


Small footprint, high performance

Design of an air-insulated switchgear substation based on new technology

Lei Jing, Hans-Erik Olovsson, Jianzhong Fan, Richard Thomas



As cities grow, so does their hunger for electrical power. To achieve the necessary bulk transmission, the highest voltage level of a city's power supply is continuously changing: from 110 kV to 220 kV, even reaching 500 kV in some mega-cities in China and other countries. This calls for extra-high-voltage (EHV) substations to act as load hubs in the city. However, such developments lead to a conflict between substation footprint and power requirement. In general, the higher the voltage level, the more power a substation handles and the larger the area it needs. Such demands, however, conflict with typical limitations that are prevalent in city areas. The shortage of land is the most important among these and the huge investment cost is also a very serious challenge. Furthermore, as an energy distribution center for very many people, such a substation must perform with high reliability and availability. All this underpins the case for a compact substation, featuring smaller footprint while reduced customer costs and a maintaining high availability.

Today's technology is making these objectives attainable. Firstly, new primary equipment permits a drastic reduction in the footprint area. A revolution in circuit-breaker design led by ABB is allowing switchgear configuration or even integration to be redefined, decreasing costs both in terms of land acquisition and equipment cost. Secondly, innovative optical sensors are replacing the traditional expensive and large current transformers (CT). These non-traditional CTs are so small that they can be easily integrated with the breaker in the same circuit. Thirdly, the use of such sensors is an integral aspect of a digital substation. This not only enhances substation performance, but also saves on investment, eg, cables for secondary instrument transformer circuits and for the control of circuit breakers, disconnectors, and earthing switches.

In an urban substation, the key factor is land-related cost.

Traditional air-insulated substations

Utilities must meet huge construction and installation costs when investing in a substation. Obviously, primary equipment, such as transformers and circuit breakers, are very expensive, especially when these are for extra high voltages. Further, the substation automation system (SAS) is itself cost-

ly to install, not only because of the large numbers of intelligent electronic devices (IED) and computers, but due to the extensive cabling for measurement and control.

However, in an urban substation, the key factor is land-related cost. The purchase is an integral part of this process, but is only the last step. Unlike general commodities, land cannot be obtained with money alone. Safety, environment, and noise are all factors to be considered in the approval of a substation. The smaller the plot of land, the less impact a substation has on its surroundings.

1 shows the single-line diagram (SLD) of a 500 kV substation [1]. In this substation, there are six 500 kV diameters ($1\frac{1}{2}$ circuit breaker scheme) and twelve 220 kV double busbar bays.

In this substation, all primary equipment is so large that often an area of 60,000 m² is used **2**. Obviously, it is difficult to find a suitable location for such an installation in the city.

The fast-increasing power demand, however, makes such substations indispensable. Plans of the Beijing electric power company see a 500 kV double-ring network around the city being completed in 2010. This will feature 10 substations (each for 500 kV and 2600 MW). These include four

load-hub substations located in the city center. The demand for and value of land is so high, that any compact substation solution becomes attractive. One obvious approach is to use gas-insulated switchgear (GIS), which would occupy only 30,000 m² for the same SLD as in **1** [1]. This will, however, be more costly than air-insulated substations. According to China State Grid [1], a GIS substation requires around 40 percent higher investment. Therefore, an alternative for the traditional air-insulated switchgear (AIS) substation, with less footprint and customer cost is required.

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The technology solution

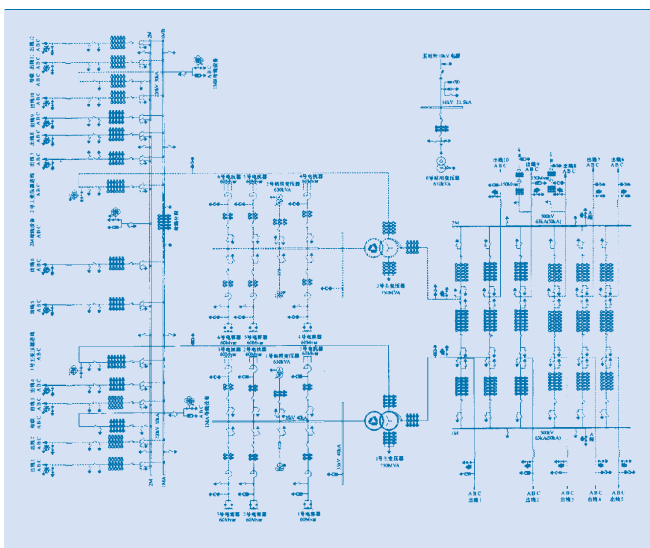
Applying new technologies, ABB can design AIS substations with reduced installation cost and a smaller footprint.

New circuit breaker

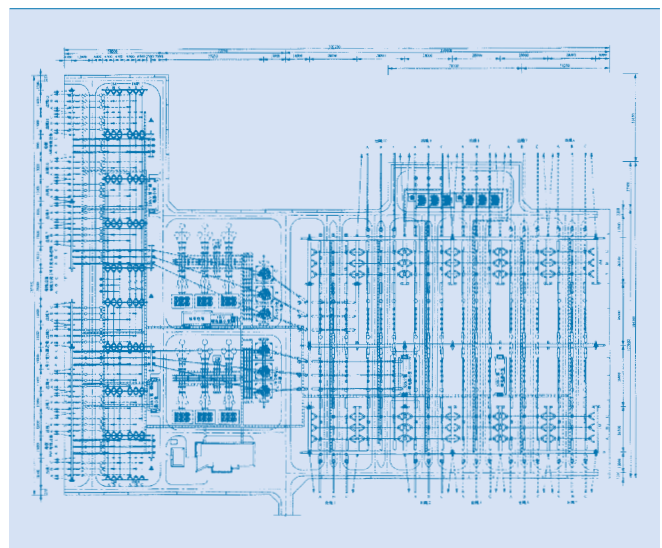
A section view of a 500 kV bay is shown in **3**. The diagram shows that the disconnectors take up most of the space as each circuit breaker needs two disconnectors for safe isolation.

With the modern and well proven SF₆ circuit breakers (CB) of the self blast

1 Single line diagram (SLD) of a typical 500 kV substation



2 Layout of a typical 500 kV substation using air-insulated switchgear (AIS)



Powering the economy

and/or puffer type, ABB now can offer an alternative that provides opportunities to both simplify substations and save space. A new disconnecting circuit breaker (DCB), named “Combined”, has been developed and manufactured [2]. The disconnection func-

tion for Combined is integrated in the breaking chamber. There are no additional contacts or other components for the disconnecting function in the SF₆ breaking chamber. When the circuit breaker contacts are in the open position, they can be mechanically

locked in the open position, fulfilling the disconnecting function requirement and maintenance on adjacent parts of the switchgear or network can be carried out. Further, eliminating the air-exposed disconnector contacts also provides for lower maintenance and higher switchgear reliability. Disconnecting CB requirements are specified in the IEC standard 62271-108 [4].

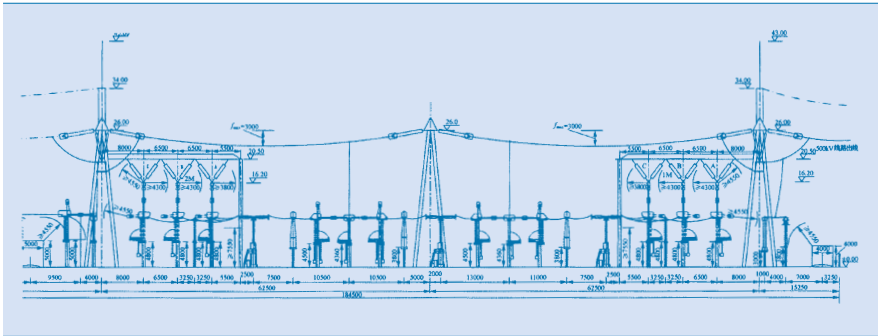
With the modern and well proven SF₆ circuit breakers of the self blast and/or puffer type, ABB now can offer an alternative that provides opportunities to both simplify substations and save space.

DCBs can save not only equipment cost, but also reduce the footprint and related construction costs while increasing availability. A layout comparison between conventional and Combined 145 kV based switchyards is shown in [5].

Innovative sensors

Besides the disconnector, the traditional CT (current transformer) also occupies a lot of space in [3]. However, new sensing technology makes the alternative solution possible.

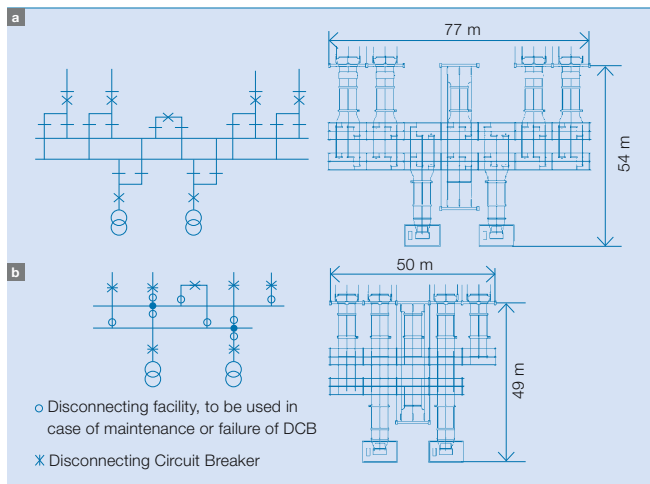
3 Section view of a 500 kV 1½ diameter



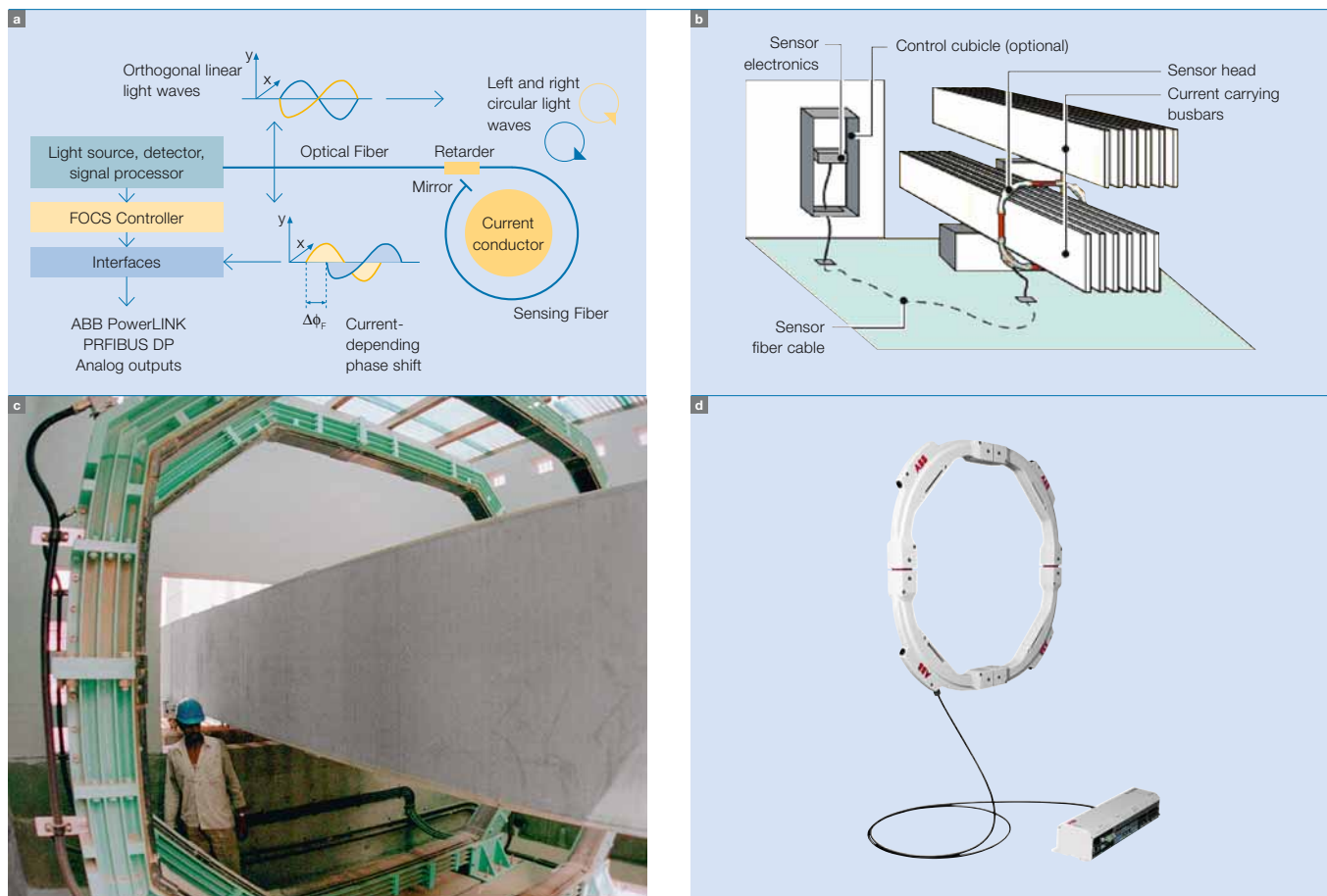
4 Disconnecting circuit breakers with two a and one b breaking chamber



5 Space requirement of 145 kV substation (traditional) a compared to the same functionality achieved with the “Combined” breaker b



6 ABB FOCS measuring principle **a**, installation **b**, two conventional Hall effect dc current transducers for 400 kA **c** and the measurement coil **d**.



Innovative sensors are beginning to replace regular CT in recent years. Fiber-optic current sensors (FOCS) present an excellent alternative [3]. Using the Faraday Effect, FOCS can easily measure the current with a fiber optic loop placed around the conductor. The resulting simple installation is shown in **6**. Another benefit is the smaller footprint compared to the large electromagnetic CT.

Additionally, in respect to digital signal processing, FOCS can interface with process-level devices in a substation automation system (SAS). Consequently, the IEC 61850 process bus (-9-2) concept can be implemented, reducing need of secondary cabling and simplifying construction and commissioning work.

IEC 61850-9-2 application

As mentioned above, FOCS can transfer all measured values in digital format. Thus, if a FOCS is applied with an IEC 61850-9-2 compatible merging

unit, the digital values can be transmitted to bay level IEDs via the fiber optic network, replacing the large amount of copper cables. Figure **7a** represents the technical evolution of SA from Process (bottom) up to NCC (top) from conventional (left) to intelligent (right). Figure **7b** shows the architecture of IEC 61850 based SAS, which is the concrete implementation of the intelligent system in Figure **7a**. For a three-phase power line, at least three groups of measuring cables are eliminated with the intelligent system. Furthermore, as there is no magnetic saturation in FOCS, one set of FOCS can be used for both monitoring and protection, or even metering. In this way, further cabling can be saved.

Moreover, if an intelligent breaker IED, compatible to IEC61850-9-2, is designed and embedded in the circuit breaker, the control will use the same fiber-optic network with current and voltage sensing function. The control

cable is then also replaced by the network, resulting in a more reliable and cost optimized SA system.

Layout reconfiguration and optimization

Based on the new technologies above, the substation footprint can be reduced by more than 50 percent, while at the same time increasing its availability and reliability.

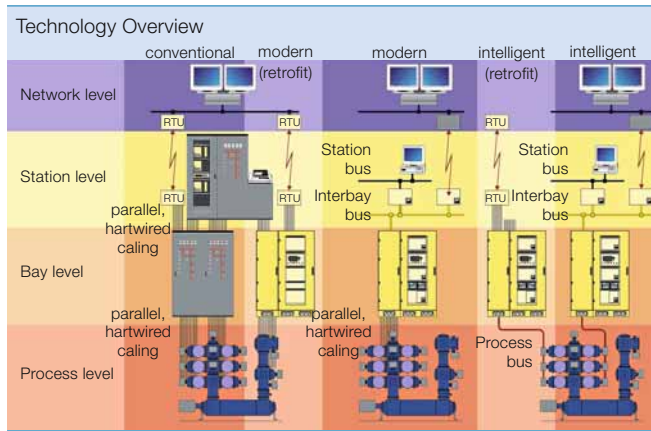
Using the Faraday Effect, FOCS can easily measure the current with a fiber optic loop placed around the conductor.

Moreover, the use of DCB not only permits the disconnecter to be eliminated, but also allows the busbar topology to be improved. Since the maintenance interval for a Combined DCB is 15 years, the replacement of double by a sectionalized single bus-

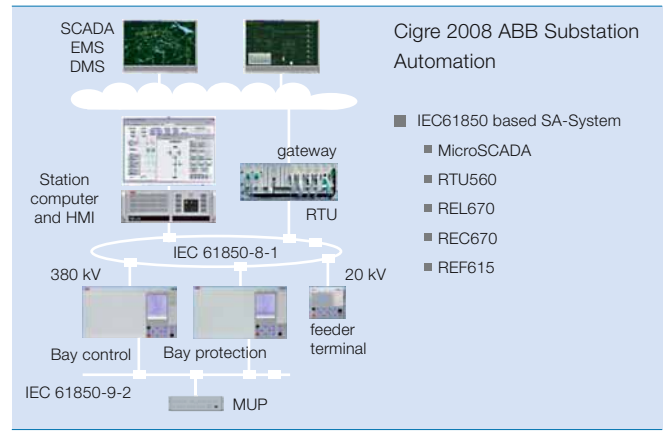
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7 Digital substation configuration

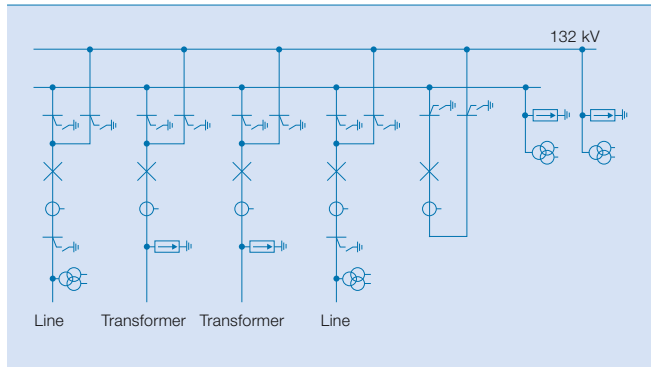
a SAS evolution



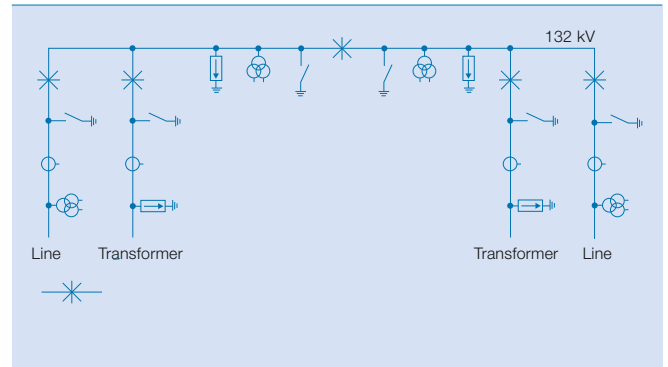
b IEC 61850 based SAS



8 Traditional switchgear layout with disconnectors and circuit breakers



9 Switchgear with disconnecting circuit breakers (DCB)



bar system is justified without availability being compromised. Comparing the layouts in 8 and 9, it can be seen how busbar and related disconnectors are eliminated, simplifying the layout.

The use of a combined disconnecting circuit breaker as primary equipment opens the opportunity for greatly improved efficiency in substation construction, operation and layout.

In addition, because FOCS and an intelligent interface are used, the cable and related auxiliaries can be done away with, resulting in a much simplified control setup and simplifying connections to the primary equipment.

Switching ahead

An air insulated substation can be designed to be more reliable and cost efficient by introducing new equipment and technologies. The use of a combined disconnecting circuit breaker as primary equipment opens the opportunity for greatly improved efficiency in substation construction, operation and layout. The innovative current sensor together with an intelligent interface enables the implementation of the IEC 61850-based process bus protocol.

Lei Jing

ABB Corporate Research
Beijing, China
lei.jing@cn.abb.com

Hans-Erik Olovsson

ABB Power Systems
Västerås, Sweden
hans-erik.olvsson@se.abb.com

Jianzhong Fan

ABB Power Systems, HVDC
Beijing, China
john-jianzhong.fan@cn.abb.com

Richard Thomas

ABB Power Products
Ludvika, Sweden
richard.thomas@se.abb.com

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