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Latest development in transmission with 800 kVDC

A.Williamson	U. Åström	V. F. Lescale	D. Wu	B. Westman
ABB	ABB	ABB	ABB	ABB
South Africa	Sweden	Sweden	Sweden	Sweden

INTRODUCTION

The use of 800kVDC has been found attractive for transmitting high powers (up to 6400MW) over long distances (above 1000km), especially in India, China, South Africa and Brasil. Efforts have thus been devoted to develop the necessary technology, and they have been more intense in the last year or so. Regarding converter stations, the following aspects are presented succintly in this paper: converter configuration, insulation principles, equipment considerations and station layout.

CONVERTER CONFIGURATION

The rating of the foreseen transmissions, 6000~6400 MW, makes it necessary to have more than one converter group per pole. This will minimize the disturbances at faults and increase the reliability and availability of the transmission.

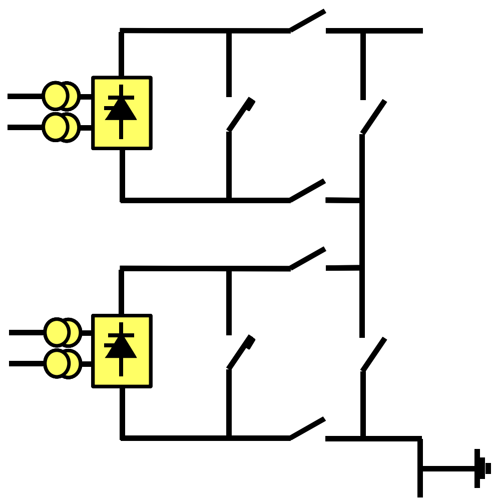

Fig 1 Converter arrangement with two 12-pulse groups in series per pole

Another reason for dividing into more groups is the transport restrictions (size and weight) of the converter transformers. A scheme with more than one series group per pole is not new, in fact it was used in the mercury arc valve projects from the mid 60's, where six-pulse groups were connected in series to achieve the desired voltage, and each group had a by-pass breaker, should the group need to be taken out.

The Itaipu ± 600 kV HVDC project is the only project with thyristor valves that has two 12-pulse groups per pole and the operation experience is excellent. The arrangement in the DC-yard will be almost the same as for the ± 500 kV projects but with all equipment rated for ± 800 kV. The only "new" equipment is the by-pass arrangement with disconnectors and high-speed breakers for each group, see Fig. 1

INSULATION COORDINATION

A. General

For 800kVDC stations, the basic ideas for insulation coordination are the same as those applied for lower voltages, but for 800kVDC it is economically beneficial to control the expected stresses to an even higher degree, and to keep insulation margins tight.

Controlling the overvoltages aims at improving the economy of a given system. Too loose control results in costly equipment, and too tight control results in costly arrester schemes and shielding. Regarding margins, a similar situation appears: too small margins result in costly equipment failures, too large margins result in costly equipment. There is a human factor in the latter aspect, though: Adding margins may save some engineering costs. For 800kVDC, the savings in engineering are far outweighed by the savings in equipment and more detailed studies and control are justified.

B. Case study

An insulation coordination study has been performed for the dc side of an 800kV HVDC transmission system. The data for the system has been assumed based on the best available estimates to the authors, with regard to preliminary design of the equipment expected for such an installation. Further, the study showed that splitting the smoothing reactor function in two equal inductances, one at the neutral, and one at the pole yields significant advantages: Balancing the inductance reduces the ripple appearing on the arresters in the upper 12-pulse group, making it possible to lower their protective level.

C. Protection scheme (controlling the stresses)

In addition to the use of modern, highly effective arresters permitting very good ratios between steady state voltage and protective levels, the protection scheme arrived at included more arresters than are usually applied at HVDC schemes of, e.g. 500kVDC. The arresters beyond the "usual" ones were located to directly protect:

- Valve side of converter transformers at the uppermost 6-pulse bridge
- 800kVDC bus outside the upper smoothing reactor protected with several arresters at specific locations on the bus
- Across the smoothing reactor on pole side
- 800kVDC bus on valve side of smoothing reactor
  (The cost to benefit ratio of this arrester proved to be sensitive to station design parameters, and its use will have to be decided on a case-by-case basis)

D. Insulation margins (Deriving withstand from stress)

At the resulting stresses for 800kVDC equipment it is extremely important to have economy-dictated margins. There is no room for additional margins based on subjective appreciations or for increasing calculated withstand levels to "the next higher standard level", since there is no interchangeability of equipment between different stations as is normal for ac equipment.

In some HVDC transmissions, for thyristor valves, by extension, the same insulation margins used for conventional equipment have been required. There are a couple of important points why the same margins need not be used. One point is the extremely well known voltage grading along the valve, transiently, dynamically, and also as a function of time after application of a dc field, and even as the years pass, whic is also different from conventional equipment.

Because of the above, the insulation margins for the thyristor valves need not cope with the same uncertainties as for, eg transformers. The margins advocated by the authors are thus:

Insulation margins			
Insulation type	Oil	Air	Valves[1]
Lightning	20%	20%	10%
Switching	15%	15%	10%
1 Across single valve			

E. Study results

From the studied transmission, the resulting stresses, or more accurately, the resulting protective levels, for the most important equipment are listed below.

Protective levels (kV)		
Location	**Switching**	**Lightning**
Converter transf. Valve side	1410	1442
Smoothing reactor. Across	NA	1800
Smoothing reactor. To earth	1382	1522
Thyristor valve. Across	405	386
Thyristor valve. Top to ground	1381	1412
DC bus. Line side	1382	1592

EQUIPMENT CONSIDERATIONS

A. General

The equipment affected by the increased voltage level is of course limited to apparatus connected to the pole bus, such as converter transformers, wall bushings, thyristor valves, DC-voltage divider etc. The main part of the equipment within the converter station is not exposed to DC, such as AC yard apparatus, control and protection and auxiliary systems.

The most significant difference between equipment for HVDC compared with equipment for HVAC is the need for proper DC grading for HVDC equipment.

When applicable, HVDC equipment is built up by modules where each module is provided with a proper resistive voltage grading resistor as well as an AC/transient grading capacitor. With a proper voltage grading, the voltage stress in the modules will be the same, regardless of if the module is part of an 800 kV apparatus or a 500 kV apparatus. This is applicable for thyristor valves, filter capacitors, voltage dividers etc. For oil/paper insulation systems the situation is more complicated, since it is not possible to arrange the DC grading with physical resistors, but the DC grading must be secured by other measures. For outdoor equipment exposed to pollution and rain/fog, the coordination between the internal and external voltage grading is an important issue.

At present, prototypes for all essential apparatus are manufactured, and will be subject for a long term test at at elevated DC voltage at STRI test laboratory in Ludvika.

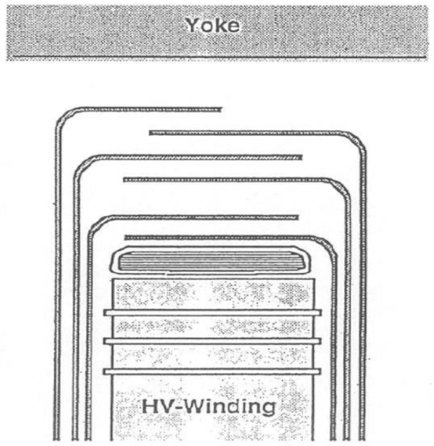

Fig. 2. Transformer main insulation

B. Converter transformers

As has been described above, for most equipment the DC grading is done by using real resistors. This is not the case for the insulation inside the converter trans-formers. The insulation system in the transformers is built up by a system of oil and paper, and thus the resistivity of these materials will determine the DC-grading. In the same way, the dielectric permittivity will give the transient voltage distribution.

In analogy with other equipment, the stressed volume in a converter transformer is split up in sub volumes by cellulose barriers, see Fig 2, and the stress in each point should be well within the acceptable criteria.

Since the resistivities of oil and paper vary with temperature and aging, the voltage distribution must be calculated for several different conditions. Also, the resistivity of the media is time dependent.

The electric conduction in oil is done by electrons as well as by ions. When a DC field is applied across an oil gap, the ions will be drained out after some time, and thus the resistivity will change. To be able to calculate the actual stresses and time constants during polarity reversal for example, a calculation model including the ion conduction must be used. Such a calculation tool has been developed by ABB and is used for converter transformer design [3].

EXTERNAL INSULATION

The research project on the external insulation for 800 kV was awarded to STRI in 1992 by ABB [4]. A large number of experiments were performed in STRI's laboratory with pollution test ability up to 1200 kV DC. It is clear from laboratory studies, [5-7], that a linear relationship holds in pollution tests between the required creepage distance and the applied voltage for the same type of insulator except for SDD levels lower than 0.03mg/cm^2. The result shows that relative large shed spacing is of importance for good rain and pollution performance.

The authors' group has performed reviews on the operational experience of the existing HVDC stations worldwide. Some of the outcomes of these studies were published successively, e.g. [8-10]. The operational experience from existing HVDC stations, from 250 to 600 kV, has shown that the flashover rate of these stations has no direct correlations to the voltage levels of the stations. It has also been shown that there is no tendency and need to choose a higher value for the specific creepage distance because of higher voltage level. With suitable design and maintenance, a very low flashover rate of 0.05 flashovers per pole per year has been achieved in a total of 80 poles (47 stations) around the world supplied by ABB. The use of hydrophobic coatings and booster sheds has been proved to be very effective in improving the dielectric strength of the insulators. The well known uneven wetting flashover phenomena on, mostly, wall bushings has been prevented with insulators with hydrophobic surface. Good operational experiences with silicone rubber insulators in DC lines and stations, even with shorter creepage distance than that of porcelain, have also been reported [11][12].

The most important factor for insulator selection is the site conditions. One should be aware that insulators under DC voltage might collect more pollution than insulators under AC voltage at the same site [13]. In order to make long-term measurement on site, the authors group can provide a portable test station that measures pollution, leakage current on insulators under DC voltage [14].

Instead of using extremely long ceramic insulators for UHVDC in heavily polluted areas, there are many alternative solutions that can lead to an optimized design. The use of insulators with good ability to retain a hydrophobic surface is a good solution. These include composite insulators, ceramic insulators with hydrophobic coatings, as well as hybrid insulators. Today, composite insulators of various types can be used on all insulators in DC yard including station post insulators. Other alternatives such as indoor DC yard can and have also been successfully built and operated.

STATION LAYOUT

There are many different ways to arrange the converter area. One attractive alternative is presented in Fig. 3. The different 12-pulse groups are completely separated, to minimize the interaction between the groups and thus maximize the reliability.

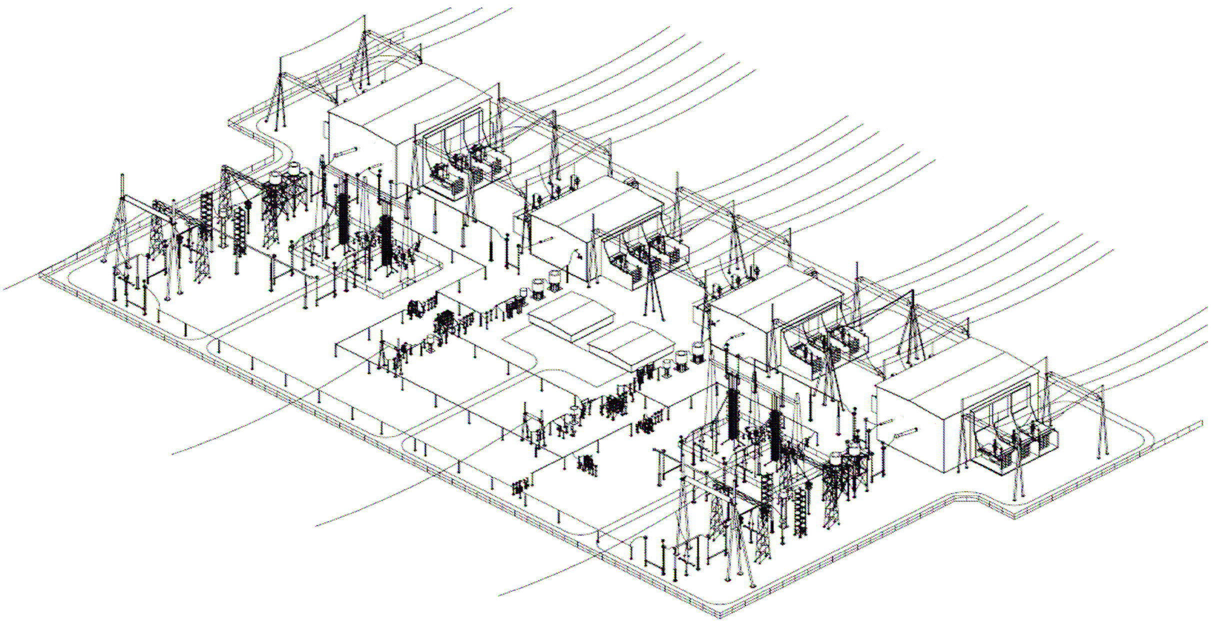

Figure 3. Layout for converter area

The use of quadruple valves gives a very compact valve hall design with a significantly higher space utilization factor compared with a double valve design. As mentioned above, two winding, single phase converter transformers are foreseen. All 800kVDC station and apparatus insulators are composite insulators, giving an insulator length of about 10 m, that will be sufficient even in polluted areas

CONCLUSIONS

800 kV HVDC is economically attractive for bulk power transmission, 6000 MW, over long distances, 2000-2500 km. With the present experience of HVDC as a sound base, it is possible to design an HVDC system for 800 kV with reasonable efforts in R&D by using building blocks that have been used for lower voltages. With proper separation and proper structure of the control and protection and auxiliary systems, the reliability and availability will be as good as, or even better than, for converters at lower voltage.

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