

ABB

The corporate
technical journal

review

The ever-shrinking GIS 11

AIS switchgear for all seasons 16

Focus on ecological footprint 28

Scaling up the voltage 37



Special Report
High-voltage products

Power and productivity
for a better world™



Growing energy demands and increasing concern over climate change are significantly impacting the way electricity is generated and in turn transmitted and distributed. The result is the emergence of more environmentally friendly, flexible, interconnected and smarter grids. But even as ABB addresses these new aspects, grid reliability and efficiency remain at the core of the company's fundamental priorities.

High-voltage (HV) products play a key role in this as they enable several critical functions that ensure safe, reliable and efficient passage of electricity. Switching, protection and control, enhanced efficiency and minimization of losses, ensuring power quality and mitigating environmental impact are some of the areas in which ABB's HV products support power plant operators, transmission and distribution utilities as well as industrial and commercial infrastructure sectors.



Welcome to a high-voltage world

- 6 The world of high-voltage power**
A concise history

Power of the portfolio

- 11 Compact and reliable switching**
Smaller, more efficient and simpler gas-insulated switchgear
- 16 Enhancing grid reliability**
The evolution of air-insulated switchgear and components
- 20 Pushing the limits of technology**
As a market leader in generator circuit breaker technology, ABB has a global installed base of more than 7,000 units
- 24 The power of collaboration**
Service solutions across the product life cycle

Shaping the evolving grid

- 28 Improving eco-efficiency**
ABB's high-voltage technologies are rising to the challenge
- 33 Power quality matters**
Eliminating reactive power and harmonics with capacitors and filters
- 37 Raising the bar**
UHV switchgear and components
- 42 Power on the move**
Integrated, modular and prefabricated switchgear bundles with extended functionality for modern HV substations

Back to the future

- 47 Pioneering change**
How ABB remains a leader in the ever-changing world of high-voltage power

High-voltage products



Bernhard Jucker
Head of Power Products division

Dear Reader,

ABB's high-voltage (HV) products heritage dates back more than a century to the inception of the grid. ASEA, an ABB parent company, delivered one of the world's first HV circuit breakers in 1893, which supported the construction of ABB's and the world's first commercial three-phase AC power transmission link, bringing hydropower to a large iron-ore mine in Sweden. Among the many technology milestones over the years ABB also pioneered the development of gas-insulated switchgear (GIS) in 1965.

Today ABB is a global leader in HV products with a manufacturing footprint comprising more than 40 production centers around the world and a sales and service network spanning over 100 countries. In line with ABB's local approach we are constantly calibrating our manufacturing footprint to be close to our customers and to meet their local needs more efficiently. For instance, ABB recently announced new production facilities in India and Saudi Arabia.

When it comes to technology and innovation ABB remains committed to collaborating with its customers and addressing their needs, challenges and opportunities. ABB's innovations and product launches bear testimony to this commitment. For example, ABB has significantly reduced the footprint of its latest generation of GIS products, the most recent being the 72.5, 245 and 420 kV. And the company developed 1,100 kV and 1,200 kV products to address emerging market needs for bulk power transmission over long distances at ultrahigh-voltage levels to minimize losses.

ABB's latest range of generator circuit breakers (GCBs) is taking power plant availability and reliability to higher levels. The recently introduced 72.5 kV PASS (Plug and Switch System) hybrid switchgear solution for wind applications is an example of the company's renewables focus from a high-

voltage products perspective. ABB also continues to facilitate a smarter grid through plug-and-play, remote access and sensor-enabled solutions such as the FOCS (fiber optic current sensor). When it comes to monitoring and control, Switchsync – a microprocessor-based controller for circuit breakers deployed for transient reduction and improved power quality – and the Circuit Breaker Sentinel™ for condition monitoring of SF₆ circuit breakers are two of ABB's latest offerings. Eco-efficiency remains a major thrust of the company's R&D efforts to address the environmental challenge. The considerably reduced footprint of the latest generation of ABB products minimizes SF₆ gas requirements. Not long ago ABB announced a breakthrough in SF₆ gas recycling. The recently launched 72.5 kV CO₂ circuit breaker is the first in a new series of eco-efficient live tank breakers, which substitutes SF₆ gas with more environmentally friendly alternatives – a quest ABB plans to continue.

High-voltage products play an integral part of several emerging power trends, such as compact and intelligent substations, HVDC and UHVDC transmission links, integration of renewable energies and the evolution of stronger, smarter and more flexible grids.

We hope this special edition of *ABB Review* sheds light onto the world of electric power from a high-voltage product perspective. And as we address the challenge of providing safe, reliable and adequate electricity for all, we must remain mindful of our environmental responsibility – as the old proverb states, "We do not inherit the earth from our ancestors; we borrow it from our children."

Happy reading!

Bernhard Jucker

Giandomenico Rivetti





The world of high-voltage power

A concise history

FREDI STUCKI – One of the greatest achievements of modern society is the electrical power grid. When the Westinghouse Electrical Company built the first workable AC (alternating current) generating unit in 1895 in Niagara Falls, electricity turned from a scientific curiosity into a useful application for society. It also quickly became clear that electricity could only be economically transmitted over long distances at high voltages. This was the only way to connect the large power plants that were usually located near fuel sources like coal mines to load centers that needed the electricity, such as towns, cities and today's megacities. Finally, development of high-voltage switching devices made it possible to safely connect several generation units and multiple loads to the same electrical line, which has resulted in the complicated but efficient meshed arrangement that is today's electricity grid.

1 Gas-insulated switchgear (GIS), Sempersteig, Zurich, 1967



2 Dead tank breaker, United States



Depending on the convention of the local electrical power industry, high voltage is from 52 kV to 72.5 kV, and has a practical upper limit of about 1,200 kV, although earlier studies and demonstration projects are as high as 1,500 kV. The technical challenge from the beginning for high-voltage products has been the battle between mechanical, thermal and dielectric properties of the materials used to make them, starting with paper and oil for insulation, and air, oil and sulfur-hexafluoride-gas-immersed switching devices to interrupt the current. Besides the power transformers, which at that time already existed, other high-voltage components had to be developed to complete the grid, including power capacitors, high-voltage resistors, overvoltage protection devices and, of course, measurement transformers for current and voltage. All of these devices were connected to electromechanical relays to control and monitor the primary equipment.

Since those early times, electromechanical equipment has undergone significant improvement as a more detailed understanding has emerged of the basic physics of materials under electrical and thermal stress, in particular understanding of the dominant insulation media oil, paper and porcelain. For switching devices, bulk oil breakers were later replaced by minimum oil breakers, where the oil volume was reduced to the amount needed

for extinguishing the arc. Later on, it was found that oil could be replaced by introducing a high-pressure air flow into the arcing zone. Only later were the phenomenal dielectric properties of sulfur hexafluoride (SF_6) gas discovered, which resulted in the introduction of the first high-voltage gas-insulated switchgear (GIS) by BBC, one of ABB's parent companies, in 1965 → 1. From then on the focus was on improving the understanding of breaker physics, which resulted in more powerful interrupters capable of interrupting short-circuit currents from 25 kA typically up to 80 kA, and from many series-connected interrupters to a maximum of one interrupting unit for up to 420 kV and even 550 kV circuit breakers. As an example: In 1998 ABB was the first manufacturer to provide a dead tank breaker (DTB) with 245 kV and rated short-circuit currents of 80 kA for the US market → 2.

Additionally, the increased knowledge of thermal and dielectric gas properties paired with computer simulations of hot gas flow helped to further develop basic switchgear function to a level where, according to latest Cigre statistics, the reliability of SF_6 circuit breakers improved to a low value of 0.3 failures per 100 circuit-breaker-years of operation, which is an order of magnitude better than the first two pressure SF_6 breakers, and cannot even compare with devices based on earlier oil technology → 5. → 3 shows 420 kV live tank breakers (LTBs) from the late 1960s, in comparison with a modern type of LT BET2, with two interrupting units in series and no need for grading capacitors → 4.

The technical challenge from the beginning for high-voltage products has been the battle between mechanical, thermal and dielectric properties of the materials used to make them.

Title picture
ABB's disconnecting circuit breaker

3 420 kV circuit breaker airblast technology from 1955 with 10 interrupting units in series



4 Modern 420 kV SF₆ circuit breaker with two interrupting units in series



Liberalized electric power markets in various countries have made reliability, compactness and efficient use of substation area more and more important.

Innovation in high-voltage equipment

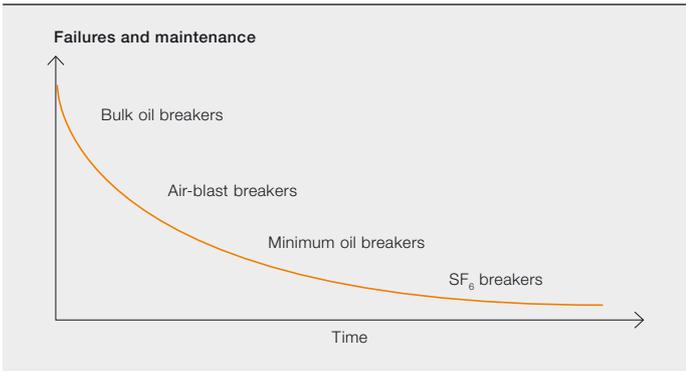
Different global requirements have led to the emergence of various types of high-voltage switchgear → 6. Primarily, these include LTBs, in which the main insulation is air and the active part on high-voltage potential is connected to overhead power lines; DTBs, a version predominantly used in the United States, in which the interrupter is contained in a pressurized metal tank on ground potential; and GIS, which is used mainly indoors or wherever a small footprint is essential. Liberalized electric power markets in various countries have made reliability, compactness and efficient use of substation area more and more important. ABB pioneered the development of switchgear products with additional integrated functions like the Plug and Switch System (PASS), which led to the development of mixed technology switchgear that provide a functional blend of AIS (air-insulated switchgear) and GIS technologies.

Launched in the late 1990s, PASS is a modular concept that combines the main breaking function in a metal enclosure (as in a DTB) with a combined disconnecting/earthing switch and current measurement. PASS is a very versatile HV product. It can be configured to fit all AIS substation layouts, such as single

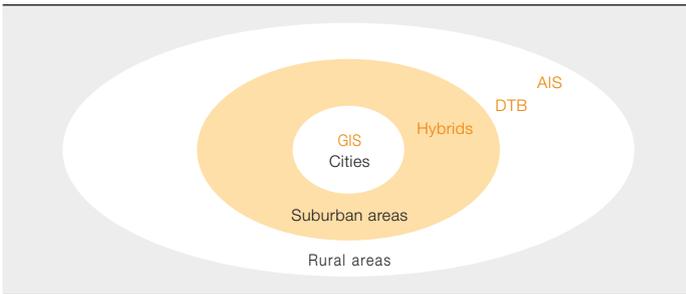
busbar, double busbar or H-bridge, and can be installed in new installations or retrofitted into existing substations for substantial space savings. This new HV switching machine comes fully factory assembled and tested, which means minimum time for field installations, as well as reduced lead times in tendering and overall project execution. PASS and in general mixed-technology switchgear solutions are becoming more and more popular, in particular because they offer greater flexibility in new substation layouts. Since its introduction, ABB has sold more than 8,000 PASS or hybrid switchgear bays worldwide → 7.

Another example of pioneering HV switchgear concepts is the disconnecting circuit breaker (DCB) first launched by ABB in 2000. The most unreliable switching device in AIS substations is the open-air disconnector, used primarily to isolate circuit breakers or other HV components for maintenance purposes. In a DCB, the air-insulated disconnector is simply avoided and becomes part of the SF₆ gas protected main breaker. As the maintenance interval of modern HV SF₆ circuit breakers is now 15 years or more, keeping unreliable air disconnectors makes no sense in many cases. With the introduction of the IEC standard for DCBs (IEC 62271-108) in 2005, the

5 Failure rate of different breaker technologies



6 ABB has a comprehensive HV switchgear portfolio depending on space and reliability requirements.



acceptance of this technology grew significantly, resulting in more than 1,500 ABB DCB installations worldwide for all voltage levels up to 550 kV.

Beside compactness, the most important advantage of integrating functions is reliability, because more components are in a protected gas environment. The move from electromechanical relays to digital protection devices has replaced bulky instrument transformers used to measure voltage and currents as well as multiple redundant electromechanical tripping relays. In their place are a few sensors with local preprocessing intelligence, connected to numerical bay and station control devices by low-power analog signals, or fiber-optic digital connections. Pioneered by ABB, these devices represent the first step into the world of digital substations, later to become widely known as smart substations. For example, in the late 1990s ABB introduced a smart GIS solution featuring electronic current sensors with optical voltage transducers, supervision of actuators and integrated digital protection and control.

The big breakthrough for digital substations came with the emergence of the international substation automation standard IEC 61850, which solved the

engineering nightmare of integrating various proprietary solutions. Not only was the problem of interoperability between devices from different suppliers solved, but IEC 61850 also created a future-proof standard that is immune to the fast developing and ever-changing digital world.

Recent developments and outlook

The continuous drive to increase reliability and availability of electrical power is reflected in the latest revision of the HV switchgear standard IEC 62271-100, where new tough requirements were set for mechanical (M2) and capacitive switching (C2), as well as electrical endurance (E2). These efforts, in combination with smart grid initiatives, have resulted in an increased trend toward online monitoring of all primary switchgear functions at the bay and substation level. This is necessary to move away from fixed maintenance schedules, and to be able to plan well ahead for revised maintenance schedules, minimizing outage times. The new generation of smart substations will implement what has been learned in the past, increasing the safe, reliable and flexible operation of HV equipment that is capable of meeting future demands on the AC power grid.

7 The PASS is a versatile and modular HV switching machine for new and retrofit applications.



The new generation of smart substations will implement what has been learned in the past, increasing the safe, reliable and flexible operation of HV equipment that is capable of meeting future demands on the AC power grid.



Another HV challenge is the efficient transmission of bulk power over long distances. Recently, new installations of ultrahigh-voltage (UHV) technology demonstration projects have emerged in China and India. One can say that the rise of UHV technology (defined as voltages above 800 kV for AC transmission, and 800 kV and above for direct current or DC transmission) was triggered by energy-hungry emerging countries, where abundant but remote energy supplies had to be flexibly connected to megacities and fast-growing industrial load centers far away. UHVAC power lines are also being planned as a strong backbone to support the rapidly evolving grid infrastructure. One example is the 1,100 kV ultrahigh-voltage alternating current (UHVAC) demonstration project in China, a 650 km power line from Jindongnan via Nanyang to Jingmen, with a maximum transmission capacity of more than 5,000 MVA.

ABB participated in a joint effort with a local supplier to design and deliver the first 1,100 kV hybrid GIS (mixed technology switchgear) for the Jingmen substation, which successfully went into operation in December 2008 → 8.

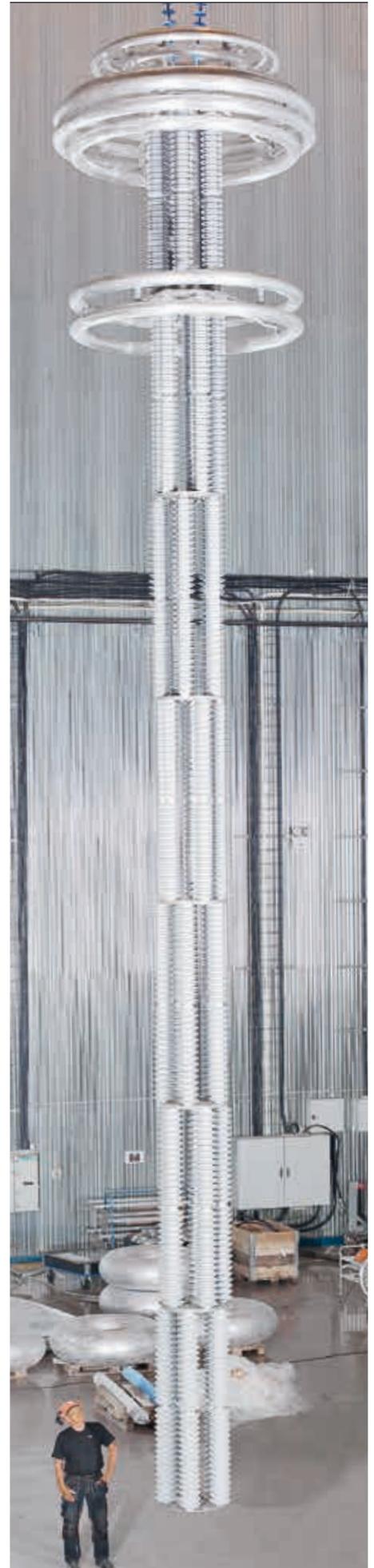
Despite the controversy over UHV transmission – in particular its commercial viability – State Grid Cooperation of China decided to boost HVDC technology

to UHV levels as well. Starting with ± 500 kV to 800 kV DC, the first commercial installations went into operation in 2010. ABB has in recent years successfully completed tests of all 1,100 kV UHVDC components, and is ready for future HV grids in the years to come → 9.

As a world leader in HV products, ABB is committed to improving and exploring advanced HV technologies, and investing in pilot installation projects to explore new technologies that sustainably support the growth in demand of electric power around the world.

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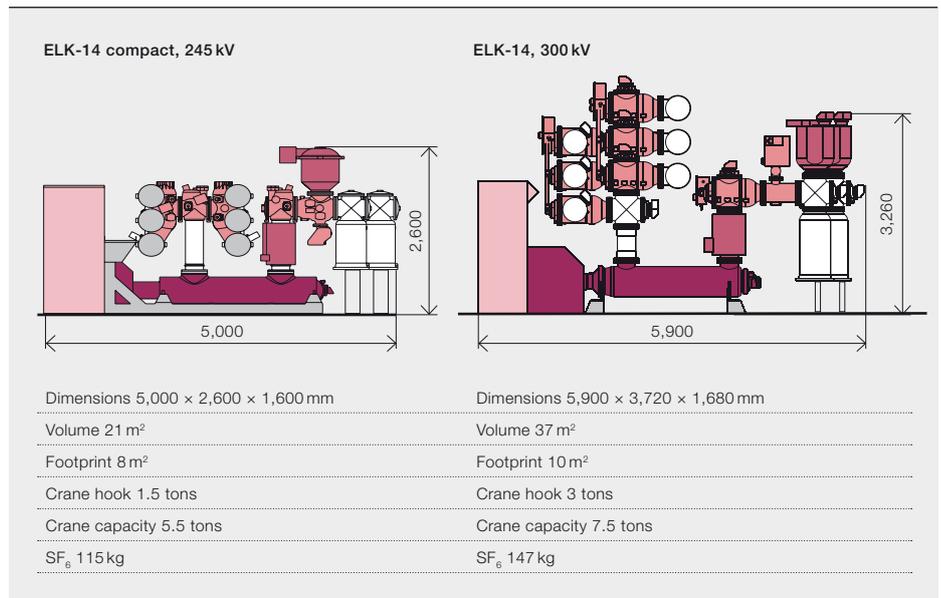
Compact and reliable switching

Smaller, more efficient and simpler gas-insulated switchgear

HANS-DIETER SCHLEMPER – Gas-insulated switchgear (GIS) operates invisibly – no movement, just a faint hum, betrays the flow of bulk AC power. At first sight uncomplicated-looking, a closer examination reveals the complexity in the variety of configurations, engineering investment and installation effort found in a typical GIS installation. Now, however, ABB's new compact GIS switchgear makes

everything much simpler. Even at 420 kV ratings, the switchgear is assembled as a complete bay in the factory, including wiring and testing. Installation is fast and easy: Bays move on wheels to their final destination and they can be assembled in a day. The compact dimensions leave more space for access, fit in even smaller buildings and save on resources such as SF₆ and metals.

1 ELK-14 compact, 245 kV compared with its predecessor



Much electrical switchgear is found out in the open, so the electrical breakdown properties of air have to be taken into account in its design. As a result, switchgear installations can take up substantial real estate. Where space is costly or limited, or where the environment is challenging, GIS is an ideal alternative. In GIS equipment, switching is done inside a gas-filled sealed vessel. The gas has much better insulation properties than air, so equipment can be made a lot smaller. Substations located underground in cities, inside hydropower dams, in high-value real-estate areas or in containers could not be realized without GIS technology.

GIS is suitable for use in harsh environments such as deserts, high-altitude locations or offshore oil platforms. Its low noise levels and low electromagnetic emissions allow operation in residential areas or in sensitive industrial plants. GIS also improves the grid's efficiency as it enables power to be transmitted at higher voltages closer to the load centers in cities.

Title picture

ABB's new GIS products greatly speed up and simplify installation. The GIS ELK-3 compact product is shown here.

The first GIS was installed in 1965 and used sulfur hexafluoride gas (SF₆) as insulation. Today, GIS switchgear is available from 52 to 1,200 kV rated voltage [1]. Current trends and needs in GIS include:

- Less complex, more standardized designs that inherently improve reliability and ease project engineering, production, installation and maintenance. Purchase and use of GIS should become simpler, delivery times shorter and service life longer.
- Smaller dimensions that save resources,

GIS is suitable for harsh environments such as deserts, high-altitude locations or offshore platforms.

- Digital controllers and electronic measuring equipment that provide comprehensive monitoring, supervision and control functions.
- Higher continuous current and short-circuit current ratings.
- Less use of SF₆ and reduction of SF₆ emissions.

ABB's new GIS products for 72.5 kV, 245 kV and 420 kV, launched in 2010, 2011 and 2012 respectively, address these trends. The entire family is built on common design principles and the family members share many common components.

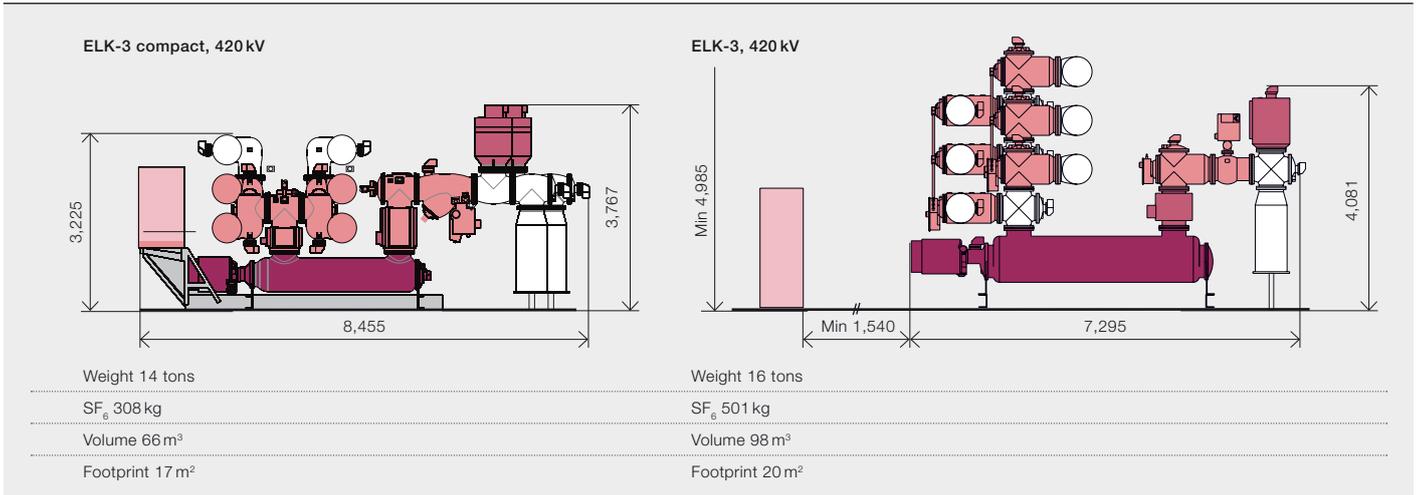
Compact and efficient

The new products mark a significant advance in footprint reduction – be it in terms of dimensions or use of raw material and SF₆.

The new portfolio is based on advanced circuit breakers with small dimensions and small drives. The ELK-14 compact, 245 kV GIS features an advanced double-motion Auto-Puffer™ (self-blast) circuit breaker. A single pole requires less than 900 J of stored energy to interrupt a short-circuit current of 50 kA. The ELK-14 compact has 43 percent less volume and weighs 2 tons less than the predecessor product → 1. The result is a compact bay that fits into containers that are used for shipment or even as a permanent housing.

The ELK-3 compact, 420 kV GIS features a new, single-interrupter puffer breaker with an excellent two-cycle performance at 63 kA/60 Hz and plenty of reserve for short-line faults and other duties. The ELK-3 compact circuit breaker uses just one interrupter where two interrupters in series and a larger drive were needed in the past. The savings in dimensions and weight are significant → 2.

2 ELK-3 compact, 420 kV compared with its predecessor



Low-pressure aluminum die casting and 3-D finite-element stress calculations enable the design of enclosures with complex shapes that still meet pressurized vessel standards at high safety margins. The result is “skinny” enclo-

Simplicity

ABB’s new GIS consists of a set of highly-standardized building blocks that can be configured to the specific user requirements at a very late stage of the production process. This reduces

delivery time. Even at 420 kV, the GIS is equipped with integrated local control panels mounted directly on the steel support carrying the bay. Instead of wiring the bay on-site to a distant

control panel, all the cabling is done at the factory in a controlled environment with automated testing facilities. Any wiring mistakes are corrected before the bay leaves the factory.

Installation time nearly halved

The new GIS designs enable complete wired bays to be shipped in containers or on flat racks. A typical 420 kV substation now requires only 44 shipping units and 53 coupling steps compared with the 80 shipping units and 74 coupling steps of the predecessor product.

On site, 420 kV bays are wheeled from the unloading platform into the building to their final destination. After leveling, coupling adjacent bays and connecting them to the substation control systems takes only a few hours. Before leaving the factory, bays are prefilled with SF₆ at a transport pressure slightly above 1 bar, which significantly reduces time and effort for on-site gas handling.

The entire family is built on common design principles and the family members share many common components.

GIS improves the grid’s efficiency as it enables power to be transmitted at higher voltages closer to the load centers in cities.

ures that minimize the enclosed volume and, thus, the SF₆ content. A good example is the ENK GIS type for 72.5 kV rated voltage that uses a mere 27 kg SF₆ per bay (for a typical double busbar bay with cable connections) – less than half that used by traditional designs. Or the ELK-14, which uses 115 kg SF₆, 32 kg less than the predecessor product.

Best of both worlds

Traditional GIS often uses single-phase enclosed designs for 245 kV. Although they would reduce complexity, three-phase enclosed GIS components for 245 kV are large and difficult to design. ELK-14 compact is innovative: All components are three-phase-enclosed but, instead of three-phase partition insulators, as used at 145 kV, it uses single-phase insulators. Together with skinny enclosures, ELK-14 is somewhere in between traditional single-phase and three-phase design and combines the best of the two approaches.



The GIS consists of a set of highly-standardized building blocks that can be configured to the specific user requirements at a very late stage of production.

In all, installation time is cut by some 40 percent.

Easy access operation

Although there is little maintenance required, all relevant parts, such as drives, view ports, gas density sensors, gas filling valves and terminal blocks are easily accessible – thus shortening maintenance or repair times.

A unique feature is that the drives and position indicators for disconnectors and grounding switches are located underneath the local control panel → 3. The user can access the drives from the operator's aisle for emergency manual operation with a hand crank or to lock them with a padlock. Access ladders or scaffolding is no longer required. Besides, drives are plug-in units and they can be easily pulled out of the cabinet for inspection or maintenance.

Convenient access to viewports, gas valves and monitors is provided by platforms and catwalks. These are an integral part of the GIS and no longer require custom designs.

Digital sensors and smart switchgear

Today's practice of measuring basic parameters using inductive current transformers (CTs) and voltage transformers (VTs) has parallels with the changeover from vinyl records to CDs: Gone was the distortion created by analog reproduction as CDs and optical links ensured low-cost, interference-

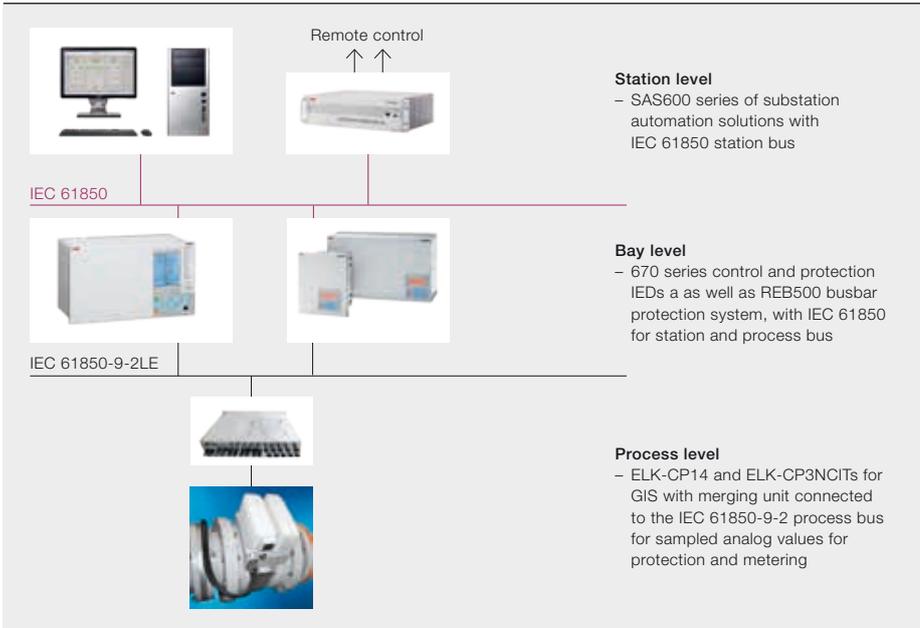


free audio reproduction every time. Current and voltage measurement in substations is undergoing a similar transformation. The old problems caused by transient performance and saturation of CTs, over/under-burdening, cable length or cross section and troublesome relay input impedance are being banished by the adoption of electronic precision transducers for current (ECTs) and voltage (EVTs). These come with digital interfaces and connect as easily as a CD player to protection relays with digital inputs. Their stability, dynamic range and precision are outstanding – a single ECT provides both class 0.2 metering data and precision current data in the kiloampere range.

Consequently, most of ABB's GIS equipment is now available with compact ECTs and EVT's employing Rogowski coils and capacitive voltage transducers [2] → 4. They connect to any relay with an IEC 61850-9-2-compatible digital optical interface, eg, ABB's Relion series.

Although not yet commonly used, ECTs and EVT's, together with intelligent bay controllers, such as ABB's REC670, and protection devices, form the basis of a digital control panel. Replacing bulky hardwired controls and a sizeable binder of schematics, a digital control panel has a network interface based on IEC 61850 data models and communication protocols. The GIS bay is delivered with an electronic capability description in XML – ready to be loaded,

5 Schematic diagram of a digital control system for a GIS bay



6 Gas density monitoring system, MSM



browsed and integrated into the substation automation system → 5.

As part of the new portfolio, ABB's engineers have developed a comprehensive but simple-to-operate gas monitoring system called modular switchgear monitoring (MSM) that can be added to conventional controls or digital control panels → 6.

MSM's main task is to detect even small leaks at rates as low as 0.5 percent per year with a set of linear prediction filters.

On site, 420 kV bays are wheeled from the unloading platform into the building to their final destination.

The filters are tuned so as to distinguish leaks from natural density variations stemming from inhomogeneous temperature distributions in gas compartments. Unlike traditional gas density monitors, which would flag an alarm first when 5 to 10 percent of the SF₆ had already leaked, MSM alerts the operator when as little as 1 to 2 percent of the gas has escaped.

Case study: Revsing substation

Energinet.dk owns and operates the transmission grid and the natural gas system in Denmark. The company builds intelligent infrastructure to inte-

grate renewable energy sources and focuses on providing Denmark with green energy. Energinet.dk selected GIS technology for new 420 kV substations to reduce space consumption and visual impact.

A project currently underway is the construction of a new 400 kV connection between Kassø, near Aabenraa, and Tjele. A 400 kV double-circuit line, installed on tubular towers designed to blend into the landscape, will reinforce and renew Jutland's grid. The line will replace the approximately 45-year-old single-circuit line operating on the section today. The project received funding from the European Union's trans-European energy networks program.

Part of the project is Revsing substation. It forms a node with other 420 kV connections along the line. Energinet.dk selected the ELK-3 compact based on a comprehensive list of selection criteria that reflect the company's demands. Decisive features were the low SF₆ gas content, the compactness (resulting in a small building, crane and basement) and the short installation time.

Revsing substation will be commissioned in 2013. The new line is scheduled to commence operation in 2014.

Though established more than 40 years ago, GIS technology is still rapidly developing. It continues to serve as a key element in growing grids. The installation of GIS is becoming faster and the operation easier. Compact designs use less raw materials and SF₆. Safeguarded by digital controls and monitoring functions, GIS technology is steadily improving its excellent environmental compatibility.

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Enhancing grid reliability

The evolution of air-insulated switchgear and components

RICHARD THOMAS, HANS MATSES – For more than 120 years now, ABB has been supporting society’s need for electricity by developing the safest, most reliable and affordable products, solutions and services for the delivery of electrical power. A core element is the company’s high-voltage (HV) air-insulated switchgear (AIS). Its development throughout the years has been characterized by functionally focused design, utilization of the most appropriate materials according to their purpose and the quest for simplicity in design. This has led to inherent robustness, minimal material use and lowest operational power losses.

The two main operational stresses experienced by HV AIS equipment are current and voltage. HV equipment must also not only manage normal voltages and currents, but – most importantly – must fulfill required safety and security concerns when faults and operational extremes occur on the electric power network. Circuit breakers must be able, on command, to interrupt currents up to full short-circuit ratings within milliseconds and without failure. Surge arresters must limit overvoltages within microseconds. Voltage and current transformers must continually provide accurate measurement data on the load and status of the power system. Additionally, apparatus like circuit breakers are required to perform their switching operations up to several times a day after extensive idle periods.

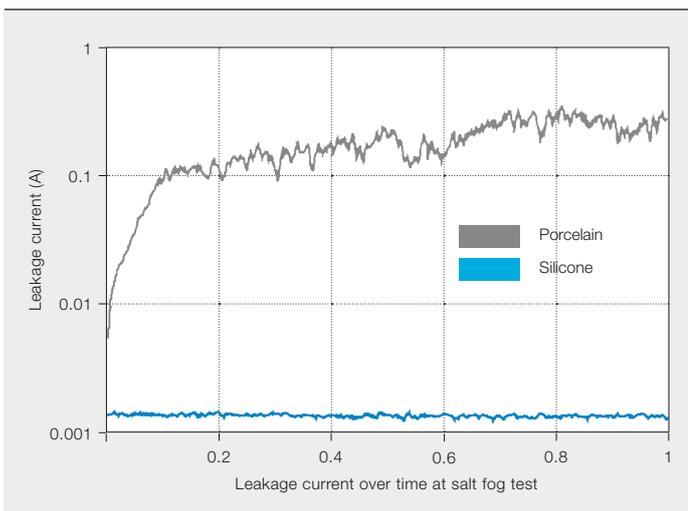
Power utilities and society rely on the equipment in electric power network to withstand these extremes, so that elec-

tricity remains available when it is most needed. HV AIS equipment must therefore also withstand a wide range of environmental stresses including extremes in ambient temperature, humidity, aerial pollution (natural eg, salt or man-made), severe weather (eg, cyclones, hurricanes) and even seismic events.

ABB is a pioneer in controlled switching and today has the largest installed base of controlled switching circuit breakers (over 3,700 installations accumulated over the past 25 years).

Selecting, developing and incorporating the most appropriate materials for managing the operational and environmental stresses HV AIS equipment must withstand is fundamental to the enduring success of ABB’s HV AIS solutions. For example, the use of composite silicone rubber insulators instead of porcelain ones lowers equipment weights by 20 to 40 percent. They also inherently increase safety by being nonshattering and also

1 Besides being lighter and more shatter-resistant, silicone rubber also has lower leakage currents.



improve seismic and pollution withstand performances. The significantly lower leakage current of silicone rubber compared with porcelain insulators during a salt-fog test is shown in → 1. Such insulators reduce the weight of circuit breakers, instrument transformers and arresters, and make substations significantly safer and more reliable. ABB has delivered over 60,000 silicone rubber composite insulators worldwide → 2.

With respect to internal insulation, ABB's SF₆ live tank breakers are designed for ambient temperatures down to -60 °C, which results in using the least amount of SF₆ per interruption rating of any breaker design available. The use of quartz sand in combination with oil as the insulating medium in its IMB current transformers (CT) significantly reduces the volume of oil required; for example, using this technique the oil volume is reduced by about 425 liters for the 550 kV IMB CT. In addition the quartz sand provides the IMB greater strength to withstand the high mechanical stresses that occur during short-circuit conditions in the network. Another recent addition to ABB's innovations in this area is the dry pre-assembled cable termination. This technology eliminates the use of oil in cable terminations and makes their installation easier and quicker.

Optimization of ABB AIS designs is also clearly demonstrated beyond materials selection. ABB is the first and only HV live tank breaker supplier to not require grading capacitors at 550 kV up to 63 kA. This significantly reduces the weight of the circuit breaker and also dramatically

reduces leakage currents across an open breaker and eliminates the risk of ferroresonance in the power network. ABB also has the only 800 kV live tank breaker with only one spring-operating mechanism per phase, which dramatically reduces the complexity of the circuit breaker control and operation, improving overall reliability and providing the optimal device for controlled switching at the highest voltage levels.

Other highlights of ABB's design innovations in AIS can be seen in the following applications:

Overvoltage control

ABB has developed and produces its own metal-oxide varistor blocks for surge arresters that provide the maximum protection by triggering at the lowest overvoltage protective levels for the full energy dissipation requirements. Additionally with the high field strength of ABB's metallic oxide varistors, material, weight and size of arresters is reduced → 3.

Enhanced power quality

ABB's capacitors and capacitor banks designed in modular banks cater to the widest range of power quality applications from power factor correction to harmonic content filtering.

ABB is a pioneer in controlled switching and today has the largest installed base of controlled switching circuit breakers (over 3,700 installations accumulated over the past 25 years). The primary benefit of controlled switching is to minimize the level (size) of transients

2 HV equipment with composite insulators



ABB's SF₆ live tank breakers are designed for ambient temperatures down to -60 °C, which results in using the least amount of SF₆ per interruption rating of any breaker design available.

propagated on the power network due to normal switching of capacitors, reactors, transformers or lines in the power system, and ABB offers the largest application range.

Functionally focused flexibility

Functional modularity is a defining aspect of ABB's ability to provide the widest range of HV AIS products and solutions.

An example of the advances in HV AIS equipment technology gained by ABB through dialogue with customers is the development of the disconnecting circuit breaker (DCB).

While developments in circuit breaker technology throughout the past 70 years has led to continuously higher reliability and lower maintenance, disconnecter technology has remained relatively unchanged. This resulted in ABB's live tank

3 Surge arrester



4 Disconnecting circuit breaker



5 Success story: Statnett's substation in Grytten



- 30 percent reduction in substation space
- Maintenance intervals increased from three to 15 years

Statnett's Grytten substation is a key component of the Norwegian regional grid, and the sole electrical supply point to the area around Åndalsnes. The substation was built in 1965 and progressively built up as a dual busbar system with an auxiliary busbar connecting four line bays and two transformer bays. The dual busbar system was necessary to guarantee uninterrupted service during transformer and circuit breaker maintenance. The final station had 81 single-pole disconnectors for facilitating maintenance.

Disconnectors and older circuit breakers were maintained at three- to five-year intervals. Moreover, the disconnector main contacts were inspected using thermal imaging on a yearly basis to detect any overheating tendencies.

In Statnett's maintenance plans, the useful service life for disconnectors was set at 35 years and the disconnectors at the substation were scheduled for replacement. It had also been decided to replace the substation's control equipment.

During subsequent planning, the question came up as to whether the devices should be replaced one at a time or whether a new, all-embracing solution should be considered. Statnett had studied the solution at Norsk Hydro's facility in Sundalsöra and looked at a solution with disconnecting circuit breakers (DCBs).

Availability calculations showed reduced annual downtime with the DCB. To further reduce maintenance needs, Statnett chose MotorDrive™ as the operating mechanism for the disconnecting circuit breakers. The optimized design with just one moving part in the operating mechanism reduces mechanical stress to a minimum. Electronically controlled operation is accomplished without mechanical stopping, which means very quiet operation.

In addition, new current and voltage transformers and surge arresters were provided with newest ABB designs with ABB silicone rubber insulators.

The new switchgear occupies about 30 percent of the space of the old switchgear. The freed space can now be used for any other needs that may arise in the future.

In practice, the only devices that require maintenance are the disconnecting circuit breakers. A 15-year maintenance interval was proposed for full inspection. Every other year, visual inspections of the devices will be conducted, but without removing equipment from service.

Statnett has obtained new switchgear based on modern technology with a minimum of maintenance requirements. The substation, which is situated at an important location in the grid, has high availability and is very operationally friendly.

The short installation time and the well-planned switchover of operations enabled the entire modernization project to be conducted without interrupting service to customers.

breakers (LTBs) providing higher reliability and having lower maintenance needs than any available disconnector and spurred ABB to develop the DCB. In a DCB, the disconnecting function is integrated with the circuit breaker and therefore the need for separate disconnectors is eliminated. Additionally the high electrical endurance and voltage withstand strength available in ABB's live tank breakers, coupled with the added safety and pollution withstand of silicone rub-

ber composite insulators, has put ABB in the unique position of having the world's largest range of DCBs, that is from 72 to 550 kV and up to 63 kA → 4.

DCB solutions provide many savings and benefits for power utilities, including reduced substation footprint, simplified substation design, higher power network availability and significantly lower total life-cycle costs → 5.



Future technologies today!

ABB continues to lead in HV switchgear technology solutions, making further advances in reduction of materials, increases in functionality and reduction in environmental impact. Examples of futuristic technologies from ABB include the following.

Motor drive

First released in 2000, over 500 high-voltage breakers with a motor drive and based on the live tank breaker and hybrid technology platform have been delivered. The motor drive provides the optimal operating mechanism platform for future circuit breakers with IEC 61850-9-2LE process bus control.

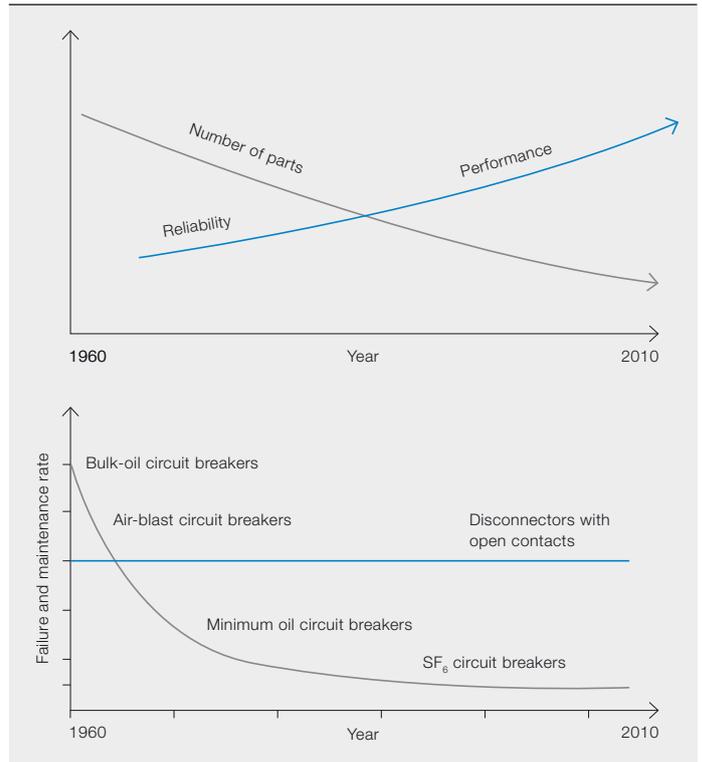
Fiber optic current sensor (FOCS)

When integrated with the disconnecting circuit breaker, FOCS provides a footprint reduction of over 50 percent compared with the conventional solution of live tank breakers with disconnectors and current transformers → 6. The solution eliminates a large part of the conventional wiring, secondary safety risks with conventional CTs, and has no saturation effects. In addition it is compatible with the IEC 61850-9-2LE, thus providing greater flexibility in substation protection configuration and operation through advanced process bus communication of current measurement data.

The LTA, which is the first high-voltage circuit breaker to use carbon dioxide (CO₂) as an insulating and arc-extinguishing medium, offers a suitable alternative to conventional SF₆ gas breakers. The LTA provides a reduction of about 18 percent or 10 tons in CO₂-equivalent global warming impact over an approximate 30-year product life cycle. It is currently available for 72.5 kV networks as a conventional circuit breaker as well as a disconnecting circuit breaker.

Numerous advantages

By utilizing modern material and design methods, high-voltage air-insulated switchgear from ABB helps utilities and industrial customers worldwide to reduce costs and at the same time reduce environmental impact. The decreased size and weight of equipment also lowers transport costs and impacts, as well as requirements on foundations and installation work. The equipment's additional integrated functionality (such as disconnecting circuit breaker and integrated fiber optic current sensors) in combination with the latest designs of capacitors, voltage transformers, arresters as well as control functions, offers compact designs that reduce space requirement of substations while enhancing reliability and safety → 7.



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Further reading

- ABB Controlled Switching Buyers and Application Guide
- ABB Live Tank Breaker Application Guide
- ABB Disconnecting Circuit Breaker Buyers & Application Guide
- www.dcbsubstations.com



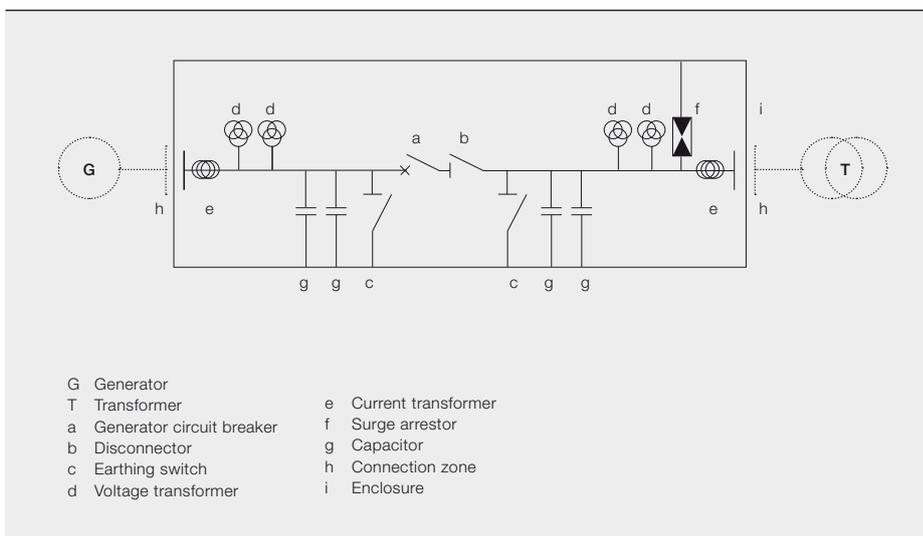
Pushing the limits of technology

As a market leader in generator circuit breaker technology, ABB has a global installed base of more than 7,000 units

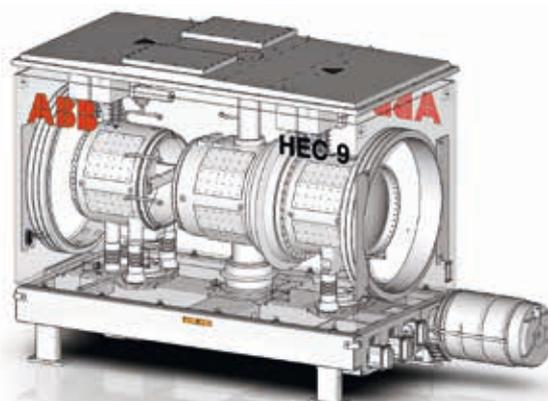
GIOSAFAT CAVALIERE, RÜDIGER KREISEL – Generator circuit breakers (GCBs) are now widely used in power plants for the connection between the generator and main transformer. In the event of a short circuit, equipment damage can be

reduced or even prevented by using a GCB. If faulty currents are not interrupted quickly, the transformer and generator are likely to be damaged and inoperative for weeks, or even up to a year.

1 Single line diagram HEC 9



2 One pole of generator circuit breaker system HEC 9



In the early days of breaker technology, conventional distribution breakers were used as GCBs. Then, with larger generators in power plants and increasing output from these generators, the machine ratings exceeded the load currents and short-circuit levels of the switchgear available. Therefore, the “unit connection” (ie, a connection without a circuit breaker between a generator and the associated main transformer) became the accepted standard power plant layout.

BBC, one of the two companies that became ABB in 1988, developed and introduced GCBs with air-blast technology in the 1950s and the first units were installed in power plants in North America and Europe. Nowadays, GCBs are recognized for their many advantages compared with the unit connection, such as simplified operational procedures, improved protection of generator, step-up and unit auxiliary transformer and higher power plant availability.

GCB technology advances

ABB further pioneered the development of circuit breakers that use phase-segregated busducts with higher unit ratings in

the 1960s. In the 1980s, ABB successfully introduced SF₆ GCBs using a three-phase system in single-phase enclosures. Meanwhile, the life-cycle costs of installed GCBs with air-blast technology became too expensive in terms of service and maintenance costs, therefore ABB continued to develop state-of-the-art SF₆ GCB technology throughout the 1990s and phased out air-blast technology. Since then ABB has introduced various new types of GCBs with increased functionality to the market – most recently type HEC 9 with the world’s highest short circuit current breaking capability at 250kA using SF₆ technology at a rated maximum voltage of 31.5kV.

HEC 9’s development is an upgrade of the design and development of the GCB type HEC 7/8, which is able to cope with short-circuit currents up to 210kA and to handle rated currents of 50,000A or

more, where the latter requires forced air-cooling. Increasing demands – mainly from newly developed nuclear power reactors like the Westinghouse AP1000 or Areva’s EPR – showed that short-circuit currents above 210kA combined with generator voltages of up to 30kV are realistic.

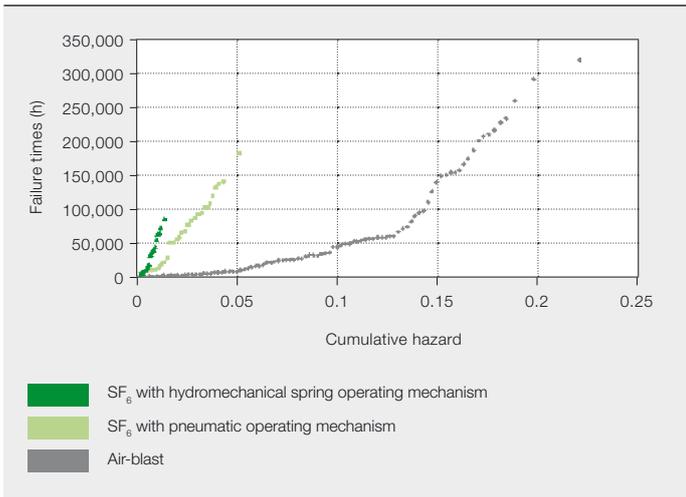
The success story of HEC 7/8 immediately led to the decision to use its design principle in the HEC 9 along with the same functionality, just at a higher energy level. Consequently the total size and mass of the HEC 9, as well as the required operating energy, increased compared with HEC 7/8 → 1.

To limit transport weights and sizes as well as allowing the use of the well proven operating mechanism HMB 8 of HEC 7/8, it was decided to build HEC 9 as a single-pole operated system, ie, the three poles

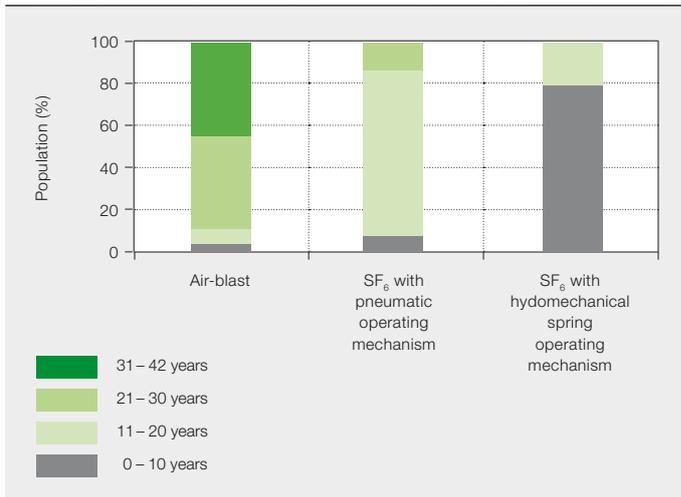
Title picture

SCANA’s power plant VC Summer, in South Carolina, United States, which uses ABB’s HEC-7 GCB

3 Hazard plot per GCB technology

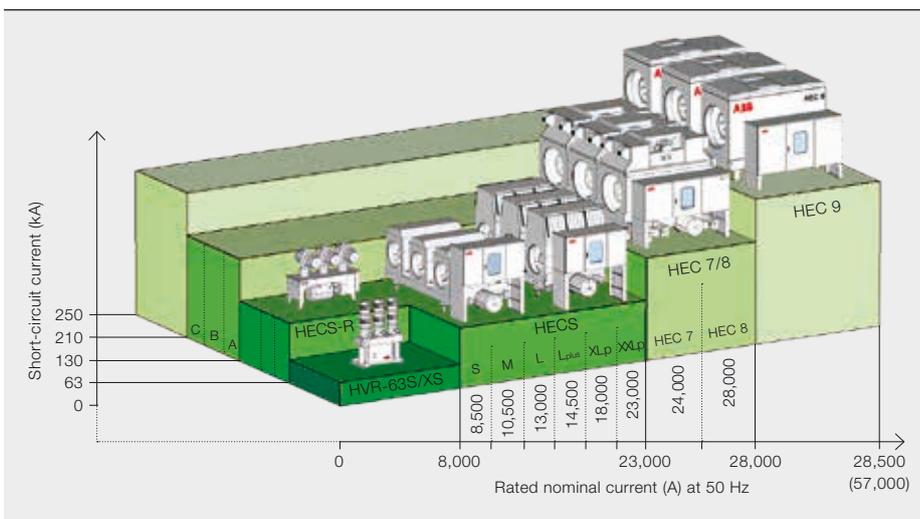


4 Population per GCB technology and age



SF₆ GCBs are much more reliable than air-blast GCBs.

5 ABB's GCB product portfolio



are mounted on individual pole frames together with their own operating mechanisms, which now offered three times more operating energy per pole, compared to the smaller HEC 7/8 → 2.

Using detailed and advanced simulation tools meant it was possible to reduce the number of development tests as well as shortening the development time. Additionally development tests are necessary to avoid unwelcome surprises during the type testing phase. A big effort has been put into a firm measurement technique, withstanding high pressures, temperatures and mechanical shocks.

Another big effort has been to carry out temperature rise tests where the maximum temperature of the equipment is measured at various positions under different normal current ratings and different cooling conditions. In the ABB High Current Laboratory normal currents of up to 50 kA for both 50 and 60 Hz can be run.

All of the necessary type tests have been carried out exceeding today's standard requirements for GCBs. For example, the generator source short-circuit current up to 200 kA with a high degree of asymmetry of more than 120 percent, and additional tests showing higher dielectric or mechanical limits.

Air-blast compared with SF₆ technology

SF₆ GCBs are much more reliable than air-blast GCBs. The difference between the reliability parameters of air-blast and SF₆ GCBs can be mainly attributed to the higher complexity of the former technology and to the aging of its components. Compared with SF₆ circuit breakers, much higher pressures are used in air-blast circuit breakers.

Pressurized air has a relatively long time constant to recover to its nonconducting state so special means need to be applied to reduce the rate-of-rise of transient recovery voltage to values the cir-

cuit breaker can cope with. A resistor is generally mounted in parallel to the interrupting chamber of air-blast GCBs.

The disadvantage of this solution is that additional interrupting units are required to interrupt the resistor current. These additional interrupting units increase the complexity of the system, lead to additional sources of failure and in turn reduce the overall reliability of the GCB.

It is the operating mechanism that is the main source of major failures in high-voltage breakers [1]. The hazard rate of an air-blast GCB is 5.6 times higher when compared with an SF₆ GCB with a hydro-mechanical spring operating mechanism. Air-blast GCBs are equipped with a pneumatic operating mechanism. In this respect, the pneumatic drive has a failure rate 2.6 times higher than a state-of-the-art hydromechanical spring-drive-equipped ABB GCB [2] → 3.

6 Success story: VC Summer

VC Summer is a nuclear power plant owned by SCANA. The plant is just outside Columbia, South Carolina, United States. Originally commissioned in 1984, the plant has a net capacity of 966 MW. Legacy DR air-blast GCBs were part of the original construction to protect the turbine generator.

The core issue

An unfortunate cooling system issue in July 2001 was the first sign that something was not as it should be. This eventually led to an unplanned 10 day outage in October 2009 after which it was decided to replace the legacy product. Since ABB's GCB plant in Zurich, Switzerland, had not produced any DR air-blast breakers since 1996, this posed a significant challenge to the plant.

ABB's GCB service team in Princeton, New Jersey, United States, provided a swift solution by utilizing their customer network. The same model legacy breaker was relocated from another plant. Using parts from the other site and the Swiss ABB factory, ABB's service crew was on-site to get the unit back in service. However it was recognized that the solution was a "band-aid" and concerns about reliability remained.

The customer's engineering task force team had to weigh their options and figure out a proactive and, most importantly, safe solution. From six options – including the risky choice of eliminating the GCB altogether – VC Summer decided it was time to make an investment in the dependable and easy-to-maintain ABB HEC-7 GCB.

Hatching a plan

ABB was awarded the order and work began. Despite extensive analysis at the plant, including 3-D laser surveys and electrical simulations, it is impossible to prepare for every possible eventuality.

When the breaker arrived, the team discovered that it could not fit through the delivery hatch. Due to a modular design and the availability of the ABB team, some removable components were removed to make clearance and then replaced.

The breaker was fully commissioned and closed by May 2011. During a presentation at ABB's customer event, Automation and Power World 2012, the customer stated: "Extensive on-site testing by ABB gave us full confidence in the breaker. To date, the breaker has been at load with no issues."

Operation and maintenance personnel can have peace of mind knowing the exact status of the new breaker thanks to the GMS 600 monitoring system paired with HEC-7. The state-of-the-art device allows communication directly with the plant monitoring system to give full visibility of the status. A full spare phase module and drive mechanisms further ensure that the plant can optimize availability. In addition, ABB has factory trained and certified personnel to perform the aftermarket field services required to keep the equipment operating properly and safely.

7 GCB type HEC 9 at a factory acceptance test



The mechanical endurance of an air-blast GCB is also much shorter than that of an SF₆ GCB, which leads to a lower maintenance frequency, lower operating costs, and also to a higher availability of the SF₆ GCB.

Furthermore air-blast is an obsolete technology that has several disadvantages compared with SF₆ GCBs. For example higher noise levels, longer opening times, longer-lasting downtime due to maintenance operations and lower availability of spare parts. In the surveyed population the vast majority of air-blast GCBs are older than 20 years. The average age of the population of air-blast GCBs is 29.4 years; in other words, 1.7 and 4.3 times older than that of SF₆ GCBs with pneumatic operating mechanisms and hydromechanical spring drives, respectively → 4.

Reliable and safe power generation

ABB GCBs are suitable for application in all kinds of new power plants such as thermal, gas turbine, nuclear combined cycle, hydro and pumped storage power plants, as well as for replacement or retrofit in existing power stations when they are modernized and/or extended → 5 – 6.

As a market leader in GCBs, ABB has a global installed base of more than 7,000 units. ABB GCBs are produced in Europe's 2010 Best Factory Award winning plant, which is in Switzerland, using an advanced flow production system that can assemble and test a breaker in only 2 days versus 2 to 3 weeks using the previous production system.

Protecting the world's largest power plants

ABB leveraged more than 10 years of calculations and testing with the HEC 7/8 to produce the HEC 9. It has a compact design and offers an integrated system solution that provides a 20 year service interval that gives the end user a low life-cycle cost with maximum system availability → 7.

HEC 7/8 as well as HEC 9 are used in the most prestigious power plants of any kind in the world such as in the largest thermal power units rated from 600 to 1,000 MW, hydropower units from 650 MW and above and nuclear power units up to 1,800 MW.

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- [1] "Final Report of the 2004–2007 International Enquiry on Reliability of High Voltage Equipment. Part 2 – Reliability of High Voltage SF₆ Circuit Breakers"
- [2] M. Palazzo, et al, "Reliability Analysis of Generator Circuit-Breakers, CIGRE Session 2012."



The power of collaboration

Service solutions across the product life cycle

HERB ROGERS, SUDHAKAR KUCHIBHOTLA, MONICA LAMBE – High-voltage circuit breaker equipment represents a substantial investment for any company. So, when it comes to maintaining or replacing it, all options have to be considered. Often, the most cost-effective option is to partner with a full-service OEM expert who will employ the latest technology during maintenance cycles and seek life extension opportunities, such as retrofits or component replacement. In some cases, total replacement, removing obsolete equipment or technology, may be best. Remote monitoring and advanced inspection techniques, such as radiography, will often eliminate the need for intrusive maintenance programs, or early replacement altogether. ABB has developed service strategies to suit the many different maintenance and replacement scenarios encountered in the high-voltage circuit breaker world.

1 La Foretaille GIS substation in Switzerland. The older-generation circuit breaker type SN was replaced by an ELK SP2-1 with AHMA drive.



To retrofit is to exchange worn parts or outdated components while maintaining the original plant and equipment configuration. Often, in a substation, original equipment, such as the housing and busbars, remains in good condition and it is only the moving circuit breaker parts that need to be replaced. Mechanical equipment wears out long before stationary assets. Retrofitting extends service life without the high costs, major disruption and extended time scales associated with a complete replacement project. The work can also be staged to spread out cost and minimize disruption.

Often, a new breaker will not be compatible with old equipment. In such a case, ABB will supply special conversion kits that enable quick installation without structural modifications to the original setup.

ABB's breaker and drive retrofits ensure that the client receives long-term equipment reliability with the latest technology and minimal outage time – all at a reasonable cost.

Title picture

Just what strategies are available to improve high-voltage circuit breaker equipment performance while holding down costs?

Retrofit examples

ABB has supplied several clients with replacement breakers for their gas-insulated switchgear (GIS) instead of revision solutions. Invariably, the replacement breaker was of a newer type and the flange distance and other parameters had to be matched. For example, in the Netherlands (Rijswijk substation) and in Switzerland (Katz substation) first-generation GIS ECKS breakers were successfully replaced with ELK SP 2-1 breakers and AHMA drives. The motivation for the replacement was dwindling repair expertise and the increasing difficulty experienced in sourcing spare parts. In the La Foretaille substation in Switzerland, a similar replacement was undertaken (in this instance an ELK SN breaker type was replaced by ELK SP 2-1), the motivation here being impending high overhaul costs → 1.

Not all older breakers have a new equivalent. Therefore, ABB specially made a few retrofit breakers that could replace older breakers of types SL211, SL2-2, SN212, SL3-2 and SN312. These have been type-tested as per the latest applicable standards and are manufactured in the controlled environment of an ABB factory.

The EGL 380kV substation at Filisur, in Switzerland, is the first to have such a specifically developed retrofit breaker installed → 2. The client had originally considered overhaul of their HKA 8 drive, but decided instead to install the new HMB 8 drive. ABB also proposed replacing their complete SL3-2 breaker and drive with a newly developed retrofit SP 3-1 breaker. This new breaker has only one single arcing chamber – repre-

senting state-of-the-art GIS technology – and therefore needs only a (smaller) HMB 4 drive. The client quickly opted for this proposal – extended substation life, continued availability of spare parts and lower maintenance costs being the convincing arguments. The actual circuit breaker exchange at site took only two days and the switchgear resumed normal operations with minimal downtime.

An alternative to changing the complete circuit breaker and drive is to change only the drive itself. In Spain, at the La Muela pumped storage substation, a retrofit drive solution was developed to replace the old HKA 8 drive on a SL 3-2 breaker → 3. The HKA drive was dismantled from the breaker pole and a new HMB 8 drive was fitted, with necessary adjustments (damping). The homologation tests were conducted on-site. Satisfied with this solution, the client, Iberdrola, decided to implement the same retrofit drive solution in the remaining bays at the same substation. In the Seinäjoki and the Tammisto substations in Finland similar drive replacements were undertaken.

Extension

ABB has developed cost-effective upgrade, extension and retrofit programs that enable low-risk and phased migration to the latest technology. After a complete site evaluation, ABB will develop a customized implementation plan for migration of the installed equipment.

One good example of this centers on the delivery of two 132 kV gas-insulated ELK-04 switchbays to the 30-year-old Al Bakir trans-



The motivation for the replacement was dwindling repair expertise and the increasing difficulty experienced in sourcing spare parts.

former substation in Iraq. This investment became imperative in light of the growing power demand caused by the construction of a steel factory nearby and to be able to adequately interface to the Iraqi grid. The main deciding factor for the customer was that the ELK-04 design could be adapted to fit into the restricted space available. The customer received competent consulting support during the engineering stage and now has a reliable 132 kV substation, security of energy supply and guaranteed personnel safety. The previous infrastructure was kept and further extension is now simplified thanks to the use of standardized adapters.

Asset optimization

ABB recognizes that industry needs are changing as resources become limited and have, therefore, established expertise in remote monitoring of all critical substation diagnostic metrics. One such service combines ABB's universal breaker monitor with deep operational and diagnostic expertise to give real-time asset optimization and to allow remediation prior to failure.

This approach has been taken within New York's electrical power grid, which is highly dependent upon the health and reliability of the high-voltage cross-state ties between the NYISO's transmission owners, such as the 362 kV lines connecting Rochester Gas and Electric (RG&E) with New York Power Authority. To help enhance the reliability of this transmission corridor, RG&E has equipped its type PMI capacitor bank break-

ers, which support the critical east-west tie, with real-time remote condition monitoring and has also instituted proactive maintenance practices. Of particular interest for first-trip analysis of the transmission line breakers was acquiring a means of recording all trip and close operations, as well as the timing statistics, of those breakers.

ABB has equipped a fleet of 18 RG&E 121 kV and 362 kV PMI breakers with ABB's asset optimization (AO) system. The system monitors a myriad of breaker status and performance parameters via wireless communication. Data from each breaker is gathered by its onboard Circuit Breaker Sentinel™ (CBS). Each CBS has been paired with a cellular communicator – decidedly the most cost-effective means of delivering data to a central office, especially from substations lacking a network structure. The CBS-based monitoring approach was especially appealing to RG&E since the units and their wireless communication architecture function independently of the utility's transmission line operating and control system. That separation exempts the monitoring system from NERC-CIP (North American Electric Reliability Corporation's Critical Infrastructure Protection plan) requirements. The accumulated CBS data is processed at RG&E's central office by ABB's AO system, which delivers real-time, independently accessible data to detect circuit breaker health and performance conditions before a failure occurs. The AO system thereby assists circuit breaker problem diagnosis and offers corrective recommendations. Its

3 La Muela GIS substation, Spain. The HKA8 drive was replaced with the HMB8 on SL3-2 circuit breaker.



alerts vary in complexity from identifying status changes in an intelligent device to identifying abnormal conditions. The system includes an independent ABB redundant archiving system to ensure reliable storage of long-term data. With this reliability improvement RG&E was able to obtain a rate increase from the local regulatory commission.

Radiography

Radiography is an x-ray imaging technology, employed here in an external environment,

Call Henry Inc. is the high-voltage on-site support service contractor at the NASA Glenn Research Center in Cleveland, Ohio. The Center leads NASA's research and development in the area of aero-propulsion and specializes in turbo-machinery, power, propulsion and communications, while also conducting research in various microgravity science disciplines. Obviously, power supply reliability is critical to such a facility.

In February 2006, Call Henry contacted ABB on behalf of the center regarding the health of their 26 ABB 38PM40-20 SF₆ power circuit breakers. A review of the maintenance data carried out by the center and Call Henry highlighted the fact that many of the center's circuit breakers were between 10 and 14 years old, with one

breaker having completed over 2,700 operations during its lifetime. It was apparent that these breakers were working hard and were due for an internal inspection. A site visit was coordinated between the center, Call Henry and ABB in order to perform the inspection. The work scope consisted of external diagnostics testing, heavily featuring the use of radiography. The driver for this approach was a desire for cost and outage time reduction, while certifying the long-term integrity of each breaker and, more impor-

tantly, its power supply. The radiographic inspection resulted in entry being made to one breaker to remediate a hardware problem and reduction of the SF₆ gas moisture content in seven others. Nineteen were spared any entry or intrusive maintenance whatsoever and over 380 man-hours of intensive, internal inspections were saved. A crane, with operator, and gas cart rental were also saved.

The external diagnostic testing and resulting maintenance ensured continued and reliable operation of the center's fleet.

Replacement

Equipment can be completely replaced at the end of its service life, or if better technology has become available. In the case of generator circuit breakers (GCBs), upgrading the turbine and generator will also necessitate the replacement of the GCB. GCBs may also be replaced if obsolescence results in nonavailability of spare parts or inadequate engineering solutions.

One example of this concerned the spring-loaded hydraulic circuit breaker operating mechanisms in five transformer substations in Kuwait City, owned and operated by the Kuwaiti Ministry for Electricity and Water (MEW). Considering the increasingly critical spare parts situation for the existing operating mechanisms, which are nearly 30 years old, the proposal submitted by ABB to replace the existing units with 48 HMB-8 operating mechanisms was positively received by the MEW. An essential aspect of this decision was ABB's quality assurance and the guaranteed availability of the related spare parts. As a result, the MEW acquired a dependable spare parts supply, high substation availability and reliability, better personnel safety, uncomplicated adaptation and replacement, and, of course, a simplified operation.

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ABB's breaker and drive retrofits ensure that the client receives long-term equipment reliability with the latest technology and minimal shutdown time – all at reasonable cost.

that captures detailed digital images of a circuit breaker's critical internal components. These images are then reviewed by OEM experts, who check dimensions and tolerances against original component and assembly drawings. Radiography eliminates the need to breach the sealing system of the equipment being diagnosed, thus increasing equipment reliability and making infiltration of external contaminants a nonissue.



Improving eco-efficiency

ABB's high-voltage technologies are rising
to the challenge

NAMITA ASNANI, FREDI STUCKI – The growing population and prosperity of people around the world can be directly linked to the rising demand for energy, which is to a large extent produced by burning fossil fuel. Very often the generation of electricity occurs far away from load centers and urban areas, requiring an efficient means of bringing the power to the industrial sites and the densely populated areas. The most eco-efficient way to transfer energy from one point to another in a power transmission network is through the use of high-voltage technologies. As a pioneer in this field, ABB is continually working to design and manufacture products that have the lowest environmental footprint and as a result improve the eco-efficiency of today's power grids. At the same time, the company strives to enhance its existing high-voltage products with respect to reliability, efficiency and full life-cycle cost.



ABB launched a patented technology for the comprehensive recycling of contaminated SF₆ gas, based on an energy-efficient cryogenic process.

One technology that is used extensively in the electrical industry for dielectric insulation and current interruption in circuit breakers, switchgear and other high-voltage equipment is the inert gas known as sulfur hexafluoride (SF₆) → 1. It is used in applications in the magnesium and semiconductor industry, and also has some uses in military applications.

ABB mainly uses SF₆ in high-voltage electrical equipment. The gas has excellent insulating and arc-quenching properties, enabling the design of more compact equipment. Land use, energy consumption, losses and waste are all considerably reduced, while the ability to recycle is enhanced.

ABB goes to great length to ensure that SF₆ gas is not allowed to escape into the atmosphere when equipment is manufactured, erected, serviced or scrapped and that any hazardous and decomposed products are disposed of in a compliant and environmentally responsible manner. The company is continually researching viable alternatives, seeking to reduce the amount of SF₆ used in its products.

High-voltage CO₂ breaker

One promising alternative to SF₆ is to use carbon dioxide (CO₂) as the insulating and arc-extinguishing medium. ABB's high-voltage live tank breaker LTA 72D1 is the first high-voltage circuit breaker to use CO₂ in this way → 2.

The LTA 72D1 circuit breaker is currently available for 72.5kV distribution networks with short-circuit breaking current

ABB's new LTA circuit breaker will reduce CO₂-equivalent emissions by about 10 tons or 18 percent over a 30-year lifetime.

requirements up to 31.5kA. It is available as a conventional circuit breaker as well as a disconnecting circuit breaker (DCB).

The evaluation of the LTA circuit breaker's environmental impact of over its life cycle has been made with regard to global warming potential (GWP). GWP is the value that describes the contribution of a substance to global warming over its lifetime. The result is expressed in CO₂ equivalent emissions over the product's life cycle. The graph in → 3 compares the

Title picture

SF₆ recycling centers such as this one in Australia enable the potentially harmful gas to be reused again and again.

SF₆ is a man-made gas and is one of the six greenhouse gases listed in the Kyoto Protocol.* Today SF₆ accounts for only about 0.1 percent of mankind's contribution to the greenhouse effect even though it has a global warming potential that is 22,800 [1] times greater than carbon dioxide.

SF₆ facts

- Nonflammable gas that is used in electrical equipment
- Nonpoisonous
- Does not destroy the ozone layer
- Equipment used in SF₆ processes is extremely safe
- The gas is collected and recycled if a piece of equipment or a substation needs to be opened
- Can be removed from the ecosystem through a thermal process that transforms SF₆ into the natural substances fluorspar and gypsum
- Very high dielectric withstand capability
- Effectively quenches arcs in circuit breakers
- SF₆ apparatus are compact and almost maintenance-free
- In electrical applications, SF₆ is only used in sealed/closed and safe systems

Footnote

* The Kyoto Protocol is an international agreement designed to reduce greenhouse gas emissions. See: *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, United Nations, 1998.

Reference

- [1] Intergovernmental Panel on Climate Change, Working Group 1, Climate Change 2007, Chapter 2.10.2.

life-cycle environmental impact of ABB's LTA CO₂ circuit breaker with ABB's LTB SF₆ circuit breaker over a service life of 30 years. As per estimations based on recommended methodologies of the Intergovernmental Panel on Climate Change, by replacing SF₆ with CO₂, CO₂-equivalent emissions can be reduced by about 10 tons or 18 percent over a 30-year lifetime.

Yet another method of reducing the environmental footprint and increasing grid eco-efficiency is SF₆ recycling → 4. ABB recently launched a patented technology for the comprehensive recycling of contaminated SF₆ gas, based on an energy-efficient cryogenic process. The purity of recycled SF₆ gas using the newly developed technology is more than 99.9 percent and is in accordance with technical grade IEC 60376 (the standard for new gas), which enables SF₆ to be reused again



One of the largest generators of electricity and the largest generator of heat in Europe, Vattenfall is a pioneer in developing and adopting new technologies that facilitate the production of energy in an environmentally sustainable manner. ABB's LTA CO₂ disconnecting circuit breaker (DCB) takes Vattenfall a step closer to its goal.

The DCB is a concept pioneered by ABB in the year 2000. By integrating the disconnecting function within the breaker, the DCB does away with the need for separate disconnectors and increases equipment reliability and availability. It also improves the eco-efficiency of equipment throughout the life cycle by using fewer primary apparatus and consequently, fewer raw materials. DCBs also create lower electrical losses during the use phase due to lower electrothermal losses. Last but not least, they can reduce the physical footprint by as much as 60 percent.

The LTA CO₂ concept breaker was installed in a pilot project at a 132/45 kV substation in Sweden in 2010, and has performed faultlessly since then. Operated by Vattenfall, the substation comprises six 132 kV and nine 45 kV bays.

The LTA CO₂ DCB, which is positioned as a busbar circuit breaker, performs a dual role, functioning as a capacitor bank circuit breaker for part of the year and as a line circuit breaker for the remaining period. In a year, the equipment performs almost 400 breaking operations.

While the LTA 72D1 is designed for a rating of 72.5 kV, its outstanding performance at 145 kV confirms that it has the potential to support far higher voltage levels of CO₂ technology.

and again. Using recycled SF₆ gas helps reduce carbon emissions and has a cost savings potential of up to 30 percent. The greatest technical advantage of the new process relative to earlier technologies is that it can efficiently recycle SF₆ irrespective of the type or level of contamination. The older technologies suffer from an inability to treat all contaminants and all contamination levels in one process. Furthermore, the level of automation in the new process allows significantly greater throughput.

Online monitoring of SF₆ gas with the CBS line of products

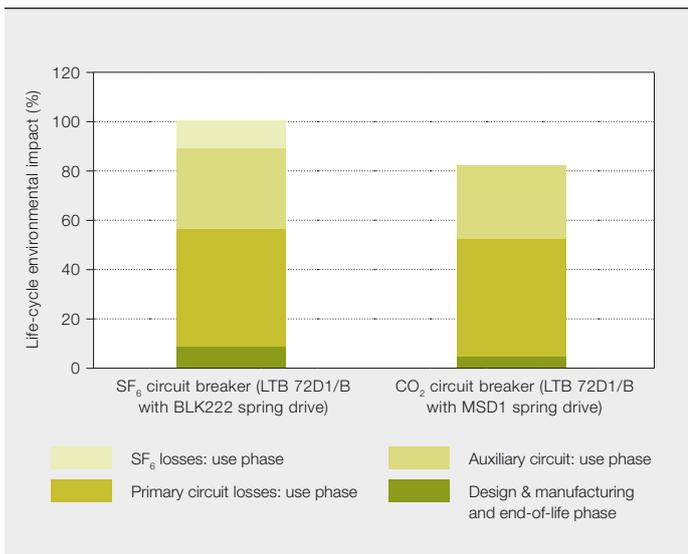
Minimizing gas leaks is also of great concern when it comes to SF₆. Online monitoring of equipment using SF₆ gas enables continuous supervision and thus faster dispatch for any SF₆ gas leak repair. ABB's Circuit Breaker Sentinel™ line of condition monitors includes a com-

compact electronics and sensor package to determine temperature-compensated pressure in single-compartment SF₆-insulated switchgear – the CBS-F₆. The Windows-based software enables remote online monitoring and continuous trending of deviations from the required pressure → 5.

Fiber optic current sensors

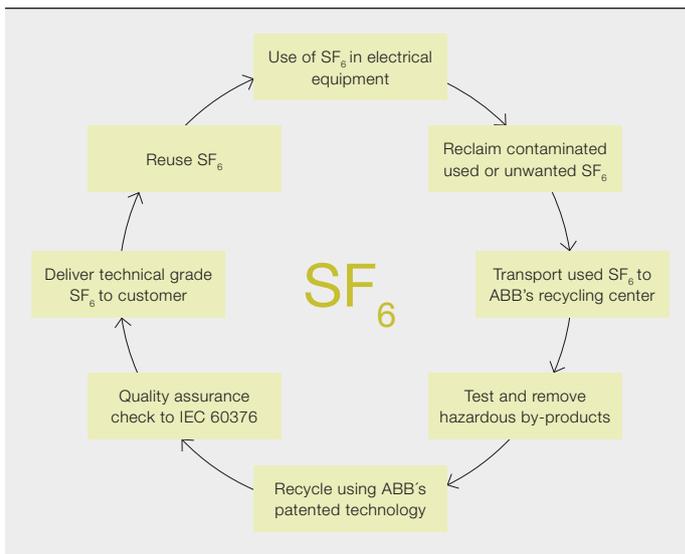
In recent years, current and voltage sensors have started to replace regular oil-insulated instrument transformers in smart switchgear applications. For high-voltage air-insulated substations a fiber optic current sensor (FOCS) is a smart alternative to traditional current transformers. FOCS offers a "plug and play" solution and, with its digital interface, is designed for IEC 61850 communication. The sensors improve eco-efficiency by eliminating oil or SF₆ as insulation media, thereby removing the risk of oil spills or

3 Comparison of the life-cycle environmental impact of ABB's LTA CO₂ circuit breaker and ABB's LTB SF₆ circuit breaker



Comparison is based on recommended methodologies of the Intergovernmental Panel on Climate Change (IPCC) and ISO standards.

4 Cryogenic recycling of SF₆ gas



5 ABB's Circuit Breaker Sentinel CBS-F₆



ABB makes use of easily recyclable and disposable material in its products to the greatest extent possible.

gas leakages. FOCS also eliminates the need to use tons of material, such as aluminum, copper cables, steel and concrete foundations, and substantially reduces the substation footprint. ABB's FOCS is integrated with live tank circuit breakers, including disconnecting circuit breakers → 6.

Dry cable terminations

ABB's dry self-supporting cable termination comes preassembled and prefilled with an electric insulating elastomeric silicone compound from the factory → 7. This prefabrication means there is no risk of incorrect handling or risk of oil or chemical leakage during transportation or at site. Dry solutions have the added advantage that, in the event of a failure, they are less likely to cause damage to surrounding equipment and, more importantly, are less likely to cause personal injury.

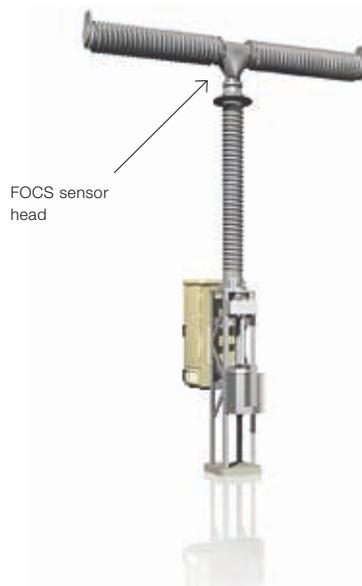
Addressing the life cycle

In each phase of a product's life cycle there are environmental implications such as power losses and waste production. ABB adheres to ISO standards to measure and assess the environmental impact of its products throughout all phases of the products' life cycle. Broadly speaking, these phases are: manufacturing, use and end-of-life. For high-voltage products a life cycle is usually between 30 and 40 years. ABB leverages its 100+ years of experience in high-voltage technology to continually improve product design and as a result reduce environmental impact in all phases of the life cycle.

Manufacturing phase

In this phase ABB's objective is to reduce the embodied energy in its products. Embodied energy is the sum of all the energy required to produce goods or

6 FOCS integrated with ABB's disconnecting circuit breaker (DCB)



usually accounts for 70 to 80 percent of the total environmental impact. For example, circuit breakers use energy in their drive mechanisms. ABB uses compact spring drive mechanisms that require low energy, replacing bulky hydraulic drives that consume far more energy over their life cycle. Additionally, as current flows in the conducting parts of the equipment, there are some associated electrothermal losses. ABB's special designs and materials ensure low resistive losses. Insulating mediums used in high-voltage products such as SF₆ gas and oil will, if leaked, negatively impact the surrounding environment. ABB thus ensures SF₆ gas leakage rates consistently below 0.5 percent by using special well-proven sealing systems for indoor and outdoor applications, down to -55 °C.

The end-of-life phase

In addition to employing the latest recycling technologies, ABB makes use of easily recyclable and disposable material in its products to the greatest extent possible. Proper documentation with clear declarations also reinforces improved recycling and disposal.

Improving the eco-efficiency of ABB's products and solutions is a continuous journey and encompasses conducting research and development to discover breakthrough technologies as well as continuously evaluating and lowering the environmental impact of existing products and solutions.

7 Kabeldon TD 145 : Dry pre-assembled cable termination for 145 kV

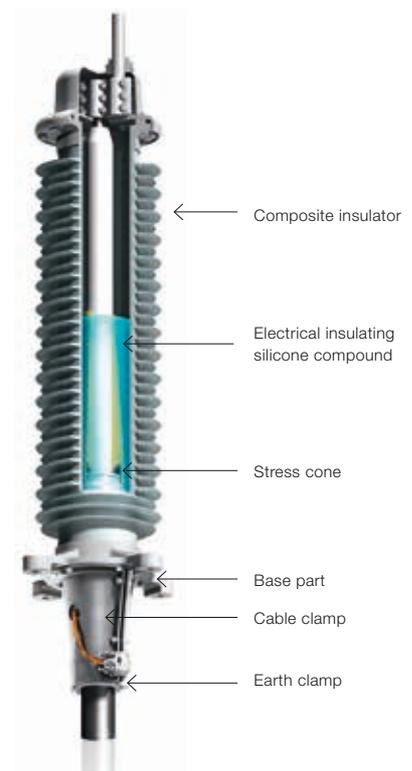


ABB leverages its 100+ years of experience in high-voltage technology to continually improve product design and as a result reduce environmental impact in all phases of the life cycle.

services. Over the years ABB's products have become lighter, which means they use less material per kV and kA of power transmitted. In addition, the volume of SF₆ gas used in ABB's products is decreasing. For example, from 1995 to 2012 the SF₆ gas volume in a 420 kV AIS CB has dropped by 20 percent, and from 2006 to 2012 the SF₆ gas volume in a 420 kV GIS bay has fallen by 40 percent. As a general practice, ABB always aims to use the most energy efficient processes in the manufacturing phase.

Use phase

Due to the long life cycle of high-voltage products – generally between 30 and 40 years – as well as other factors (eg, operational energy use), the use phase

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Further reading

- www.iso.org
- B. Alexander et al., "SF₆ and a world first: ABB launches the first-ever SF₆ recycling center," *ABB Review* 1/2012, pp. 22–25.



Power quality matters

Eliminating reactive power and harmonics with capacitors and filters

KURT SCHIPMAN – Poor power quality is becoming an increasing cause of concern for both the users and the suppliers of electrical power. Consequences of poor power quality include reduced efficiency in the generation, transport and use of electrical power and an increase in system breakdowns. System reliability decreases and

operational costs increase. The introduction of renewable power sources into the grid adds further challenges with respect to load demand management and voltage stability. ABB is a pioneer in, and offers a complete portfolio of, products that address a wide variety of power quality problems in all voltage categories.

1 Benefits of good power quality

Utility benefits	Industry benefits
Enhanced asset utilization	Reduction of electricity charges
Lower network losses and CO ₂ emissions	Lower network losses and CO ₂ emissions
Expansion of network capacity	Grid compliance
Voltage stability	Increase in plant capacity
	Higher productivity (ie, fewer outages, lower operating costs)

2 ABB power quality portfolio range

Below 1 kV	Above 1 kV
Capacitor units for power factor correction	Capacitor units for power factor correction
Automatic switched capacitor banks (contactor/thyristor)	Special capacitors (eg, surge capacitor)
Stepless reactive power compensators	Fixed and switched capacitor banks (metal-enclosed)
Active harmonic filters	Fixed and switched capacitor banks (open-rack)
Power factor controllers	Passive harmonic filters
Active voltage conditioners	Static var compensators (SVC)/series compensation
Industrial UPS systems	STATCOM/SVC Light products
Battery energy storage systems (including reactive power and harmonic control)	Battery energy storage systems (including reactive power and harmonic control)

An ideal electrical AC supply system voltage is sinusoidal with a constant amplitude and frequency. An ideal AC load current is sinusoidal at the same frequency and in phase with the voltage. Such a system is the most stable, will run with minimal losses for a given requirement and can be said to have optimal power quality. In real life, many factors cause deviation from the ideal situation and the power quality deteriorates. Consequently, installation lifetime and running efficiency decreases, and running cost increases. If production is stopped unexpectedly, eg, due to poor power quality, major costs are incurred [1]. The benefits of good power quality are manifold → 1.

Poor power quality has many sources:

- Reactive power, which causes line losses and voltage variations, and loads the supply system unnecessarily.
- Harmonic pollution, which causes extra stress on the networks, potentially leading to equipment malfunction, and makes installations run less efficiently.

- Load imbalance, (eg, in single-phase railway applications or office buildings). The unbalanced loads may result in excessive voltage imbalance, causing stress on other loads connected to the same network and leading to an increase of neutral current and neutral-to-earth voltage build-up in four-wire systems.
- Voltage variations (eg, dips, sags, swells) that can lead to load malfunction and, when repetitive, can lead to flicker problems. Voltage variations can be caused by load current variations, or by external factors such as transmission or distribution line incidents (eg, lightning strikes).

In order to maintain good power quality on the network, utilities invest in power quality equipment themselves and/or put a suitable tariff/penalty structure in place aimed at limiting the effects caused by network users. Network users install power quality equipment to comply with regulations and/or to obtain optimal system efficiency.

World leader in power quality

ABB delivers a complete portfolio of power quality products and know-how in the low-voltage (LV), medium-voltage (MV) and high-voltage (HV) areas with a focus on efficient and environmentally friendly power transport to, and power usage by, resources connected to the grid → 2. ABB has been driving development in the field of power quality for over 70 years.

In real life, many factors cause deviation from the ideal situation and the power quality deteriorates.

Reactive power compensation

The inductive series impedance of overhead lines results in reactive power consumption. This increases with the square of the current, causing a voltage drop and, consequently, a reduction in the capacity of the line to transmit power. To limit these effects, reactive power compensation equipment, such as shunt capacitor banks, is usually installed. The capacitor banks protect against adverse effects of voltage variations by maintaining a sufficiently high voltage level, thus

Title picture

What can be done to combat reactive power and harmonics in the power grid?

3 Dry ABB capacitors for HVDC Light and SVC Light applications

ABB has always been at the forefront of dry capacitor technology. After pioneering it for LV AC applications many years ago, ABB mastered and perfected dry capacitor technology to produce capacitors for high-voltage DC (HVDC) applications.

ABB dry capacitors are substantially smaller than their conventional equivalents, making them ideal for situations that require high energy density – in HVDC Light and SVC Light applications, for instance. At the heart of these applications sits a voltage source converter (VSC) where the capacitor acts as the voltage/energy source. The higher the converter powers become, the higher the stored energy capability has to be. The latest converter topologies also require higher current densities.

In addition to their compactness and higher power density capability, ABB's dry capacitors for DC applications have many more advantages such as self-healing, superior end-of-life performance and low inductance, making them extremely suitable for very demanding applications.

contributing to the security and reliability of the grid. In addition, the compensation results in reduced system losses.

The higher its voltage, the greater the transmission capacity of the grid. The use of shunt capacitor compensation permits an increase in the active power that can be transmitted, thereby reducing the risk of voltage collapse phenomena. ABB's capacitor banks are used by many transmission and distribution operators.

In addition to capacitors for reactive power, ABB is at the forefront in the development of dry capacitor technology for DC applications → 3.

Boosting efficiency in Bangladesh's grid

The Power Grid Company of Bangladesh (PGCB) selected ABB's HV open-rack capacitor bank to improve the performance of its 132kV transmission grid, parts of which were suffering losses because of voltage drops and poor power quality.

The new reactive power compensation equipment was installed in the eight PGCB substations where losses were greatest and power flows most critical.

4 110kV passive filter installation in Poland



After installation, the power factor increased from 0.88 to 0.98, a significant achievement. The voltage rose by 3 to 5kV compared with the initial situation. Raising the voltage of the system reduced the losses and improved the amount of active power that could be delivered to the end users.

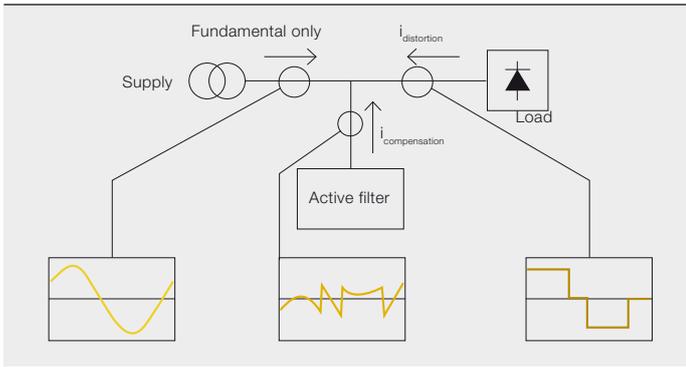
The combined improvements in power factor and voltage allowed the equivalent of 34 MW of extra power to be brought into the grid, without needing to build any additional generation capacity. The ability to deliver this additional power has significantly improved PGCB's revenues.

Overall, the project had a payback time of 18 months. The cost was a fraction of the capital that would have been required to build an equivalent conventional fossil fuel power plant and an additional transmission line. Also, because the ABB system recovers lost capability rather than generating new additional power, there are no significant continuous operating costs and no extra greenhouse gas emissions.

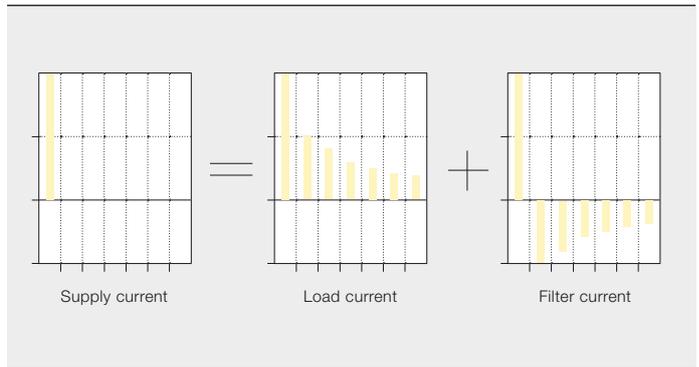
In addition to the open-rack models, ABB offer a complete range of metal-enclosed capacitor banks (MECBs) for customers who have limited footprint, or who want full integration with a high degree of

ABB has been driving development in the field of power quality for over 70 years.

5 Connection diagram of the most commonly found active filters



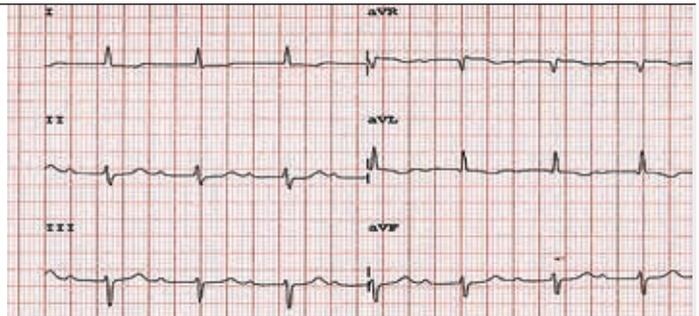
6 Principle of the frequency-domain filtering approach



7 ECG recorded in the emergency department



7a Before installation of ABB active filters



7b After installation

embedded protection. These banks can be installed inside or outside and are typically used in industrial applications or distribution utility applications, eg, for the compensation of grids or wind farms.

Improving power quality actively

The increasing prevalence of nonlinear loads in all types of industrial and commercial applications has resulted in the introduction of potentially harmful levels of current harmonics into the power network. Historically, passive filters have been, and are still being, proposed to mitigate harmonic pollution → 4. In LV installations, these solutions are much less applicable, eg, due to overload risk where load patterns are dynamic.

ABB modular active power quality filters (PQFs) avoid the problems of passive filters by using power electronics hardware that continuously monitors current harmonics in real time and cancels them out by injecting currents of exactly the opposite phase. The feeding transformer then sees a clean sine wave – the optimal supply current waveform → 5.

For best performance throughout the high filter bandwidth, two key control aspects of the ABB active filters are:

- Use of a genuine closed-loop control for optimal filtering performance.

- A frequency domain approach to the processing and control of the polluted current allowing the customer to target the pollution in an optimal way → 6.

In addition to active harmonic filtering, ABB active filters can also:

- Perform stepless reactive power compensation of inductive and capacitive loads – useful/required in modern buildings with a lot of computing equipment.
- Perform load balancing. This enables neutral systems to be offloaded and ensures that neutral-to-earth voltages are kept to minimal levels, thus restoring installation safety and increasing installation reliability.

ABB active filters suppress ECG interference

Harmonic-producing hospital loads introduced electromagnetic interference severe enough to disrupt electrocardiograph (ECG) monitoring and recordings in the new emergency department at the Royal Melbourne Hospital in Australia. As a result, the new ECG facility could not be used.

Investigations involving ABB revealed that the source of the interference was harmonic currents flowing in the mains cable. This interference was suppressed

by ABB active filter technology and the ECG equipment could then be successfully utilized [2] → 7.

ABB was a pioneer in power quality technology and, today, offers extensive experience as well as a portfolio of products to help customers combat the increasing power quality challenges they face in all voltage categories.

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- [1] European Copper Institute, "European Power Quality Survey," 2002
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Raising the bar

UHV switchgear and components

WALTER HOLAUS, MICHAEL LANE, RICHARD THOMAS –

The reliable supply of electrical energy is a backbone of the modern economy. Its ability to operate safely and reliably mainly depends on high-voltage switchgear.

The continuing demand for higher transmission power and lower transmission losses per line favors the use of ultrahigh-voltage (UHV) levels – applying rated voltages of 800 kV, 1,100 kV and 1,200 kV.

1 Examples of ABB leadership in AIS UHV switchgear

1965	World's first 800 kV live tank circuit breaker (air-blast)
1989	World's first 300 kV single-element SF ₆ live tank breaker
2001	World's first 800 kV DTB (dead tank breaker)
2008	World's first 800 kV SF ₆ live tank breaker with single mechanism per phase
2009	World's first 550 kV SF ₆ live tank breaker without grading capacitors
2010	First DCB with integrated fiber optic current sensor installed
2011	World's first 1,100 kV UHVDC bypass breaker installed
2012	World's first 1,100 kV UHVDC surge arrester, coupling capacitor and capacitor filter developed and tested

2 1,100 kV UHVDC components



Both AC and DC UHV systems are necessary to handle the increase in electric energy consumption and to back up the existing transmission system. They are, in effect, the highest density, highest efficiency electric power super highways. Bulk power transmission over big

revision purposes. ABB's portfolio comprises AIS LTBs (air-insulated switchgear live tank breakers) and DTBs (dead tank breakers), and hybrid switchgear and GIS (gas-insulated switchgear) portfolios, which each have their specific characteristics to best meet customer needs. Designing and building HV switchgear capable of meeting the stringent safety, performance and reliability demands for UHV power systems is a significant challenge, but one where ABB has consistently

Metal enclosure and SF₆ gas insulation enable the development of more compact high-voltage switchgear.

distances is – naturally – a topic for big countries. Therefore, UHV installations have been built in countries such as China, Russia, India, Canada, South Africa and the United States. However, the ongoing urbanization as well as the change in energy production to renewables and offshore power now make the UHV technologies a topic virtually everywhere.

Ultrahigh-voltage AC grids require electromechanical switchgear that can cope with the switching demands for normal operation, for protection in the event of a short circuit and for maintenance and

taken the lead over the past 50 years through technical innovation and close dialogue with the utilities.

A key aspect of ABB's successful leadership in supporting UHV power system implementation is the strength and flexibility of its modular design and production approach for all its HV switchgear breaker solutions including LTB, DTB, hybrid and GIS. ABB has the strongest single-element interrupters for both live-tank and metal-clad solutions, as well as the world's most comprehensive range of breaker operating mechanisms, enabling ABB to rapidly develop reliable,

Title picture

765 kV substation in India under construction



high-performance switchgear to meet customer's needs.

ABB's leadership in switchgear design extends beyond interrupters and operating mechanisms to other core components for UHV technology, such as composite insulators using silicone rubber for bushings, metal varistor technology for overvoltage protection, nonconventional instrument transformers and sensors for current and voltage measurement.

Air-insulated UHV technologies

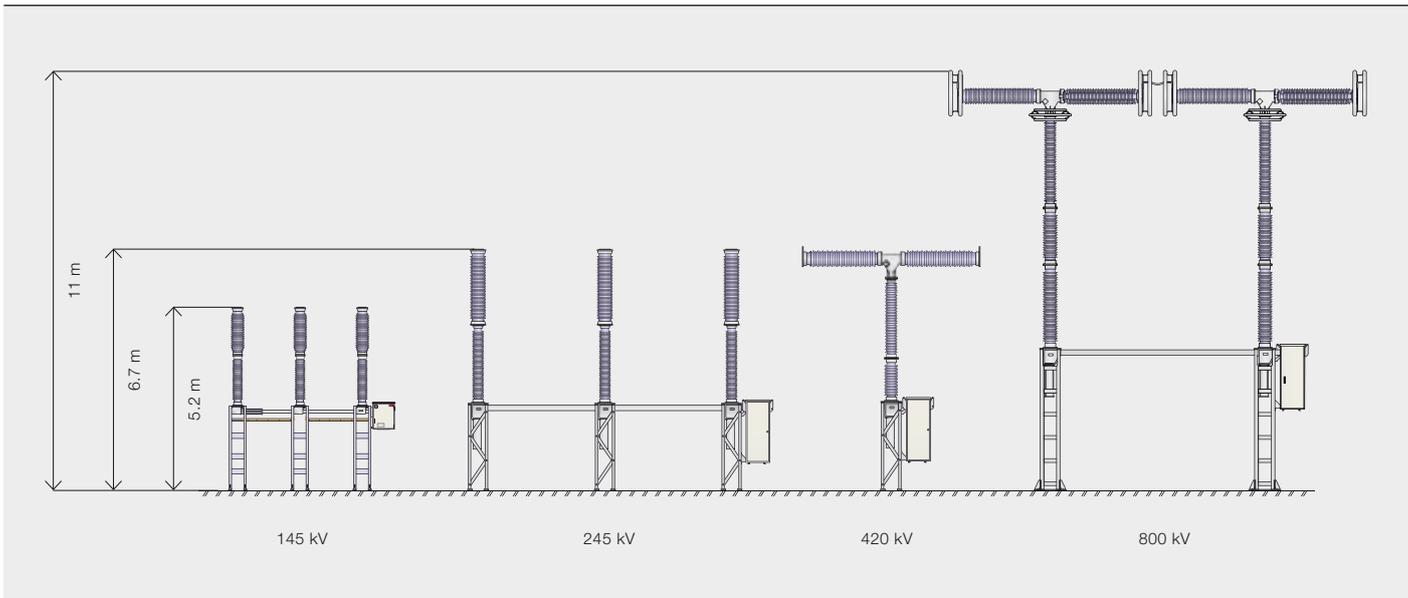
Electrical grids and the corresponding substations are often air-insulated – the high voltage is kept away from both the ground and people by distances of tens of meters → 1-2.

The strength and reliability of ABB's live tank interrupters and drives – built on single-element interrupters up to 300 kV, 5,000 A, 80 kA and able to operate in climate extremes from -60°C to +50°C – provide the foundation for providing the most reliable and proven live-tank switchgear solutions up to 1,200 kV and even up to 80 kA. By coupling knowledge and experience in composite insulators and the ability to integrate advanced technologies such as ABB's fiber optic current sensors, ABB can offer the safest, most reliable and most

ABB continues to invest in the development of new products, upgrades and higher voltage levels.

compact UHV AIS solutions for both AC breaker and DC switching applications. ABB live tank solutions are supporting and protecting UHV power systems across the world in China, India, Canada, Russia, the United States, Ukraine and Venezuela, among many other locations → 4.

The backbone of ABB's UHV dead tank circuit breakers are single-element interrupters rated up to 362 kV, 63 kA and 5,000 A. Utilizing tank heaters, the circuit breakers and drives are capable of operating in climate extremes from -50°C to +40°C. The interrupters and drives provide the foundation for the most widely installed and proven dead tank circuit breakers up to 800 kV. For the future, similar interrupters and drives utilized in GIS for the Bina Substation project in India, provide the foundation for extend-



The world's first 1,100 kV AC grid in China has been under successful commercial operation since it was energized.

ing the dead tank circuit breaker capabilities up to 1200 kV. In 2000, ABB was the first to install an 800 kV dead tank circuit breaker. Since then, the 800 kV dead tank circuit breaker has been supporting UHV power systems worldwide, notably in China, the United States and South Africa.

Gas-insulated UHV technologies

Metal enclosure and SF₆ gas insulation enable the development of more compact high-voltage switchgear. One of ABB's predecessor companies introduced GIS technology to the market in 1965 with the first 170 kV GIS underground substation being installed in the Zurich city center in Switzerland the following year. In 1976, ABB delivered the first 500 kV GIS to Claireville, Canada.

With the installation of the world's first 800 kV GIS in South Africa in 1986, ABB has proven its technology leadership at the ultrahigh-voltage level. This so-called alpha substation has been in operation for more than 20 years without failures or unplanned interruptions.

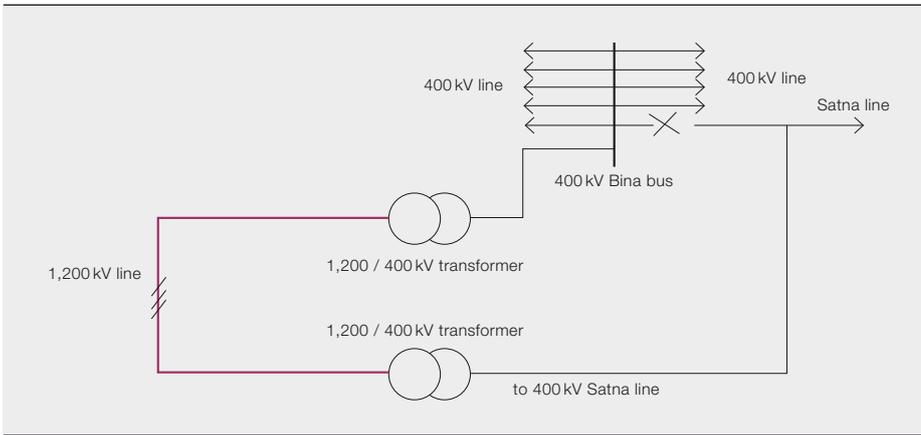
The world's first 1,100 kV AC grid in China has been under successful commercial operation since it was energized in 2009. For this grid, ABB developed a complete GIS components portfolio, including circuit breakers with closing resistors, disconnectors, earthing switches, current transformers, busbars, bushings and insulators, and tested it together with the Chinese switchgear manufacturer Xian Shiky. ABB shipped

the core components for the 1,100 kV hybrid GIS installation to Jingmen substation and continues to supply core components such as spacers, interrupters and circuit breaker drives to several Chinese switchgear manufacturers for ongoing and further extensions of the 1,100 kV grid in China → 3.

In India, an ultrahigh-voltage grid is also in the testing, planning and execution phase. The execution of this 800 kV AC transmission grid comprises several substation tenders including ultrahigh-voltage GIS and AIS switchgear. ABB is renewing its 800 kV GIS design, which has been shipped to this alpha substation to fit it to today's standards for routine and type testing and to upgrade to state-of-the-art technology. Part of this renewal program is to perform a complete type-test series according to the latest standards and the customer Powergrid of India.

The 1,200 kV AC transmission grid in India is now in its testing phase and Powergrid of India has set up a 1,200 kV test station at Bina to allow manufacturers to install and test their UHV equipment. The test station is powered by transformers connected to the 400 kV grid on both ends of a short overhead transmission line. This allows power flow through 1,200 kV equipment to ensure real test cases for the equipment → 5.

5 Power flow from Satna to Bina will be diverted via a 1,200 kV test station.



Powergrid of India has set up a 1,200 kV test station at Bina to allow manufacturers to install and test their UHV equipment.

6 Comparison of main equipment ratings for ELK-5 and Bina requirements

Parameter	ELK-5	Bina specifications
Um	1,200 kV	1,200 kV
System voltage	1,150 kV	1,150 kV
Rated lightning impulse withstand level	2,400 kV	2,400 kV
Rated short-duration pfwv to ground	1,100 kV, 1 min	1,150 kV
Rated short-duration pfwv across isol. distance	1,100 + 635 kV	1,400 kV
Rated lightning impulse wv. across open gap	2,400 + 900 kV	2,400 + 690 kV
Rated switching impulse wv. to ground	1,800 kV	1,800 kV
Rated switching impulse wv. across open gap	1,675 + 900 kV	1,675+(980) kV
Rated frequency	50 Hz	50 Hz
Rated normal current for feeder circuits	5,000 A	5,000 A
Rated normal current for main busbar circuits	8,000 A	
Rated short time withstand current	50 kA, 3 s	50 kA
Rated peak withstand current	135 kA	135 kA
Partial discharge level of each GIS component	<3pC at Um/ 3	

ABB has agreed to invest in a hybrid GIS test pole to be installed and tested at Bina test station. A GIS is named “hybrid” if the busbars are air-insulated but all other equipment such as circuit breakers, bushings, busducts, connecting elements, manually operated disconnectors, current transformers and PD sensors are of gas-insulated design. For this test pole the GIS components of ABB’s ELK-5 GIS are applied, as the type tests conducted on it already cover the specified values requested by Powergrid of India → 6.

The 1,200kV hybrid GIS test pole is being assembled and factory tested in ABB’s switchgear factory at Vadodara, India under witness of Powergrid of India. Installation and commissioning took place in February 2013.

Leadership in switchgear

ABB is the technology and market leader in most UHV AC switchgear technologies and continues to invest in the development of new products, upgrades and higher voltage levels, and pursues market opportunities for both AIS and GIS substations.

The latest UHV development in AIS technologies is the installation of a 1,100kV bypass circuit breaker. In GIS technology, the upgrading of ELK-5 equipment to the 1,200 kV voltage level used in India and the corresponding hybrid GIS pilot installation at Bina substation are both ongoing.

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Power on the move

Integrated, modular and prefabricated switchgear bundles with extended functionality for modern HV substations

PER SKARBY, KENNETH N. JABRAND, ALBERTO ZULATI – Electricity market liberalization is forcing utilities to be nimble concerning their obligations to keep a reliable supply of power flowing. At the same time, they also face the challenge of connecting a rapidly increasing number of renewable energy generators to the grid in a way that does not threaten overall power quality. It is to help utilities meet these two challenges that ABB has built upon decades of technical achievements in high-voltage substation technologies with advanced degrees of compactness, availability and automation to expand its prefabricated and functionally integrated offerings into fast-deployable switchgear bundles. ABB's integrated gas-insulated switchgear (GIS) and Plug and Switch System (PASS) are two concepts that have taken conventional switchgear technologies to new levels of prefabrication, mobility and functional integration. They are designed to respond to increasing needs of renewable integration, fast installation and quick power restoration after a natural disaster.



Because the PASS-based MFM is so transportable and so simply installed it is ideal not only for covering substation outages but also for providing power infrastructure for disaster recovery.

Integrated GIS is defined by its functional integration and the inclusion of a housing that enables a wide spectrum of auxiliary equipment to be installed and configured in the factory, with flexible connection options that include cable terminations, busducts or bushings for overhead lines.

PASS switchgear has a modular design that allows several elements to be combined. These elements include the circuit breaker, combined disconnecter-earthling switch, outdoor SF₆/air bushing, slip-over current transformers, voltage transformers, cable entry/exit and surge arresters. All PASS solutions are delivered fully assembled and factory tested.

Both of these products are at the heart of ABB's integrated, modular and prefabricated extended-functionality switch-

gear bundles for modern high-voltage substations.

Integrated GIS applications

Prefabrication and functional integration of switchgear are concepts that have converged toward, and reached a substantial degree of, standardization at medium-voltage and medium-power ratings.

Products in this segment include, for example, ABB's "electrical houses" and compact secondary substations (CSSs), which have existed for some time. The same concept is now also available in the high-voltage segments up to 420 kV.

This builds on and extends ABB's well-proven and reliable GIS product portfolio. The growing demand for power in expanding urban areas as well as in the mining and oil and gas industries requires a power supply that is both flexible and

available at short notice. In urban expansion, substation appearance is also of great importance. Common to nearly all applications, however, is the fact that power interruption, no matter how short, can be very costly, can disrupt the lives of thousands and can severely upset industrial production. Reliability and availability remain, therefore, a priority item on utili-

Integrated GIS units can easily be transported to the next site – this reduces the “stranded asset” drawback typically encountered by conventionally installed switchgear.

ties' agenda. This is a major driver for the adoption of GIS technology.

Electrical infrastructure is reaching the end of its life cycle in several cities around the world. In these places, overhead lines

Title picture

This PASS-based MFM, pictured in Algeria, can be installed and put into operation within hours of arrival on site.

1 Integrated GIS



2 Integrated GIS – available ratings

GIS Product	Voltage class (kV)	Breaking current (kA)
ELK-04	72.5 – 145 170*	40 50* 63
ELK-14	170 – 300	63
ELK-3	420	63

* 170 kV voltage class has a 50 kA current rating.

Substantial reduction in installation time is achieved by carrying out all the planning, design, assembly, testing and quality control in the ABB factories.

are often converted to cable systems to free up land and improve visual appearance. A logical next step is to convert traditional air-insulated substations. Here, integrated GIS can provide a more compact, less obtrusive and better-protected replacement substation → 1. The building's outer features can easily be adapted to blend into the local environment.

Urban grid conversions by, eg, undergrounding, are typically lengthy projects and integrated GIS units are well suited to serve as temporary installations throughout the construction phase. Once the cabling has been completed, it is even possible to switch the connection type from the old overhead line connected by a bushing to the newly installed cable system. For redundant installations (eg, double busbar schemes) these steps can be taken without power interruption. This greatly minimizes the impact on users and the supply of electric power. Once the project has been completed, the result is a well-protected, safe and visually compelling installation.

Due to its prefabricated design and fast deployment, integrated GIS is also ideal for industrial applications in the oil and gas, and mining sectors. Modern gas-insulated switchgear has a lifetime in excess of 30 years and this often exceeds localized industrial processes such as mining or oil and gas drilling. However, integrated GIS units can easily be transported to the next site. By providing this mobility, the electrical equipment can be

3 Integrated GIS in Anchorage, Alaska



redeployed, thus reducing the “stranded asset” drawback typically encountered by conventionally installed switchgear.

Predesigned and, largely, standardized configurations ensure high quality and reliability. For the customer, this translates directly into a more homogeneous installation base that, in turn, reduces both staff training needs and spare part inventory. Substantial reduction in installation time, compared with conventional substations, is achieved by carrying out all the planning, design, assembly, testing and quality control in the ABB factories → 2.

Alaska – integrated GIS success story

In 2009, the city of Anchorage in Alaska wanted a new substation quickly to address a growing demand for power. In addition to the time constraint, the customer also required the substation to be as discreet as possible as the space allocated for the project was close to a shopping center. Needless to say, the equipment also had to withstand Alaska's freezing climate and frequent seismic events.

ABB responded by providing an ELK-04 123 kV GIS substation. This was installed and energized in only a few weeks → 3–4. The substation consists of a four-breaker ring integrated into two 40-foot containers. The local control cubicles are also fully integrated inside the containers.

4 Integrated GIS – exterior view



The integrated GIS met all the customer's requirements and, based on the success of the first project, the customer ordered their next substation using the same layout.

PASS family

The PASS family covers a wide range of currents and voltages → 5. ABB launched PASS M0S 420kV with a breaking current of 63kA in the first quarter of 2013. Although complex configurations like PASS M0S imply significant size, it is still delivered fully assembled and tested. Keeping this important characteristic is a decisive competitive advantage at this rating.

PASS modularity and flexibility allow the design of very compact solutions. For example, two PASS double circuit breakers can be combined into a MOH to fit any H-scheme substation layout.

Pass-based MFM (Multi-Functional Modules)

The number of power plants is rising faster than substations can be built. This has led to the development of a quick-install solution – MFM. To be able to offer a complete mobile installation and short installation times, ABB developed a solution that uses prefabricated module bays as building blocks → 6.

The Multifunctional Module (MFM) includes all the HV, MV, power transformer and auxiliary equipment merged into one single module.

5 The PASS family

Assembly module	Voltage class (kV)	Breaking current (kA)
PASS M00	72.5 – 100	40
PASS M0	123 – 170	50 (145 kV 63kA 60Hz)
PASS M0S	252	50
PASS M0S (Q1 2013)	420	63

6 Prefabricated PASS-based MFM bays like this make up the basic elements of a fast-deployable substation



The PASS-based MFM is a new approach to prefabricated solutions: The integration of the PASS into the power transformer makes the MFM the most compact solution ever designed in the mobile module business. The overall dimensions are such that the modules can be transported by normal commercial vehicles and, thanks to the provision of a lifting system, the operations for the loading, unloading and positioning on site can be carried out without the need for a crane or lifting gear.

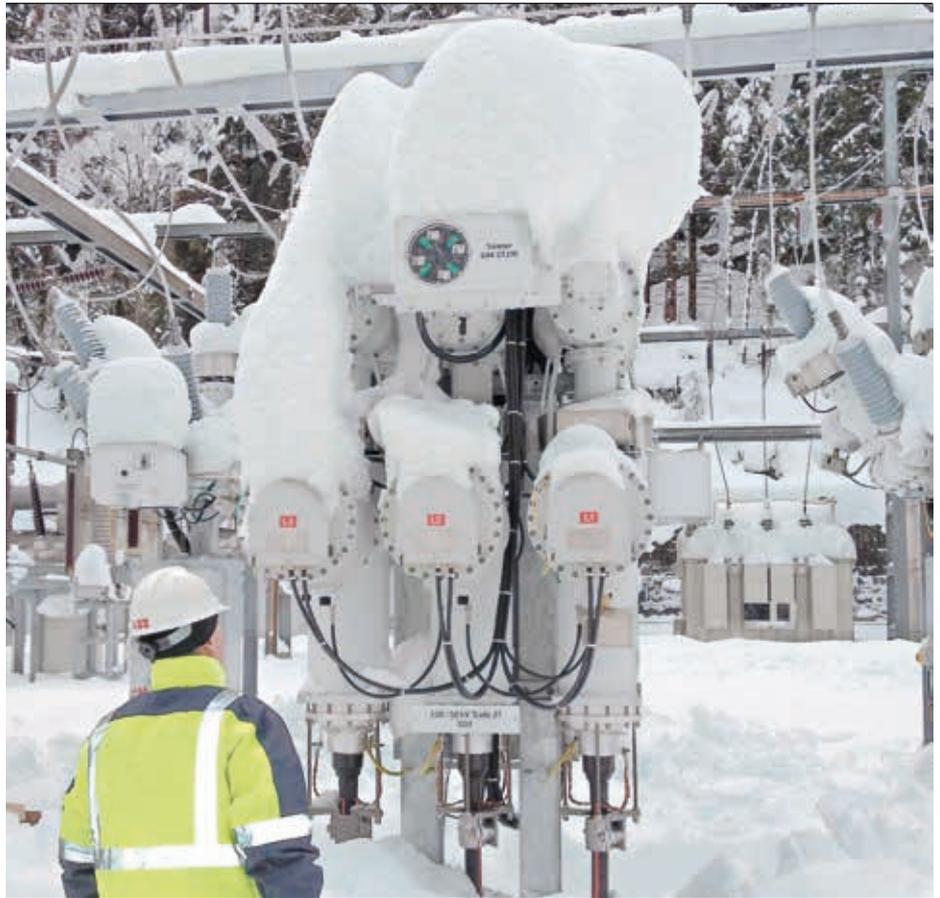
An MFM may be composed of three HV line bays (single busbar type) equipped with cable plug-in terminations. It can fit on a 40-foot standard trailer that can be freely moved by road without oversize load permits. The LV section can be assembled in a transportable container on the same standard trailer. All these features allow full assembly and testing of the entire mobile solution in the factory. The MFM can also be equipped with a service station voltage transformer designed to be connected directly to the high-voltage network to guarantee an uninterrupted 230 VAC power supply.

The PASS-based MFM was conceived to be small and easily transported. Because it is so transportable, and so simply installed, it is ideal not only for covering substation outages during refurbishments but also for providing power infrastructure in case of major faults due to catastrophic events.

Although complex configurations like PASS M0S imply significant size, it is still delivered fully assembled and tested.

Pre-designed and, largely, standardized configurations ensure high quality and reliability.

7 The PASS family can be installed in the most extreme climates – cold as well as hot.



Algeria – PASS-based MFM success story

Twenty-six MFMs will supply energy derived from mobile gas turbine generators provided by Energy Services Inc. (ESI), a Pratt and Whitney subsidiary, in different regions of Algeria → 7. ESI, who issued the order to ABB, will provide the ABB MFMs to Sonelgaz, the state-owned utility responsible for electricity and gas distribution.

Sonelgaz supplies more than 6 million households with electricity – representing a 98 percent coverage of the country. Algeria is the largest country on the African continent and has over 225,000 km of power lines, serving a population of 37 million. It is expanding the size of its transmission network to reach isolated communities and to support hydrocarbon developments in the Sahara Desert.

ABB's MFMs, which can be installed and put into operation within hours of arrival at site, will provide the generators' connections to the 60/220 kV Algerian grid. For ESI, it is crucial to be able to move the equipment by truck across all types of terrain, including mountains and des-

erts. MFMs can be transported by sea, road and air and will be used for electrical energy generation in different sites in Algeria, dramatically increasing the network power capability. ABB products were chosen because the MFM concept allows extreme flexibility and is the ideal solution for quick connection of distributed generation to the existing grid.

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Pioneering change

How ABB remains a leader in the ever-changing world of high-voltage power

RICHARD OULTON – The market and landscape for electrical transmission and distribution technologies continues to unfold and develop at different speeds, shaped by regional variations in infrastructure development. However, fundamental business drivers remain the same whether the focus is on replacing old assets, securing energy supply or building new infrastructure. These drivers include very challenging capital markets, continually emerging technologies and stiff competitions, which are reshaping how and where electricity is generated, transmitted, distributed and indeed used in many regions of the world. ABB remains a market leader and is helping to redefine many aspects of these exciting developments in the power markets. ABB's innovation and technology leadership has been demonstrated time and again in the high-voltage (HV) power world, establishing the company as both a trusted partner and supplier of high-voltage products.

ABB was formed in 1988 by the merger of two European power industry giants: ASEA from Sweden, and BBC from Switzerland. The history of these two giants dates back to the 1800s, and fortunately each of these pioneering companies established factories and sales offices in many corners of the world, an adventurous legacy, which has helped lay the foundations for much of ABB's current success.

At the core of this strategy was the goal to be close to markets and customers served, which is why ABB's high-voltage products business is present in more than 100 countries. While the overriding technologies may be similar, different regions and countries are continually demanding specific developments and applications, so being close to individual markets helps ABB to better understand and translate customer needs into appropriate products, solutions and services.

Innovation at ABB is not solely about providing groundbreaking technology, but actually applies to many aspects of the company's broad portfolio, business model and people – this is a clear differentiator in today's very competitive marketplace.

Driving competitiveness on the supply side

ABB's high-voltage products business alone is supported by about 40 factories spread across many countries throughout North and South America, western and eastern Europe, Asia and Australia. This global footprint enables ABB to leverage manufacturing volumes and

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supply chain sourcing around the world, while a growing number of local assembly units ensures customers receive maximum value, including engineering, installation and commissioning support.

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1 Commitment to operational excellence



ABB's generator circuit breaker (GCB) factory in Zurich, Switzerland was voted European Factory of the Year in 2010 (Die Beste Fabrik 2010) at the "Best Factory Conference" organized by the German business journal, *Wirtschaftswoche*. The selection jury included industry specialists and academics from leading international business schools, including INSEAD and WHU-Otto Beisheim School of Management.

The ability to maximize efficiency and productivity were among the main evaluation criteria. The jury appreciated the factory's layout, ergonomically designed workstations and state-of-the-art logistics systems. The modernized and streamlined production processes increase both productivity and manufacturing capacity. Relative to the old production site, space in the new facility was reduced by half, production capacity doubled and delivery time cut from weeks to days.

ABB continues to make investments that optimize this footprint and expand its global reach → 1-2; for example, the company is currently building new facilities in Saudi Arabia and India that are designed to meet local customer demands and needs. Another clear example is our approach and flexibility in sourcing. Subject to customer preference and approval, ABB can leverage its global footprint and offer alternate factory production. This is advantageous to both the customer and ABB, as it provides the flexibility to reduce lead times and increase speed-to-market as per customer requirements.

ABB's field service organization is another very important part of the company's business offering, one where a local presence is fundamental. ABB's High Voltage Products business unit currently employs more than 1,000 experts around the world in 26 service centers that are geographically positioned to rapidly respond to any current or future life-cycle service requirement.

The high-voltage power market is changing, a fact which ABB has recognized early, adapting its portfolio and skill base

accordingly. More and more customers require some form of remote monitoring, and this capability is not only changing ABB's resource needs, but those of its customers. The ability to remotely monitor substation assets for all critical diagnostic metrics to assure increased reliability is now available. Another focus area is to provide the most advanced methods to minimize the end-of-life environmental impact of all original equipment manufacturer (OEM) assets. These services provide the end customer with the confidence and security that asset disposal truly will have minimal impact.

Another recent development is ABB's mobile service container, which drastically reduces outage time in environmentally harsh and remote locations. HV breaker repair and refurbishment in harsh weather conditions like snow, rain, or sandstorms can make working on-site nearly impossible, and can also impact the integrity of a repair. Yet transporting the unit to a service facility is also usually impractical. Under these conditions, another solution is the mobile service container → 3, a 40-foot container suitable for land and sea freight that is fully equipped with all the necessary tools to

2 R&D – Investing for tomorrow

ABB's global R&D organization consists of about 8,000 scientists spread around the world in seven research centers located in the United States, Switzerland, Sweden, China, India, Germany and Poland. These labs collaborate with about 70 universities globally on an extensive range of subjects. The company's in-house, high-power laboratories are equipped with the latest state-of-the-art facilities.

To keep up the constant stream of new products and technologies ABB globally invests over \$1.3 billion in R&D annually. In the high-voltage products business, the

stream of recent innovations includes new gas-insulated switchgear (GIS) concepts; a high-voltage circuit breaker with an alternative insulating gas for enhanced eco-efficiency; ultrahigh-voltage technologies for 1,100 kV ultrahigh-voltage direct current (UHVDC) and 1,200 kV alternating-current (AC) transmissions; generator circuit breakers (GCBs) for the world's largest power plant units, rated up to 1,800 megawatts (MW); and sulfur hexafluoride (SF₆) cryogenic recycling technology. These are only a few of the outstanding technologies that clearly signal the innovation focus of ABB's high-voltage products business.

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3 ABB's mobile service container.



service, repair and refurbish ABB's HV circuit breakers. The service container is widely used in northern Europe, and has also been deployed to China and Azerbaijan.

Building domain competence through close customer contact

ABB's high-voltage products business serves many markets, channels and applications. Span of supply can vary from a single product or spare part to a complete, integrated high-voltage substation or solution. A clear strength of ABB is its ability to offer customers complete and comprehensive products, systems and service portfolios.

At the same time, ABB can also provide customized solutions and responses to specific requests – such as reducing substation footprints and creating spe-

cial substation configurations – utilizing innovative, flexible products. Another ABB initiative is the establishment of regional power quality centers in markets close to customers; these centers offer solutions to improve power quality and energy efficiency in power networks. The centers specifically focus on ABB's capacitors and filters product line, which is a vast portfolio of products that provide an optimal application range based on local requirements. Power quality centers can help find the best technical solution for every need. They solidify ABB's technical expertise in a region, and enable the company to develop a reliable service partner network. They also help to fine-tune ABB's product portfolio by providing valuable market feedback to product development and design centers. ABB has established seven power quality centers so far, covering North



4a Air-insulated switchgear



4b PASS switchgear

America, South America, Europe, the Middle East and Africa, South Asia, India, and China.

ABB sales and marketing teams play a key role by remaining close to ABB customers. Growing and developing local organizations and people is the fastest way to enter local markets and establish sustainable customer relationships. A key focus for ABB involves taking the appropriate time and making the investment to ensure competent, customer-facing organizations that support and develop local markets.

Listening to customers is one thing, but it is also essential to invest the time to understand them and their businesses. Beyond pure business interactions, ABB generally proactively invests substantial resources in order to understand what customers in all global markets really think, to better understand and even anticipate their needs. This process marks what ABB does well, but also identifies from a customer perspective what must be improved. Internally known as the Net Promoter Score (NPS), the results are shared openly throughout the business, and help to drive improvements across functions and business areas. Having surveyed more than 15,000

customers in 2012, initial analysis indicates customers like ABB's technical support, industry and applications knowledge and partnering for mutual benefit. On the whole, customers appreciate ABB's domain competence, but the same survey also indicates they would like to see improvements in some areas, such as on-time delivery and lead times.

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As a result of the NPS survey, these areas are the focus of increased management attention to improve customer responsiveness.

Staying abreast of global trends

In a rapidly urbanizing world, space is at a premium, and in response the footprint of ABB's high-voltage switchgear has become smaller and smaller. For example, ABB's hybrid high-voltage switchgear modules can reduce switchgear bay space requirements by 60 percent, compared with conventional air-insulated switchgear technology → 4.



Another rapidly growing need is for renewable energy products. As offshore wind generation advances toward higher-capacity turbines with ratings of 5 MW and more, losses that occur during energy transfer will escalate unless higher voltages are used. This is leading to an increasing number of applications for high-voltage equipment in the wind energy market. ABB meets this demand with the new and compact high-voltage, multifunctional switchgear module PASS M00, which can be inserted and fitted in the narrow spaces of a wind tower → 5.

To facilitate quick access to the electric grid with minimum work on site, ABB has made several of its high-voltage products available as plug-and-play solutions. This eliminates on-site assembly work, as products are factory sealed under controlled conditions, which helps to reduce commissioning time and ensure superior and consistent product quality.

The future belongs to smart grids. In order for a grid to become smart, it must first be able to access and integrate the real-time status of its numerous components. ABB's intelligent switchgear solutions provide digital output according to international standards and facilitate remote data monitoring and control.

Another significant trend in high-voltage markets is ultrahigh-voltage bulk power transmission over long distances, with minimal losses and low environmental impact. ABB's latest technology advancements in these areas are highlighted in this special edition of *ABB Review*.

A famous proverb says change is the only constant, and that is ABB's guiding principal. By constantly evolving with customers and markets, ABB can better understand current and future needs and provide maximum value. This effort is spread across all functions of ABB's business, from R&D, manufacturing and supply chain management to marketing, service and skills development.

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High-voltage products. Ensuring reliable and efficient power supply even in harsh conditions.

ABB offers a broad spectrum of high-voltage products with ratings up to 1,200 kilovolts that help enhance the reliability, efficiency and quality of power. The range includes products such as generator circuit breakers, air, gas and hybrid switchgear, instrument transformers, disconnectors and power capacitors – all complemented by a comprehensive service offering. Designed to minimize footprint and environmental impact these robust products are capable of withstanding harsh conditions including temperatures ranging from (–ve) 55 degrees Celsius (°C) to (+ve) 55 °C. With a 125 year heritage of technology and innovation and a presence in over 100 countries, ABB continues to shape the grid of the future. For more information, please visit us at www.abb.com/highvoltage