

Breaking news

Ultra-high-voltage switchgear to power China

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China is in urgent need of electrical power. Huge power plants are built all over the country and the enormous flow of electrical power to the large megacities has to cross several thousand kilometers from the source to the end user.

At those dimensions, losses of the power lines can be significant. The State Grid Corporation of China (SGCC) is thus aiming for 1,100 kV as the voltage level for AC transmission to keep losses as low as possible, a step into a new area of electrical grids.

ABB, together with its partners and suppliers, has developed the heart of such a system – a gas-insulated switchgear design – that could pass all the tests with this groundbreaking technology.



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Reliable supply of electrical energy is one of the backbones of modern economies. Its safe and reliable operation mainly depends on high-voltage switchgear – the core part of an electrical power system. The high-voltage circuit breaker in this switchgear is often the last line of defense when big systems must be protected in the event of a short circuit.

Electrical grids and the corresponding substations are well known as air-insulated systems in which the high voltage is kept away from both the ground and people by distances of tens of meters.

Another much more compact way of building high-voltage switchgear is the gas-insulated design – gas-insulated switchgear (GIS) **Factbox 1**.

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GIS technology was introduced to the market in 1966 with the first 170 kV GIS underground substation delivered to the Zürich city center **1**. In 1976, ABB delivered the first 500 kV GIS to Claireville, Canada. With the installation of the first 800 kV GIS in South Africa in 1986, ABB has proven its technology leadership also at the ultra-high-voltage (UHV) level **Factbox 2**. This so-called alpha substation has been in operation for more than 20 years without any failures or unplanned interruptions. The 500 kV GIS in Itaipu, Brazil is still the world's largest installation but will soon be overtaken by the ABB GIS inside the Three Gorges Dam in China.

China and innovative GIS technology

China is a huge country where electric power generation happens mainly in the western parts and load centers are typically found in the coastal region – thousands of kilometers apart. Both AC and DC UHV systems are necessary to handle the increase in electric energy consumption and to back up the existing transmission system [1,2].

The State Grid Corporation of China (SGCC) – one of ABB's biggest customers – began designing an AC system with a rated voltage of 1,100 kV a few years ago [3]. This project initiated extensive research and development efforts in research institutes and at equipment manufacturers [4]. To

finally determine the technical feasibility, a group of three Chinese and two Japanese GIS manufacturers and ABB were asked by SGCC to take part in the development of UHV GIS equipment for the Chinese UHV AC demonstration project. It was established in 2008 in central China and

Factbox 1 Gas-insulated switchgear (GIS)

Gas-insulated switchgear is widely used in high-voltage transmission and distribution systems. ABB is the leading supplier of GIS at transmission voltage levels. ABB GIS products range from 72 kV up to 800 kV rated voltage with rated currents up to 4,000 A and a short-circuit current switching capability up to 63,000 A. GIS is used in indoor and outdoor applications. The functions provided by GIS are switching, disconnecting, earthing and measuring. As a system with many

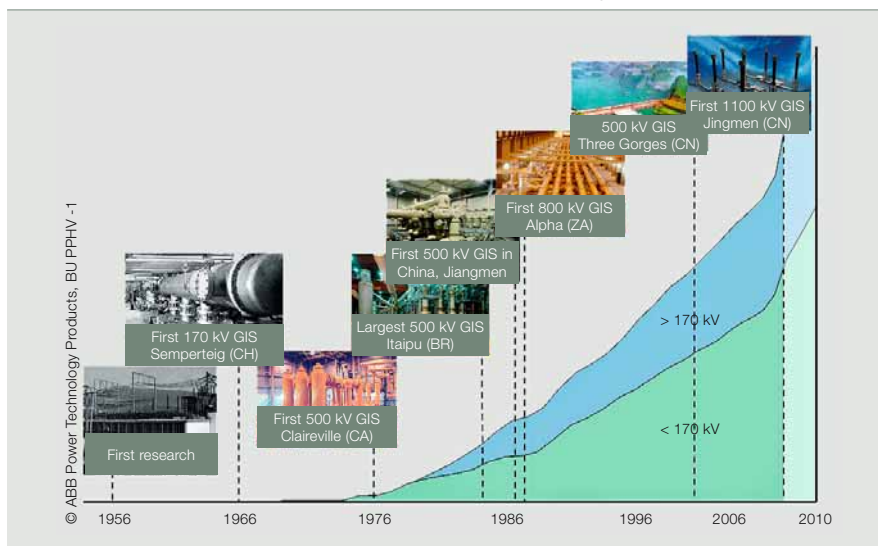
components, each GIS is optimized for the required application. GIS components have a coaxial design with an inner and outer conductor, filled with sulfur hexafluoride (SF₆) gas at several hundred kPA overpressure. They are connected to each other by bolted flanges – this is why GIS looks like pipelines from outside. Substation designs are called “hybrid GIS” if parts of it (eg, busbars or connections to overhead lines) are air insulated.

Factbox 2 Ultra-high voltage (UHV)

Electric power systems are operated at different voltage levels to optimize transmission efficiency, minimize electrical losses and material consumption, and maintain maximum operational safety. The IEC standards provide standardized voltage levels up to 800 kV. Systems operated at a rated voltage above 550 kV are called “ultra-high-voltage” systems. They are used when several thou-

sand MW of electric energy have to be transmitted over hundreds of kilometers. As transmission losses are comparably lower at higher voltages, a step from 550 kV to 1,100 kV reduces the losses by a factor of four. Therefore, UHV systems are especially suitable to efficiently transport bulk power over large distances.

1 ABB's GIS history: from first research projects to the world's largest installation within 50 years



Product innovations

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ELK-5 UHV GIS development project

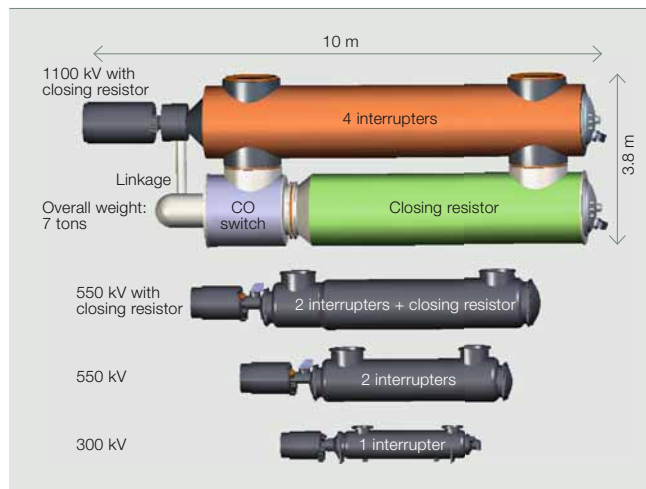
To design and install this 1,100 kV GIS, ABB and Xian Shiky, the biggest Chinese supplier of GIS, established a joint development project called “ELK-5” (ELK is the name of ABB’s GIS systems; 5 indicates the new performance level). The focus for ABB in this joint effort was on the overall design of the hybrid GIS and on the production and shipping of core components, while Shiky focused on production of all other components, type testing – under supervision of SGCC and KEMA experts – and the assembly and installation of the switchgear at Jingmen. A very demanding schedule was set by SGCC – after its start in November 2006 the first installation at Jingmen was to be energized by the end of 2008. Accomplishing this in two years would be a world record for upgrading a GIS to a new, demanding voltage level, during which time the development, verification, type testing, production and installation would also occur. To meet this challenge, ABB assembled a project

team with up to 20 specialists and provided priority access to other experts and test facilities.

Doubling the voltage level

The insulation performance of GIS depends on many parameters – the gas pressure, the electrode geometry, the voltage-pulse form applied and the polarity or the purity of the SF₆ gas, to mention a few. Even though many of these parameters have been studied as a function of the electrical field strength, phenomena can change significantly in different field configurations. The crucial factor in the GIS design for a new voltage level therefore is the understanding of the various voltage-dependent physical phenomena of electrical insulation. Specific scaling rules have to be applied for every individual component and finally to the whole system. Of special interest are the effects that gain importance at high voltage levels, eg, the so-called very fast transients (VFT) that occur when operating a disconnector.

2 Dimensions of ABB circuit breakers from 300kV to 1,100kV



An especially challenging task is to find the optimal gas pressure for this very high voltage level. There is a trade-off between parameters with positive and negative pressure influence on the insulation performance. ABB studies concluded that a rather small SF₆ gas pressure is best suited for UHV GIS components.

Robustness of the design and operational availability are also key points. Therefore, the following design rules were applied to the UHV GIS design:

- Single phase encapsulation for interrupters
- Separate compartment for closing resistors
- Safe margins for all electrical parameters

The enormous dimensions of the 1,100 kV switchgear require extensive mechanical calculations. Scaling of mechanical parameters, eg, drive energy, speed of contacts or bursting pressure capacity are also very non-linear. In fact, such a development project requires at least as many mechanical engineers as electrical engineers.

All mechanical and electrical design was carried out with true 3-D calculation tools and, whenever possible, proven manufacturing processes were chosen.

Circuit breaker – the core component

The circuit breaker is a switchgear component capable of safely turning on and off under all switching conditions, such as normal operation or fault clearance. Its operation is accomplished within 50 milliseconds after triggering.

The 1,100 kV circuit breaker is an extension of ABB’s existing circuit-breaker portfolio. It consists of two tanks – one for the interrupters and one for the closing resistor. The interrupters and the CO switch that inserts the closing resistor are both operated by a single spring-hydraulic drive, which has been specifically developed

3 The ABB GIS circuit breaker with the drive unit during assembly in the factory



by ABB for this application [5, 6, 7]. A comparison of ABB's circuit breakers for different voltage levels is given in 2. The rated values of 1,100 kV, 4,000 A correspond to a rated power of 7,600 MW for the three phases. This is more than the average electric power consumption of Switzerland.¹⁾ With this rating the circuit breaker would be capable of turning on and off the electrical power of Switzerland.

The total weight of this modern UHV circuit breaker is only 7.5 tons due to the optimized number of interrupters and the aluminum enclosures 3.

Since it was the world's first equipment rated at 1,100 kV, it had to be tested according to international and Chinese standards; the equipment suppliers and especially the test laboratories thus faced big challenges. Type testing for the circuit breaker was accomplished at Xihari test laboratories in Xian and at ABB in Switzerland 4.

Huge efforts were required to perform the power tests in Xihari at the 1,100 kV level. The most demanding topics were:

- Manufacturing and testing required the intercontinental transport of UHV equipment. Airfreight of complete circuit breakers and other equipment was required to meet the tight schedule of the project.

- Extensive space requirements for the laboratory: The combined voltage tests needed two bushings at a distance of more than 13 m, with each of them a distance of more than 10 m to the laboratory walls.
- The power-switching tests were mostly performed on one-half of the circuit breaker only, as no sufficiently high voltage was available to stress the full-size breaker. This so-called half-pole testing requires a specific enclosure and voltage grading calculations.

As a result of the careful design and manufacturing, the circuit breaker could be successfully tested during the first test series.

The UHV GIS disconnecter

The basic function of a disconnecter is to disconnect parts of the GIS to safely do maintenance work on the disconnected and earthed parts.

The focus for ABB in this joint effort was on the overall design of the hybrid GIS and on the production and shipping of core components.

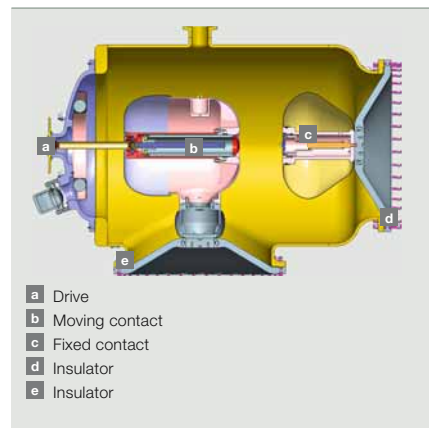
Compared with a circuit breaker, it may operate rather slowly within a few seconds. ABB's 1,100 kV discon-

necter is designed in a 90-degree setup with a visible gap of the inner conductor of less than 300 mm. This gap can withstand more than 3,400 kV

Factbox Ratings specified for the 1,100 kV GIS demonstration project

■ Rated voltage	1,100 kV
■ Rated lightning impulse voltage	2,400 kV
■ Rated equipment current	4,000 A
■ Rated busbar current	8,000 A
■ Rated short-circuit current	50 kA

5 Cross-section of the UHV disconnecter



6 Arrangement for disconnecter switching tests at the STRI laboratory



4 Development team and test pole for the 1,100 kV circuit breaker at Baden Power Lab (Switzerland) after T100s test



Product innovations

during high-voltage testing. It is one of the clear advantages of an SF₆ GIS design: to insulate very high voltages across small distances. Exposing conductors in open air to 3,400 kV would require a minimum clearance of 13 m to prevent flashovers.

The disconnector switching type tests were performed at the Swedish Transmission Research Institute (STR) in Ludvika, Sweden, the only lab with corresponding facilities [5, 6]. The comparably slow operation of a disconnector leads to sparking during closing and opening in the contact gap. These sparks generate the very fast transients (VFT) that propagate through the GIS, a phenomenon that puts the highest EMC (electromagnetic compatibility) requirements on the components undergoing the test.

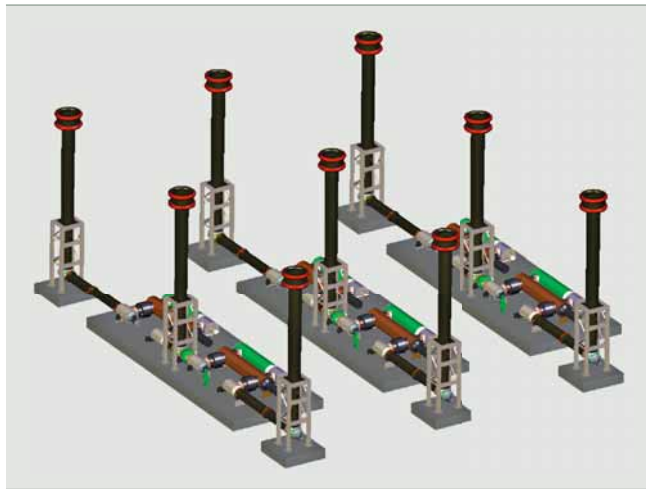
The first UHV GIS substation

After development and the successful type testing in 2007 and of 2008, ABB and Shiky began to assemble and ship the first equipment to the substation at Jingmen. This substation includes an almost complete set of GIS components, such as circuit breakers with closing resistors, disconnectors, earthing switches, current transformers, busbars, bushings and insulators [7].

Extensive layout studies to find the optimum arrangement of the GIS components proved that a “flat” setup with good accessibility would be best suited for the Jingmen hybrid GIS substation [8]. The layout has the following characteristics:

- All GIS switching equipment is placed close to ground level.
- The flat arrangement improves robustness against seismic stresses.
- All the drives are placed at a height within 1.5 m of the ground, which provides convenient and safe access for operators during installation and maintenance.
- No platforms or ladders are needed.
- The layout can be easily extended in the busbar direction.
- It requires a minimum of steel construction as a bay structure.

7 Layout of the Jingmen 1,100 kV hybrid GIS substation



- The on-site workload is small and allows for fast installation.

The substation was installed in 2008 near the city of Jingmen in Central China. It will transmit part of the energy produced by the Three Gorges power plant to the northern part of China.

Meeting the challenge

The ELK-5 development project was a big challenge in many respects: a pioneering design in an unprecedented execution time and a cross-continental cooperation with suppliers and partners in Europe and China, who with very different cultural backgrounds worked closely together.

Type tests of the ELK-5 components were carried out simultaneously in Chinese, Swedish and Swiss laborato-

ries. This project was not only the start of a new era in ultra-high-voltage transmission but also a powerful demonstration of the combined engineering capabilities of the world's technology leaders.

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Footnote

¹⁾ 5th Annual Report of SwissEnergy 2005/2006.

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