Disconnecting Circuit Breaker
Maximum availability with minimum footprint

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Air insulated substations with DCBs give maximum availability with minimum footprint

HANS-ERIK OLOVSSON, CARL EJNAR SÖLVER, RICHARD THOMAS – The development of circuit breakers (CBs) has led to a change of design principle for substations. Previously the substation's design was based on the fact that CBs needed a lot of maintenance and were therefore surrounded by disconnectors (DSs) to enable maintenance without disturbing nearby circuits. With today's CBs having a maintenance interval of 15 years plus, the design principle is more focused on the maintenance of overhead lines, transformers, reactors, etc. The change of design principle has enabled the integration of the disconnecting function with the CB, thereby creating a new apparatus called a disconnecting CB (DCB). Since the primary contacts for DCBs are in an SF_6 protected environment, free from pollution, the disconnecting function is highly reliable and the maintenance interval is increased, providing greater overall availability of the substation. In addition the DCB solution reduces the substation footprint by about 50 percent, see Figure 1a and 1b.

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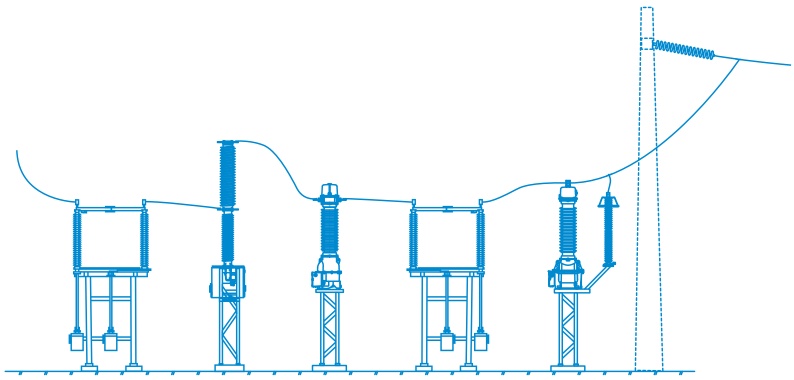


Figure 1a

A traditional substation with circuit breaker and disconnectors

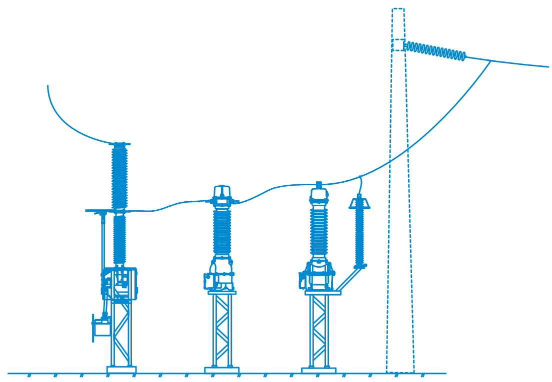


Figure 1b

The disconnecting circuit breaker solution reduces the substation footprint by about 50 percent

Development in circuit breaker (CB) technology has led to a significant decrease in maintenance and an increase in reliability. The maintenance intervals of modern SF_6 CBs requiring the de-energising of the primary circuit is now 15 years or more. No significant improvements in maintenance requirements and reliability have been made with open air DS, which during the same period focused on cost reductions by optimising production materials. The maintenance interval for the open-air DS's main contacts is in the order of two to six years, depending on user practices and pollution levels (ie, industrial pollutants and / or natural pollutants, eg, sand and salt).

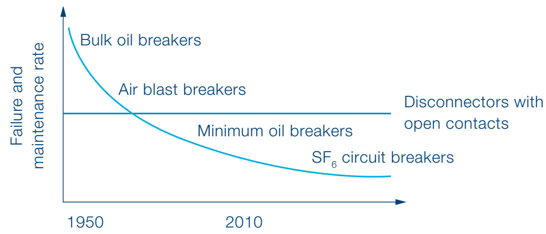


Figure 2

Development of CBs and corresponding reduction in failure and maintenance rates

Reliability of CBs has increased due to evolution of primary breaking technology, from air blast, oil minimum, SF6 dual pressure into today's SF6 single pressure type CBs. At the same time the number of series interrupters has been reduced and today live tank CBs up to 300 kV are available with one interrupter per pole. Removal of grading capacitors for live tank CBs with two interrupters has further simplified the primary circuit and thus increased the availability. Today CB's up to 550 kV are available without grading capacitors, enabling the development of DCBs up to this voltage level. Operating mechanisms for CBs have also improved going from pneumatic or hydraulic to spring type, leading to more reliable designs and lower maintenance, see Figure 2.

In the past the design principle when building substations was to "surround" CBs with DSs to make the frequent maintenance of CBs possible. Due to the large reduction of failure and maintenance of CBs, the disconnecting function today is required more for the maintenance of overhead lines, power transformers, etc. The reduced maintenance on CBs together with customer's reliability problems with open-air DSs, led to the close co-operative development of the DCB with some of ABB's major customers [1, 2, 3]. The DCB combines the switching and disconnecting functions in one device, reducing the substation's footprint and increasing availability [4]. The first installation of the DCB was in 2000 and today DCBs are available from 72.5 kV to 550 kV voltage level.

Design of disconnecting circuit-breakers

n a DCB, the normal interrupter contacts also provide the DS function when in an open position. The contact system is similar to that of a normal CB with no extra contacts or linkage system, see Figure 3. The DCB is equipped with silicone rubber insulators. These insulators have hydrophobic properties, ie, any water on the surface will form droplets. As a result they have excellent performance in polluted environments and the leakage current across the poles in the open position is minimized.

DCBs will significantly reduce maintenance in air insulated switchgear (AIS) substations and reduce the risk of failure due to pollution. By replacing the combination of CBs and open-air DSs with DCBs in substations, availability will be significantly improved.

A DCB has to fulfill both applicable CB standards and DS standards. A specific standard for disconnecting circuit breakers was issued by IEC in 2005 [5]. An important part of this standard was the combined function tests. These tests verify that the disconnecting properties of the DCB are fulfilled during its service life, despite contact wear and any decomposition by-products generated by arc interruption. This is ensured by making all the breaking and mechanical tests first and thereafter confirming the disconnecting dielectric properties.

The DCB is available for rated voltages from 72.5 to 550 kV, see Table 1. Around 900 three phase units have been installed or ordered.

Safe earthing

When a part of a substation or network is to be maintained or repaired, one or more DSs are opened to isolate it from the rest of the system and the isolated equipment is earthed for personal safety. This can be achieved in different ways:

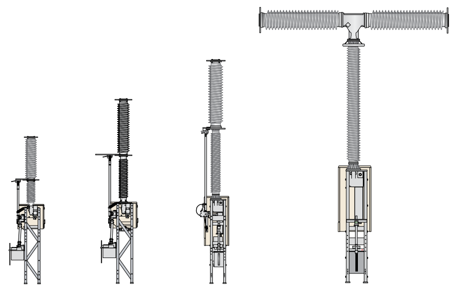
– With conventional air-insulated DSs, the visible open contact gaps verify that the part of the system is de-energised and then the isolated system is earthed
– DCBs are locked in the open position in a failsafe way. The locking consists of electrical blocking of the operating mechanism, as well as mechanical locking of the linkage system to the main contacts. Thereafter the adjacent earthing switch is closed. The visible closed earthing switch verifies that the part of the system is de-energised and safe for workers.

Maintenance aspects

In the past the complexity of CBs required high maintenance, which focused attention on how to isolate them, while keeping the other parts of the substation in service. The main reason for DSs introduction about 100 years ago was to enable CB maintenance. Single-line configuration was thus built-up with CBs surrounded by DSs to enable CB maintenance, see Figure 6 on next page.

A traditional double busbar solution with separate CBs and DSs versus a sectionalized busbar solution with DCBs, for a 132 kV substation with four overhead lines, two power transformers and one bus-coupler or bus-section CB, are

Figure 3
DCB LTB 145 kV. The earthing switch is integrated on support structure



Type	LTB 72,5	LTB 145	HPL 170-300	HPL 362-420	HPL 550
Rated voltage, kV	72.5	145	170-300	362-420	550
Rated current, A	3150	3150	4000	4000	4000
Circuit-breaking capacity, kA	40	40	50	50	63
Rated frequency, Hz	50/60	50/60	50/60	50/60	50

Table 1
The range of Disconnecting Circuit Breaker

shown in Figure 9 on page 6. The DCB solution will reduce the switchyard area by more than 40 percent. Outages for an incoming / outgoing bay, due to maintenance on the switchgear main apparatus are shown in Figure 4 below. Assumed maintenance intervals are in accordance with manufacturer's recommendations, ie, 5 years for open air DS and 15 years for CB and DCB. Introduction of the DCB thus reduces the average maintenance outage from 3.1 to 1.2 hours per year.

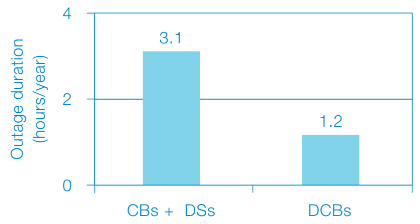


Figure 4
Outage duration due to maintenance of 132 kV switchgear apparatus

The reduction of maintenance activities will give the following advantages:

- More satisfied consumers (depending on substation / network topology, the maintenance work can lead to loss of power supply to some consumers).
- Less risk of system disturbances (black-outs) since the risk for primary faults during a maintenance situation (ie, when there are people in the substation) is higher than during normal service and during maintenance a system is "weaker"because not all equipment is in service
- Lower employment costs for maintenance work on site
- Higher personnel safety since all work on the substation's high-voltage system has the potential risk of injury due to electrical shock, or falling from heights, etc.

The disconnecting facility is a point in the switchgear that is prepared for fast opening of the primary connection between the DCB and the busbar. When the DCB is disconnected in this way the other parts of the substation may be re-energised while work continues on the DCB itself.

Fault aspects

Equipment and apparatus are getting more and more reliable, however faults still happen even though they occur with longer mean time between failures (MTBF). Faults are a stochastic process, which means that even with very long MTBF, the fault could happen at anytime and ABB's customers must design the substations accordingly. When clearing a fault there is also a slight risk that some CB should fail to open, requiring back-up CBs to operate.

For the single line configuration shown inFigure 9 on next page, a primary fault on one of the outgoing objects, plus CB failure for that bay, would lead to de-energisation of one busbar section. A failure in the bus-section or bus-coupler breaker will lead to loss of the whole substation. For important substations it might not be acceptable from a system security perspective to have a risk of loosing the whole substation at a primary fault. To make the substation "immune" to busbar faults and to minimize the disturbance if a CB fails to open at a primary fault, 1 ½-breaker or 2-breaker configurations can be used, see Figure 5.

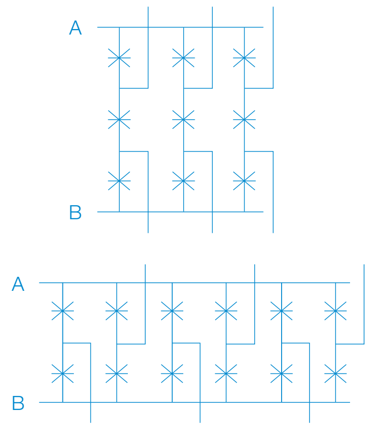


Figure 5
Single-line configurations "immune" to busbar faults

InFigure 10 on page 7 single line diagram and corresponding space requirement is compared, for a traditional type of solution with CBs and DSs versus a solution with DCBs, for a typical 420 kV substation with three OH-lines, two power transformers and one shunt reactor. By using DCB the outdoor switchyard area is reduced by almost 50 percent.

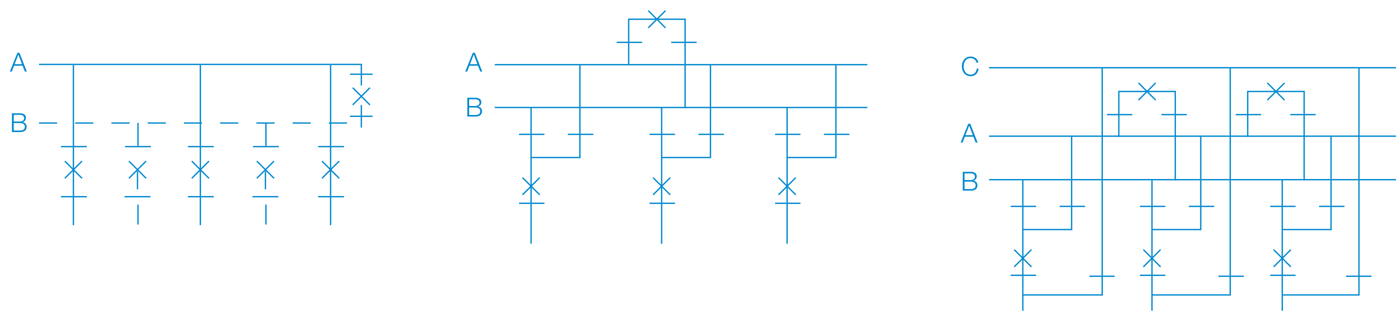


Figure 6
Different types of single-line configurations based on the requirement for the frequent maintenance of CBs, which are no longer required

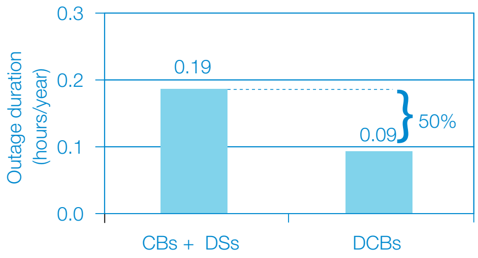
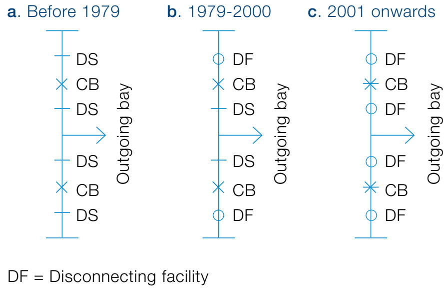


Figure 7
Outage duration due to primary faults in the 400 kV switchgear.



8a Solution with traditional apparatus
8b Modified version by removing busbar DS
8c DCB solution

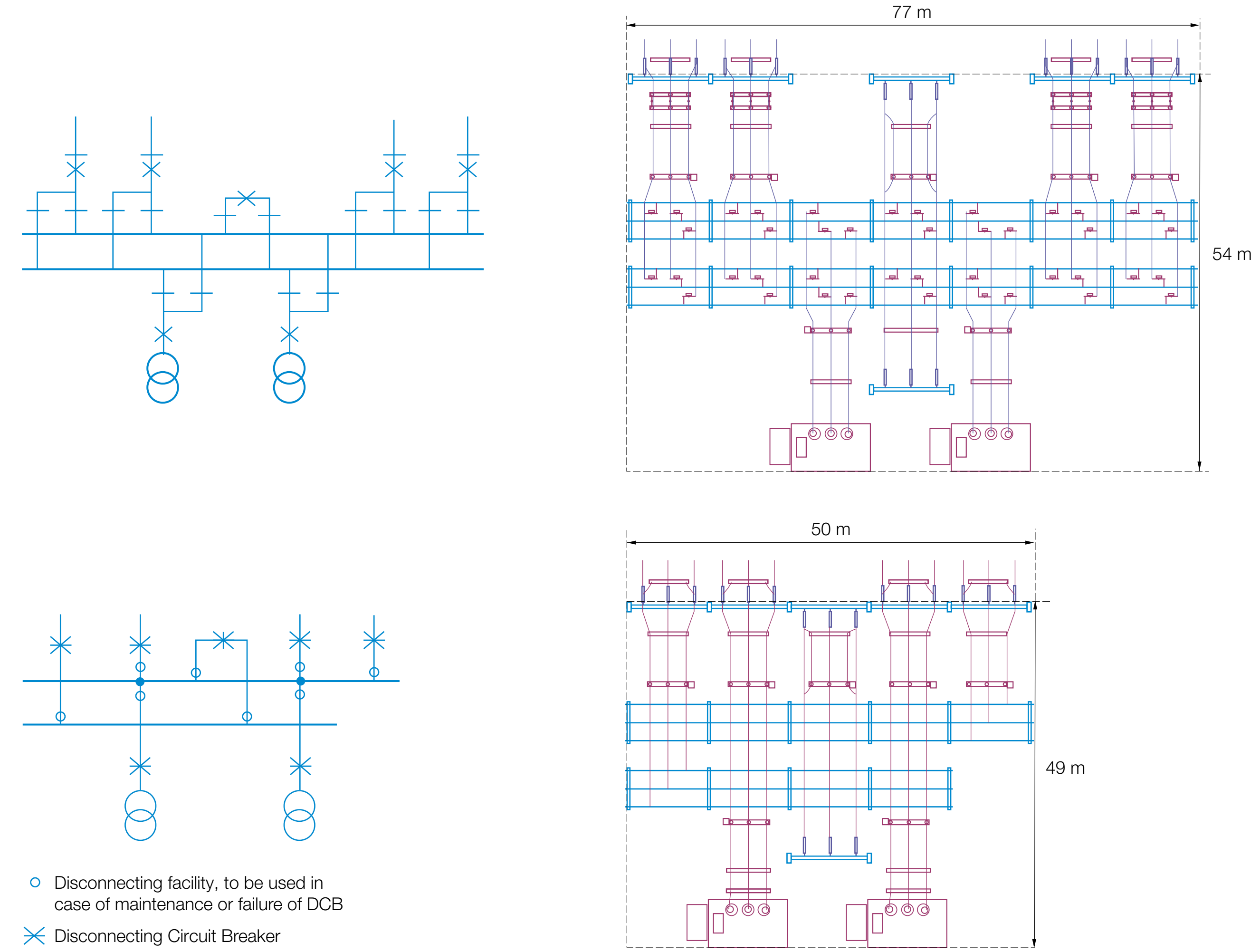


Figure 9
Single-line and layout for 132 kV traditional CBs and DSs vs the DCBs solution

Outages for an incoming / outgoing bay, due to faults in the switchgear, are shown in Figure 7 on page 6. Failure frequency input are taken from international statistics sources, such as CIGRE and CEA, which gather information from apparatus in service. Since the DCB is very similar to a traditional CB, failure statistics are assumed to be the same for CB and DCB. The introduction of the DCB thus reduces outages by 50 percent. Unplanned outages may be very problematic and lead to loss of power supply to consumers, which is not acceptable “no black-outs please”.

Application of DCB

DCBs can be applied in most traditional substation configurations, and directly replace traditional CB / DS arrangements. This reduces the substation’s footprint substantially, reduces maintenance activities and reduces outages due to maintenance and faults, ie, increases availability. The increased availability could be used to simplify the single-line configuration and still keep the availability to the level it was before.

The total investment cost for the substation could be decreased using DCBs (depending on the cost of preparing land, piling, blasting, land fill, etc., which would differ from case to case). Operation costs will be reduced thanks to lower costs for outages (this is usually the highest cost) and maintenance.

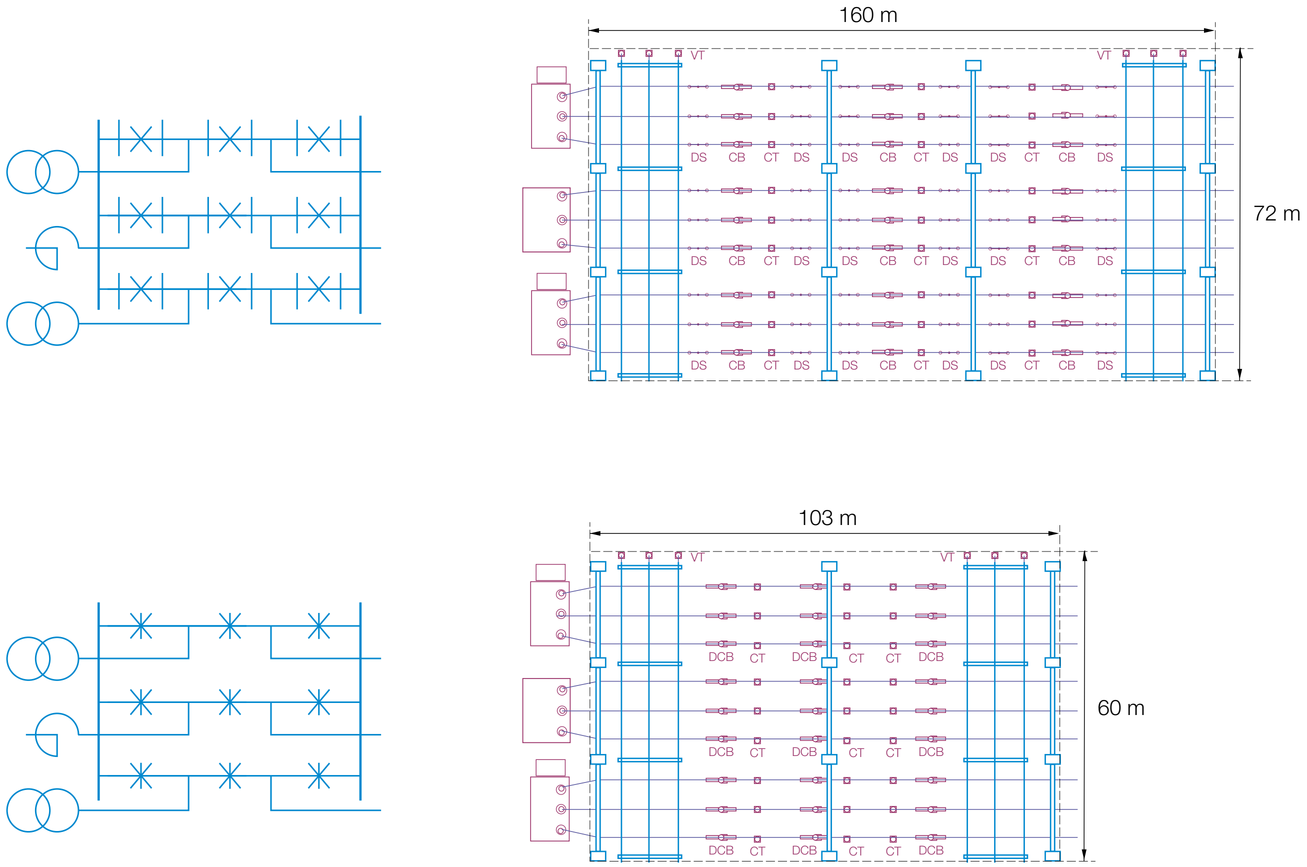


Figure 10

Single-line and layout for 420 kV traditional CBs and DSs vs the DCB solution

Example – 420 kV substation in Sweden

Svenska Kraftnät (SvK), the transmission system operator (TSO) in Sweden, is responsible for the 420 kV and 245 kV systems in Sweden. The Swedish 420 kV system started in the 1950s, and was real pioneering work since it was the first system in the world at that voltage level. Today the Swedish 420 kV system consists of about 70 substations, most of which are coming to the end of their life, so SvK now makes a complete renewal (retrofit) of about 3 substations per year.

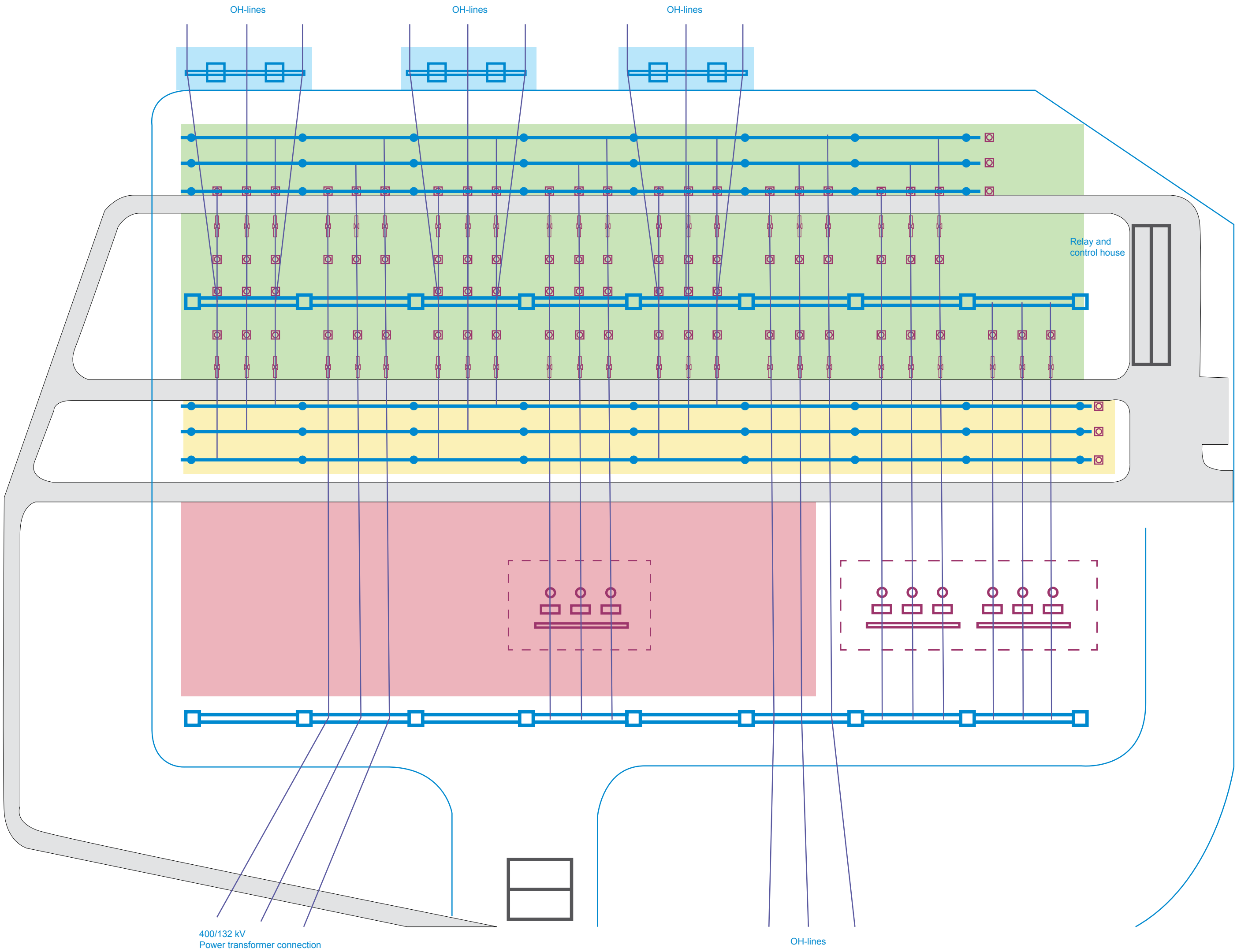
Basic principle for renewal of the substations is to make a complete exchange of all primary and secondary equipment. By doing a complete renewal, a number of technical and commercial advantages can be obtained such as:

- Future work will be minimized since all equipment has the same “vintage”.
- Single-line configuration can be adapted to developments of high-voltage apparatus and to possible changes in the importance of the substation to the network since it was originally built.
- Outage times can be kept to a minimum by using the existing equipment to keep the substation in service during the renewal.
- SvK personnel can concentrate on a few larger projects and the renewed substations will not need any “attention” for many years after the renewal.

Already by the end of the 1970s the open-air DSs were identified as apparatus that required high levels of maintenance compared to CB, so SvK started to reduce the number of DS in their substations, see Figure 8b. When DCB’s were introduced in 2000, SvK made the first installation in a 245 kV station to obtain operational experience of this concept. In 2001 the first 420 kV substation renewals using the DCB started and since then the DCB solution has been used exclusively for large and important substations in the 2-CB scheme in Figure 8c. For the smaller 245 kV substations, the single busbar scheme is also applied. SvK’s operating experience with DCB is good.

The footprint of the substation is reduced by almost 50 percent when going from the traditional CB / DS to the DCB solution. This reduction of the footprint can be advantages, not only for new substation, but also when making substation renewals, see Figure 11. During these renewal works the old apparatus (pink) together with old busbar (red) is kept in service, while the new equipment, including a second busbar are erected in the area labelled in green on opposite side of the old busbar. Thanks to the small footprint of the new primary equipment the three existing line towers marked in blue can be kept in the original position saving cost, outage time and reduce risks.

After installing and testing, the service is changed to the new equipment. The complete renewal of this substation was done with less than one week of outage.



Existing line towers can remain due to low space requirement of DCB.

New equipment located beside old substation equipment

Old main busbar reused and extended.

Location of old equipment.

Outage less than one week for whole renewal of S/S.

Figure 11

Example of renewal of a Swedish 420 kV transmission substation

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