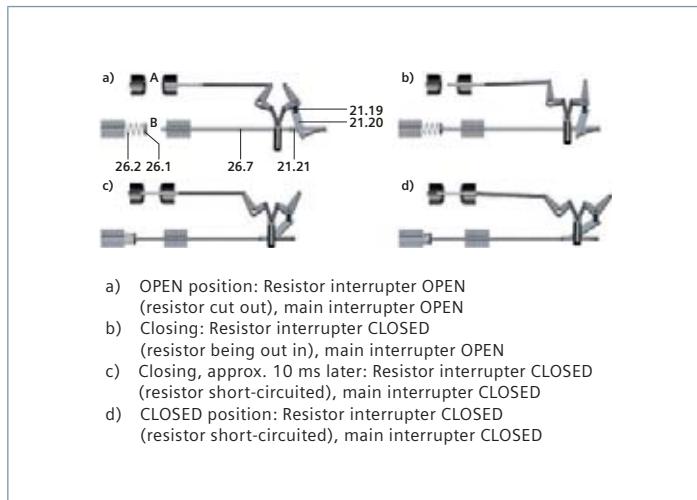


Figure 8: Closing Resistor – Closing (Operation Mode).

The operation mode of the closing is shown schematically

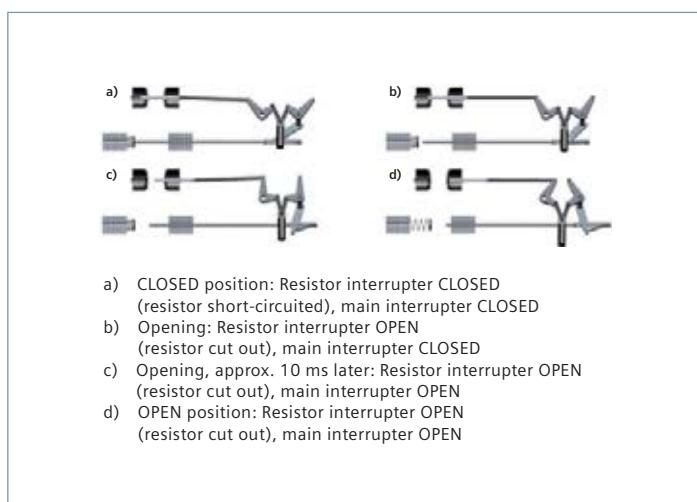


Figure 9: Closing Resistor – Opening (Operation Mode).

The operation mode of the opening is shown schematically

Transport and Installation

The same installation concept as that of outdoor circuit-breakers applies across the board for all 3AP high-voltage circuit-breakers from 72.5 kV to 800 kV. The individually tested circuit-breakers at the SIEMENS factory are disassembled into a few self-contained modules for transport. The 800 kV high-voltage circuit-breaker is disassembled into three compact transport units and can then be quickly re-assembled on the customer's premises, see Figure 10.

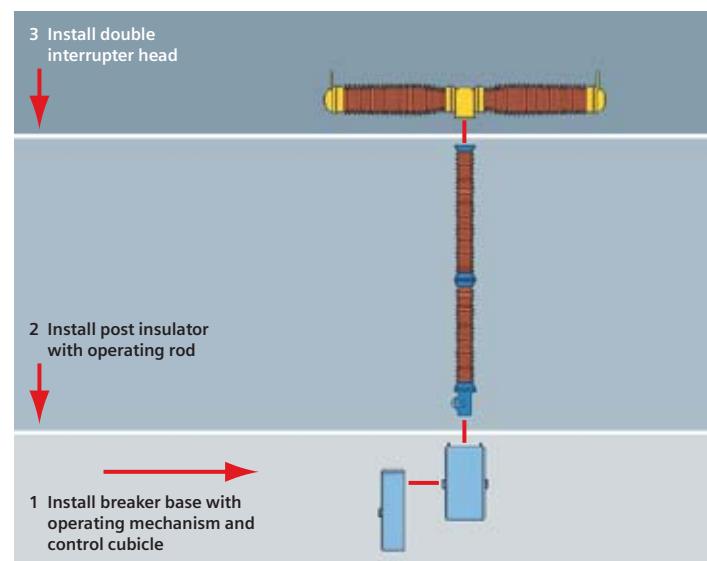


Figure 10: Schematic representation of the assembly of a pole column with double break assembly

Summary

With the logical development of the 3AP high-voltage circuit-breaker, a 3AP product series from 72.5 kV to 800 kV with self-compression system and spring drive mechanism is available, alongside the 3AP4/5 800 kV outdoor breaker.

By using components from the modular systems of the 420 kV, 550 kV and 800 kV circuit-breakers, Siemens has been able to rely on its long-standing knowledge of the endurance of circuit-breakers, manufacturing processes, installation procedures, testing and commissioning.

The high quality achieved through this knowledge and the outstanding technical characteristics are what single out the new 3AP4/5 800 kV high-voltage circuit-breaker.

Further details can be found in the following publications:

- [1] Fredrich, D.; Schuler, K.; Trapp, N.:
Circuit-Breaker Platform for 550 kV. SWICON 2008,
SEVENTH INTERNATIONAL CONFERENCE ON SWITCH GEAR
& CONTROL GEAR, Mumbai, India
- [2] Marin, H.; Knobloch, H.; Schramm, H.-H.; Stenzel, P.:
The dynamic self compression HV SF₆ circuit-breaker for
high ratings.
MatPost '99, Lyon (France), 18/1 Nov. 1999
- [3] Siemens AG: unexamined German application 2316009.
German Patent Office, 1973

Horst Waage

Disconnecting Circuit-Breakers (DCB)

Based on the successful 3AP circuit-breaker series, which has been in service since 1996 at many substations all over the world, Siemens developed disconnecting circuit-breakers for the voltage levels 145 kV and 420 kV.

Introduction

All energy providers are faced with increasing cost pressure. This is why they strive for higher reliability, reduced outage times and lower maintenance costs. If an existing substation is to be extended, the limited space at the site could be a problem – particularly in Northern countries where snow and ice on disconnector contacts can lead to failures. The solution to these problems is "disconnecting circuit-breakers (DCB)", which are now established as a reliable element at many substations.

What is a Disconnecting Circuit-Breaker?

A DCB combines the function of a circuit-breaker with the function of a disconnector (combined function): two switching devices in one. The breaking units assume the task of breaking and disconnecting. No further contact systems are required for disconnecting, which means the DCB must also fulfill the demands of both devices; this is specified in the new standard IEC 62271-108.

The distinctive features of DCBs are:

- A blocking system (electrical and mechanical) that prevents unintentional closing of the open circuit breaker.
- Composite insulators to avoid leakage currents over the open disconnector/circuit-breaker.
- The kinematic chain between the CB drive, position indicator and breaking unit must guarantee a correct indication of the breaker/disconnector position even if one breaking unit is blocked in the closed position by a mechanical failure and an open operation is released.
- Optional earthing switch integrated on the same base frame. In this case, an electrical and mechanical interlock between the blocking system and earthing switch is required.
- The possibility to lock the blocking system in a blocked position and the earthing switch in a closed position with the aid of a padlock.



Figure 1: The 3AP1 FG 145 kV DCB with earthing switch

Advantages of DCBs

The first advantage of a DCB in comparison to the classic arrangement of a circuit-breaker and separate disconnector is that there is no unprotected contact system of the disconnector. This means improved reliability with no problems arising as a result of dirt, snow and ice on the contact system. Furthermore, the disconnector and circuit-breaker have the same maintenance intervals, which reduces maintenance costs.

The second advantage is that the price of one integrated switching device is less than the price of two or three (with earthing switch) single devices.

Thirdly, installation time is reduced because only one device is to be installed, instead of two or three. Finally, the DCB has a real space saving design. New substation layouts are possible in smaller areas (Figure 2) and instead of two or three foundations for separate devices, the DCB needs only one. The most significant advantage is the protected contact system of the disconnector; however, it must be borne in mind here that the contact system itself – particularly the isolating distance on the open disconnector – is not visible.

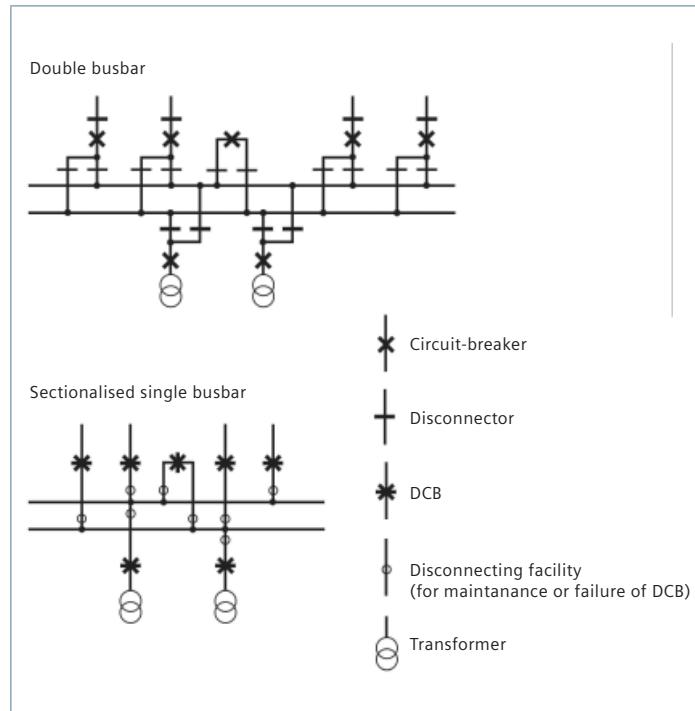


Figure 2: A conventional single line compared to a single line with DCBs

DCB Projects

Brought about by the needs of customers from northern Europe, Siemens started the development of a 420 kV DCB in 2008, and one year later launched the 145 kV DCB project. Both disconnecting circuit-breakers are based on and originate from well-known and proven Siemens products with over 10 years of operational experience. The **3AP2 FI 420 kV DCB** is based on the 3AP2 FI 550 kV and the **3AP1 FG 145 kV DCB** on the 3AP1 FG 170 kV breaker.

Both developments involved the following:

- The integration of a mechanical blocking system with optical position indicator in the existing base frame
- The additional application of a motor drive for the mechanical blocking system
- The modification of the control unit for the electrical interlocking system
- The substitution of porcelain insulators for composite insulators
- The strengthening of specific parts of the kinematic chain
- The application of a special density monitor with knee-point-characteristic, that provides the breaker for low temperatures and reduced SF₆ density (this is not specific to DCBs, but was a requested by the first customer)
- For the 145 kV DCB: integration of an earthing switch with own motor drive and mechanical interlock

Furthermore, it was necessary to perform several tests. The most important were:

- Combined function test according to IEC 62271-108
- Mechanical endurance test with 10000 operations for breaker and blocking system (this also means the disconnecting function)
- Test of kinematic chain
- Power tests with reduced SF₆ density to qualify the breaker for low temperatures
- Mechanical endurance test with 2000 operations for the earthing switch



Figure 3: The 3AP2 FI 420 kV DCB on an installation site in Sweden

DCB Product Range

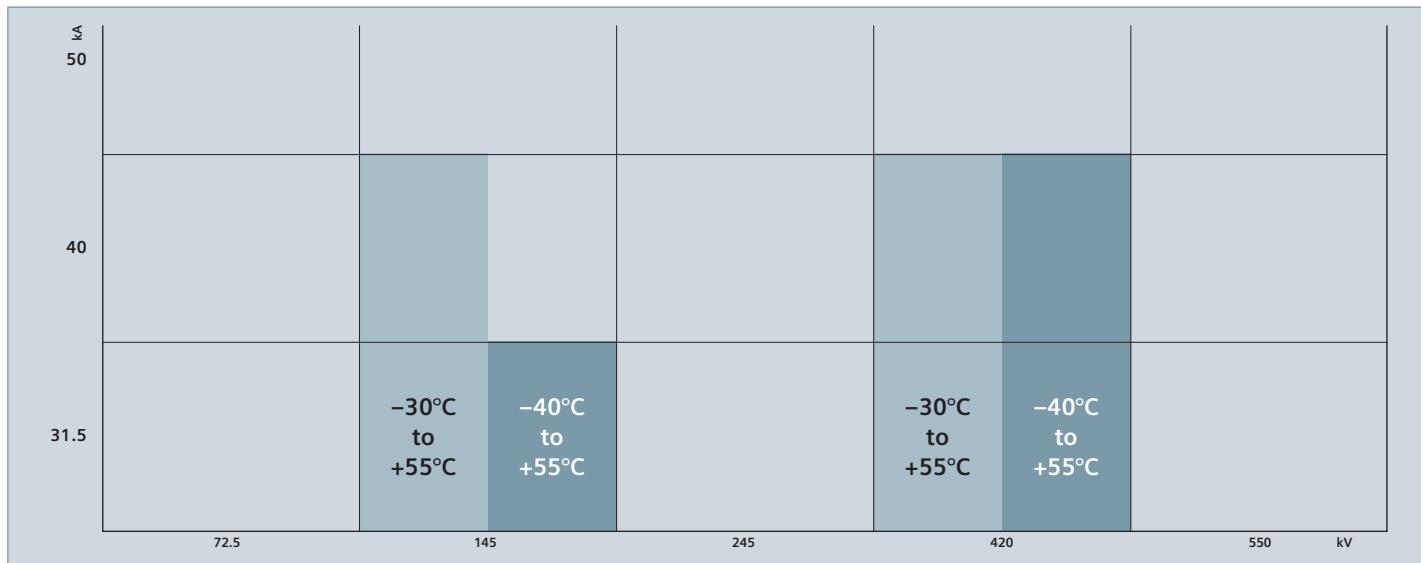


Figure 4: The product range of the 145 kV and 420 kV DCB

Technical Data of DCBs

	3AP1 FG 145 kV DCB	3AP2 FI 420 kV DCB
Rated voltage	145 kV	420 kV
Rated normal current	3150 A	4000 A
Rated frequency	50 Hz	50 Hz
Rated short circuit breaking current		
at -30 °C	40 kA	40 kA
at -40 °C	31.5 kA	40 kA
Temperature class	-30 °C (-40 °C)/+55 °C	-40 °C/+55 °C
Classification		
Circuit-breaker	M2, C2	M2, C2
disconnector	M2	M2
earthing switch	2000 operations	-

Figure 5: Technical Data of the 145kV and 420kV DCB

The Combined Function Test

The combined function test according to IEC 62271-108, which is the characteristic test for DCBs, shall now be described in detail: As with conventional disconnectors, the dielectric withstand across the isolating distance is essential for the safety of the maintenance staff when it comes to DCBs. The dielectric requirements for the isolating distance must be guaranteed not only with new DCBs, but also after years of service and many operations. This is why the combined function test includes a mechanical endurance test with 10000 operations and a T100s short-circuit test duty. With contaminated insulating gas and abrasion of the breaking unit caused by these preloads, the breaker must perform the dielectric test of the isolating distance. It is not permissible to open the breaker between the tests or to substitute the used insulating gas for new gas.

Another option, according to the standard, is to perform this test with two breakers, one for the mechanical preload, the other for the short-circuit test duty. Finally, both breakers must pass the dielectric test.

The Blocking System in Detail

When the DCB is in the OPEN position, an unintended CLOSE operation must always be prevented, which means a mechanical blocking system is required. In the case of the 145 kV DCB, it is located near the corner gear lever of pole B (Figure 6), which is directly linked to the spring drive mechanism.



Figure 6: Blocking system and corner gear lever in the base frame of the 145 kV DCB

The blocking system itself consists of a massive, adjustable track and a movable slider, which is operated by an individual motor drive. The corner gear lever of pole B has a special nose that corresponds to the slider of the blocking system. When the

slider is in the blocked position, the area where the nose needs to execute the CLOSE operation is blocked. Figure 7 shows a schematic view of the corner gear levers and the movable slider of the blocking system.

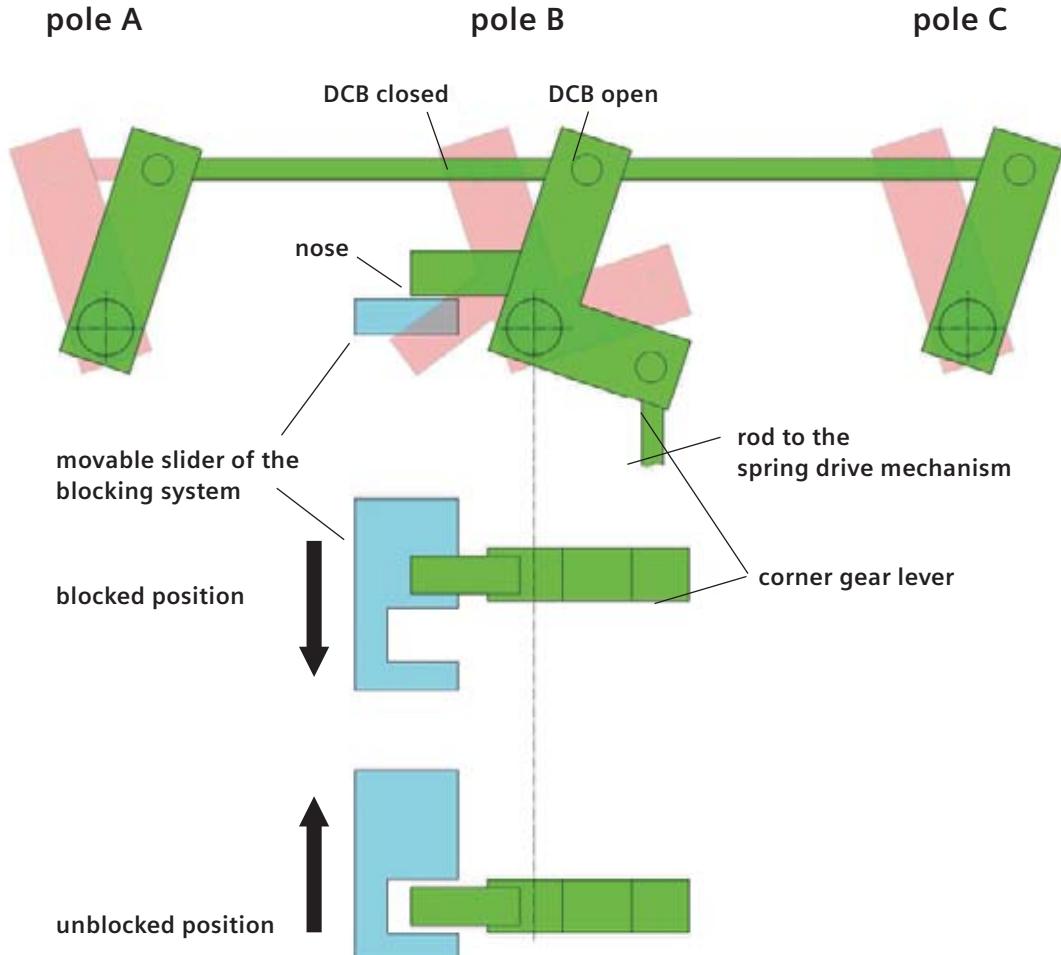


Figure 7: A schematic view of the blocking system

The Operating Positions

Figure 8 illustrates the different operating positions of the 145 kV DCB between the closed circuit-breaker and the open, earthed and completely locked breaker.

Step	Circuit-breaker	Blocking System (electrical & mechanical)	Earthing switch (with interlock to Blocking System)	Lock of Earthing switch (with padlock)
1	closed (ready to open)	unlocked (not possible to lock)	open (not possible to close)	unlocked (not possible to lock)
2	open (ready to reclose)	unlocked (ready to lock)	open (not possible to close)	unlocked (not possible to lock)
3	open (not possible to close)	locked (ready to unlock)	open (ready to close)	unlocked (not possible to lock)
4	open (not possible to close)	locked (not possible to unlock)	closed (ready to open)	unlocked (ready to lock)
5	open (not possible to close)	locked (not possible to unlock)	closed (not possible to open)	locked (ready to unlock)

Figure 8: The operating positions of a DCB with earthing switch

1. Step: The circuit-breaker is closed, and it is not possible to lock the blocking system of the breaker or to close the earthing switch.
2. Step: The circuit-breaker is now open and the blocking system is still unlocked, but now it is possible to lock the blocking system or close the breaker again (the small blue arrows symbolise the next possible operations: from here to the lower/upper box)
3. Step: The blocking system is locked and the earthing switch is still open, but now it is impossible to close the circuit breaker. The next possible operations: to close the earthing switch or to unlock the blocking system again.
4. Step: The earthing switch is closed and it is not possible to unlock the blocking system of the breaker. Next possible operations: to lock the earthing switch with a padlock or to open the earthing switch again.
5. Step: The earthing switch is locked with a padlock and circuit-breaker, and the blocking system and earthing switch are locked in their current positions.

Additionally, it is possible to lock the blocking system itself in the locked position with a padlock that is independent from the position of the earthing switch. For closing the circuit-breaker, follow the procedure described, only in reverse.

Future Prospects

It is likely in future that other voltage levels or other circuit-breaker types such as dead tanks or GIS breakers will also be designed as disconnecting circuit-breakers, or that additional components such as current transformers will be integrated because – for these types as well – DCBs also improve reliability, lower product and maintenance costs as well as reduce the space required at substations.

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circuit-breakers for rated voltages of 72.5 kV and above

Carsten Protze

Disconnectors and Earthing switches for 800 kV DC substations

1 Introduction

The disconnector and earthing switch portfolio of the Siemens business unit E T HP has been enhanced by the development of 800 kV DC disconnectors and earthing switches for ultra high voltage direct current (UHVDC) technology. Double side break disconnectors with built-on earthing switches have been chosen for the 800 kV DC voltage level thanks to the success of this type at the 500 kV DC and 800 kV AC voltage levels.

2 Application

Apart from the bypass circuit breakers, disconnectors and earthing switches are the only mechanical switches in a UHVDC system. The 800 kV DC disconnectors can be grouped according to their tasks and locations within these substations:

- Bypass disconnector
in parallel with upper 12-pulse valve group
- Group disconnector
between upper 12-pulse valve group and pole bus (± 800 kV DC)
- Bus disconnector
between transmission line and pole bus (± 800 kV DC)
as well as between transmission line and neutral bus
- Filter disconnector
between filter and pole bus (± 800 kV DC)

The earthing switches ensure a safe connection to earth for parts of the system that are switched off. All earthing switches were designed as build-on earthing switches at disconnectors as a result of the layout of the 800 kV UHVDC substations.

3 Requirements and tests

In the absence of standards for UHVDC disconnectors and earthing switches, the development and type tests are based on analogies with AC equipment standards and on client specifications. The type tests have been performed in close contact with the client.

The fact that the tasks of the 800 kV DC disconnectors are different is reflected in the requirements listed in the tests sections. Despite the partly different requirements it was succeeded that based on the design of the bus disconnector (figure 1) the designs of the other applications could be achieved by adding or changing disconnector components.

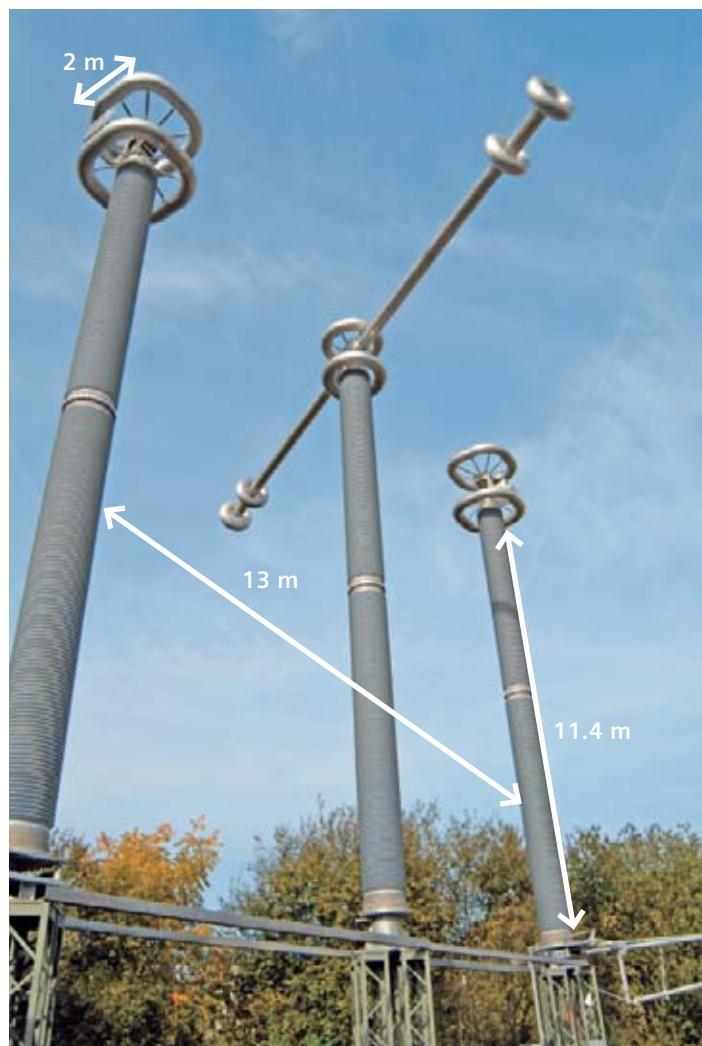


Figure 1: Dimension of 800 kV DC disconnector

3.1 Insulator Tests

The insulators are a key component of the disconnector. The creepage distance requirements for the insulator material in relation to the outer diameter of the insulator, as well as the mechanical requirements, have resulted in a hollow, gas filled composite insulator. Due to manufacturing limits the insulators consist of two parts screwed together with a hollow space in the centre. The specified creepage distance is 47 mm/kV at an insulator diameter of 700 mm. The insulator is filled with a gas mixture of SF₆ and N₂ at a pressure of 0.2 MPa. The unusually large diameter of the insulator ensures that the mechanical requirements are fulfilled.

The following type tests were carried out on the insulator itself and its material:

- cantilever bending tests (Figure 2)
- internal pressure tests
- on-load deflection tests
- water diffusion tests

All insulator tests were performed successfully in the laboratories of Tyco Electronics in Wohlen (Switzerland). The mechanical dimensions of the disconnectors are based on these test results.



Figure 2: Setup for cantilever bending tests

3.2 High Voltage Tests

The high voltage tests started with preliminary studies on the dielectric dimensions of the disconnector. The high voltage laboratory at the Technical University of Dresden (Germany) assisted in conducting these tests. The studies focused on the behaviour of the insulators and the disconnector gap under switching impulse voltage stress (figure 3) as well as the appearance of corona in dry and wet conditions.



Figure 3: Preliminary study on disconnector gap with switching impulse voltage

Parameter	Value
Rated DC voltage	
terminal – earth	800 kV
between terminals	400 kV ^a 800 kV ^{b c d}
DC withstand voltage	
terminal – earth	1200 kV
between terminals	600 kV ^a 1200 kV ^{b c d}
Switching impulse withstand level	
terminal – earth	1790 kV
between terminals	1060 kV ^a 1790 kV ^{b c d}
Lightning impulse withstand level	
terminal – earth	2205 kV
between terminals	1330 kV ^a 2205 kV ^{b c d}
RIV level @ 1040 kV DC	< 2500 µV

Table 1: High voltage requirements for

- a) Bypass disconnector
- c) Bus disconnector

- b) Group disconnector
- d) Filter disconnector

The parameters for the dielectric and RIV type tests are listed in table 1. Here the impulse withstand levels are corrected for installation at an altitude of 2000 m. The ultra high voltage test levels and the dimension of the disconnector placed high demands on the test laboratory. The new high voltage laboratory of Hochspannungsgeräte Porz (HSP) in Troisdorf (Germany) with a test hall of 50 m x 35 m x 28 m provided a test facility where all dielectric and RIV type tests could be performed successfully (figure 4).



Figure 4: Setup for high voltage tests

3.3 High Current Tests

The high current requirements (table 2) are divided into a short circuit test for all disconnector applications as well as a commutation test for the bypass disconnector and a making and breaking current capacity test for the filter disconnector. All these tests were performed at the high power laboratory of FGH Engineering & Test in Mannheim (Germany).

During the peak and short time withstand current tests, the disconnector showed no visible reaction. As a result of the mechanical dimensioning for the seismic conditions and of the current path for 5000 A permanent current, the effect of a 50/20 kA – 1 s short circuit current on disconnector is minimal. The test was passed successfully.

Parameter	Value
Peak and short time withstand current	50 kA peak / 20 kA rms – 1 s
Transfer current @ 80 V peak recovery voltage	2500 A rms ^a
Making and breaking current capability @ 56 kV peak recovery voltage	100 A rms ^d

Table 2: High current requirements for

- a) Bypass disconnector
- b) Group disconnector
- c) Bus disconnector
- d) Filter disconnector

The bypass disconnector has the task of transferring the current from the parallel bypass circuit breaker if the parallel 12-pulse valve group is out of service and the permanent current through the bypass is greater than the permitted permanent current through the bypass circuit breaker. The client's calculations demonstrate that when the bypass circuit breaker and bypass disconnector are closed at the same time, the maximum current through the disconnector is less than 2500 A. During re-transfer of the current to the bypass circuit breaker when the disconnector opens, a maximum recovery voltage of 80 V peak can occur. Within these parameters a type test according to the IEC standard for AC disconnectors demonstrated that the bypass disconnector is capable of transferring this current during closing operation as well as during opening operation.

The filter disconnector is the only switching element between the pole bus and the filter. Therefore this disconnector must be able to switch the filter on or off during normal service of the UHVDC system. The size of the filter current depends on the filter capacity and the ripple at the pole bus. The client indicated that the filter current is 100 A and the recovery voltage is up to 56 kV immediately after current breaking. During the closing operation a prestrike occurs because of the electric potential difference of up to 800 kV between bus and filter. In the type tests this effect was simulated with a thin pre-arching wire providing a connection within a typical flashover distance. The corona rings coming in contact with the arc are made of stainless steel. These rings, together with an arc-carrying contact system, make up the features of the filter disconnector. The making and breaking current capacity was demonstrated successfully in 10 close-open cycles where the test was carried out nine times at 100 A and once at 160 A (figure 5).



Figure 5: Breaking current capacity tests

3.4 Mechanical Tests

The parameters for the mechanical tests are listed in table 3.

Parameter	Value
Mechanical endurance	2000 CO
Seismic withstand capability for ground acceleration	0.3 g

Table 3: Mechanical requirements

As with double side break disconnectors at lower voltage levels, the maximum speed of the rotating current path tube must be limited. This is induced by limiting collision energy when the current path reaches the fixed contact during closing operation. In case of the 800 kV DC disconnectors, it was necessary to decrease the collision speed further while at the same time increasing the speed during switching operation for an acceptable operation time. This particular travel characteristic was implemented on the motor drive. The mechanical endurance tests of 2000 close-open cycles for disconnector and earthing switch were performed successfully at the FGH test laboratories too. The seismic withstand capability tests were performed with a dynamic computational simulation using the commercial software ANSYS in the mechanical laboratories of Siemens in Berlin (Germany). For the calculation of the mechanical stresses the equipment was modeled and the loads were implemented according to the client's instructions and IEC standards. The specified seismic withstand capability of 0.3 g was proven.

3.5 Temperature Rise Tests

Despite a maximum DC current of 4000 A in the first UHVDC system for further projects currents up to 5000 A DC can be achieved. Therefore the current path of the disconnector has been designed for the upper level (table 4).

Parameter	Value
Temperature rise	5000 A ^{a b c} 100 A ^d

Table 4: Temperature rise requirements for

- a) Bypass disconnector
- b) Group disconnector
- c) Bus disconnector
- d) Filter disconnector

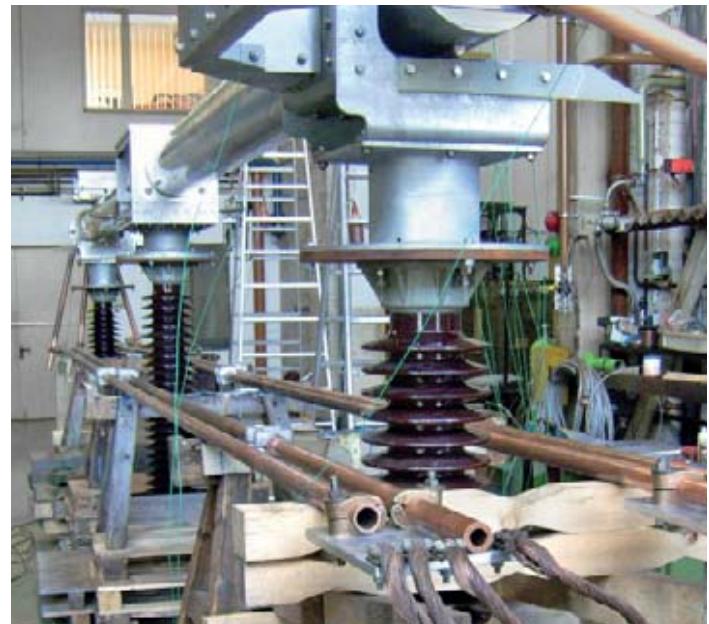


Figure 6: Setup for temperature rise test

Due to the mechanical caused design of the current path, the aluminium tube is far from its thermal limits when loaded with 5000 A DC. However, the actual design of the contact system with its fingers and blocks is dimensioned for 5000 A DC. The capacity to carry permanent 5000 A DC was proven in a temperature rise test at the HSP test laboratories (figure 6). Despite the requirement of 100 A for the filter disconnector, the current path design of the bus disconnector is also used for the filter disconnector due to mechanical reasons.

4 Conclusion

The development and type tests of the 800 kV DC disconnectors and earthing switches was completed on schedule thanks to the outstanding commitment of all staff and laboratories involved. The disconnectors and earthing switches for the first UHVDC system in the world were delivered in July 2008. The disconnectors and earthing switches are currently being installed and will be put into service along with the entire UHVDC system in 2010.

Klaus Schuler

Modern stored-energy spring operating mechanism for high-voltage circuit breakers

1 Introduction

Circuit breakers have a protective function in high-voltage transmission and distribution systems. Their high reliability and continuous availability are basic service requirements. Circuit breakers are used in all environmental conditions in countries throughout the world. The interrupter system and the operating mechanism are the main components of circuit breakers. For realization of these pretentious requirements the two systems have to be coordinated for each breaker type. Extensive experience in development is a prerequisite when designing both components. This is why all well known suppliers have one source for development and production. A further explanation is the direct interaction between the interrupter system and operating mechanism.

The requirements of the interrupter and arc-quenching systems determine the energy of an opening operation. An interrupter system with arc assistance has a much lower operating energy than a system that needs most energy the operating mechanism's energy to compress the SF₆ and to cope with the increased pressure due to the heating of the gas (puffer system). The magnitude of energy influences the selection of the appropriate operating system.

2 Arc-quenching systems with SF₆

Siemens started developing SF₆ circuit breakers at the end of the 1950s. The first double-pressure SF₆ breakers for 123 and 245 kV where shipped in 1964 [1, 2].

In 1974, Siemens developed the next generation of SF₆ breakers, using a single-pressure system (puffer system) for arc-quenching, see 2.1.

This system dominated the product family for over 25 years and was very successful [3, 4].

At the beginning of the 1990s, the next milestone in development was the self-compression interrupter system, which uses arc assistance to build up pressure, see 2.2.

Now all circuit breakers in the Siemens product portfolio from 72.5 kV up to 800 kV use the same interrupter system principle. This system is established in live-tank and dead-tank circuit breakers, DTC (dead-tank compact in hybrid technology) and in GIS/HIS [5-9].

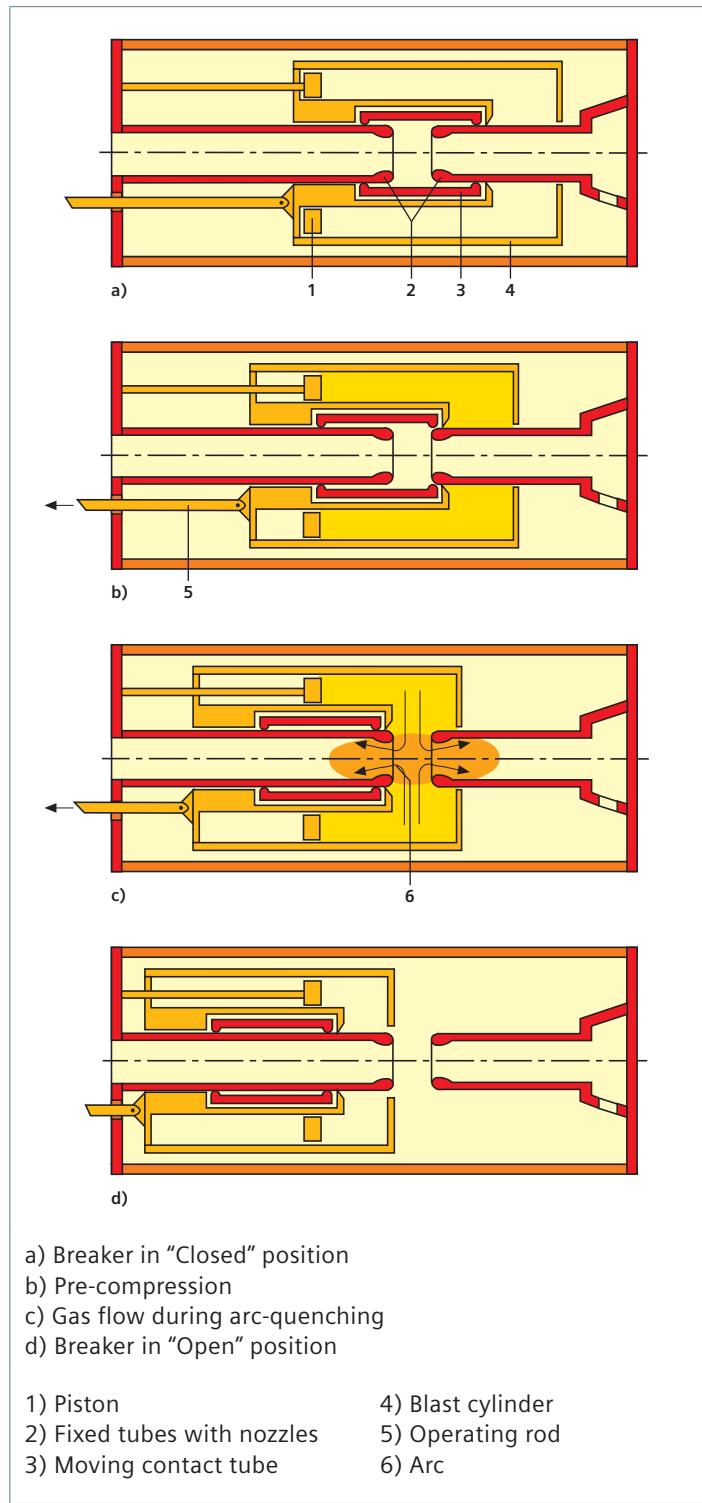


Figure 1: Principle of the puffer interrupter system

2.1 Puffer interrupter system

The current path is formed by the terminal plates, two fixed tubes and spring-loaded contact fingers arranged in a ring in the moving contact tube.

The fixed tubes are connected by the contact tube when the breaker is closed. The contact tube is rigidly coupled to a blast cylinder, the two forming the moving part of the interrupter chamber, together with an annular fixed piston in between. The moving part is driven by an operating rod, increasing the SF₆ pressure between the piston and the blast cylinder.

When the contacts separate, the moving contact tube, which acts as a shut-off valve, releases the compressed SF₆. An arc is drawn between one nozzle and the contact tube. The blast cylinder encloses the arc-quenching arrangement like a pressure chamber. The compressed SF₆ flows radially into the gap by the shortest route and is discharged axially through both nozzles. After arc extinction, the contact tube moves into the open position. The principle of the puffer interrupter system is shown in Figure.1.

2.2 Self-compression interrupter system

The self compression interrupter system represents a further step in the development process. This system utilizes the high energy of the arc for building up the pressure of the SF₆ during opening for arc quenching. The conducting path of the interrupter unit consists of the contact carrier, the base and the moveable contact cylinder. In the closed position, the current flows via the main contact and the contact cylinder. This system uses different effects for arc quenching, depending on the magnitude of the current to be interrupted: breaking operating currents and breaking fault currents.

Breaking load currents

During the opening operation, the main contact opens first, and the current commutes to the still closed arcing contact. As opening continues, the arcing contact opens and an arc is drawn between the contacts. At the same time, the contact cylinder moves into the base and compresses the SF₆ gas located there. This gas compression creates a gas flow through the contact cylinder and the nozzle to the arcing contact, extinguishing the arc.

Breaking short-circuit currents

In the event of interrupting high short-circuit currents, the SF₆ gas between the opening arcing contacts is heated up considerably due to the energy of the arc. This leads to a pressure increase in the contact cylinder.

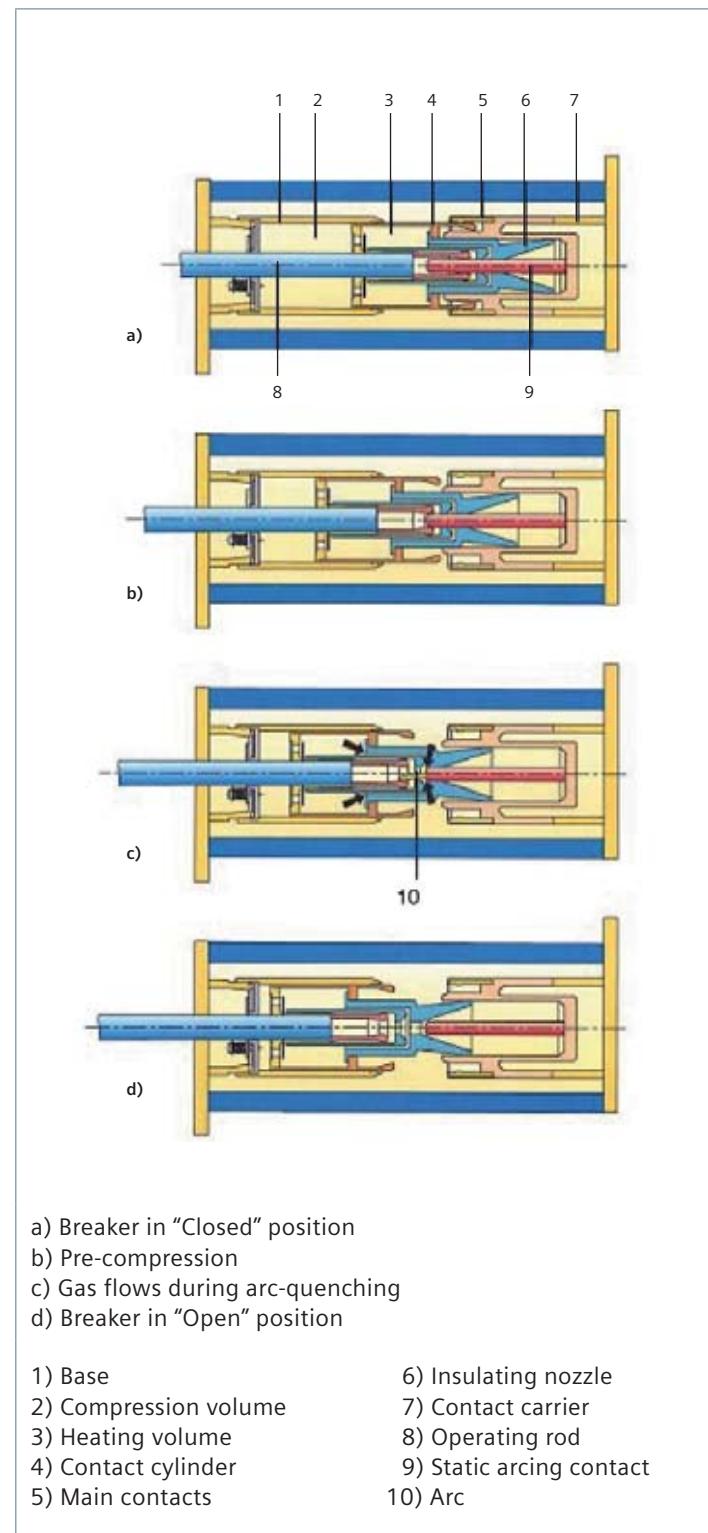


Figure 2: Principle of the static self-compression system

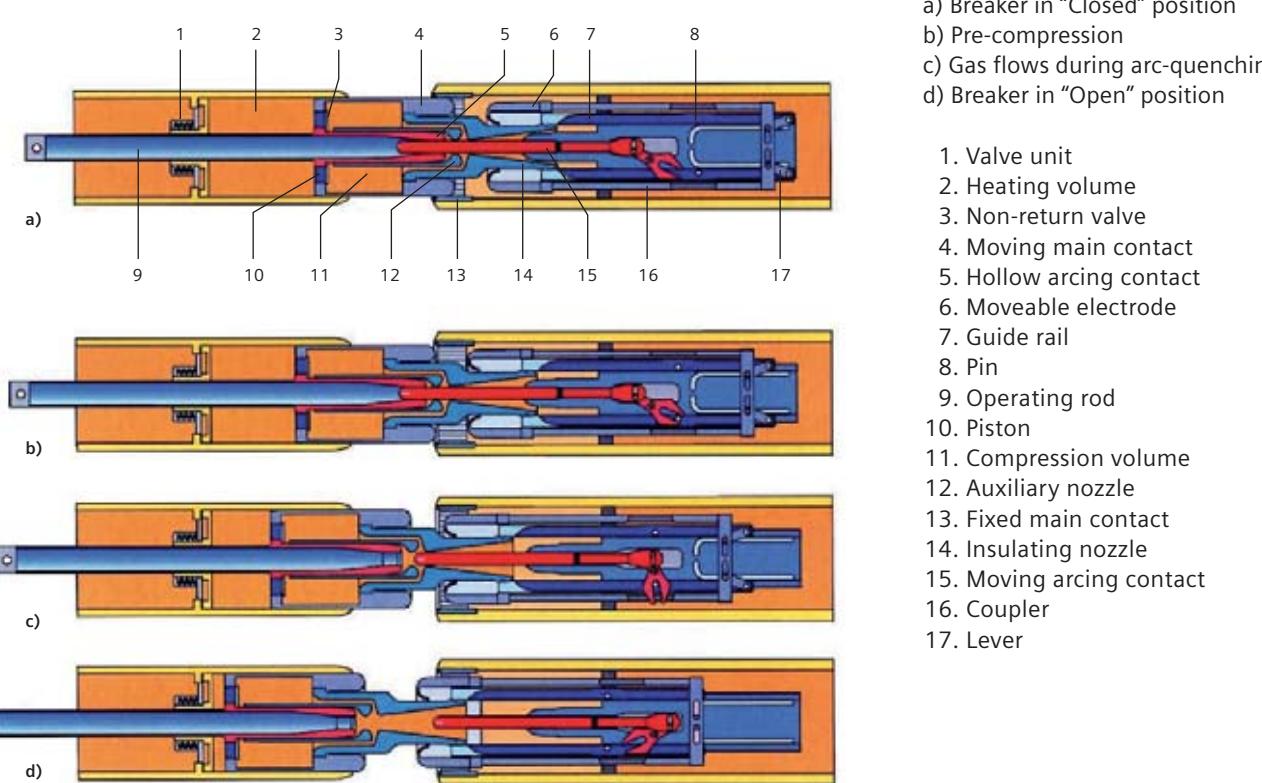


Figure 3: Principle of the dynamic self-compression system

As opening continues, this increased pressure initiates a gas flow through the nozzle extinguishing the arc. In this case, the arc energy is used to interrupt the short-circuit current. This energy need not to be provided by the operating mechanism. The principle of the self-compression interrupter system is shown in Figure 2 and Figure 3.

There are two design versions of the self-compression system, with the same basic function:

- Static self-compression system
- Dynamic self-compression system

The static self-compression system has a static arcing contact and is shown in Figure 2. Circuit breakers for 72.5 to 145 kV use this system.

The dynamic self-compression system is necessary for 170 up to 800 kV and is shown in Figure 3. With this design different velocities for the main contacts and arcing contacts are possible, see Figure 4. The velocity of the main contacts is low to limit the necessary mechanical energy for the interrupter operation. The high velocity of the arcing contacts reduces the arcing time, increases the rate of voltage withstand recovery and ensures a restrike-free capacitive switching capability. A moveable electrode shields the arcing contacts in all positions during the opening and closing strokes [6].

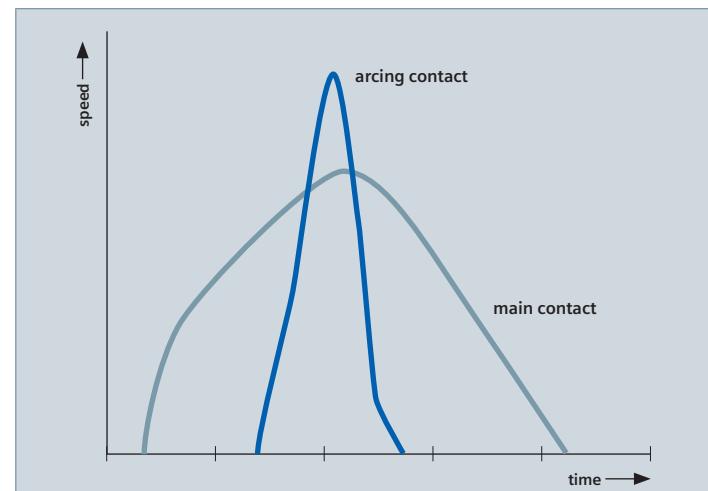


Figure 4: Speed for arcing contact and main contact versus time

3 Operating mechanism

Operating mechanisms with a stored-energy system are necessary for high-voltage circuit breakers. Only with this kind of system is it possible to fulfill the requirements in terms of short reaction time, contact speed, operating forces for the interrupter system and size of the circuit breaker.

High operating energy for arc-quenching in the interrupter system is required for high-voltage SF₆ circuit breakers with puffer system. Apart from movement of the contact parts, most of the energy is required to compress the SF₆ in the blast cylinder (puffer system). With the development of this system comes the introduction of hydraulic operating mechanisms with high-pressure starts, see Figure 5. The operating energy needed for an interrupter system with arc assistance is much lower. The stored-energy spring operating mechanism is optimal for this system, see Figure 6.

3.1 Hydraulic operating system

The first circuit breaker with hydraulic operating mechanism was introduced in 1969. This first design was a combination of hydraulic operation for closing and spring operation for opening [2]. In 1973, the next step was a fully hydraulic operating mechanism for closing and opening [4].

The operating system includes the operating cylinder, main and pilot valves, solenoids for closing and opening, accumulator and an oil tank. These components are assembled as one block in a

compact design. The energy required to operate the operating cylinder is supplied by the accumulator. A moving piston divides the accumulator into two chambers. One chamber is filled with compressed nitrogen, acting as a cushion; this pressurizes the hydraulic oil in the second chamber via the moving piston. The filter, motor and pump are located in a cabinet. The components are connected by high and low pressure pipes. The entire operating system is completely separate from the SF₆ gas compartments.

Closing

The main valve is opened by means of the closing solenoid and the pilot valve. High pressure from the accumulator is applied equally to both sides of the piston by the operating cylinder. The breaker is closed via couplers and operating rods moved by the force acting on the larger area of the piston. The hydraulic operating mechanism is designed to ensure that the breaker maintains its position even in the event of pressure loss.

Opening

The main valve is operated by the opening solenoid, thus relieving the larger area piston side of pressure. The pressure, which is now acting on the smaller piston area only, causes the piston to move into the opening position. The principle of the hydraulic mechanism is shown in Figure 5.

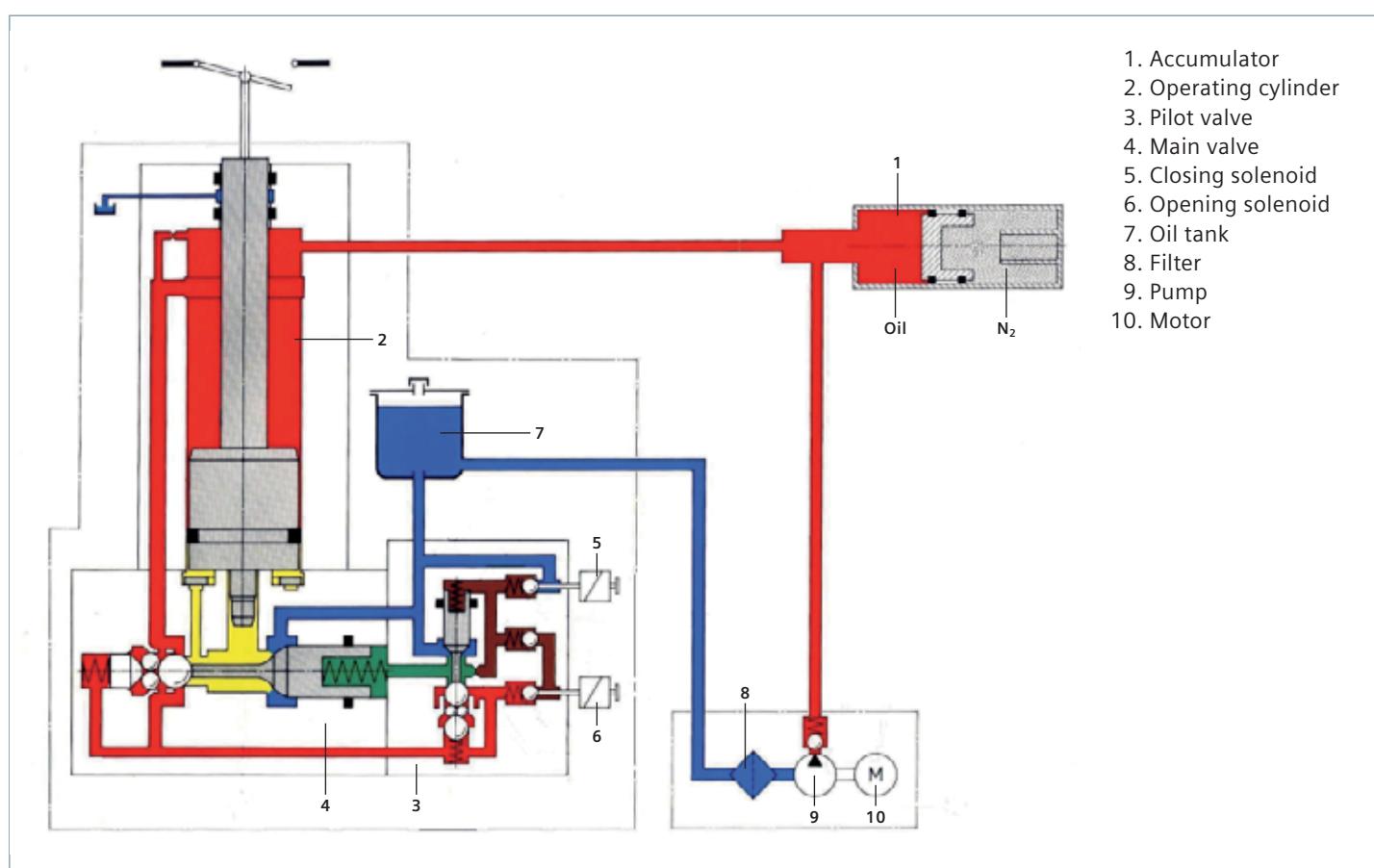


Figure 5: Principle of the hydraulic operating mechanism

3.2 Stored-energy spring operating mechanism

In 1992, Siemens started serving the market with a high-voltage circuit breaker with a stored-energy spring operating mechanism. The new design was based on over 30 years of experience producing medium-voltage circuit breakers. The operating mechanism is assembled in one compact and corrosion-resistant aluminum housing.

The housing includes all parts of the operating mechanism, see Figures 6:

- Motor, charging gears and charging shaft
- Solenoids and latches for opening and closing
- Operating shaft and operating rod
- Closing and opening spring
- Damper for opening and closing

The charging time of the springs is short enough to allow all normal duty cycles like O – 0.3 sec – CO – 3 min – CO or CO – 15 sec – CO.

All shafts and latches are supported by anti-friction bearings and lubricated with grease for a large range of low and high ambient temperatures. The entire operating system is completely separate from the SF₆ gas compartments.

Closing

The closing spring is charged by means of motor, gears and charging shaft in a latched position. The solenoid for closing opens the latch. The energy from the closing spring closes the breaker and charges the opening spring by means of the cam plate, operating shaft and operating rod. The breaker and the operating mechanism are then in closed position. After reaching this position, the opening spring will be charged automatically. In this position both springs are charged and the operating mechanism is ready for an OCO operation.

Opening

The solenoid for opening opens the latch. The energy from the opening spring operates the breaker in the open position by means of the operating rod.

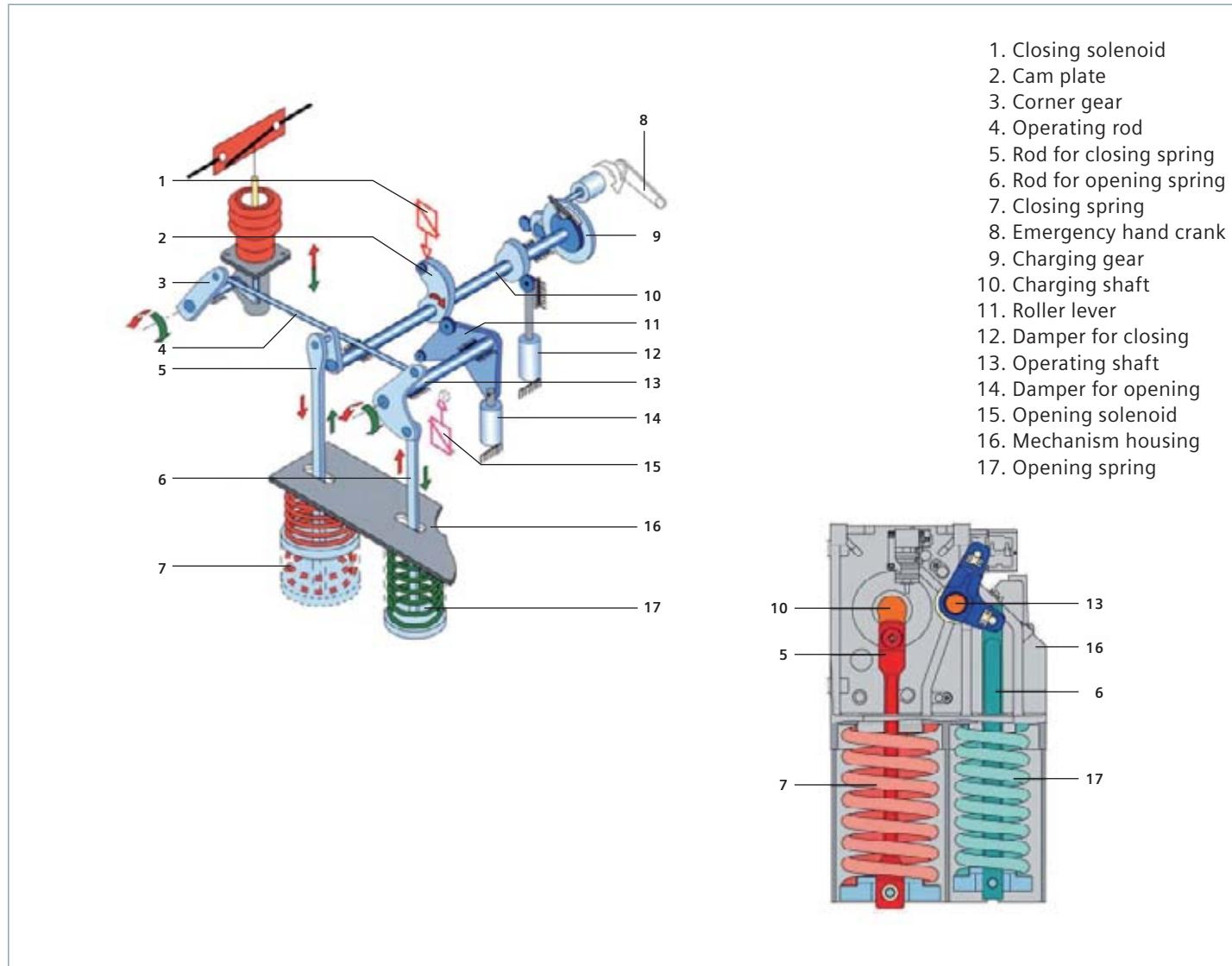


Figure 6: Principle of stored-energy spring operating mechanism

4. Reduction of operating energy

For the same ratings of a circuit breaker, the comparison of the two arc-quenching systems shows that the energy necessary for opening is much lower for an arc assisted interrupter system than for a puffer system. The lower operating energy reduces the dimensions and masses of all moving parts of the kinematic chain. Reduced dynamic forces and smaller inside parts are the prerequisite for a lighter and economical design of the complete circuit breaker. The diagrams in Figures 7 and 8 show the results for a circuit breaker with a rated voltage of 550 kV and short-circuit breaking current 63 kA with two interrupter units per pole. The circuit breaker with the arc assisted self compression interrupter system and stored-energy spring operating mechanism, one for each pole, needs 65 % less energy for opening and has 25 % reduced weight. The stored-energy spring operating mechanism is designed to be maintenance-free and the breaker is type tested for 10,000 operations (class M2). The 550 kV circuit breakers present a true 2 cycle break time for 50 and 60 Hz according to IEC and IEEE standards

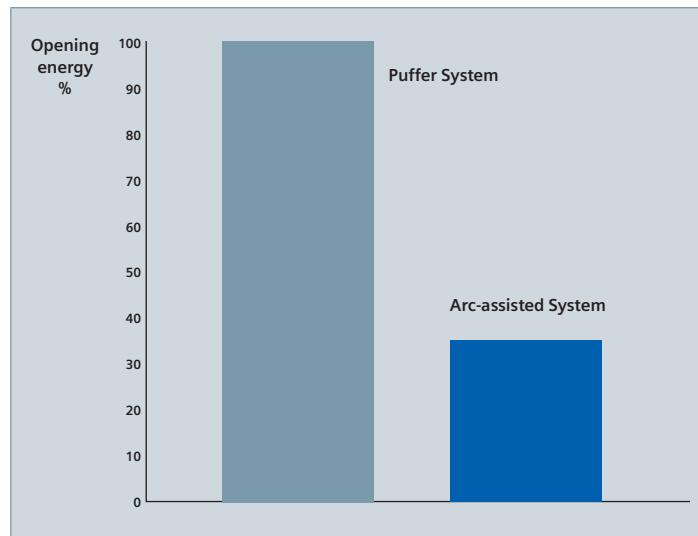


Figure 7: Opening energy for a 550 kV circuit-breaker with different arc-quenching systems

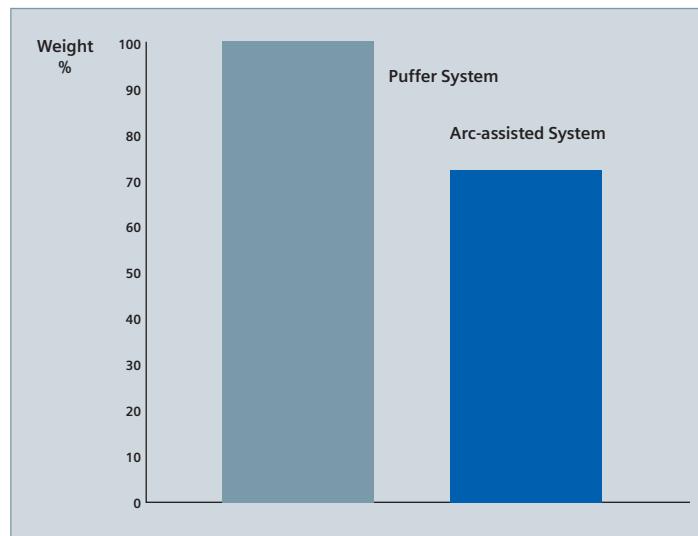


Figure 8: Weight for a 550 kV circuit breaker with different arc-quenching systems

5 Summary

The explanations show that a consistent exploitation of the energy from the arc reduces the necessary operating energy for arc-quenching. The self-compression interrupter system with arc assistance is able to fulfill all requirements for rated voltage levels from 72.5 to 800 kV with short-circuit breaking currents up to 80 kA according to current IEC and IEEE standards. For this interrupter system a spring- stored energy operating mechanism is the best combination for a modern circuit breaker. This breaker design is established in the complete product portfolio from 72.5 kV up to 800 kV in live-tank and dead-tank circuit breakers, DTC (dead-tank compact in hybrid technology) and GIS/HIS.

The manufacturer has to handle only one system. The manufacturing process is optimized and very efficiently for purchase high quantity of each parts, time of passage in assembling and routine-testing. The result is a high quality of all products. The customer participated from the high quality level of one system and from the operating experiences for this product family which adding up to more than 450 000 circuit breaker bay-years.

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Three-Pole Controlled Auto-Reclosing of Shunt Compensated Transmission Lines

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1. Introduction

Energising and re-energising during an auto-reclosing operation of shunt compensated transmission lines cause switching overvoltages on the transmission lines. The use of circuit-breakers equipped with closing resistors is a conventional method to reduce these switching overvoltages. Another method to limit these switching overvoltages is the installation of surge arresters to protect the electrical equipment. In some rare cases synchronous control units have been applied as an alternative method to reduce the switching overvoltages.

This paper presents a new controller for a synchronized energising of a shunt compensated transmission lines during auto-reclosing using signal evaluation methods to calculate the prospective characteristic of the voltage across the switching contacts of the circuit-breaker. This algorithm takes into account the electromagnetic and electrostatic coupling of the pole re-energised first to the second and third closing pole. By the comparison between existing solutions of re-energisation of shunt compensated transmission lines in an auto-reclosing operation the advantage of the new controller is shown.

2. Switching overvoltages on transmission lines in general

Re-energising of a shunt compensated transmission line during a three-pole auto-reclosing is a rapid changing of the system parameters of the electrical network generating transient overvoltages.

To compare the switching overvoltages caused by reenergising using the new controller with existing solutions simulations were carried out with the Alternative Transient Program (ATP). Figure 1 shows a schematic network diagram for a 550 kV application.

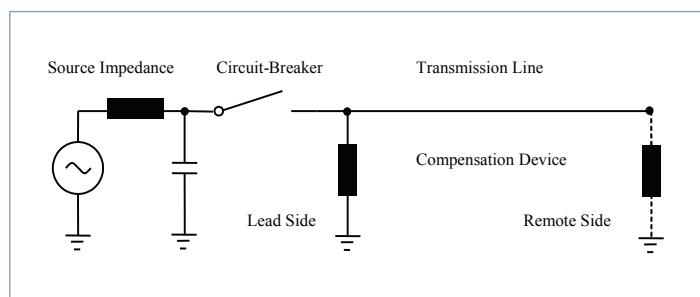


Figure 1: Schematic diagram of the shunt compensated transmission line network

The supply side is represented as source impedance and an ideal voltage source. The prearcing of the circuit-breaker includes the rate of decay of dielectrical strength (RDDS) characteristics of the circuit-breaker. Therefore the prearcing starts when the voltage difference from source and line side falls under the RDDS characteristic of the circuit-breaker. Common values for the RDDS characteristics are between 0,5 and 1,0 p.u./ms.

The interconnection point of the compensation device was varied between the lead, the remote and both sides of the transmission line. The degree of compensation was varied between 30 and 80%. The transmission line was modelled as a travelling wave model and 300 km long. In case of simulation with surge arresters they were applied at the remote line side and the parameters of the surge arresters correspond to line class 5 surge arrester. The maximum switching overvoltages at the remote line side under different conditions of energising a shunt compensated transmission line are shown by the way of the cumulative frequency distributions (cdf) as a result of the simulation in Figure 2. Without any limiting measures the overvoltages reach values up to the range of 3.0 times higher than the rated line-to-ground voltage on the remote line side (1 p.u. = 450 kV in a 550 kV network application). With the installation of surge arrestors the peak values are limited to the protection value of the surge arrestors and reach values in the range of 2,3 p.u. Another conventional method to reduce these overvoltages is the use of circuit-breaker fitted with closing resistors. In such cases the switching overvoltages are substantially reduced in the range of 2,0 p.u.

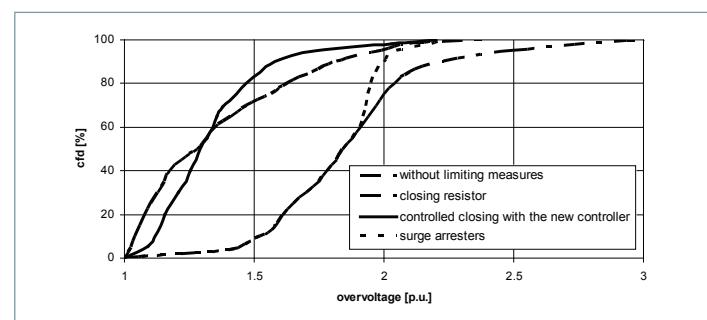


Figure 2: Cumulative frequency distribution for overvoltages

- Without limiting measures;
- Using closing resistors, only;
- Controlled closing with the new controller;
- Using surge arrestors, only

The simulation with the new controller shows that switching overvoltages are reduced in the range up to 2,0 p.u. Compared with the classic methode, the use of closing resistors, the number of switching operations with higher overvoltages is even lower. In addition the maximum overvoltage for both applications is given in table 1.

Quantil	Closing resistor	New controller
95 %	2.05 p.u.	1.95 p.u.
99 %	2.38 p.u.	2.13 p.u.

Tabel 1: 95 % and 99 % value for switching overvoltages for different closing strategies

The results show the advantages of the controller for controlled closing of a shunt-compensated transmission line during an auto-reclosing.

For the controlled closing of the circuit-breaker it is necessary to have the electrical contact at optimal time instants in the three poles, that means at voltage zero across the contacts of the circuit-breaker. For calculation of the time instants for energising, the voltage signals across the circuit-breaker have been analysed.

3. Estimation of the voltage across the circuit-breaker during a three-pole auto-reclosing operation

During the dead-time of a three-pole auto-reclosing of a shunt compensated transmission line voltage oscillations appear after opening the circuit-breaker on the line side. The frequency of these oscillations during the dead-time of the auto-reclosing is defined by the resonant circuit of the individual phase and depends on the design of the transmission line and the degree of compensation and it is different in each phase.

The voltage across the contacts of the circuit-breaker is the voltage difference between source and line side voltage. To achieve the closing at voltage zero it is necessary to estimate the voltage signal across the open contacts of the circuit breaker during the dead-time in each pole.

To get this signal information different methods of calculation are used. A conventional method is the use of pattern recognition [1].

3.1 Pattern Recognition

The algorithm based on pattern recognition analysed the envelope curve of the oscillation voltage signal across the open contacts of the circuit-breaker. The calculated switching instant should be close to the node point of the envelope curve, which means voltage zero across the contacts of the circuit-breaker. The result of a simulation based on the pattern recognition method is shown in Figure 3 for a 80 % compensated transmission line.

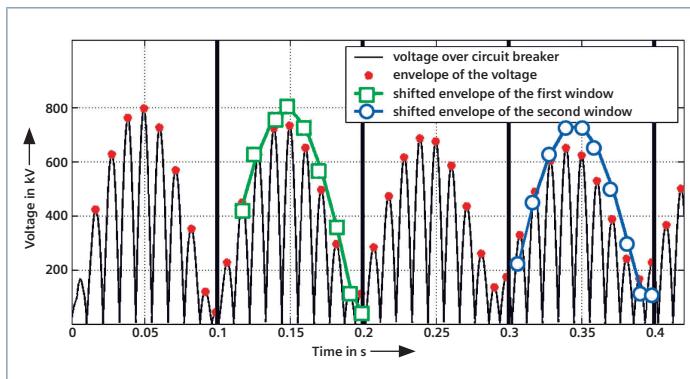


Figure 3: Calculation and switching instant (80 % compensation degree)

The figure shows the voltage across the circuit-breaker as an absolute value. The first time window (0 to 100 ms) is used for scanning the incoming voltage signal. In the following second time window (100 to 200 ms) the envelope curve is calculated, parallel the actual voltage signal is scanned again. In the third time window (200 to 300 ms) the comparison with the calculated and shifted envelope from the first time window with the second scanned signal occurs.

The time shift parameter corresponds to a fixed length of time window. If a correspondences of these two envelops is detected the time instant could be calculated in the fourth time window (300 to 400 ms) by shifting the second scanned window.

In the example the earliest calculated re-energising is in the fourth window after 0.39 s. To re-energise at the previous node point in this constellation it is not possible due to the fixed time window length of 100 ms and the necessity of minimal three cycles for calculation.

Another problem of the algorithm used pattern recognition is the dependence of the time windows length from the oscillated frequency. To show this dependence simulation are presented in Figure 4 with different lengths of time windows on a 30 % compensated transmission line.

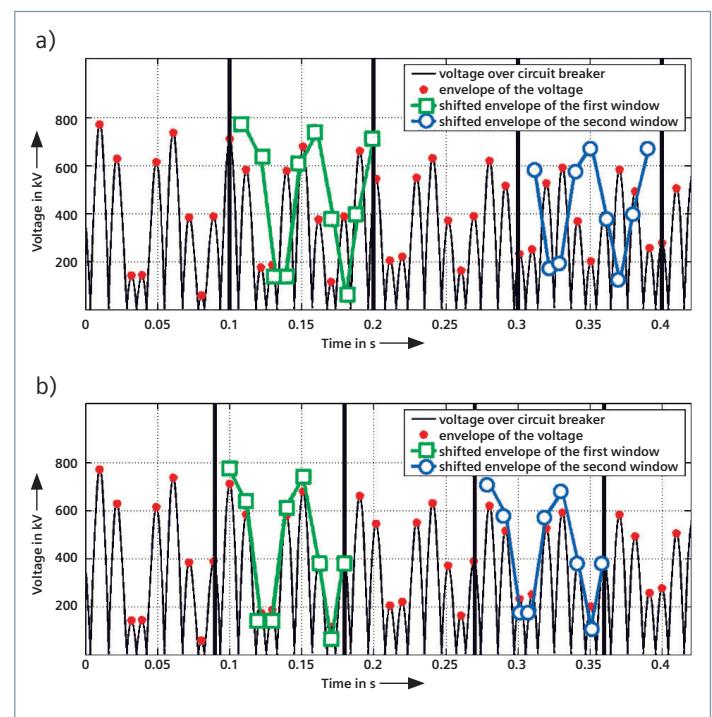


Figure 4: Calculation and switching instant (30 % compensation degree),
(a) window length – 100 ms,
(b) window length – 90 ms

Figure 4 (a) shows the calculated envelope for the time window length of 100 ms used in the example before.

The calculated node point of the shift envelope voltage curve give in this case an insufficient result of the calculation. By variation of the time window length (reducing to 90 ms) it gives a sufficient result for the controlled closing (see Figure 4 (b)).

The results of simulation show a dependence of the algorithm used pattern recognitions for calculating the switching time instant. On the one hand the earliest time instant for re-energising could be first in the fourth time window of calculation. If the time window length is e.g. 100 ms the earliest closing is possible between 300 to 400 ms. On the other hand there is a strength dependent between the length of the time window and the degree of compensation e.g. no sufficient result in the second example with a time window of 100 ms.

The main advantage of the algorithm via pattern recognition is a low amount of microprocessor-power. Therefore results are possible for define ratio of compensation, that means a fitted time window length for the calculation. This dependence limits the application of the algorithm via pattern recognition due to different degree of compensation under service conditions.

3.2 Prony Method

The algorithm based on the Prony Method [2] and used in the new controller superimposes the actual waveform across the open circuit-breaker by a sum of sinusoidal and exponential damping functions. The time window length used for calculation has likewise a constant length.

The lowest recognisable frequency is independent of the evaluation window used for scanning the incoming voltage. The scanned data samples are described by the following summation with a p-term complex exponential model.

$$(1) \quad x[n] = \sum_{k=1}^p A_k \exp[(\alpha_k + j2\pi f_k)(n-1)T + j\theta_k]$$

In this equation the signal is spited in the amplitude A_k , the damping factor α_k , the sinusoidal frequency f_k and the sinusoidal initial phase shift θ_k . For real data samples the complex exponential (1) can be written as complex conjugate pairs of equal amplitude in the form

$$(2) \quad x[n] = \sum_{k=1}^p h_k z_k^{n-1}$$

where the complex constants h_k and z_k are defined as

$$(3) \quad h_k = A_k \exp(j\theta_k)$$

$$(4) \quad z_k = \exp[(\alpha_k + j2\pi f_k)T]$$

The algorithm is divided in time windows. In the first time window (0 to 100 ms) the signal is scanned. In the second time window the parameters of the signal from the first window are calculated, likewise the voltage signal is scanned again. By a comparison between the measured and calculated signal, the quality of the parameters can be fitted. The first comparison begins in the third time window and ends with re-energising of the transmission line. The voltage signals calculated by the use of the Prony methode from the examples used in chapter 3.1 are presented in Figure 5.

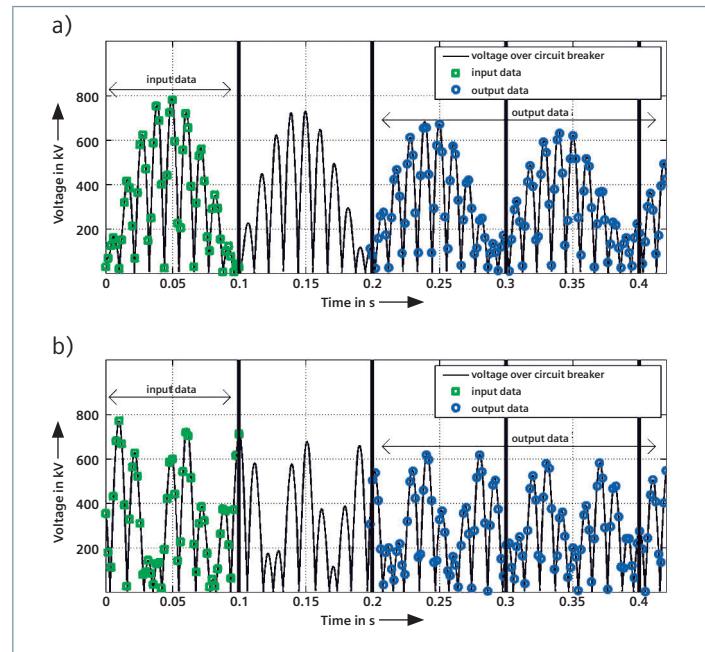


Figure 5: Calculation and switching instant,
(a) 80 % compensation degree,
(b) 30 % compensation degree

It is an advantage of this algorithm to calculate signal components independent of the time length of the calculation window. Based on these results the future of the oscillated voltages can be exactly calculated, including the rate of rise at voltage zero crossing.

Using this algorithm allows to calculate any time instants for controlled closing beginning with the third time window. Circuit-breakers with closing times of 50 ms can be re-energised with dead-times of 300 ms for any degree of common compensation level. The lowest simulated level of compensation was 30 %. Incorrect results may occur in the presence of high noise levels, which may be created by analog digital Converters. To avoid these phenomena numeric algorithms are used [3].

A main advantage using the Prony Method is the exact information of the estimated signal at voltage zero crossing. Based on this information the optimal switching instant can be calculated including the RDDS characteristic of the circuit-breaker.

4. Optimal switching instants

The optimal switching instant for energising of transmission lines is the time instant at voltage zero across the open contacts of the circuit-breaker. If the RDDS characteristic of the circuit breaker is lower than the decay at voltage zero of the oscillating voltage the target closing instant of the circuit-breaker has to be shifted out of the optimum switching instant (see RDDS characteristic S1 in Figure 6).

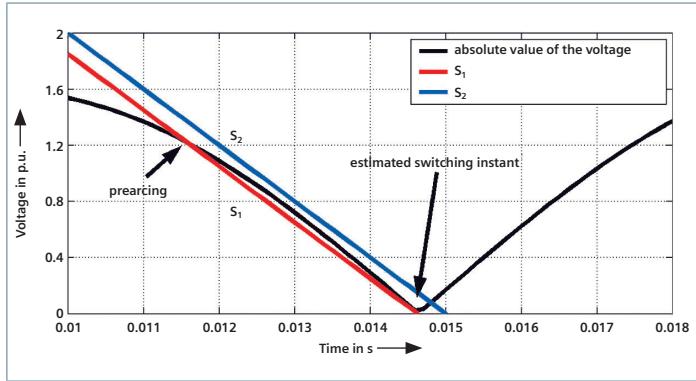


Figure 6: Comparison between RDDS and oscillated voltage

Without time shift the pre-arching takes place before the estimated switching instant. Therefore a time shift out of the estimated switching instant is important. The length of the time shift depends on the RDDS characteristic and the waveform of the estimated voltage. S2 shows the shifted RDDS characteristic curve in Figure 6.

After re-energising the first phase, the calculated voltage zero crossings for the second and third closing poles are no longer valid caused by the mutual influence of the first energised phase. After energising the first pole the oscillation voltage changed the waveform in the other two poles.

A switching sequence to minimise this influence was created. Therefore the pole with the smallest rise of voltage at voltage zero crossing will be calculated and will be the pole re-energised as third pole at this time instant. The voltage zero crossings of the other poles immediate before this calculated time instant are the switching instants for these poles. If there are no preliminary zero crossing close to the pole, the second smallest rise of voltage in zero crossing will be selected. With this closing sequence a minimisation of switching overvoltages in all three poles is given.

An example for a calculation of the time instants for controlled closing including this closing sequence is presented in Figure 7. The voltage zero crossing with the smallest rise is detected in pole L3 and select for the third closing instant. The preliminary zero crossing in pole L1 (second switching pole) and L2 (first switching pole) are the switching instants of the other poles.

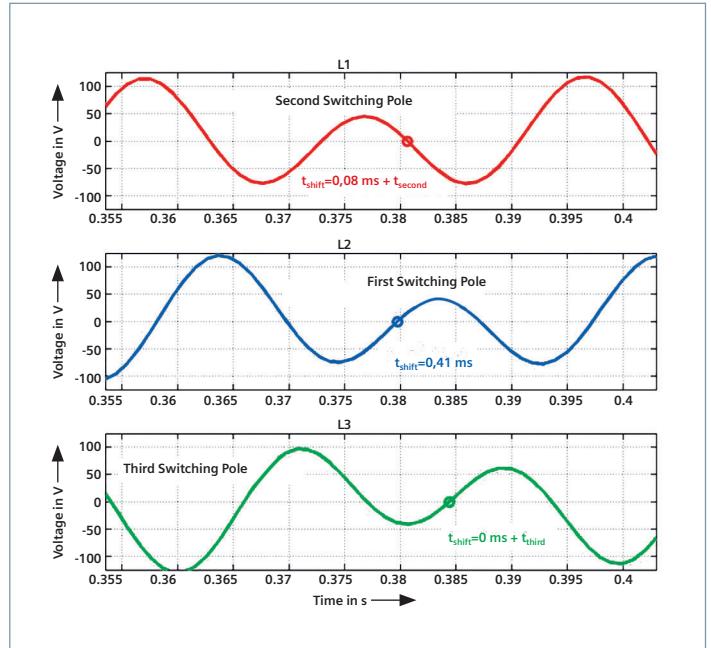


Figure 7: Selection of switching instants

In case of compensated lines is to re-energise at voltage zero across the contacts of the circuit-breaker is an essential requirement but not a sufficient assumption. To improve the controlled switching the rise of voltage on the bus bar and on the line side has to be taken into consideration. The closing operation will be achieved if both voltages have the same rise.

In comparison with the pattern recognition the Prony Method needs higher demands on the power of the microprocessor. Therefore the time interval for the calculation is independent of the compensation. The other advantage is the exact calculation of the signal used for the minimisation of the mutual influence of the first energised pole to reduce switching overvoltages.

5. Results of the simulation

The next step was testing the algorithm under a real-time environment. Therefore the toolbox xPC from Matlab was used together with a Pentium PC with 350 MHz as target hardware. More than thousand combinations of different source, transmission line and compensation devices parameters have been tested (e.g. length of the line, transposition, damping, short-circuit power of the supplying system, location and the ratio of compensation and the position of the failure were varied). Figure 8 gives the voltage curve for one closing operation for the three poles for a particular example.

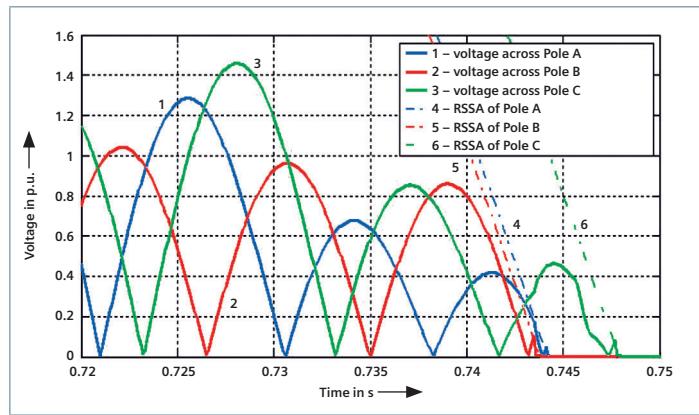


Figure 8: Example for the simulation of a controlled closing during a three-pole auto-reclosing

The voltages across the poles of the circuit-breaker are represented by absolute values. After energising the first phase (red curve) a voltage influence occurs in the other two poles. The making voltage of all poles in this simulation are less than 0,1 p.u. The values of the making voltage over all simulations are presented by the way of cumulative frequency distribution in Figure 9. The maximum values over all variations for the last closing pole is 0.6 p.u. The 50% value is 0.3 p.u. These values correspond with an overvoltage at the remote line side shown in Figure 2.

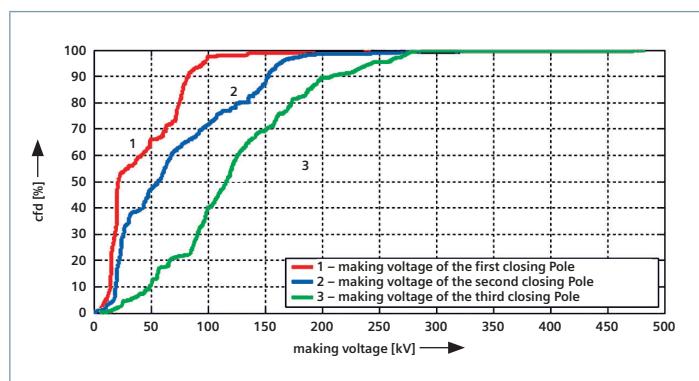


Figure 9: Results of three-pole auto-reclosing

6. Controller PSD03

The design of the new controller PSD03 (Point-on-wave Switching Device) based on more than 10 years of experience with controlled switching. This includes applications e.g. capacitor bank and reactor switching, energising of transformers and uncompensated transmission lines up to 800 kV. The new controller PSD03 continues this tradition. Based on the approved technology the new design is an enhancement (Figure 10). The oscillate voltage signal is calculated with an add-on processor. Therefore no change in the approved technology has been carried out.



Figure 10: Controller PSD03 for applications e.g. controlled switching of shunt compensated transmission lines

7. Conclusion

The advantage to calculate the exact future of the oscillation voltage during a three-pole auto-reclosing via the Prony Method is shown. Re-energising the compensated transmission line after the dead-time at an optimum time instants can be done. With the knowledge of the RDDS at voltage zero crossing a closing sequence can be given reducing the mutual coupling caused by the line energised first.

For an optimal controlled closing operation with small transient overvoltages at the remote end of the transmission line, the closing operation in the voltage zero crossing is not sufficient enough. To get satisfactory results the complex closing strategies include the rise of the bus bar and the line side voltage during the dead-time of the auto-reclosing. Therefore an algorithm based on pattern recognition is not suitable.

With controlled closing of the circuit-breaker the switching overvoltage is reduced to values known from circuit-breakers fitted with closing resistors. Therefore controlled closing is an alternative relating to the switching overvoltages. Concerning economical aspects controlled closing is an alternative. In the future field test of re-energising of compensated transmission lines with the controlled switching device PSD03 are planned. Controlled re-energising of compensated transmission lines will reduce the stress of the electrical equipment.

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Norbert Trapp

High-Voltage Circuit-Breakers – Certified Quality

Product Certificate – what is it and in which way can I benefit from it?

What is a product certificate?

A product certificate gives evidence for both,

- the manufacturer's competence to produce the regarded circuit-breaker to the relevant laws, standards and rules and
- the fulfilment of all pertinent standards by the regarded circuit-breaker.

In a product certificate it is confirmed that the manufacturer applies a certified quality management system in accordance with ISO 9001. Furthermore, the strict conformity of the product to the applicable standards, i.e. for example IEC 62271 – 1 and IEC 62271 – 100, is certified. This includes the conformity of the rated values, the design, the routine tests and the completeness of successful type tests to the applied standards in their presently valid editions – please, find also the illustration in appendix 1. The product certificate may also comprise tests in addition to the usually mandatory type tests, tests to any other standard or a client's specification.

The term "Product Certificate" must not be mistaken for the term "Type Test Certificate"; the latter describes a certain level of a type test report which may be issued, if in addition to the relevant standards certain rules given by STL (Short-Circuit Testing Liaison) are fulfilled. Product certificates comprise distinctly more than type test certificates, as those are just one of the five elements of product certificates.

Who is authorised to issue a product certificate?

A product certificate is issued by an independent certification body which is accredited on the basis of ISO/IEC 65 and EN 45011. The product certificates held by Siemens – please, find them listed in appendix 2 – are issued by the certification body of PEHLA Product Certification (Germany), a member of STL like for instance CESI (Italy) and KEMA (Netherlands). PEHLA Product Certification is accredited by "Deutscher Akkreditierungsrat (DAR)" and is presenting themselves on the following web-site <http://www.pehla-certificate.de/index.htm> and a list of product certificates issued is shown under the category "Certificates" in <http://www.pehla-certificate.de/english.htm>.

Which are the conditions to be fulfilled

by the certified product?

Every condition concerning design, construction and testing given by the relevant standards has to be covered by the product. The ratings of the circuit-breaker have to be according to the standards and proven by successful type tests in independent and accredited STL laboratories strictly in accordance with the relevant standard and the applicable STL rules. The design of the tested specimens of the circuit-breaker has to be identical to the drawings submitted by the manufacturer; the identification of each specimen tested has to be strictly without any gaps. Evidence has to be given that the routine tests are carried out fully in accordance with the relevant standards. By the use of the manufacturer's quality management system a high product quality is safeguarded. It is secured that the design type-tested is maintained throughout the entire product life span.

Which are the conditions to be fulfilled by the manufacturer of the circuit-breaker?

The manufacturer must apply a quality management system according to ISO 9001, including appropriate structures and processes in organisation, development, procurement, production and quality assurance; the manufacturer must hold a valid quality management certificate issued by an authorised certification body (normally different from the body authorised for product certification). Modifications of the product have to be explained immediately to the product certification body. In the case the conditions for granting the certificate are no longer met, the certification body will withdraw the product certificate or impose conditions on the manufacturer which he has to fulfil in order to keep the product certificate.

Which is the period of validity of a product certificate?

At first the validity is limited two five years, if neither the design of the product nor the relevant standards and specifications change in this period of time. Furthermore, the quality management certificate must be kept by the manufacturer without any interruption. In case of changes the product certification body decides on the steps necessary to maintain the product certificate. The manufacturer has to inform the certification body about every design modification which may touch the validity of the certificate. After the validity period of five years the certificate may be prolonged by another five years, if both the standards and the design of the product remained unchanged.

What can the client benefit from the product certificate?

The client can rely on the judgement of experts in the field of high-voltage circuit-breakers, who verified the full conformity of the circuit-breaker with all relevant standards, including design, type tests and routine tests. Furthermore, it is confirmed that the manufacturer of the circuit-breaker holds a valid quality management certificate. Complete evidence on these facts is given in a single document. The client has no longer to check the variety of documents (mostly many hundreds of pages of test reports, drawings etc.) in finicky work lasting for days or even longer. Now the clients assure themselves by means of no more than a few pages of the certificate of the high quality level of the product they are going to purchase. Independent experts, who have already done the entirety of technical and formal checks, account for the compliance of all relevant rules, standards and laws.

The completeness of the documents on which the circuit-breaker is based on is always ensured. The certificate is continually founded on the respective current version of the standards.

The client does not need to engage own personnel with expertise in the complicated and often changing details of the standards. Nevertheless, if requested by the client the documentation or parts of it can be handed over to the client either in paper or in electronic form.

By the use of the product certificate, it is easy for the client to make a distinction between a high quality circuit-breaker and a low level product which may even seem to be type-tested to the standards, however, some minor but not less important facts may be missing without becoming conspicuous to a less experienced eye.

Complementary explanations of the manufacturer are verified by an expert, it is no longer the client's task to check whether the manufacturer's arguments hold water or not.

In the past the client got a pile of test reports. But these documents did not content evidence on the quality management system of the manufacturer. The fulfilment of the requirements regarding design and construction and the conformity of the routine tests with the relevant standards were not included, too. Thus, the product certificate represents a higher level and an improved quality of product documentation.

Since the product certificate is always based on the present status of the relevant product standards, acceptance tests requested and paid by the client are no longer needed as long as the client's specifications stay within the limits given by the standards.

Thus, the immense costs caused by type test repetitions can be saved. At any time the conformity with the present standards is ensured.

While a test report or even a type test certificate can always refer to the individual tested specimen of the circuit-breaker only, the product certificate relates to the entire type of the product, i.e. each of the great number of single copies of the circuit-breaker during its complete product life time.

How are product certificates used by the manufacturer?

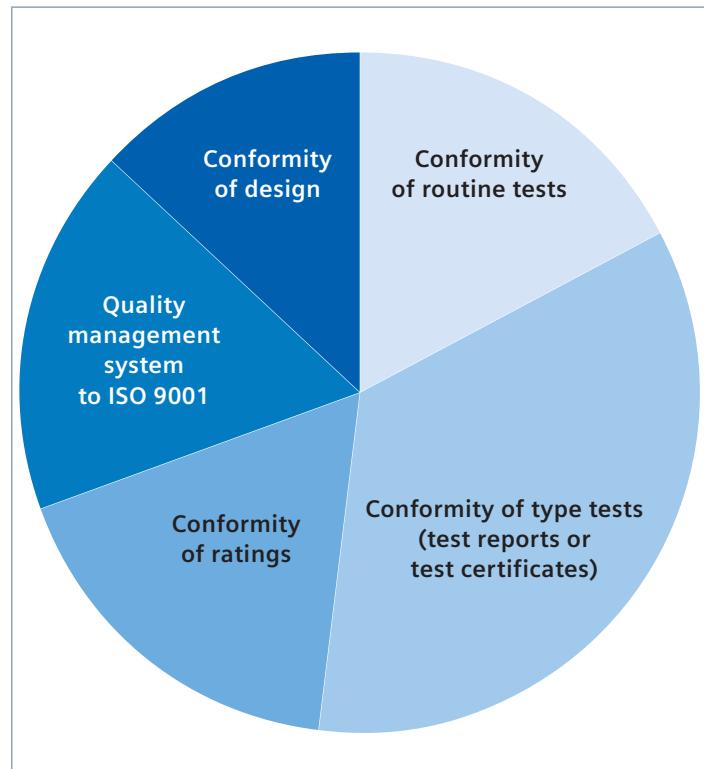
Normally the manufacturer is able to present product certificates for his main products. These product certificates are based on the relevant standards, in the regarded case on IEC 62271 – 1 and IEC 62271 – 100. IEEE applications are more or less covered, since the requirements of IEC and IEEE are almost identical.

If a client specifies a circuit-breaker strictly in accordance with the IEC standards, this circuit-breaker is usually completely covered by the product certificate, additional documents are not needed.

In the case of special requirements the client will get the product certificate which covers the standard requirements and in addition confirmations and manufacturer's declarations which are dealing with the requirements exceeding the limits given by the standard. The conformity of the respective circuit-breaker with regard to the additional features is confirmed by these supplementary documents. The same applies for minor deviations between the certified and the delivered design of the circuit-breaker, e.g. the circuit-breaker may be certified for a control voltage of 125 V and delivered for 220 V. In such cases the manufacturer gives the necessary evidence for example by means of a supplementary document as mentioned above provided the applied standards allow for these modifications and give justification for not to re-test. This procedure, in compliance with IEC 62271 – 1, subclause 6.1.2, avoids providing product certificates for hundreds of minor design modifications per circuit-breaker which would be with regard to costs and expenditure neither useful nor justifiable for both the client and the manufacturer.

In appendix 3 2 the product certificate issued for the circuit-breaker type 3AP1 – 245 kV / 50 kA / 4000 A / 50 Hz 3AP2/3 DT 550 kV – 4000 A – 63 kA – 60 Hz is shown as an example.

The Five Fundamental Elements of Product Certificates



Product Certificate



Product Certificate

Michael Gerlach

Capacity of switching test facility expanded

Investing in quality

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The Siemens Berlin switchgear plant, has been developing and manufacturing products such as low-oil circuit-breakers, SF₆ circuit-breakers, isolators, grounding switches, arresters, vacuum circuit-breakers and metal-enclosed switchgear for medium- and high-voltage installations since 1910. These devices are tested in an in-house switching test facility using two large generators with currents up to 100 kA and voltages up to 1050 kV in various ways including the use of synthetic test circuits.

To take into account market requirements and standards, customer requirements and ever-decreasing product development cycles, the development skills and the processes involved and used in test laboratories need to be constantly improved and adapted. In response, Siemens AG has invested a total of approximately 2.5 million euros over the past few years to upgrade its in-house test facility to address the above requirements as well as future requirements. The expansion of the synthetic test circuits and the installation of new instrumentation equipment in the switching test facility are described in detail below.

Synthetic testing

There is not a single performance test facility in the world where the installed generator output - not even the feed power available from the mains in mains-powered test facilities – is sufficient to generate the testing power required to test high-voltage circuit-breakers for voltage levels above 245 kV. The two surge-power generators in the test facility each generate a voltage of 20 kV at 50 kA or 35 kV at 40 kA. As a result, voltages far below today's standard nominal voltage levels for power transmission systems where voltages of up to 1100 kV on the one hand and currents of up to 100 kA on the other are reached. Admittedly, voltages can be stepped up to 420 kV using series-connected transformers though a sufficient current level is not reached in the process.

Synthetic test circuits are used for high voltage levels for this reason. When using these test circuits, the high current – 63 kA for short-circuit tests, for example – is supplied by the generator. The recovery voltage – i.e. the voltage which occurs in the system after the breaking of the short-circuit current, for example 420 kV – is supplied by a synthetic high-voltage circuit which includes a spark gap, a capacitor bank to be charged beforehand and various oscillating circuit elements.

Expansion of the synthetic breaking test circuit

The synthetic circuit technology at the Berlin test facility (Figure 1) has been expanded further over the past few years to take into account the increasing test requirements which have developed for high-voltage circuit-breakers as a result of the technical trend towards ever-increasing voltages for individual switchgear units.



Figure 1: Configuration of the first synthetic circuit from 1962 in the switching test facility

The latest and also most comprehensive expansion was initiated in March 2004, with the commencement of the planning phase, and successfully completed in September 2005 (Figure 2). The following objectives were set for this:

- to provide IEC-compliant facilities for testing up to a voltage level of 550 kV (previously up to 420 kV), including 4-parameter test circuits;
- to increase partial automation of the facility;
- to expand the synthetic making test circuit for single-phase tests at the voltage level 550 kV and three-phase tests at the voltage level 245 kV and
- to replace components, some of which were more than 40 years old.



Figure 2: New synthetic circuit after the upgrade in 2005

In the future, time will be saved when setting up circuits and new interconnections as a result of the partial automation of various capacitor banks. Four new capacitor chargers were set up containing a total of 136 capacitors, each with $40 \mu\text{F}$ at 25 kV, which can be switched by pneumatic remote control, individually or in groups, in series or in parallel.

A spark gap, consisting of interlocking cylinders with graphite electrodes, with a current-carrying capacity of up to 12 kA, was set up as the result of a redesign with a damped current flow duration of up to 300 ms. The new reactance coils produced by Trench in the oscillating circuit have been designed for higher voltages and higher currents while mechanical integrity has been improved at the same time. As a result, the possibility for expanding other test circuits has been provided for. By installing a new faster charging system for which the polarity can be reversed in a matter of seconds by remote control, charging voltages of up to 900 kV can be reached. As a result, tests such as the condition check in accordance with IEC 62271-100 can now also be carried out.

Expansion of the synthetic making test circuit

However for the purpose of performance tests, the relevant standards require not only breaking operations but also making operations under short-circuit conditions. A synthetic making test circuit developed by the Russian test institute VEI in Moscow was put into operation for voltages of up to 420 kV with currents of up to 63 kA back in 2003 (Figure 3). The set-up chosen, with a rotating self-centering arc and a simple self-triggering system, means that the equipment is extremely reliable, as is the triggering process.

With the implementation of a second stage within the synthetic making test circuit, it is now also possible to carry out making tests for rated voltages of up to 550 kV with currents of up to 63 kA. The set-up chosen, in the form of two independent units, has also made it possible to carry out three-phase making tests for rated voltages of up to 245 kV.

As a result, it is possible to carry out tests based on test requirements in accordance with IEC 62271-100 up to rated voltages of 550 kV/63 kA as the non-salient pole and 800 kV/63 kA as the half-pole in line with IEC and other standards at the high-power test facility in Berlin.



Figure 3: Synthetic making test circuit: spark path tower (left) and charging system (right)

Instrumentation equipment in the switching test facility

In order to meet the ever-increasing requirements being set for instrumentation equipment for switching tests, i.e. improved accuracy of measurement, faster transmission of measured values and evaluation as well as the simplification of procedures for producing test documentation, new instrumentation equipment from Bitgate has been successfully introduced in the switching test facility. The system is based on the analog-to-digital conversion of measurement data at the measuring point, with galvanic isolation between the measuring point and the display and processing location in the form of a fiber-optic link. The decision to choose this system was made after a test phase involving various commercially available systems. In the process, the systems were tested in the immediate vicinity (approximately 25 cm) of current-carrying conductors using a current intensity of up to 100 kA and voltages of up to 800 kV. The innovative configuration of the hardware, the practice-oriented selection of the fiber-optic conductors and their rugged plug connectors (MIL standard), the highly efficient shielding of the transmission modules against interference fields and the associated high mechanical integrity as well as the fact that the manufacturer guaranteed intensive collaboration during the integration of test facility-specific software solutions were all factors of decisive importance which lead to the system being chosen. After installing the system which consists of two units each with 15 measurement channels, including fiber-optic transmission, this was brought into use in January 2007 after a short running-in phase, and the old system completely eliminated. With the new system it is now also possible to fulfill the STL regulations (short-circuit testing liaison) for testing computer-controlled analysis systems. As a result, the system can thus also act as a reference measurement system in STL shunt calibration.

Components of the test system

Each channel consists of a transmitter (sensor) with a resolution of 14 bits, a maximum sampling rate of 100 MSample/s per channel, corresponding to 100 million measurements per second with a memory depth of maximum 1 GB total memory per channel. Each channel in the system functions as a separate, independent transient recorder and its parameters can be adjusted independently of all other channels. Despite this, display shows real-time allocation of the separate channels.

The transmitter is connected with a receiver module in the rack via a fiber-optic cable with a length of up to 3 km. Up to four transmitters can be connected to one receiver module. Depending on rack size and number, up to 256 channels can be recorded simultaneously (Figure 4).

A fiber-optic patch panel was installed in the test facility, this allowing any arbitrary transmitter in one of the three existing test halls to be connected with any of the receiver racks by patching short fiber-optic bridges. Digital transmission guarantees that a calibrated transmitter can be operated on any receiver module without losing calibration. In addition the system performs an automatic internal offset and gain compensation before each measurement.



Figure 4: Each transmitter (bottom right) can be connected with any receiver rack (centre) via a fiber-optic patch panel

After the measurement data from the transducer are acquired in the transmitter unit, they are then transmitted directly via the fiber-optics to the receiver in the rack. Pre-processing takes place there and the data are sent via a gigabit network to a connected PC for further processing. Within a few seconds of completing the measurement, the data can be displayed on screen. For display, two screens can be connected to the system to depict differently processed data and analyses in different windows. The operating system used is Microsoft Windows XP (Figure 5).



Figure 5: Both measurement values and pre

Thanks to suitable integration of Word as a report generator package and Excel for table calculation for processing measurement data and results, the possibilities for further data processing on the PC are extensive. Information can be generated in tables automatically or graphs and data transmitted by "drag and drop".

Sequential control allows not only free input of formulas but also selection of control actions and requests for parameter input or result-dependent jump operations. The user can program his own routines using the tools supplied or have the manufacturer develop these if the internal analysis functions for evaluation of the digital measurement signals for power test facilities using the algorithms suggested by STL, etc. are not sufficient. I/O boards can generate fiber-optic signals to control external devices, where an internal level trigger can be used to react to a measurement signal, and also receive fiber-optic signals in order to trigger a measurement for example.

A "live view" immediately after arming shows the active signals in a window similar to an oscilloscope. Here, on reaching a particular signal level, either the measurement proper can be triggered or a signal can be output to the fiber-optic output on the I/O board. In the test facility this option is used for diverter testing according to the latest standards by setting a controlled pre-load on the diverter and starting the electronic time control unit (sequencer) of the test facility at a set time. An optional converter in the receiver makes it possible to record light pulses by optical path meters as scalable routing via connection with an optic fiber.

The internal video player option allows measurement data and video data to be synchronized. It is irrelevant whether the data come from a webcam, a camcorder or a high-speed camera. Several players from different cameras can run simultaneously. This allows video recordings of tests to be synchronized with a current signal in the test facility.

The system is characterized by high resistance to the interference fields present in the test facility and has operated to date without any significant deficiencies. Even dropping a sensor complete with battery, weighing around 5 kg, from a height of around 1.5 m did not degrade system function, but merely left a hole in the concrete floor.

One particular feature of this facility is the close collaboration with the manufacturers in further development of software in parallel with operation of the test facility, taking into account the wishes of the test facility operator in connection with handling of the program and the inclusion of automatic analysis routines. The many years of experience of the test facility in handling digital measurement technology brings benefits for both sides. Integration of the fiber-optic system and digital transmission could bring substantial time savings in calibration and adjustment, and increased precision.

Control Room

As part of the renewal of the instrumentation equipment, the old equipment was removed from the test facility control room. Elimination of the instrumentation preprocessing room, which had since become too small, made room for a larger PEHLA observer and customer area. The preprocessing room was relocated to a larger adjacent area. These building measures improved the control room environment, leading to a more relaxed working atmosphere for the staff participating in the tests. This simultaneously allowed integration of the new instrumentation equipment inclusive of a fiber-optic patch panel.

Summary

The conversion and expansion of the synthetic test circuits has allowed the test facility to perform tests in-house, which previously had to be contracted out to external test facilities. This has led to savings in cost and time in the development of power switchgear. High readiness of the test facility ensures prompt response to widely varying test requirements. Introduction of the new instrumentation equipment leads to more accurate measurement values with a more efficient, time-saving approach. This also facilitates the generation of test documentation due to simplified processing of the oscillograms produced. Upgrading tidied up the control room, yielded a less stressful working atmosphere and thus allow test engineers, customers, observers and acceptance test inspectors to concentrate better on their work.

Karl Mascher, Klaus Schuler, Peter Stenzel

Development Process for High-Voltage Circuit-Breakers

1 Introduction

Circuit-breakers have a protective function in high-voltage transmission and distribution systems. High reliability and continuous availability of these important components are basic long-term service requirements. Circuit-breakers are used in all environmental conditions in countries throughout the world. The market requirements for switching capacity, space saving, more integrated function, product- and live cycle costs are constantly on the increase. The consequences for manufacturers of this rapid technological progress are shorter development cycles. As a global market leader in high-voltage circuit-breakers, Siemens has over 100 years of experience and know-how. Design and test engineers with long-term experience, modern design tools, an extensive range of test equipments, excellent connections to universities and research institutes, established cooperation with suppliers and outstanding production techniques all form the basic for successful products.

2 Development process

International standards like IEC and IEEE set out the requirements for designing and testing circuit-breakers to guarantee standardized operability worldwide. These standards, along with special customer requirements and the Siemens management handbook for quality, environmental protection and health and safety protection based on DIN EN ISO 9001 and DIN EN ISO 14001 acts as guidelines during the development process.

The close linking of design and analysis procedures enables the design engineer to simulate the characteristics of the structure and performance of a new circuit-breaker on a computer before an actual prototype of the breaker exists. The results of basic tests on various components are an important part of the design input. Carrying out simulation, optimization and basic tests in the early phase of the design process takes some time, but significantly reduces expenditure on material, tools and very expensive development tests on complete breakers. Once the development tests are complete, the type tests on the pilot production series begin. Our own high-performance test fields fulfill the type test requirements, in line with international standards, for switching capacity, dielectric and mechanical tests. This paper describes the stages of the development process, from the first draft right through to delivery of the end product as well as the tools required. The process is shown in Fig. 1.

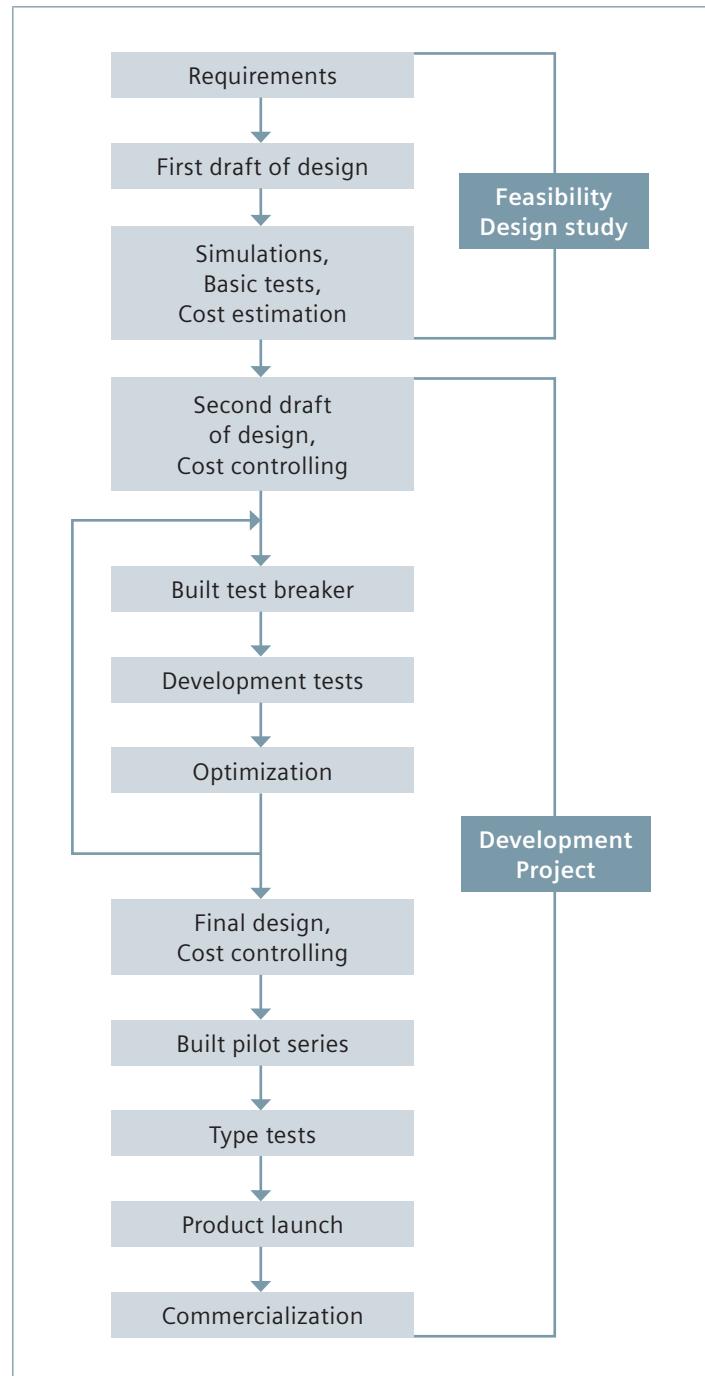


Figure 1: Workflow for the Development

3 Requirements

Development begins as soon as the product portfolio manager has supplied the project order, with all requirements set out in a marketing specification. The specification included technical, economical and environmental requirements.

Technical requirements:

- Type of circuit-breakers e.g. live tank, dead tank, GIS/HIS
- System requirements e.g. one interrupter per phase, self-compression system for arc-quenching, spring operating mechanism
- Insulating capacity
- Switching capacity
- Breaking time
- Mechanical and electrical endurance classes
- Ambient temperature range
- Pressure vessel codes
- Shipping requirements
- Relevant standards, special customer requirements

Economical requirements:

- Considering of modular design
- Product costs (material, production)
- Project costs (development cost)
- Product launch
- Manufacturing

4 First draft of design

The first draft of design for one or more variants shows the first ideas for a design which could meet the requirements. From the first draft right up to the final design, experts from all disciplines e.g. test fields; procurement, production and controlling provide their input, which is based on experience, new ideas and new production processes. The first design is only a 3D-CAD model and provides the basic for further CA calculation and simulations.

5 Computer simulation, basic tests, cost controlling

Extensive computer simulations and basic tests on sub-assemblies are more and more important in the reduction of development time and costs; when searching for the optimal form of components; for meeting the requirements of each part; and in the optimization of material costs. The first draft from the 3D-CAD-system is the basis for all analysis methods, which are based on the finite element method (FEM).

5.1 Computer simulation

5.1.1 Simulation of mechanical loads

- Switching reaction forces
- Terminal and flange loads
- Burst pressure loads
- Conductor current forces
- Wind loads
- Seismic loads

For single parts and complete components, the static and dynamic mechanical and thermal loads of the breaker must be simulated. Figure 2 shows the current density in a conductor arrangement. The current density is the basis for calculation of dimension of parts and components under short-circuit forces, e.g. 170 kA for duration of 3 seconds. Circuit-breakers that use gas, e.g. SF₆ for insulating and arc-quenching, are under constant pressure. The EN or ASME pressure vessel standards demand a burst pressure five times higher than the maximum working pressure. Using the stress analyses it is possible to optimize the vessel geometry to make sure that the stress and distortion are low and roughly balanced across all parts. The stress simulation for a vessel under burst pressure is shown in Fig. 3. The red parts are highly stressed and the sections have to be optimizing to lower value.

The analysis of the seismic withstand capability of high-voltage circuit-breakers also use the finite element method. The calculation considers the dead weight, inner pressure, terminal loads, force from wind speed and damping ratio. The results show the maximum displacement at the terminals and summary of maximum stresses for the components with the highest load under specified frequency spectra or real heavy earth quakes.

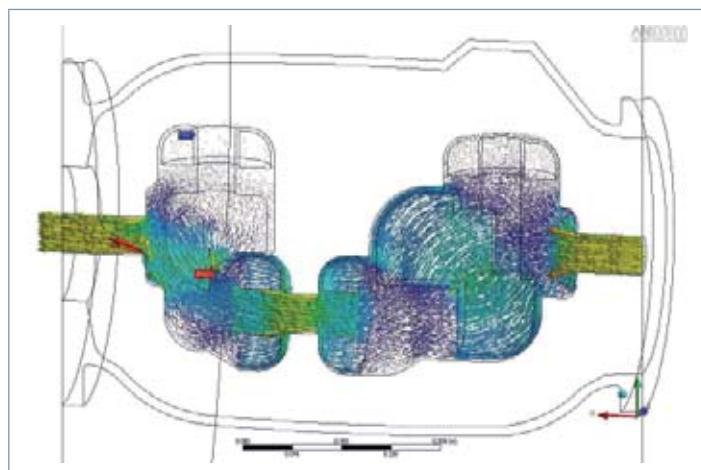


Figure 2: Current flow through a conductor arrangement

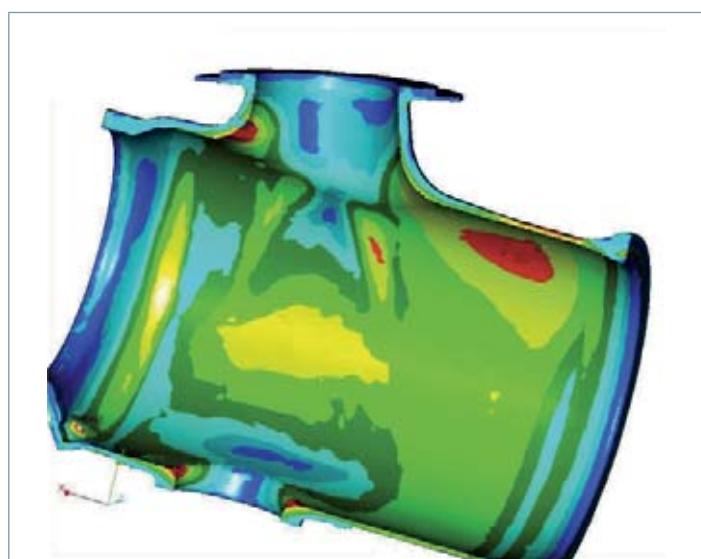


Figure 3: Stress simulation for a vessel under pressure of 50 bar

5.1.2 Simulation of dielectric loads

The simulation of electric field strength helps to optimize the contours from inside and outside parts of sub-assembly. Commercial programs for calculation of electric fields, which include different materials and dielectrics, use the boundary elements method. In case of the interrupter system it is possible to plot the field strength for different parts against the stroke during an opening operation (Fig. 4). This "dynamic calculation" indicates the speed required to open the contacts for a restrike-free capacitive switching, as well as the mechanical energy necessary for the operating mechanism.

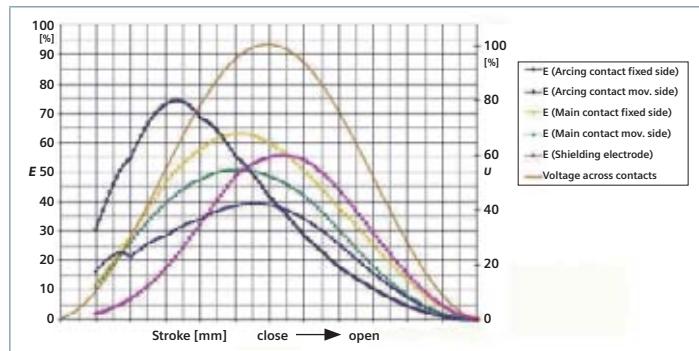


Figure 4: Electric field strength for an interrupter unit during capacity switching

5.1.3 Moving simulation of kinematic chain

The kinematic chain includes all moving components from the operating mechanism up to the interrupter unit. Fig. 5 shows a kinematic chain and the interaction between the interrupter system and operating mechanism for a GIS circuit-breaker. The simulation shows the velocity for single components during a closing or opening operation, e.g. time for contact separation or start of damping.

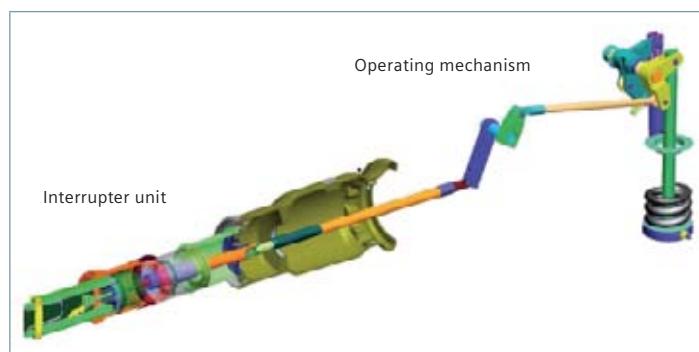


Figure 5: Kinematic chain for a GIS circuit-breaker

5.1.4 Simulation of gas flow

Modern high-voltage circuit-breaker use the insulation gas SF₆. During the current breaking process gas will be compressed and heated. This compressed gas will be used to cool the plasma column and for the deionization of the contact gap distance between the arcing contacts around the natural current zero-point. The Computational Fluid Dynamics (CFD) allows us to simulate these processes. A specialized self bespoke tool is used because of the complexity of the various physical effects taking place during the breaking process. The CFD simulation provides us with information about the SF₆ gas properties

(e.g. temperature, density) at important steps within the breaking process (e.g. instant of the maximum peak value of the transient recovery voltage), [1].

5.1.5 Basic tests

For these tests are primary the following laboratories available:

- Physic
- High-voltage
- Mechanic

Basic tests are important for fundamental studies and for verification of calculated loadings:

- For comparison of different parameters of the arc-quenching systems
- To find the right form or combination for different components in a system, e.g. form of nozzle or volume of heat cylinder
- To test the capacitive switching with calculated speed
- To test the mechanical endurances of components and sub-assemblies

Comparative examinations for the breaking capability can be carried out on original interrupter systems in a physics laboratory. The work this lab can carry out is described in detail in [2-4]. A laboratory with high-voltage testing capability is ideal for testing sub-assemblies, components and materials under dielectric loads. The mechanical tests lab accommodates a number of facilities. Heat run tests on components or complete breakers up to 6300 A, 60 Hz can be carried out there.

A hydro pulse system with two cylinders is usable for wide range of applications.

The high speed cylinder is used to simulate moving and impact loads. An input signal could be a speed or load characteristic, calculated or measured on a real breaker. During these tests on components, such as on an interrupter unit of a breaker, motion-sequences could be recorded using a high speed camera. The vibration cylinder is used for simulating transport shocks or material tests. An endurance test with 20.000 operations for an operating rod, takes 12 hours to complete.

160 hours are required to test a complete breaker with the same number of operations.

A graph plotting of force and stroke characteristics against time for an endurance test on an operation rod is shown in Fig. 6.

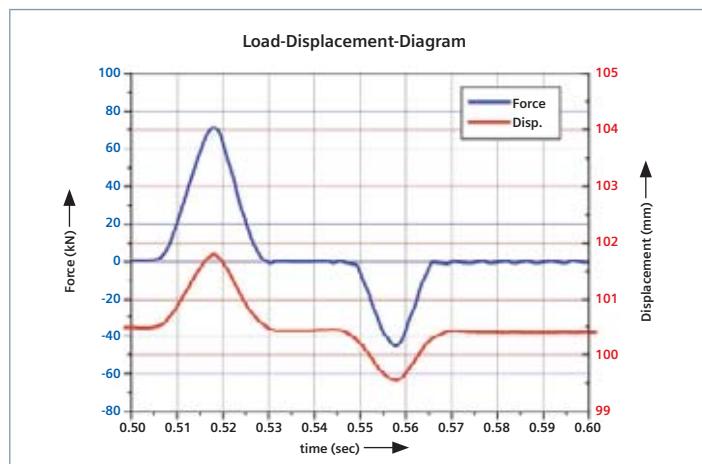


Figure 6: Endurance test for an operating rod on a hydro pulse system

5.1.6 Cost controlling

The calculation for the product costs begins with estimations and is constantly updated during the development process right up to final stage. Experience shows that most of the final product costs are fixed in the early phase of the development process with establishing of the design and manufacturing process of each part. Later in the development process is not possible to reduce significantly the product cost without altering the design.

6 Second draft of design

The second draft of design includes all results of fundamental computer simulations, basic tests, as well as estimated cost and is the document for procurement of the test breakers.

7 Built test breaker for development tests

Development tests are important for verification of all technical requirements. It is the first chance to test results of all fundamental computer simulations and basic tests on components and sub-assemblies in a complete breaker. Therefore, it is important to use sub-assemblies with their final material and design, e.g. aluminum casting. Alternative solutions could produce erroneous results and waste time and resources on

expensive tests. For some components it is practical to use rapid prototyping for the first production. For difficult casting components foundries use programs to simulate and optimize the complete casting process before the model is build. All these measures reduce technical risks and procurement time. For development and type tests of complete circuit-breakers, extensive test equipment is available in three test laboratories for high power, dielectric and mechanical tests. These laboratories are part of testing facilities of the Siemens switchgear factories in Berlin, accredited in compliance with to EN 45001 [5]. Technical data for the test equipments are shown in Fig. 7.

8 Final design and type tests

Once the development tests are complete and the design has been optimized, the production starts to build the pilot series in the final design. The pilot series is built on the production line, original tools and running through the routine tests. The type tests are for validation of all technical requirements of the final design. The test procedures will run in the accredited testing facilities of the Siemens switchgear factories in Berlin, or in third party testing facilities like PEHLA, KEMA or CESI in accordance with the international standards.

Technical data for test equipments	
Dielectric teste	
Power-frequency voltage	1800 kV
Lightning-impulse voltage	3000 kV
Switching-impulse voltage	1500 kV
DC-voltage	600 kV
Power tests	
Power for direct testing	7800 MVA
Equivalent power for synthetic testing	87 GVA
Short-circuit current at 35 KV (rms)	120 kA
Peak and short-time current, 3 phase	300 kA/120 kA, 3 s
Bus-transfer current switching by disconnectors	to IEC 1128
Individual current switching by earthing switches	to IEC 1129
Surge arrester testing	
Residual voltage measurements	
on arresters for 420 kV	up to 10 kA, 8/20 µs
on arresters for 245 kV	up to 20 kA, 8/20 µs
300 kV partial-discharge measuring cabin	Background noise level < 1 pC, even for routine tests
Mechanical tests	
Temperatur-rise testing	6,3 kA, single and-phase and three-phase
Climate chamber	
Volume	20 m ³
Dimension	4000 x 2000 x 2650 mm
Temperature range	-60 bis 80°C
Temperature difference (switching hysteresis)	3 °K
Hydro pulse system	
High speed switching cylinder (vertical direction)	250 kN
Vibration cylinder (vertical or horizontal direction)	50 kN

Figure 5: Technical Data for test equipment

9 Conclusion

The technical and economical requirements placed on circuit-breakers are constantly increasing throughout the world. Only with continuous further development in design, production and test facilities it is possible to manage these requirements and to produce competitive products. Siemens design and test engineers have extensive experience, technical experts from all disciplines, basic tests and the employment of modern design tools for computer simulation and laboratories with modern test equipments all form the foundation of product development. Consistent project management in accordance with development guidelines enables development to be transparent and succeeds, as well as reducing time and costs. Siemens has over 100 years of experience and know-how.

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Estimation of the measurement uncertainty of tests and calibrations in high-voltage test laboratories

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Abstract

When conducting tests with high voltages of some 100,000 V, special demands have to be imposed on laboratories and their voltage measurement equipment in order to minimise measurement uncertainty during tests and calibrations. To estimate the uncertainty of voltage measurements in accordance with GUM, the test circuit consisting of the voltage measurement system and the test object can easily be simulated by means of an iterative network of transmission elements. Important influencing factors include an inadequate distance from walls, a change to ambient conditions, interferences and corona discharges.

1. General

Circuit-breakers, disconnectors and surge arresters for use in medium-high voltage, high-voltage up to ultra-high-voltage (UHV) grids are just some of the products manufactured at the Siemens AG control unit in Berlin. These high-voltage devices are tested in high-voltage test laboratories to ensure that they are both usable and safe. Depending on the device standard, the product standards prescribe tests with, for example, alternating, direct and impulse voltages, as well as combination tests with these voltages. Reference is always made to IEC 60060 "high-voltage test techniques" in these relevant standards. Part 1 includes a general description of the test procedures, and defines the terms used. The test equipment is explained in Part 2, and parameters and limit values for test voltages and currents are defined. In addition to the tolerances to be maintained, draft 42/217/CD for edition 3 also specifies the maximum measurement uncertainties.

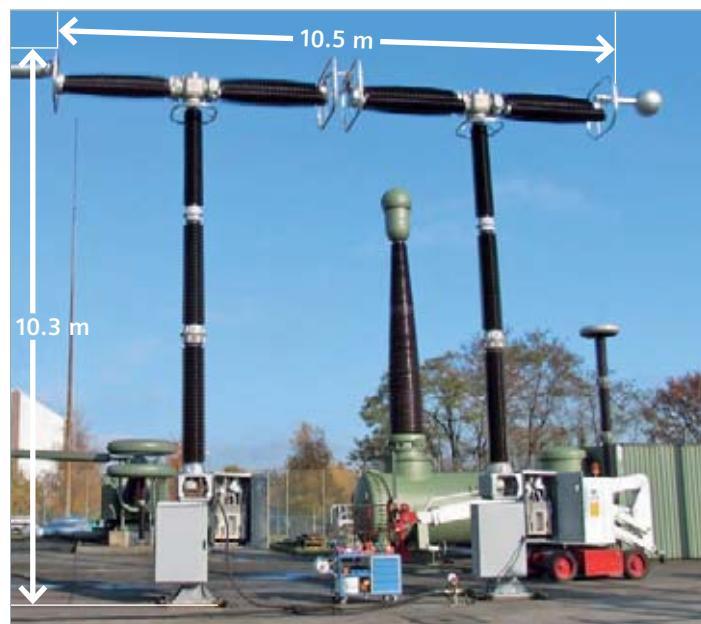


Figure 1: 800 kV circuit-breaker

2. Principle of high-voltage measurement

Depending on the level of the test voltage and the size of the test object, a high-voltage test circuit is always quite large. High-voltage and UHV devices for voltage levels of 550 kV and above boast impressive dimensions. Figure 1 shows an 800 kV outdoor circuit-breaker; breakers of this voltage level are around 10.3 m high and approx. 10.5 m long. Most test equipment is installed in indoor locations, but there are not many laboratory rooms with appropriate dimensions and equipment for testing high-voltage devices of this size. For this reason, high-voltage tests at the voltage level are often carried out in outdoor test bays.

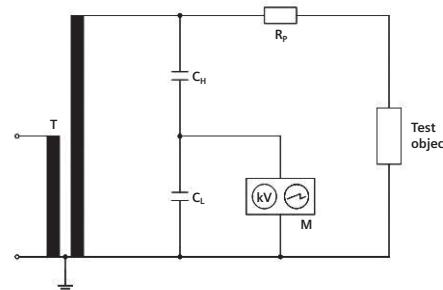


Figure 2: Test circuit for AC voltage

In order to determine the uncertainty of a high-voltage measurement, it is necessary to estimate the possible influencing factors. By using the example of an alternating current measurement, these parameters can be described in such a way that they are easy to understand. Figure 2 shows a typical AC test circuit with a voltage supply source T, a calibrated measurement system consisting of a high-voltage divider C_H and C_L , a measuring cable and the display unit M. The measurement system is connected to the test object via a connecting cable R_p .



Figure 3: 1800 kV Transformer in the outdoor test station

With voltage measurements, a voltage is created on the test object and is monitored using a measuring instrument connected in parallel. Although the measurement tells us the level of the test voltage on the measurement system, the test voltages required in standards must be shown on the test object itself and not on a measuring instrument installed somewhere near the test object. In the case of test equipment for high-voltage and UHV devices, not only are the test objects very large, but also their test equipment. The alternating voltage test facility shown in Figure 3 with a three-stage transformer cascade and high-voltage divider also occupies a large amount of space. This space requirement must be taken into consideration with high-voltage tests and calibrations.

3. Calibration of measurement systems

For a calibrated measuring circuit consisting of a high-voltage divider, measurement cable and display device, the definition of measurement uncertainty is recorded in the form of a calibration certification by means of a system calibration. If system calibration is not appropriate for technical or economic reasons, an individual calibration of all components in the measuring circuit can be performed. In the case of component calibration, the measurement system operator must define the measurement uncertainty of the overall measurement system. The length-dependent capacity and resistance load per unit length of the measuring cable must not be disregarded when determining the conversion ratio, particularly if the cable is several metres in length.

As a rule, calibrations are carried out in the air-conditioned rooms of a calibration laboratory. However, many measuring devices in high-voltage laboratories are not mobile and have to be monitored with on-site calibrations. Instead of a test object, a reference measuring system is set up in parallel with the measurement system being calibrated. By taking comparative measurements, a conversion ratio, scale factor and, if necessary, a correction factor are determined. The calibration laboratory then defines the measurement uncertainty of the test equipment to be calibrated, taking into consideration the measurement uncertainty of its own reference measurement system. The calibration result published in the calibration certificate (scale factor and measurement uncertainty) is only a snapshot. The calibration laboratory cannot define a validity period for the calibration as it does not know what happens in the test laboratory after the calibration. The operator defines a calibration interval based on his experiences, the load on the measurement system and other basic conditions independently. The measurement uncertainty defined in the calibration certificate and the

scale factor determined are only valid for the unchanged measurement chain. If the measurement system is set up at a different location, or parts of the measurement chain are exchanged for other calibrated devices, the operator must re-estimate the measurement uncertainty taking into consideration and specifying the changed basic and usage conditions; recalibration at the new location may be necessary.

4. Factors influencing the measurement result

There are many influences on a measurement system and the test object that are not always known and may need to be estimated. Below we will take a detailed look at the influencing factors that can be attributed to the test circuit and the ambient conditions. The list does not claim to be complete; on the contrary, the influences should be reassessed according to the test and the basic conditions in the laboratory. Other influencing factors should be taken from the relevant calibration certificates and the information supplied by the manufacturer on the test circuit components used.

Influencing factor	Caused by
Increased earth and stray capacitance	Distance from earthed or live parts
Drift error	Self-heating
Ambient temperature	Change to ambient conditions
Corona	Leakage currents
Other influencing factors	Depending on test assembly, measurement chain, initial conditions

Table 1: Influencing factors on high-voltage measurements

Distance from earthed or live parts

One of the most important influencing factors in high-voltage technology is the distance from other system components, ceilings or walls. As the distance decreases, the earth capacitance increases, which in turn increases the leakage current. The result is a measurable deviation in the voltage measurement.

The influence of a very narrow measuring cell on a test object or measurement divider can be readily proven.

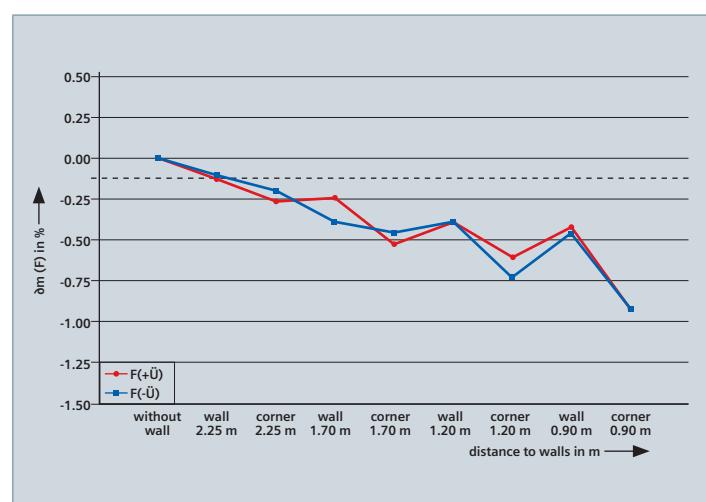


Figure 5: Influence of a wall distances on the measurement deviation at a test voltage of 150 kV

Drift error caused by self-heating

Capacitive high-voltage dividers are generally used to measure high alternating voltages, while damped-capacitive high-voltage dividers can also be used to measure pulses. In most cases, the measurement capacitor of a capacitive divider consists of at least one cylindrical capacitor located in insulating gas or insulating oil under pressure. The low-voltage part of the high-voltage divider is located in a separate housing. There are frequent changes to the capacities in the high-voltage part during use due to the heating of the dielectric, which results in a change to the conversion ratio. This influence can be reduced by implementing appropriate constructive measures. The manufacturer of the measurement divider should be consulted when estimating the drift error. The deviations depend essentially on the design of the measurement divider, as well as the voltage level and the duration of the test. It is not possible to specify a general recommended value in this respect.

The high-voltage part of damped-capacitive dividers is made up of an iterative network of capacitors and resistors in an insulating tube filled with oil. Depending on the quality of the components used, typical temperature coefficients would be $\alpha = -0.03 \dots -0.01\%/\text{K}$.

Influence of ambient temperature

The scale factors and measurement uncertainties specified in the calibration certificates are related to an ambient temperature of $20^\circ\text{C} \pm 5\text{ K}$, or $\pm 10\text{ K}$. Particularly in the case of outdoor test equipment, more extreme temperatures sometimes occur. These must be taken into consideration in the measurement uncertainty budget with high-voltage tests. In summer, surface temperatures of 50°C are not uncommon when there is direct insolation on dark porcelain insulators; similarly, temperatures can fall to -10° or lower in winter. The measurement error can be as much as several percentage points when there is a change of temperature. Deviations caused by changes to ambient conditions can be estimated in the same way as deviations caused by temperature drift. This uncertainty element only needs to be taken into account in outdoor test bays, as the temperature in test laboratories does not generally vary as much, and there is no direct insolation.

In outdoor tests, the influence of the environment is not only to be taken into consideration for the measurement divider, but also with regard to the test object, particularly in the case of oil or gas-insulated test objects. In the case of gas-insulated test assemblies, each tester must at least be satisfied that the correct (corrected) test pressure is being applied. Heating of the test object during the test as a result of an increase in the ambient temperature must be taken into account in the measurement uncertainty budget.

Corona discharges



Figure 6: Corona on shields

At high voltages, audible crackling and bright bluish corona discharges occur at the electrodes of high-voltage-carrying parts (measurement divider, feed cable, test object etc.) (Figure 6). The current pulses of the corona occur as a result of gas discharges igniting and going out when a critical field strength is exceeded. A discharge current flows, causing a voltage drop in the measurement system and/or at the test object. Corona discharges on assemblies can be avoided by selecting appropriate screens. The use of a pipe of sufficient diameter instead of a copper strand also prevents the onset of corona discharges at the voltage feed cable.

Other influencing factors

Depending on the test assembly and test, other influencing factors may need to be taken into consideration. Particularly in the case of surge voltage tests, the length and height of the voltage feed cable must be taken into consideration since the size of the area has an inductive influence on the pulse form, and also affects the time parameters and overswing in the case of quick pulses. In addition to poor earthing, the design, laying and length of the measurement cables can cause other problems, particularly with pulse voltages, as a result of interference voltage feed.

5. Estimating measurement uncertainty

Equation (2) can be solved by X:

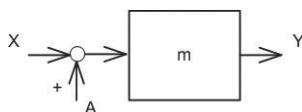


Figure 7: Transfer element

The PEHLA¹ working group 5, "Measurement Uncertainty" has decided to use an iterative network of general transfer elements – as illustrated in Figure 7 – to define the measurement uncertainty budget. An additive element (A) and an amplification factor (m) can therefore be defined for each individual element in a high-voltage test circuit. The output parameter Y can be calculated based on the transfer formula (1):

$$(1) \quad Y = m \cdot (X + A)$$

In this formula, X describes the input parameter. In an electrical system, for example, this would be the input voltage; the amplification factor m corresponds to the conversion ratio; disturbance variables or offsets would be combined in parameter A. The output voltage corresponds to parameter Y. By connecting several such transfer elements in series, the entire measurement chain from Figure 2 can be recreated (Figure 8).

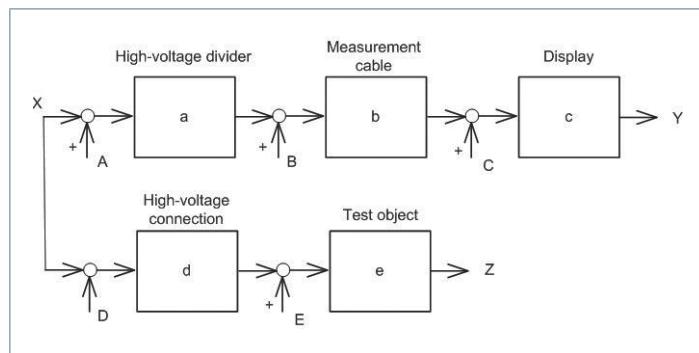


Figure 8: Measurement chain made up of transfer elements

In this measurement chain, Z describes the voltage actually present on the test object, while Y describes the test voltage measured by the measurement system. The transfer equations for these measurements chains can be derived easily:

$$(2) \quad Y = c \cdot (C + b \cdot (B + a \cdot (A + X)))$$

$$(3) \quad Z = e \cdot (E + d \cdot (D + X))$$

$$(4) \quad X = \frac{Y}{a \cdot b \cdot c} - \frac{C}{a \cdot b} - \frac{B}{a} - A$$

and used in equation (3):

$$(5) \quad Z = e \cdot (E + d \cdot (D + \frac{Y}{a \cdot b \cdot c} - \frac{C}{a \cdot b} - \frac{B}{a} - A))$$

Depending on the design of the measuring circuit, the measurement chains can easily be extended by inserting further transfer elements. The transfer equations (2, 3) are then completed accordingly. This formula can be transferred directly to common uncertainty analysis programs such as the "GUM Workbench".

Simplifications

When tests are conducted in a screened test laboratory in which temperature fluctuations are excluded during the test and adequate distances from walls and earthed parts are maintained, equation (5) can be simplified. In this case:

multiplicative influences do not occur on either the test object or the feed or measurement cable

$$(6) \quad e=d=b=1$$

no corona on the feed cable or interference on the measurement cable

$$(7) \quad D=B=0$$

Equation (5) is then simplified to give the following expression:

$$(8) \quad Z = E + \frac{Y}{a \cdot c} - \frac{C}{a} - A$$

Input parameter Y in equation (8) specifies the test voltage read on the calibrated measuring instrument, and parameter Z describes the voltage present on the test object. The influence factors are listed below:

- E: Voltage drop on the test object due to stray capacitance
- a Influences on the conversion ratio of the high-voltage divider due to heating, drift, measuring circuit, ambient conditions
- c Influences on the scale factor of the measuring instrument, which can be found in the operating instructions; unknown influences must also be estimated
- C Measuring instrument offset, which can be found in the manufacturer's instructions
- A Voltage drop on the measurement divider due to stray capacitance

Summary

Particularly in the case of tests conducted under high-voltages and in supergrids, the ambient conditions in the laboratories, such as distances from earthed walls and system parts, temperature effects and corona discharges must be factored in when determining measurement uncertainty, in addition to the test voltage. Many effects such as the influences of insufficient distances from walls or temperature changes can be recorded easily using measurement technology and specified in the measurement uncertainty budget. Other parameters, such as the influence of corona discharges, cannot be defined accurately, and must be estimated appropriately. An unfavourable test setup with poor ambient conditions can quickly result in a measurement uncertainty of several percentage points.

Notes on literature

- [1] GUM – Guide to the expression of uncertainty in measurement
- [2] IEC 60060-1 High-voltage test techniques, Part 1: General definitions and requirements
- [3] IEC 60060-2 High-voltage test techniques, Part 2: Measuring systems
- [4] ISO/IEC 17011 General requirements for the competence of testing and calibration laboratories

¹PEHLA: founded in 1960, brings together the high-voltage test bays of Germany and Switzerland under one roof. PEHLA carries out model and development tests in its test bays for domestic and foreign operators and manufacturers of electrical energy technology devices and systems. PEHLA has seven well-equipped individual test bays that have been accredited by DATEch, the German technology accreditation centre, in accordance with ISO 17025 since 1992. At international level, PEHLA is a member of the Short-Circuit Testing Liaison (STL).

Torsten Böttger

Pressure and leakage testing of cast aluminium vessels for high-voltage circuit-breakers

Durability, reliability and maximum availability in all the world's climates are what set Siemens high-voltage circuit-breakers apart. These switchgears use SF₆-gas as an insulating and arc quenching medium, meaning it is essential for the pressure and seals to be thoroughly tested for all cast aluminium vessels and covers to fulfil these criteria. This test is an integral requirement of the quality assurance process at the Berlin mechanical production facilities.

Mechanical production

Mechanical processing of aluminium unfinished castings in Berlin is carried out solely on CNC-controlled 4-axis drilling and milling centres. Fully-automated complete processing on these machining centres ensures consistently reliable quality during the overall machining process. It is particularly important to comply with the high quality requirements regarding the surface finish of the sealing surfaces and to ensure compliance with shape and position tolerances.

Figure 1 shows a cast aluminium vessel prepared for mechanical processing in a drilling and milling centre.



Figure 1: Unfinished casting housing in a machining centre

Preparations for pressure and leakage testing

Following the deburring and cleaning process, the cast aluminium vessels are prepared for pressure and leakage testing. All flange openings on the vessels are sealed with compression-proof test plates. Figure 2 shows a cast aluminium vessel in front of the pressure and leakage testing equipment. Screwed joints with a defined torque are used to secure the covers.



Figure 2: Installing the test plates

After the test plates have been installed, the test pieces are positioned on one of the stands in the pressure and leakage testing systems. The installed test plates have flanges for connecting the test pieces to the testing system. Figure 3 shows test pieces being prepared with compression-proof stainless steel tubes connecting the test pieces to the testing system.



Figure 3: Connecting the test pieces to the testing system

Conducting the tests

As part of the pressure and leakage testing procedure, technical safety (pressure testing) and functional safety (leakage testing) are verified for each individual component.

The whole test process is fully automated. The pressure is tested with air with up to twice the operating pressure (max. 22 bar) for a test period of one minute.

After the pressure test has been completed successfully, the leak tightness is tested with helium (max. 7.5 bar). The "sniff" principle is used for this test, i.e. the test piece is pressurized and the helium concentration outside the test piece is measured. The leakage rate of helium measured is converted into an SF₆ leakage rate and compared against the permitted leakage rate for the tested housing. The test period for the leakage testing is three minutes. The testing principle is illustrated in the diagram in Figure 4.

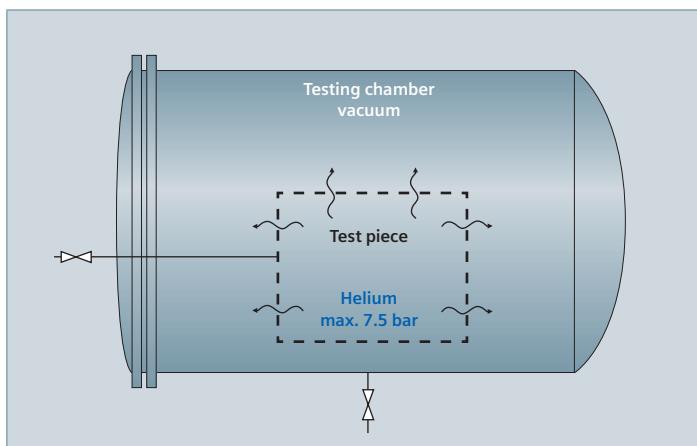


Figure 4: A diagram of the testing principle

Using helium for leakage testing offers a range of advantages over testing with SF₆. Chemically, helium is inert and therefore harmless to the environment and there is no direct risk to health. In addition, helium has better properties for leakage testing compared to SF₆ because helium molecules are smaller than SF₆ molecules. Measurements with helium therefore deliver more accurate test results.

Pressure and leakage testing is always conducted before the test pieces are painted. This ensures there are no test deviations as a result of pores closed by paint.

Following successful completion of the pressure and leakage testing, the test results are logged and saved by component in a database.

Figure 5 illustrates the testing sequence.

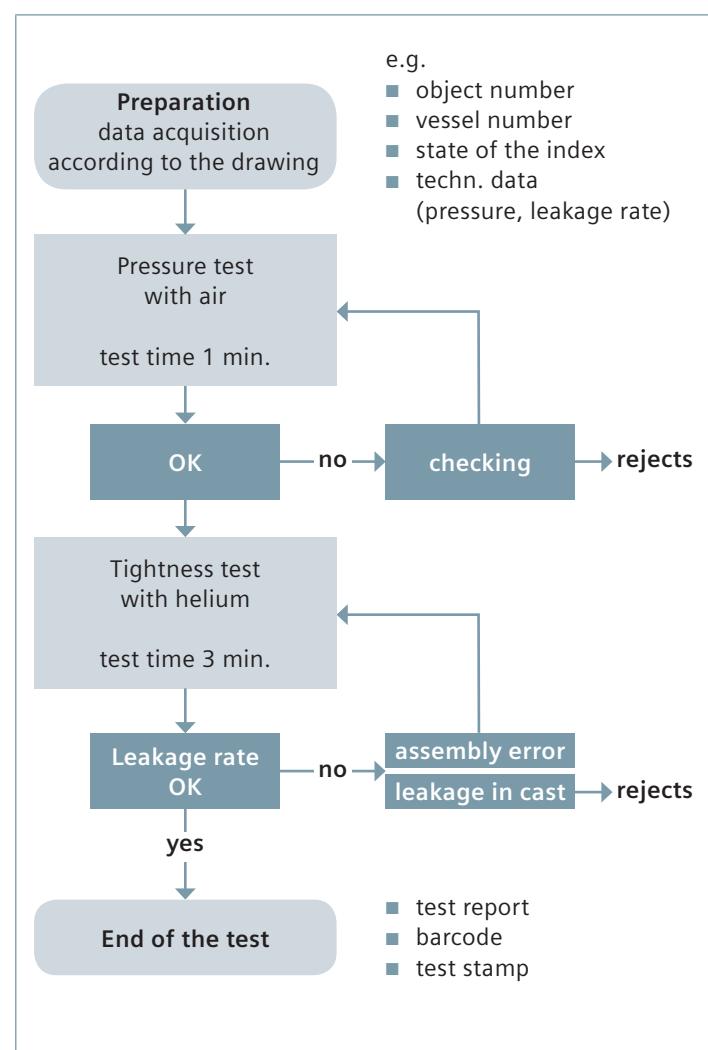


Figure 5: Test sequence for pressure and leakage testing

The IEC/TR 62271-303 standard specifies a maximum permitted SF₆ loss of 0.5% per year. The pressure and leakage testing on each individual component in our high-voltage circuit-breakers ensures compliance with this specified limit. This is guaranteed by Siemens as the manufacturer.

As part of the pressure and leakage testing procedure during mechanical production in Berlin, pressure tests are also conducted according to other country-specific regulations such as EN and ASME. Where necessary, these tests are carried out in the presence of a Lloyds inspector.

Test system data



Technical data

test chamber

diameter up to	2.100 mm
length up to	3.500 mm

max. vessel dimension

diameter up to	1.700 mm
length up to	3.000 mm

pallet transportation system

automatic and manual mode

pressure test

pressure up to	22 bar
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leakage test

helium up to	7.5 bar
vacuum in the test chamber	

test method

"sniff"-principle

cycle time

ca. 18 min.

min. leakage rate

2.6×10^{-6} mbar x l/s

Technical details

Summary

High-voltage circuit-breakers play a key role in transferring and distributing electrical energy. These units require high quality individual components to ensure reliability. The pressure tests carried out after mechanical processing of all pressurised components such as housings and covers ensures compliance with national and international pressurised vessel regulations. Testing the leak tightness of all housings upholds the manufacturer's guarantee that these comply with the maximum permitted annual SF₆ loss of 0.5 % defined in the IEC/TR 62271-303 standard.

Christian Krüger

Global service from a single source

At the high-voltage control unit on the Berlin Siemensstadt site, high-voltage circuit-breakers from 72.5 kV to 800 kV are being developed and manufactured for application in both indoor and outdoor locations.

The ongoing development of new circuit-breakers at the high-voltage control unit has enabled customer requirements and market demands to be met time and again, thus consolidating this leading market position. Service technicians completely install each newly developed breaker within the high-voltage control unit several times during the development stage in order to implement installation procedures and constructive improvements early on.

Building block principle for breakers to facilitate service

The "building block principle" applied to the breaker series and the standardised operating system mean that installation and commissioning times can be cut even further. What's more, the supply components have been carefully adjusted to make them customer friendly so it is possible to optimise and simplify the installation tools. The reliability and quality of our low-maintenance products result from the many years of operational experience with all circuit-breakers, which can be found satisfying the most varied of requirements in all areas of application right across the globe.

Today, there are more than 50,000 Siemens circuit-breakers in grid operation worldwide. The application life-span of these breakers is often in excess of 40 years.

The Berlin site provides an international service for every circuit-breaker delivered and in operation. A 24-hour hotline gives customers the opportunity to get in touch immediately in the event of any faults, which are then treated as top priority. With a targeted approach to calling up product information and direct co-operation with the development, construction, IT and production departments, the service in Berlin is able to offer professional, product-specific support.

Our specialists – involved in the circuit-breaker development processes, daily plant production processes and final assembly on the construction site – are available at any time to perform on-site diagnostics on the switchgear.

Comprehensive service

- Installation and commissioning
- Sale of spare parts for all SF₆ circuit-breakers
- Maintenance and inspections
- Customer training sessions at the company's own modern training centre or on the end equipment itself on the customer's premises
- And the highest level of priority given to the elimination of faults

The service is responsible for organising and handling service assignments, from the customer request, technical clarification, preparing the quote and processing the order through to deployment of the service technician. Other tasks performed by the service include carrying out cost-effective planning and co-ordinating the entire service assignment with the customer, as well as producing the concluding documentation.

Installation and commissioning

Qualified service technicians are always on hand for our customers. These technicians have years of international experience and undergo continuous training in current production, receiving all information on any technical changes. The customer's own personnel can also be trained by our service technicians during the installation and commissioning process. A 3AP1 FG circuit-breaker with a rated voltage of up to 245 kV can therefore be installed and commissioned by just one service technician in the space of one day. Figures 1 to 4 show the installation and commissioning of complete substations.



Figure 1: Installation of a 3AP2 FI circuit-breaker for 550 kV in Shenzhen, China



Figure 2: Installation of a 3AT3 EI circuit-breaker for 550 kV in Columbia



Figure 3: Installation and commissioning of a dead tank circuit-breaker for 550 kV with heatable thermo housing in Sokol, Kazakhstan



Figure 4: Installation and commissioning of a dead tank circuit-breaker for 245 kV in Sokol, Kazakhstan

Spare parts delivery

One additional and important task is to deliver spare parts for all Siemens SF₆ circuit-breakers. The service includes the complete handling of spare part deliveries. The request, technical clarification and quote, plus order handling and delivery to the end customer are all dealt with by a single source.

The customer can also turn to our qualified service technicians to carry out maintenance work or inspections on Siemens circuit-breakers.

This service is tailored to customer requirements, ensuring that the lifecycle costs of the circuit-breaker are kept to a minimum.

Comprehensive advice

The service offers all our customers timely, comprehensive advice.

The round-the-clock service in Berlin and the high standard of our solution expertise mean that all customers can be guaranteed quick response times in the event of faults as well as the quickest possible recovery time – as indicated by the high level of customer satisfaction.

Joerg Hellhammer

The training centre at the Schaltwerk Berlin – Information and training



Providing the right knowledge to ensure safety

Energy transfer and distribution systems and equipment sometimes represent a significant investment and may have a life-span of more than 40 years. Our information and training centre helps our customers make the most of these investments – whether it be looking at fundamental aspects of cost-efficiency or training the operating personnel, our comprehensive range of courses can provide the answers to any questions on Siemens equipment and Siemens switching technology.

All training naturally takes place in small groups, with a strong practical emphasis and focused on our customers' needs. This will enable your operating personnel to recognize when maintenance tasks will be due and to plan these in advance, thus putting your operating and maintenance personnel in a position to respond quickly and safely in the event of operating malfunctions, or to resolve switching errors methodically and therefore cost-effectively.

General and technical information courses

The right knowledge for every eventuality: general information courses offer an overview of, for example, the latest high-voltage, medium-voltage and low-voltage switching technology. Managers can also gain an insight into the financial aspects of the technology, figure 1.



Figure 1: A training course at the training centre

Technical information courses instruct operating personnel on how to work with special breakers or equipment, e.g. the design of circuit-breakers. Theory and practical application go hand-in-hand: with plant visits and intensive training on fully operational original machines, image 2.



Figure 2: Training on original machines

A course to suit everyone

Our training program is designed to be modular so that it can adapt to meet your needs: any combination of topics is possible. Just ask, and we'll be happy to advise. A selection of topics is listed in table 1.

A methodical approach

"Learning from the maker" offers a number of benefits: our courses are led by qualified teachers who use the latest methods when conducting training sessions. What's more, their wealth of practical experience means they are also familiar with conditions on the ground, figure 3 and 4.



Figure 3: Assembly training for a 3AP1 DTC 145 kV in Thailand



Figure 4: Assembly training for a 3AP1 FI 245 kV in Thailand

Our experience

The training centre was founded in 1974. It has grown steadily since then, and is now equipped with state-of-the-art machinery. Over the years, more than 10,000 participants have received training in the various topics.

We speak your language

The training is always given in your language: either in German or English, or through an experienced specialist interpreter. The course material is also available in all major languages.

All the key topics, all the time

Whether you are interested in high-voltage, medium-voltage or low-voltage switching technology, our courses always cover all relevant topics.

The training centre

The three training rooms and our extensive collection of original machinery, components and displays cover an area of 600 m². The centre is operated by a team of three trainers and an office manager, figure 5.

Experts from the test departments, the design team and the production division are on hand to offer support as required.



Figure 5: The Team

Daniela Hellenbrandt, Karsten Krause,
Jörg Hellhammer, Wolfgang Westphal

The complete package

Travel, hotel, transport in Berlin – we take care of everything, including of course a program of entertainment to help you relax and enjoy the experience.

Training Programme

- Courses on high-voltage switching technology products and high-voltage transfer products

Portfolio

- 3A circuit-breakers and 8D gas-insulated substations
- General information course on high-voltage switching technology
- Technical information course on high-voltage switching technology and gas-insulated substations (GIS)
- Technical information course on high-voltage switching technology: AS circuit-breakers (type 3A)
- Technical information course on high-voltage switching technology: outdoor circuit-breakers (type 3AQ/T)
- Technical information course on high-voltage switching technology: outdoor circuit-breakers (type 3AP)
- SF₆ operator training in accordance with EU F-Gas Regulation (No. 842/2006) Meets the requirement under Article 5 of EU Regulation 842/2006
- Commissioning PSD devices for controlled switching; for Siemens employees only
- Operating time measurement using the Actas unit from KoCoS
- Switchgear maintenance courses
- Customised courses on the customer's premises

Table 1: Selection of courses from the training program

Allard von Wiarda, Michael Thaten

Information Center Switchgear Factory Berlin

The Berlin Switchgear factory manufacturing plant develops and manufactures – as the name suggests – high, medium and low voltage circuit breakers, gas-insulated high voltage switchgear and surge arresters for high and medium voltages. The development department with corresponding test areas, and the entire prefabrication, production and assembly line, including routine testing, are all on the switchgear factory site. This facilitates efficient mutual exchange of information, from the initial concept to the final product, figure 1.



Figure 1: Switchgear factory Schaltwerk Berlin

Depending on the type, gas insulated switchgears are completely maintenance-free, or require a first inspection after 25 years, and have a life cycle of more than 50 years. So, of course, our customers would like to be informed about the functionality and quality of circuit breakers and switchgear, and last but not least about the high competence of our factory. The best way is for all interested parties to visit the factory and get a first-hand impression of our production site. Since 1973, the factory's technical information center has served this special purpose, organizing shop tours and briefings for more than 4000 visitors a year. These include approval engineers, mechanics and commissioning engineers, commercial and technical decision makers, customer management and top-ranking politicians as well. During visits, after a general presentation of the site and introduction to products and systems, technical solutions and product functionalities can be explained at different exhibition areas, using real models, figure 2 and 3.

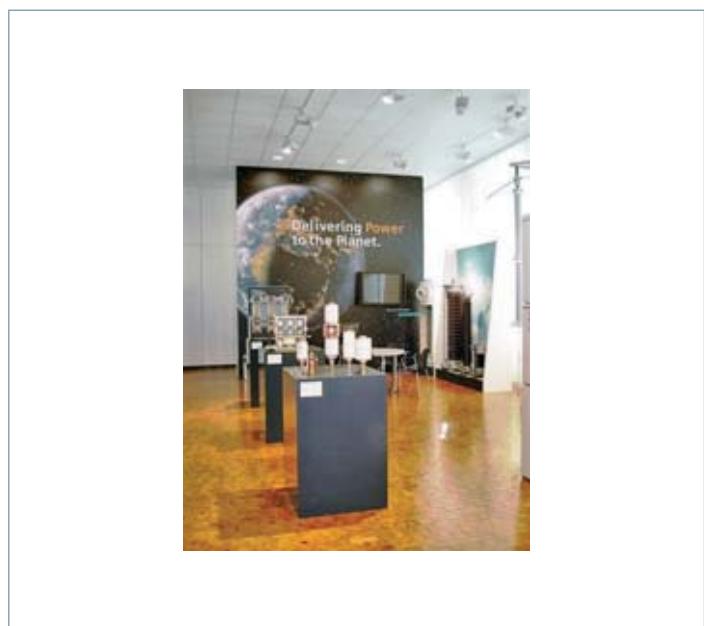


Figure 2 + 3: Showroom with real models

The development, procurement, prefabrication, assembly and routine test procedures for our various products are explained during the customer-specific shop tours. The Berlin Switchgear factory manufacturing plant is the only factory of its kind world-wide that integrates all processes – from development to final testing – at just one site.

Within the framework of circuit breaker and switchgear development, the factory operates the world's largest privately-owned test facilities, accredited and independent facilities which can test our products during development, and implement internationally recognized type tests, figure 4.



Figure 4: High Voltage Test at a 800 kV Life Tank Breaker

The high quality of our products is, among other things, a result of careful supplier selection and qualification, highly qualified goods incoming inspection, and secured material availability on the production lines. Our visitors can get a clear picture on these points at our logistics center, figure 5 and 6.



Figure 5: Incoming inspection



Figure 6: Logistics Center

A further typical feature of the switchgear plant is the high level of in house production. Based on our definition of core competences, all quality- and lifetime-relevant processes are carried out, and thoroughly checked, in the factory. This applies, for instance, to sensitive components of the interrupter unit, cast resin parts, the machining of gas tight cast aluminum housings for SF₆, and to electro-plating processes such as the electro-silvering of contacts. All these production processes are presented and explained in detail during the guided tour, figure 7 and 8.



Figure 7: Production process



Figure 8: Cast resin components

The greater part of the factory tour consists of assembly and final testing of the products and switchgear. The different final assembly areas for high, medium and low voltage circuit breakers are visited, as well as the facilities for final testing, at which routine tests are carried out on each breaker at the end of the production processes, figure 9 to 11.



Figure 11: Assembling lines for medium voltage Vacuum Breakers

During special acceptance tests in the presence of our customers, the required functionality and quality are demonstrated with exemplary components and parts. In this way, customers can satisfy themselves that the equipment produced is exactly in line with their requirements.

We are also able, of course, to present additional topics – related to the Siemens Company, to the Berlin Switchgear factory or to our product range – which are not mentioned in this article. Specialists and experts from different divisions with extensive experience can support us with this.

Generally we organize each factory tour individually, depending on the different information needs and any expectations of the customers (e.g. regarding language).



Figure 9: Assembling areas for high voltage components



Figure 10: Assembling lines for low voltage products 3WL

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