INNOVATIVE COMPACT 145/12 KV INDOOR AIR INSULATED SUBSTATIONS (AIS)

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ABSTRACT

In many cities around the world there are often outdoor AIS substations, which do not have so nice aesthetic appearance. At the time when these sub-stations were built the location was in the outskirt of the cities, but with growing cities the substations "are suddenly surrounded" with residential buildings, offices, shopping centers, hotels etc. People living or working in this area do not like the visual appearance of the substation.

Today we have the technique to locate substations inside a house of similar outlook as the surrounding buildings, thus making Substations "invisible". The footprint is significantly reduced with the indoor solutions. For rehabilitation of old substations part of the land is then unused and can be sold of or used for other purposes.

By going from outdoor AIS to indoor AIS it will be much easier to get permits, third party safety will be guaranteed and the substations reliability will increase thanks to the protection from "external" factors, e.g. weather conditions, vandalism, animals, pollution etc., which will also give a higher availability. This is of outmost importance for the asset owner since power outages are not tolerated today with the societies high dependence on continuous electrical supply, "no black-outs please".

1. INTRODUCTION

Cities around the globe are steadily expanding and also need more and more electric power since today's society is depending on continuous electric energy supply. Existing substations mostly are outdoor air insulated substations (AIS), and at the time when these were built the location was in the outskirt of the city. Today the substations are surrounded with residential buildings, offices, shopping centers, hotels etc., and the people living or working in this area do not like the visual appearance of the substations. It could also be problem with acoustic pollution from humming transformers for substations located in "quiet" residential areas.

There have been some tragic accidents where children have entered outdoor AIS substations "for fun", climbed on high voltage apparatus, causing an arc and got severely injured or killed by electrical shock. This had lead to requirements from the authorities on utilities to take steps preventing such accidents, which can be achieved by locating the equipment indoors.

Today we have the technique to locate substations inside a house of similar outlook as surrounding buildings, thus making substations "invisible". Introduction of Disconnecting CBs (DCBs), which have both breaking and disconnecting function integrated in the same apparatus, enables a minimum footprint of the AIS and thus limit the size of the building. Switchgear reliability is increased by having all primary contacts encapsulated in a controlled environment and personnel safety is ensured by making all switching with enclosed contacts, i.e. no open contacts for any switching operation.

By locating all electrical equipment indoors, enclosed by a building similar to surrounding buildings, it will be much easier to get the permits from municipal architects, local residents etc. allowing the substations to remain on their original sites when refurbish and/or rebuilding. Keeping the substations at the same location is advantageous for electrical network topology since infeed points can remain as before. Changing of a substation location will lead to substantial additional costs for the utility as well as a much bigger and complicated project taking longer time and leading to higher risks.

Going from outdoor to indoor AIS will make the substations much more reliable since the risk of primary faults (flashovers) due to external factors such as weather conditions, vandalism, animals, e.g. squirrel, birds, etc., and atmospheric or industrial pollution will be very much decreased. The conclusion "15 out of 16 failures are prevented by going from outdoor to indoor substations" was made by a customer with experience of both solutions. The reduction of failures, and thus increased reliability and availability, is of outmost importance for the utilities since there are less tolerance for power outages today, "no black-outs please".

Having the substations inside a building will also give good protection against burglary, since intruder alarm can easily be installed in the building giving instantaneous alert in case of unauthorized entry. Having the substation indoor give higher personnel and third party protection (especially children playing). The time interval between substation rounding can be increased, since full supervision of the building can be achieved from remote whereas an outdoor substation need more supervision of people going to the site checking that everything is all right. Humming from power transformers is also effectively reduced by the building and nearby residents will be happy. The area around the substation up to the building itself can be opened for public access and there is no need for fences and other obstacles for the public. Taking away the fences is an important factor making the substations a "natural" part of the community and thus making them virtually "invisible".

2. 145/12 KV SUBSTATION DESCRIPTION

2.1 Substation building

Bäckelund substation building is made of pre-fabricated design using wall elements of concrete. Facade has been added with bricks and other details to be similar to surrounding buildings. This will make the substation to blend into the surrounding very well.

Fig. 1: Exterior of Bäckelund substation

With all 145 kV primary contacts encapsulated and whole switchgear placed indoor an arc is very unlikely to happen but cannot be outruled. 145 kV switchgear room is therefore equipped with hatches that will open in case of an arc. The pressure relief hatches can be seen above the doors in fig. 1. ABB has developed a special designed computer program, which is verified by actual arc testing, that is used to calculate the number and necessary sizes of the hatches to ensure building integrity in case of an open arc.

Inside the building, in separate rooms, are also the 145/11.5 kV power transformers, 12 kV switchgear and relay and control equipment placed. Split up of rooms is shown in fig. 2. If a power transformer for some reason should need to be removed from the building, the walls in front of power transformers can easily be removed by a fork lift as the walls are built up with “module elements”. The module elements can be seen to the left in fig.1.

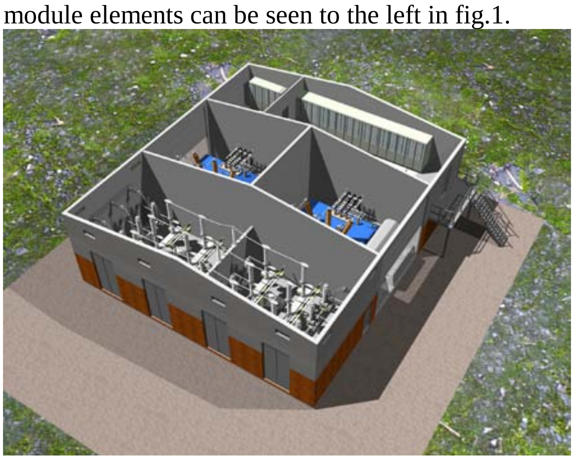

Fig. 2: Layout of Bäckelund substation

2.2 145 kV switchgear single line diagram

AIS indoor substations are suitable for smaller substations and especially H-type of single line diagram can be realised in a very cost effective way. H-type of single line diagram is very common for larger towns or smaller cities where the substation is part of a ring, with a voltage of about 145 kV, around the town. Usually there is one cable coming in from “previous” substation and another going out to the “next” substation in this ring. In the substation there are usually two power transformers feeding medium voltage (MV) switchgear, see fig. 3.

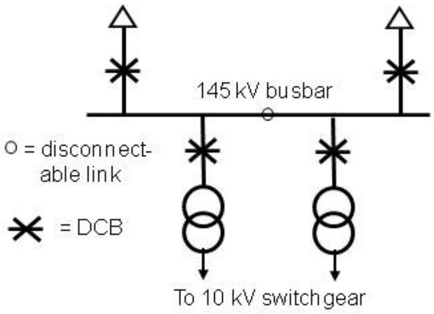

Fig. 3: Single line diagram Bäckelund substation.

2.3 145 kV Switchgear apparatuses

Over time development in Circuit Breaker (CB) technology has lead to significant decrease of maintenance and increase of reliability. Maintenance intervals, requiring de-energizing of the primary circuit, of modern SF6 CBs are 15 years or more. At the same time development of open air Disconnectors (DS) has focused around cost reductions by optimizing the material used, and has not given significant improvements in maintenance requirements and reliability. The maintenance interval for open-air DS main contacts is in the order of 2-6 years, differing between users and depending on the amount of pollution due to industrial activities and/or “natural” pollution such as sand, salt etc. In fig. 4 development for 400 kV equipment is shown and the same pattern is valid also for 145 kV apparatuses.

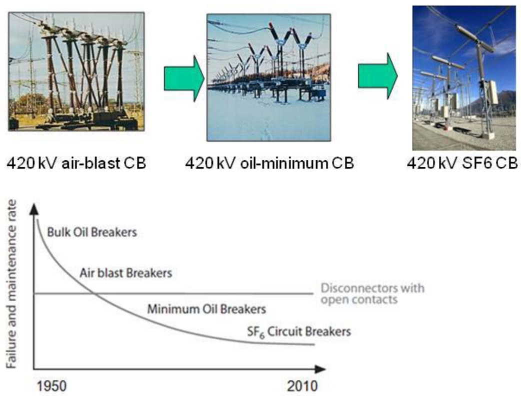

Fig. 4: Development of CBs and related maintenance and failure rates.

In the past the design principle when building substations was to “surround” CBs with DSs to make the frequent maintenance on CBs possible. Due to the large reduction of failure and maintenance rate on CBs, the disconnecting function today is more needed for maintenance of overhead lines, power transformers etc. The reduced maintenance on CBs together with customers’ reliability problems on open-air DSs led to the development of the Disconnecting CB (DCB) in close co-operation with manufacturers and users [1, 2, 3]. The DCB combines the switching and disconnecting functions into one device, reducing substation footprint and increasing availability [4]. First installation of DCBs was in the year 2000 and today DCBs are available from 72.5 kV to 550 kV voltage levels with more than 1000 three-phase units delivered.

Implementing DCB for 145 kV will mean a considerable reduction of footprint, which is illustrated in fig. 5.

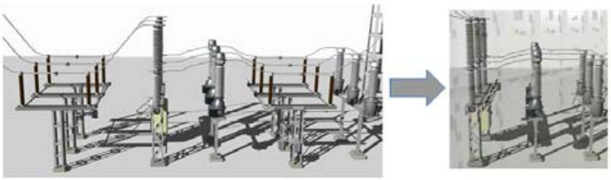

Fig. 5: Reduction of footprint by using DCB in 145 kV bay

The reduced footprint together with the fact that all primary contacts are enclosed, which means no open arc during switching makes the DCB solution ideal for use in indoor AIS solutions.

2.4 Disconnecting CB(DCB) design principle

DCB primary contact system is similar to that of a normal CB, and there are no extra contacts or linkage systems when DCB is used as a circuit breaker, see fig. 6. When DCB is to be used as a disconnector, for enabling work on other parts of the high voltage system, a separate operating device is energised, which mechanically lock the operating mechanism in open position. This will safeguard that the DCB will stay in open position during the work to be done.

Fig. 6: DCB design principle

Each electrical point of the switchgear is supplied with a motor operated earthing switch. Before any work start on the primary this is closed and the visible closed primary contact ensure that primary is de-energized and it is safe to start the work.

DCBs are always supplied with polymeric insulators of silicone rubber type to minimise possible creepage currents across interrupting chamber(s) when DCB performs the disconnecting function. This will also ensure that external insulation across breaking chamber is sufficient during the whole life length even if DCB is located in polluted areas.

DCBs have the following three positions:

- Closed (as normal circuit breaker).
- Open (as normal circuit breaker).
- Disconnected.

DCB is brought into disconnected position by energizing a separate operating device, see fig. 6. Primary contacts remain unchanged for this operation, which only makes a mechanical blocking of operating rod and electrical blocking of closing coil. For DCB in disconnected position adjacent parts of switchgear can be maintained after being earthed in the normal way. For the operation personnel putting the DCB into disconnected position corresponds to opening the disconnectors in traditional switchgear.

The integration of the disconnecting function into the CB will give significant reduction of maintenance for AIS substations and reduce the risk of failure since the CB contacts are encapsulated in SF6-gas and not affected by external pollution. It is therefore favourable especially from availability point of view to integrate the breaking and disconnecting functions into the same apparatus and thus eliminating the separate open-air DSs.

A DCB has to fulfil 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 is the Combined Function Tests. These tests are specified to verify that the disconnecting properties, i.e. dielectric withstand across open contact, of the DCB are fulfilled during its whole service life, despite contact wear and any decomposition by-product generated by arc interruption. This is ensured by making all the breaking and mechanical tests first and thereafter confirming the disconnecting dielectric properties.

2.5 145 kV DCB maintenance

Even though maintenance of 145 kV DCBs need to be done very seldom (15 years interval), the switchgear layout is prepared to enable this with minimum interruption of the service. The idea is to make the maintenance of half of the substation in sequence keeping the other half in continuous service. For this purpose the busbar is equipped with a disconnecting facility, see single line diagram fig. 3, and the following steps are done when maintenance is needed.

- Left side transformer and cable DCBs are opened. Right side cable and transformer bays are kept energized and maintain the feeding of 12 kV busbar.
- Special trained crew for live working open the discon-

nectable link in the middle of busbar, see fig. 7.

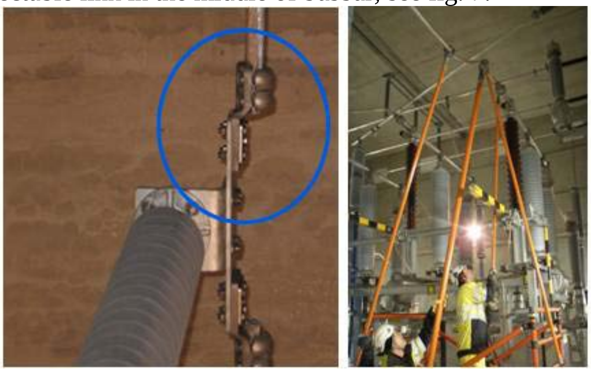

Fig. 7: Left: Detail of Disconnecting link; Right: Crew for live disconnection/reconnecting in action

- Left side DCBs that are to be maintained are earthed and maintenance can be done in de-energized state while right side of switchgear is energized and keeping the power on.
- When maintenance on left side is ready, earthing switches are opened and special trained crew for live working is reconnecting the disconnecting link and thereby energizing the left side busbar.
- Maintenance on right side of busbar DCBs can now be performed in the same way as described above, while left side cable and transformer bays maintain the feeding of 12 kV busbar.

Live disconnecting and reconnection for voltages up to 170 kV is quite easily implemented and is becoming the standard way of preparing for maintenance activities by Swedish utilities. It is used for both outdoor and indoor solutions as well as different types of switchgear single line configurations, ensuring maintenance with minimum disruption of nearby circuits.

2.6 CB + DS versus DCB availability

Availability analysis have been made comparing outages due to faults and maintenance for a traditional double busbar solution using CB + DS versus a DCB solution using a sectionalized single busbar configuration, see fig. 8.

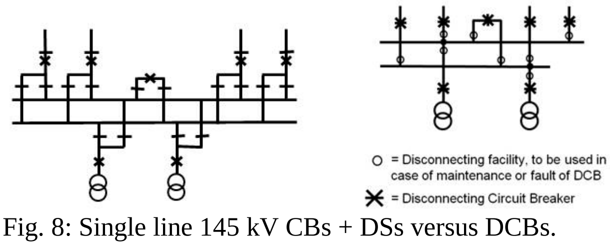

Fig. 8: Single line 145 kV CBs + DSs versus DCBs.

Outage duration due to maintenance and faults for an outgoing bay with single line configuration according to fig. 8, is shown in fig. 9. By using DCBs instead of traditional CBs+DSs, the average outage durations due to maintenance resp. faults are reduced with about 60% resp. 40%. This comparison is made for outdoor type of substations using failure statistic from CIGRE and with maintenance according to manufacturers' recommendations.

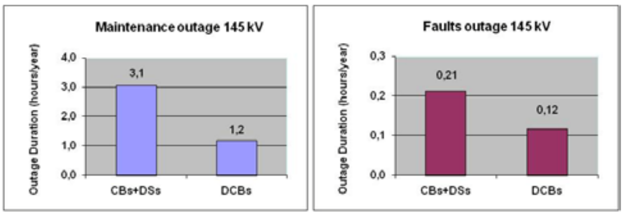

Fig. 9: Outage due to maintenance and faults for 145 kV traditional CBs and DSs versus solution with DCBs.

2.7 12 kV Switchgear

The 12 kV medium voltage switchgear is a traditional type of cubicle switchgear using withdrawable type of circuit breakers. There are about 30 outgoing bays for feeding of nearby parts of Borlänge city centre.

3. CONCLUSIONS

Indoor substations give the following advantages:
- More public acceptance due to nicer aesthetic and easier to get necessary permits for new or refurbished substations.
- Third party safety ensured by having the high voltage electrical equipment indoors. In case of break in an intruder alarm will give instantaneous alert.
- More reliable supply of energy since faults due to external reasons, animals, weather, vandalism etc. are prevented.

By using Disconnecting CBs for indoor AIS substations the following additional advantages are obtained:
- Minimum footprint and thus minimized environmental impact. The reduced footprint will also make renewals of existing substations easier.
- Highest reliability of the energy supply by having all primary contacts encapsulated leading to minimum risk of primary faults and maintenance reduced to a minimum.
- Highest personal safety for personnel, no open contacts for switching of high voltage switchgear.

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