

Compact and reliable

Decades of benefits: Gas-insulated switchgear from 52 to 1,100 kV

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It takes decades of experience to develop sophisticated technology. Over many years, ABB has developed a portfolio of gas-insulated switchgear in the 52 to 1,100 kV range. Continuous market-oriented development, creativity and competence has established ABB as a world leader in this type of technology. By constantly introducing innovative technological advancements, ABB has been able to provide a range of compact, versatile and reliable high-performance gas-insulated switchgear that continues to meet market needs and satisfy customers.



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A safe, reliable supply of electricity depends on the circuit breakers that protect our electricity grids in the event of short circuits. Traditionally, these circuit breakers, installed in power plants and substations, were air-insulated. Air-insulated switchgear (AIS), depending on the rating, requires a minimum clearance between various active parts and earth in the order of tens of meters, which means a large area is needed to accommodate the installation. As an alternative, gas-insulated switchgear (GIS) are available, allowing the circuit breakers to operate safely within a confined space. A substation using GIS can be one-tenth the size of a conventional AIS substation [1].

Market-oriented product development, together with competence and creativity, has earned ABB worldwide recognition for its comprehensive portfolio of GIS products and services.

Such GIS is produced by numerous well-known manufacturers around the globe. Many of these companies have decades of experience in the production of switchgear technology. These manufacturers have now been joined by a number of other manufacturers who have only recently added GIS to their portfolio of products. These newcomers are now competing in the switchgear market, particularly at the lower voltage levels.

At first sight, the external appearance of competing GIS products suggests only marginal differences in their layout. However, upon closer examination, it becomes clear that the products offered by the traditional manufacturers of GIS have benefited from many years of innovation, modification and product development **Factbox**.

Establishing and maintaining a high level of competence in switchgear requires highly motivated staff, capable of continuous development in the face of technological- and process-engi-

neering challenges. Market-oriented product development, together with competence and creativity, has earned ABB worldwide recognition for its comprehensive portfolio of GIS products and services.

Gas-insulated switchgear offered by ABB have benefited from many years of innovation, modification and product development.

To enable a company to cope with the technological challenges involved in the development of GIS, substantial investment must be made in research and development. This ensures that novel materials and system-related engineering technologies are incorporated in new products. Such innovation results in the development of reliable technology and ensures that technologically challenging milestones can be reached [4,5,6].

GIS technology originated in 1936, when a Freon-GIS assembly, rated at 33 kV, was demonstrated in the United States. Later, in the mid-1950s, sul-

fur hexafluoride gas (SF₆) was discovered, a gas that has excellent insulating and arc-extinguishing properties. By the mid-1960s GIS was sufficiently well developed to be commercially viable and appealing to a broader market.

Over time, progressive innovative steps have allowed ABB to develop a range of GIS rated from 52 to 1,100 kV. During this development period, many technological milestones have been achieved and protected by patents to safeguard ABB's intellectual property [7,8,9].

ABB provides a range of compact, versatile and reliable, high-performance GIS that meets market needs and satisfies customer requirements.

GIS products currently available from ABB fall into two main categories: those rated up to 170 kV **1**, which are almost exclusively of three-phase design, and those above 170 kV **2**, which are mostly of single-phase design.

Factbox Items of primary importance to GIS

- The availability of modular component design, which can be assembled in a variety of different ways to comply fully with the customer's requirements in terms of space restrictions and costs
- The provision of a safe and flexible system; the active parts of the equipment, at high-voltage potential, must interact effectively with the operating mechanism (ie, the interrupter, disconnector, earthing switches and the fast-acting earthing switches)
- The components should be traceable, consistent and have complete type-test certification, preferably provided by independent power laboratories, in accordance with international standards [2,3]
- The equipment should meet substation automation requirements such as customer-specific cabling and digital control technology; for the latter, each GIS bay should be able to link remotely to a customer's substation and control center
- The manufacturer should demonstrate competence in the handling of customer orders, managing projects, engineering, quality control, material procurement, production, assembly in the factory and on-site, including the supply of complete and comprehensive documentation
- The manufacturer should provide worldwide service coverage with quick-acting and well-trained professional teams; such teams should be able to service equipment, replace single components or modules in individual substations, and be able to replace old substation technology with new technology
- The manufacturer should maintain a highly skilled development team made up of a reliable mix of young, innovative and skilled engineers with many years of experience

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Sub-transmission GIS (< 170 kV)

In the late 1960s, encapsulated switchgear assemblies, initially equipped with low-oil circuit breakers, were replaced by switchgear using SF₆ gas. The first GIS of this kind was the EBK-01-type with a rated voltage of 123 kV, a short-circuit current rating of 31.5 kA and an operating current rating of 2,000 A. This type of switchgear was equipped with an easy-to-operate, horizontally installed, double-pressure circuit breaker. When it was introduced to the market in 1969, this switchgear was already equipped with three-phase bus-bar modules. Almost all the original first series units (bays) delivered by ABB are still in operation. In 1973, the EBK-01-type circuit breaker was replaced by the EBK-02-type, capable of operating at increased rating values of 145 kV, 31.5 kA, 2,500 A.

The next major milestone was reached with the introduction of the ELK-01-type switchgear in 1978. This switchgear (145 kV, 31.5 kA, 2,500 A) was the first fully three-phase design in the world. It was equipped with a vertical, maintenance-friendly, single-pressure, circuit breaker with puffer circuit

breaker technology. Its successor, the ELK-02, was launched in 1980. This model featured an improved modular design that clearly distinguished it from its predecessors.

ABB's ELK-03-type GIS provided increased ratings, a single housing for the disconnecting and earthing switches, and a hydro-mechanical spring mechanism to operate the circuit breaker.

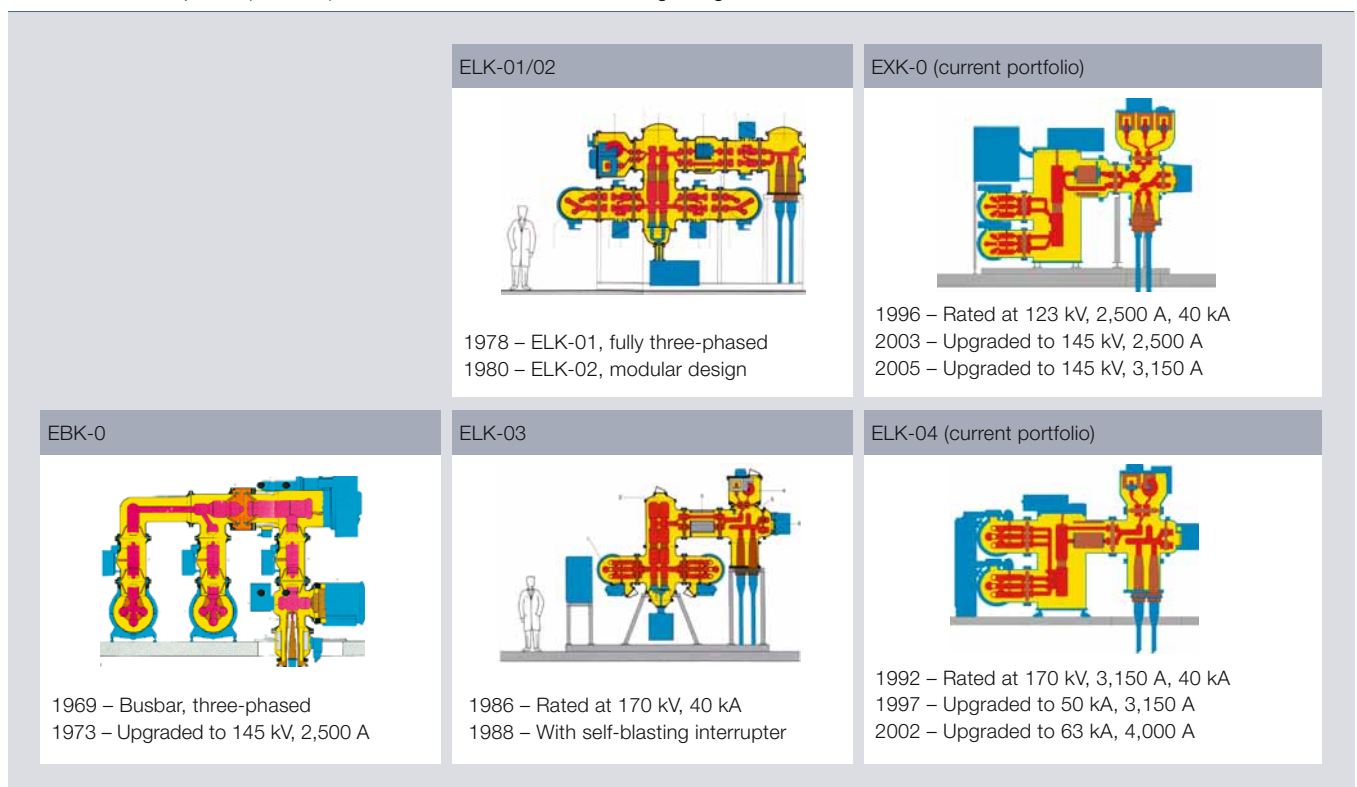
Until this time, the disconnecting and earthing switches of all switchgear models were housed separately and the circuit breakers were equipped with hydraulic operating mechanisms. The ELK-03-type switchgear (170 kV, 40 kA, 3,150 A), was launched in 1986, and provided not only increased ratings, but also a single housing for the disconnecting and earthing switches, along with a hydro-mechanical spring mechanism to operate the circuit breaker. Two years later, this ELK-03-type switchgear was modified to fea-

ture self-blasting circuit breaker technology, thus reducing the energy required for switching. Since this pioneering development, GIS rated up to 170 kV have been equipped with self-blasting circuit breakers.

In 1992 the ELK-04-type switchgear was launched (rated at 170 kV, 40 kA, 3,150 A). This new product was characterized by a further reduction in volume and a totally new design of connection between the busbar and the feeder modules. This new connection allowed unprecedented reductions in product size, enabling an entire switchgear unit to be accommodated within a single standard industrial container. Even today, years after its market launch, the ELK-04-type switchgear remains one of the most compact switchgear-types available in the 170 kV category.

Further advances in power ratings have been made with this type of switchgear, while retaining its compact design. The first of these improvements was to increase the ratings to 170 kV, 50 kA, 3,150 A in 1997, and then to 145 kV, 63 kA, 4,000 A in 2002. These versions were also

1 Historical development (overview) of sub-transmission GIS in the voltage range below 170 kV



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equipped with switching units with self-blasting technology and hydro-mechanical spring-operated mechanisms **3**.

In 1996, another model, the EXK-0 had been developed to comply with reduced rating requirements of 123 kV, 40 kA, 2,500 A. In 2003, however, the rated voltage was increased to 145 kV, 40 kA, 2,500 A and was increased again in 2005 to 145 kV, 40 kA, 3,150 A.

Over 15 years after its market launch, the ELK-04-type switchgear remains one of the most compact switchgear-types available in the 170 kV category.

As a result of further continuous developments in both switchgear types, the products, which had been initiated independently to satisfy different demands, have now evolved and converged to produce a highly standardized modular system. This not only includes the primary components, such as the circuit breakers, disconnectors and earthing switches, but also their operating mechanisms. The convergent evolution of these two near-identical products prompted the launch of a single product under the now familiar brand name, ELK-04.

Transmission GIS (> 170 kV)

In 1967, the ELK-1-type GIS was designed for single-phase and single

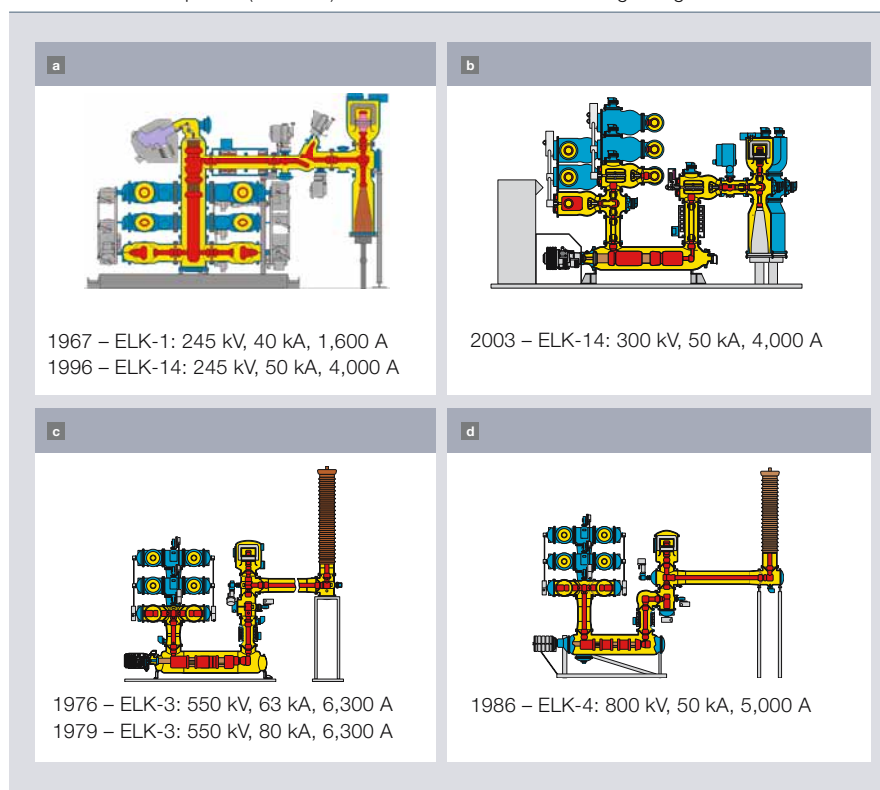
bus-bar applications for a rated voltage of 245 kV, 40 kA, 1,600 A **2a**. This type of switchgear was developed in parallel with the EBK-type switchgear to cope with higher voltage levels. The individual circuit breakers were equipped with puffer-type interrupters and were operated by separate hydraulic mechanisms.

In 1976 the first 550 kV GIS, ELK-3, was launched onto the market. The individual circuit breakers, each with three interrupting units, were the first

to be rated for short-circuit currents of 80 kA and an operating current of 6,300 A **2a**. These breakers were installed vertically, and were equipped with a hydraulic operating mechanism and closing resistors.

The ELK-3-type GIS was used in a substation for the first time in Canada in 1979. It was the first GIS to be exposed to severe climatic conditions. Since it was developed to meet specific customer requirements, special attention was given during the develop-

2 Historical development (overview) of transmission GIS in the voltage range from above 170 kV



3 Typical substation with GIS of ELK-04-type in Spain (Mallorca) **a** and replacement of AIS by GIS of ELK-04-type in the United States (California) **b**



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ment phase, not only to ensure that it would operate at higher ratings, but also that it would meet these operation requirements at sub-zero temperatures.

ABB's ELK-3-type GIS installed at the hydroelectric power plant in Itaipu, Brazil continues to protect the flow of electricity after more than 20 years of service.

In 1981, 51 bays of the ELK-3-type GIS, with ratings of 550 kV, 63 kA, 4,000 A, were installed by ABB at one of the largest transmission GIS substations in the world, at the hydroelectric power plant in Itaipu, Brazil. Each circuit breaker was positioned vertically and equipped with two interrupting units, each with an individual hydraulic operating mechanism. After more than 20 years of operation, this GIS continues to protect the flow of electrical energy to the grids of Brazil and Paraguay. Here, the challenge was to design and install a highly reliable, complex substation compatible with frequencies of 50 and 60 Hz. Individual components had to be designed in a way that would allow them to be exchanged easily if necessary.

Demand for even higher voltage transmission led to further innovations and the development of the ELK-4-type GIS, with ratings of 800 kV, 50 kA,

5,000 A ^{2d}. This model maintained its compact design, allowing a substation capable of operating at very high voltages to be installed within a limited space. Each circuit breaker was installed in the vertical position, with four interrupting units and associated closing resistors. The new product was introduced onto the market in 1986 and was first installed in South Africa at an altitude of more than 1,000 m.

In 1996, the ELK-14-type GIS was developed, using the ELK-1-type GIS as a blueprint ^{2a}. Here the ratings were 245 kV, 50 kA, 4,000 A. The interrupter was of the self-blasting type and operated by a hydro-mechanical mechanism. This was a significant milestone, since this was the first time the self-blasting principle had been used at voltages above 170 kV. Some years later, the success of the ELK-14-type GIS prompted further improvements to upgrade its ratings to 300 kV, 50 kA, 4,000 A ^{2b}. Special attention was paid to ensure that a single enclosure housed both the disconnecting and earthing switch modules.

Early in 2003, a 550 kV substation (rated at 550 kV, 63 kA, 4,000 A) was installed by ABB at the Three Gorges hydroelectric power plant in China ⁴. This is currently the largest GIS transmission substation in the world. Many technical and logistical challenges had to be solved before the last of the 73 bays could be put into operation in the autumn of 2008 ⁵. In this installation, the circuit breakers are posi-

tioned horizontally and equipped with the HMB-type hydro-mechanical operating mechanism ⁶. The layout is compact, making it possible to place the whole substation on top of the concrete dam.

ABB's ELK-5-type GIS for an ultra-high-voltage rating of 1,100 kV, 63 kA, 6,000 A is the most compact GIS ever produced for such extremely high voltages.

The most recent challenge for ABB was the development of the ELK-5-type GIS for an ultra-high-voltage rating of 1,100 kV, 63 kA, 6,000 A. This is the most compact GIS ever produced for such extremely high voltages [8]. The design is characterized by four interrupting units, connected in series and positioned in a horizontal arrangement, and is equipped with parallel closing resistors ⁷.

Modularity and scope of supply

Today, all types of switchgear have a highly standardized modular building-block design, irrespective of the voltage levels. They can accommodate a large variety of technical requirements within a small number of modules. This not only applies to the primary components, such as the circuit breaker, disconnecter and earthing switch, but also to their operating mechanisms.

⁴ The Three Gorges hydroelectric power plant in China



⁵ A 550 kV substation with GIS (rated at 550 kV, 63 kA, 4,000 A) installed within the dam at Three Gorges hydroelectric power plant in China



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All GIS-types currently available are equipped with a hydro-mechanical circuit-breaker operating mechanism, which also has a modular design. This allows the speed profile of the different interrupters to be adapted very easily, reducing switching speed, especially at the end of the motion. Therefore, the mechanical impact of the switching operation on the interrupter is very small. The energy storage in the disc springs is not restricted to the switching sequence O-0.3s-CO (open – 0.3 seconds – close-off operations) that is required to meet the relevant standards, but can provide the energy for even more complex switching sequences, eg, O-0.3s-CO-0.3s-CO, without recharging. This feature is frequently required by the Arabian and American markets. Moreover, using the various types of operating mechanisms, it is possible to achieve a timely and accurately adjustable, mechanically independent, single-pole operation with the additional benefit of a controlled switching operation.

In addition to the primary technology, with its modular design and the harmonized portfolio of operating mechanisms, the newest generation of digital control devices with the IEC-61850 communication protocol, is available [10]. The customer is offered a com-

prehensive diagnosis and monitoring system for the whole switchgear assembly. The system can be applied to several switchgear types and is designed as an add-on feature for conventional switchgear. It is characterized by open architecture and is also suitable for retrofits.

Over the years ABB has substantially reduced the amount of SF₆ gas used in its GIS despite the higher voltage ratings of newer models.

Environmental matters

Design changes and innovations in GIS technology are made to comply with market requirements and their ever-changing standards, and to reduce the environmental impact of the technology. This involves minimizing the use of potentially hazardous components during production and reducing the use of components that have complex disposal procedures at the end of their life cycles. It also involves designing products that require fewer raw materials and use fewer primary energy sources in their manufacture. In line with the aims of the

Kyoto protocol (1997) to reduce greenhouse gas emissions, efforts have been focused on reducing the volume of SF₆ gas per GIS module and thus of switchgear as a whole.

Since the beginning of GIS development, reducing the use of SF₆ has been a priority with each new type of switchgear [8]. A 40-percent reduction in the SF₆ content has now been achieved for the latest models of GIS, compared with their predecessor. It should be noted that this significant reduction has been achieved despite the higher voltage ratings of the newer types. If voltage ratings had remained unchanged, the SF₆ reduction would have been even greater.

Current market trends

With regard to both the primary and the secondary technology, all GIS types are characterized by a high degree of standardization and integration of functions. A module-oriented portfolio with a market-focused range of rating values ensures an adequate variety of products to meet customers' requirements.

On the global market, three main ranges of application and customer preferences are currently evident for GIS.

6 HMB-type hydro-mechanical operating mechanism



7 The 1,100 kV GIS substation Jingmen, China



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Extension or replacement of switchgear at substations

Often in densely populated centers of traditional industrial regions, as well as in the megacities around the world, local substations are required to meet high-energy demands. In such areas real-estate prices are high, which makes the compact design of GIS an attractive feature when compared with AIS alternatives that require considerably more (costly) land for safe operation.

Rising energy demand in the densely populated centers

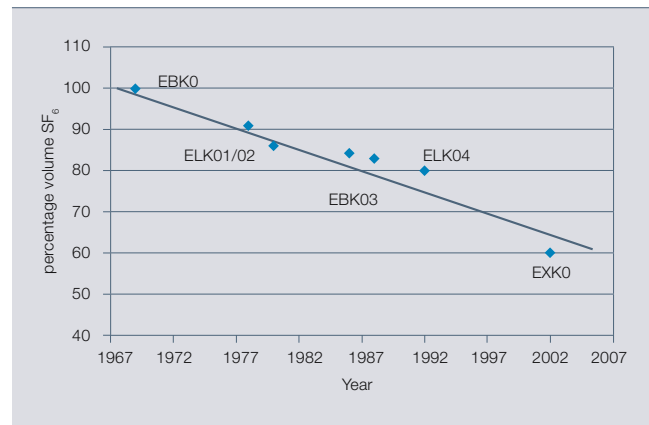
Densely populated centers of the world require higher-rated voltages, higher short-circuit currents and higher operating currents [11,12]. Greater numbers of people are living in urban centers, consuming ever-greater amounts of electricity. This demand requires efficient methods by which to transport electrical energy with low losses, reduced visibility and high degrees of safety. Efficient energy transfer can be achieved at high-voltage levels through cables. But this high voltage (HV) electricity must be reduced to lower-voltage levels using transformers in the vicinity of the end users. In densely populated centers, this leads to a persistent increase in the transfer capabilities of the networks, requiring higher nominal currents and higher short-circuit capacities within the networks.

Improved energy-technology infrastructure

New substations are required to create a new or improved energy-technology infrastructure in emerging industrial countries as well as in the countries with large primary energy resources, such as the Middle East and Russia.

The focus of new developments is to further reduce the use of SF₆ gas and to improve the energy efficiency of the entire manufacturing process. The complete GIS portfolio is set up so that state-of-the-art manufacturing technologies (machine processing of individual components), simplified assembly processes (both in the factory and in the field), together with ship-

■ Continuous reduction of the SF₆ gas shown for the circuit breakers of the switchgear in ■ having the rating parameters 145 kV, 2,500 A (figures are normalized to 100 kPa and a temperature of 20°C)



ment in standardized containers, can all be exploited.

To meet the changing and challenging market requirements of the future the following topics are of importance:

- Standardized modular component system that allows convenient and cost-effective extension of existing GIS installations and the simplified replacement of conventional air-insulated installations by GIS modules.
- Continued development in the range of switching technology, such as high-voltage switching interrupters with even lower energy demands
- Further combination of various primary functions into one module to reduce the number of flange connections

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It should not be forgotten that decades of experience at each product development step have enhanced the reliability and therefore the availability of switchgear installations, regardless of location or method of operation. For the customer, ABB's experience is reflected in lower operation costs and higher reliability over the lifetime of its products.