Substation evolution

Substation design in the 1900s and modern substations today

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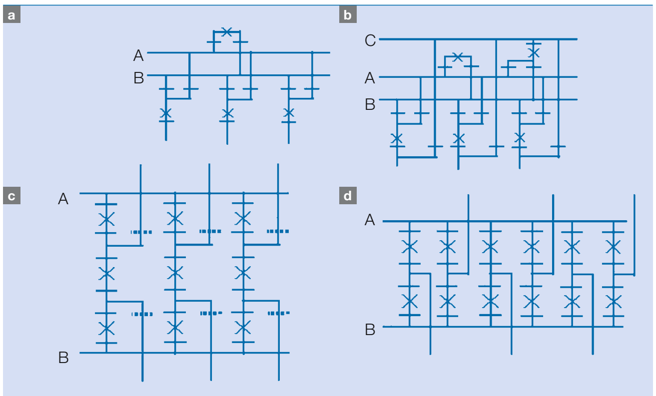
A hundred years is nothing compared with the length of time man has been roaming the earth. In terms of technology, however, it is an eternity. When ABB manufactured its first substation about 100 years ago, who would have guessed what a typical substation would be like today. Back then, the circuit breakers used were bulky and complicated, requiring constant supervision and frequent maintenance. Much of the 20th century focused on developing new technologies that would increase capacity, availability and limit maintenance, as well as addressing the issues of size, speed and automation. Some of these developments and innovations led to the launch in the 1960s of gas insulated switchgear (GIS). These smaller and compact switchgears reduced the dimensions of a conventional air insulated substation by almost 90 percent! In the 1970s, conventional electromechanical protection was replaced by static (operational amplifiers) protection, and further innovations have resulted in the current numerical control and protection systems, incorporating multiple functions and tasks, that communicate with other systems via digital technology.

For some time utilities have been able to remotely operate and control substations without the need for on-site personnel. Pre-engineered, pre-fabricated and modularized substations are available in various AIS and GIS configurations, enabling short delivery times and a high quality of installation.

When the building of electricity systems started in earnest some 100 years ago, the network wasn't particularly reliable. The circuit breakers were mechanically and electrically very complicated and required frequent maintenance. Outages due to maintenance were the norm rather than the exception. The invention of the disconnector switch certainly helped to increase the availability of these electrical networks. The single-line configurations used were such as to surround the circuit breakers by many disconnector switches so that adjacent parts of the switchgear were kept in service while maintenance was carried out on the breakers. These ideas led to the double busbar and double plus transfer busbar schemes 1a and 1b. In addition to maintenance considerations, single-line configurations were chosen to limit the consequences of primary faults in the power system (eg, if the ordinary circuit breaker failed to open on a primary fault on an outgoing object, or if a fault occurred on the busbar). For the configurations shown in 1a and 1b, these types of faults will lead to the loss of all objects connected to the busbar. To limit these consequences while still retaining the maintenance aspects, 1½-breaker and 2-breaker single-line configurations, 1c and 1d, were introduced.

1 Different types of single-line configurations: double busbar a, double plus transfer busbar b, 1½-breaker c and 2-breaker d. a and b focus on maintenance, whereas c and d cover both maintenance and fault aspects.



Today's breakers require less maintenance than their predecessors. In fact, ABB's SF_6 circuit breakers have a maintenance interval (where the primary components need to be taken out of service) of 15 years. Open air disconnector switches on the other hand still retain a maintenance interval of about four to five years in areas where there is little or no pollution. Substantially more frequent maintenance is required if the switch is located in areas with natural (ie, sand or salt) or industrial pollution.

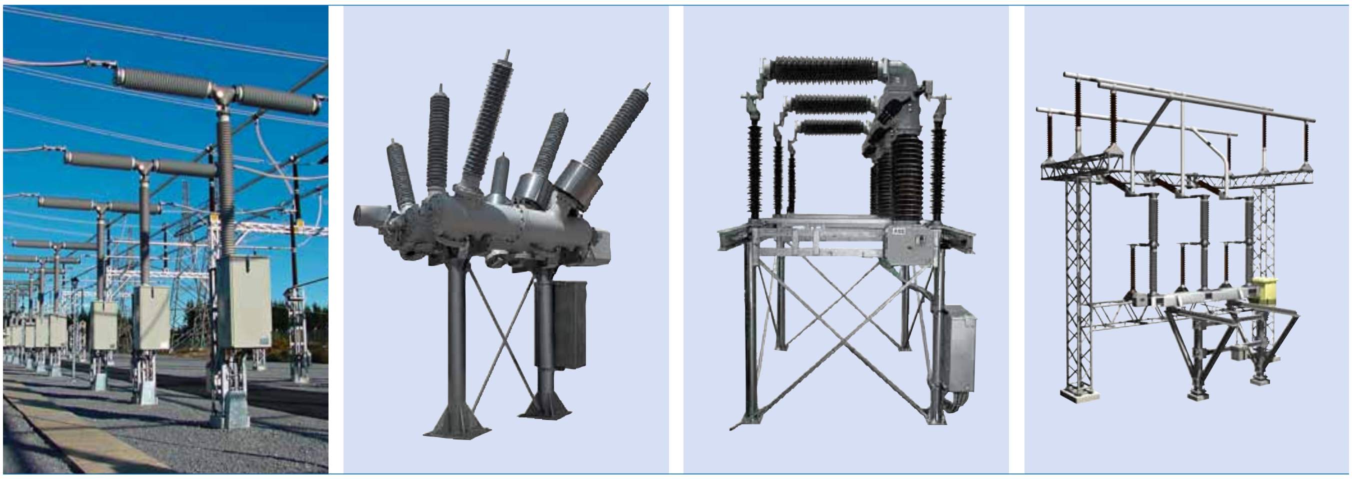
Even though disconnecting switches – or rather a disconnecting function – are needed, their maintenance requirements are simply not practical, let alone economical. A number of innovative switchgear concepts for Air Insulated Substations (AIS) have effectively made the traditional open-air disconnecting switch redundant 2. The disconnecting function has either been built onto or integrated into the breaker. This not only increases the availability of the substation, but it helps to reduce its footprint by about 50 percent. The impact of going from a traditional solution, for example a 1½-breaker solution for a 400 kV AIS with circuit breakers and disconnecting switches, to a solution using Combined (disconnecting circuit breaker) is shown in 3. The advantages of a reduced footprint include lower costs for land acquisition and preparation, the retrofitting of existing substations is easier, and the environmental impact, because of less material and therefore pollution, is considerably reduced.

Instrument transformers today

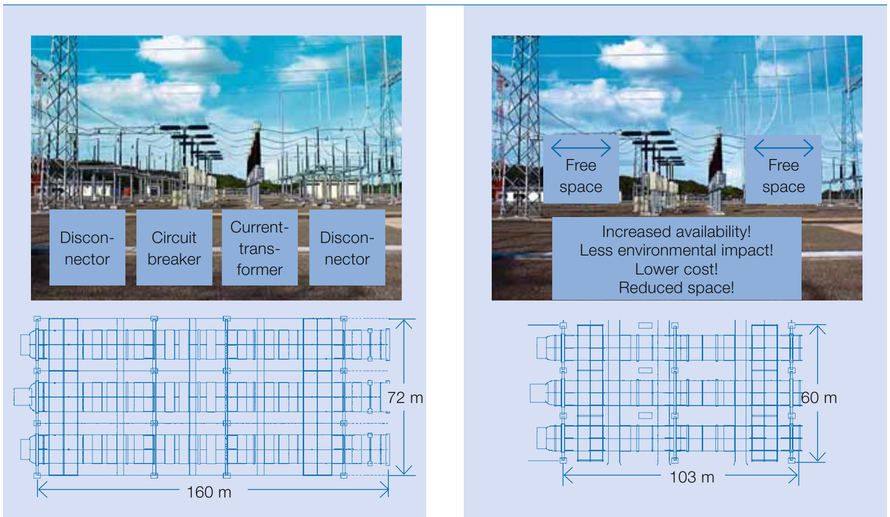
Instrument transformers pass on information about the primary current and voltages to the secondary equipment (protection, control and metering). Historically these transformers were large apparatuses composed of insulation materials, copper and iron. They were also used to power the electromechanical secondary equipment. Nowadays, the numerical type of secondary equipment gets its operating power from a separate power supply (ie, battery). In addition – thanks to

2 ABB Innovative Switchgear Modules with the disconnecting function either built on or integrated into the circuit breaker

a Combined | b PASS | c Compass | d Compact



3 The impact of changing from 400 kV traditional circuit breakers and disconnecting switches (left) to a Combined (disconnecting circuit breaker) solution. Notice the reduction in footprint size



the emergence of fiber-optic technology – the old large instrument transformers can be replaced by fibre-optic sensors that give information about primary currents and voltages. These values are transformed into digital fiber-optic signals, which are fed to the secondary equipment. Replacing traditional instrument transformers with optical sensors will further reduce the switchgear footprint and lower costs, while at the same time providing secondary equipment that is more flexible and secure.

Invisible substations

Not only has the technology behind substations changed dramatically in the last 100 years, but so too has their appearance. Many substations were originally built on the outskirts of cities or large towns, so appearances were not all that important. However, many of these substations have since been swallowed up by the urban expansion of the past few decades. Many who live near them find both the appearance and the acoustic pollution, caused by the humming of power transformers, unpleasant. To solve this problem, substations have been placed in buildings that are in harmony with those around it, and have therefore become "invisible." A reduced footprint – a 40 to 50 percent reduction for indoor AIS solutions and a 70 to 80 percent reduction for indoor GIS solutions – has greatly simplified this process. Locating equipment indoors increases the substation availability and reliability as the risk of primary failures, due to animals and atmospheric or industrial pollution, is significantly decreased for AIS and totally eliminated for GIS. Additionally, remote supervision of the building is possible, which helps increase the substation rounding interval. The substations are also protected against burglaries, and the irritable humming noise is greatly reduced. Underground GIS substations, making the substation truly invisible, have been implemented in city-centers around the world where substations at ground level are not permitted 4.

A reduced substation footprint means lower costs for land acquisition and preparation, the retrofitting of existing substations is easier, and the environmental impact is considerably reduced.

Two important considerations engineers must take into account when constructing new substations in urban areas are size and safety. Real estate prices mean the space required for these substations must be kept to a minimum, and higher standards for personal safety apply for substations in populated areas. To meet these specific requirements in and around cities, as well as adapting to individual requirements, ABB has developed a concept, known as the URBAN concept, for compact indoor substations up to 170 kV. Exclusively innovative systems from ABB's current product portfolio are used for indoor installations within this concept. Both air-insulated and SF_6-insulated modules

4 A truly invisible underground substation. The waterfall cools and hides the humming of the power transformer a, locals are invited to have their say on a proposed project b, and an underground GIS switchgear c

5 A MALTE prefabricated substation: old substation a, new substation b and interior of the new substation with a power transformer in the middle, high-voltage to the right, and medium-voltage and secondary equipment on the left c

can be used, depending on the actual requirements of the specific installation.

Prefabricated indoor substations

A pre-fabricated substation allows for quick and easy on-site installation, something that shortens the total project time and minimizes disturbances to neighbours. At the same time, the quality of the supply is higher due to complete factory testing before shipping. One example is MALTE, a type of distribution substation with a transformer size of up to 16 MVA. MALTE consists of pre-fabricated modules that are factory-tested before shipping. Primary and secondary cabling between the modules is prepared in a way that allows for rapid connection. On-site assembly and testing only takes one week, after which the substation is ready to be energized. Its footprint, of the order 100 m^2, is less than 30 percent of an outdoor AIS substation. MALTE 5 consists of three main modules:

- A *power transformer module* consisting of the main power transformer, a prefabricated foundation that also acts as an oil-pit, walls and a roof.
- A *high-voltage (HV) module* which is equipped with a removable COMPACT 52 kV circuit breaker. This module requires no foundations as it is hinged onto the side of the power transformer module.
- A *medium-voltage (MV) module* whose indoor switchgears are mounted in cubicles. In this module relay, control and auxiliary AC/DC-equipment for the entire substation is included. Like the HV module, it is also hinged onto the transformer module.

Replacing traditional instrument transformers with optical sensors further reduces the switchgear footprint while at the same time providing secondary equipment that is more flexible and secure.

As well as its small footprint and quick assembly time, MALTE, when compared to the traditional solution, offers: higher availability because the equipment is indoors; lower maintenance and rounding costs; the substation, including its foundations, can be quickly dismantled and moved; it is environmentally friendly; and finally, it is personnel and third-party safe.

Substation secondary system

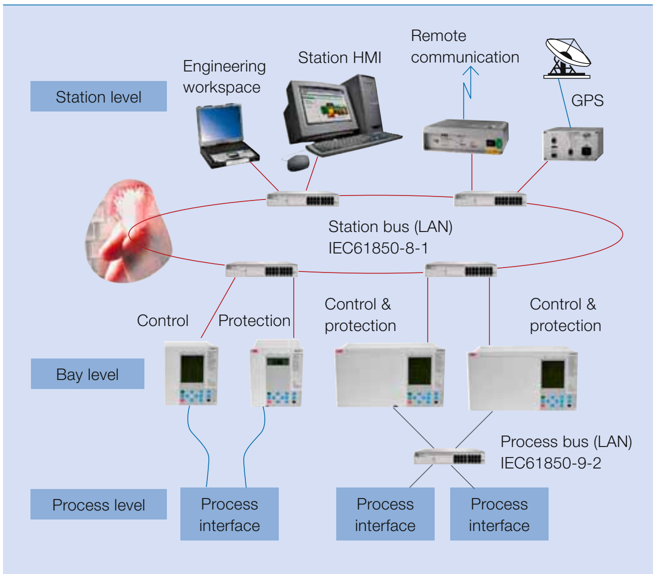
Like its primary counterpart, substation secondary systems have also changed a lot over the years. For example, the days of manual operation have been replaced by a more sophisticated form of information management. The secondary system in a modern substation 6 is used for:

- Primary system protection and supervision
- Local and remote access to the power system apparatus
- Local manual and automatic functions
- Communication links and interfaces within the secondary system
- Communication links and interfacing to network management systems

All of these functions are performed by a Substation Automation System (SAS) which contains programmable secondary devices, known as Intelligent Electronic Devices (IEDs), for control, monitoring, protection and automation. Typical characteristics of an IED include:

- It can be used for one or more switchgear bays.
- It contains independent protection functionality for each feeder.

6 The structure of a modern control and protection system



7 Pre-fabrication of a relay and control system: factory testing of complete substation equipment a, transport of whole modules to the site b and equipment in service on-site c

- It performs high-speed calculations in real-time, which will trigger a trip signal if necessary.
- The IED is intended as a combined protection and control device, but it can just as well function as a separate control or protection device.
- It can communicate with all other IEDs.

To increase SAS reliability and availability, the protection part may be duplicated to provide a redundant system. For full redundancy, all IEDs and the supporting system (like the power supply) should be duplicated, to ensure that the two systems can work independently of each other.

MALTE, a pre-fabricated distribution substation not only allows for quick and easy on-site installation, but the quality of the supply is higher.

Pre-fabrication

The pre-fabrication and pre-testing of substation automation equipment is fast becoming the norm for a modern substation. The system is delivered in sections containing all the required functions for a part of the primary system, and these sections are then simply connected together via an optical-fiber 7. Pre-fabrication has many advantages such as:

- The total costs can be kept lower due to optimized manufacturing and testing.
- The quality is higher because the module has been fully tested in-house and is shipped with all the wiring intact.
- Because much of the assembly and testing is completed before shipping, the time spent on-site is considerably reduced.
- Pre-fabrication is suitable for both "green field" and retrofit projects.
- Future retrofit is simplified and can be done with shorter outage time by replacing the complete pre-fabricated building.

Communication

Effective and fast communication between IEDs is essential in an SAS. Numerical communication had been used for many years in substations delivered by ABB, but a lack of standardized protocols limited the efficiency of SAS and restricted the mixing of ABB and non ABB IEDs. To overcome this problem, ABB has actively participated and supported IEC in the development of a standard for substation communication, known as the IEC 61850 communication standard [1].

Modern substations are generally remotely operated, and communication between the substation and the remote control center is via a wide area network (WAN). Nowadays, new overhead lines or power cable connections are equipped with optical-fiber to enable protective system communication and for the WAN.

A look into the future

The last 100 years have seen the economy move from the industrial age to the information age. A host of fascinating ideas, in particular the World Wide Web, have changed how many people and companies live and work. For example, the availability of the internet to companies like ABB means that customer contact is greatly simplified and faster. Projects can be executed using a common database assessed by both parties.

Future substation power handling equipment will be even more integrated and compact, while measuring functions and all of the secondary functions will be done using fiber-optics.

In the future, substation power handling equipment will be even more integrated and compact, while measuring functions and all of the secondary functions will be done using fiber-optics. In other words, tons of porcelain, copper and iron will be superseded by just a few fiber-optic connections. This will further speed up the delivery process, reduce the substation footprint, and make it more environmentally friendly.

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Reference

[1] **Frei, C., Kirrmann, H., Kostic, T., Maeda, T., Obrist, M.** Speed and quality. *ABB Review* 4/2007, 38–41.