Paper submitted to 14th ISH as Keynote Lecture, Beijing, China, August 25-28, 2005

Advantage of HVDC transmission at 800 kV

Gunnar Asplund, Urban Åström, and Dong Wu
ABB Power Technologies, SE-771 80 Ludvika, Sweden;
*E-mail: gunnar.asplund@se.abb.com

Abstract: The use of Ultra High Voltage Direct Current (UHVDC), i.e. voltages above the highest in use, 600 kV, has been found to be economically attractive for power blocks up to 6000 MW for distances above 1000 km, Furthermore the use of 800 kV as transmission voltage will be achievable within the near future with a limited amount of development work. None of the AC equipment, auxiliary equipment or control and protection will be affected by the increase of DC voltage. Also most of the DC equipment is easily modified for 800 kV, such as thyristor valves and DC filter capacitors. Station external insulation and line insulation must be carefully considered. In order to meet the demands, ABB has started an R&D program with the goal to develop and test equipment needed for 800 kV HVDC.

Key Words: 800 kV HVDC, Bulk power transmission, Converter stations, Insulation coordination, External insulation.

INTRODUCTION

Worldwide there is an increasing interest in the application of HVDC at voltage levels above what is presently used. The main reason is that most of the hydro power resources that are within convenient distance to the consumer centers have been exploited by now, and in order to meet the increasing demand for clean, renewable energy, remote hydro generation plants are built. This asks for efficient means for long distance, bulk power transmission, a typical scenario is 6000 MW to be transmitted 2000-3000 km. Also in countries like China and India with vast coal resources, a certain quota of hydro power is needed for stabilizing purposes.

In China large hydropower resources are available in the Western part of the country and the power will be transmitted to the industrialized regions in the Eastern and Southern areas of China

In India transfer of the hydropower generated at the Bramaputra River Basin in the North-Eastern part of India will have to be transmitted to the southern part of the country where the power is needed.

In Africa there is a great potential for power production at the basin of the Congo River near the location of Inga. Parts of the power is planned to be transmitted to South Africa.

In Brazil vast hydropower resources are located in the Amazon region, while the power consumer centers are located along the eastern coast.

In several investigations that have been carried out in the past, the common conclusion has been that for these big amounts of power and long distances the use of 800 kV HVDC is the most economical solution. [1], [2].

The realization of an 800 kV HVDC system is of course a matter of insulation. Most of the equipment will not be affected, see figure 1, and equipment for lower voltages is often built up by modules with resistive and capacitive voltage grading that can be extrapolated to higher voltages by adding more modules.

In order to meet the requirements from the market, ABB is at present working with development of equipment for 800 kV HVDC.

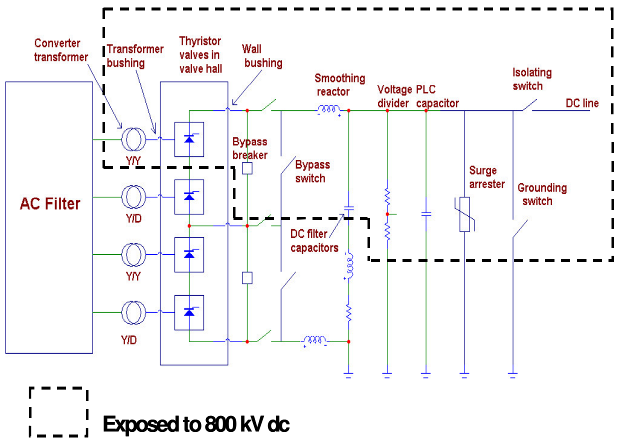

Figure 1. Simplified single line diagram for one pole

ECONOMY

The total cost for a HVDC transmission system is composed of the investment in converter stations and line and the capitalized value of the losses. For a given power the cost for the stations increases with the voltage, while the line has a minimum combined cost at a certain voltage.

A comparison of the total cost for transmitting 6400 MW over 1800 km at 800 kV AC, 800 kV DC and 600 kV DC has been done. 1400 USD/kW has been applied when calculating the value of the losses. The result is that the

800 kV DC is the most cost effective alternative depending on a higher line capacity and lower line losses. The total cost for the 800 kV alternative is 25 % lower than for 600 kV, see Fig. 2.

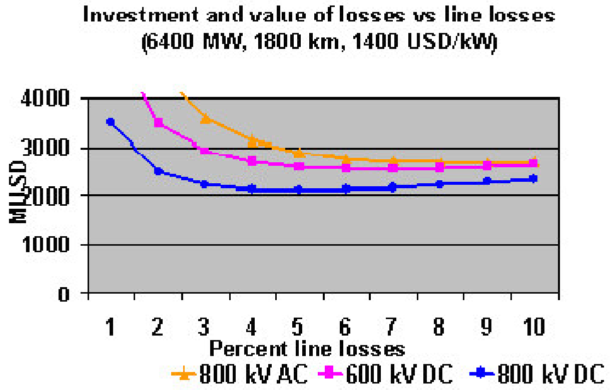

Figure 2. Cost comparison 800 kV AC, 600 kV HVDC and 800 kV HVDC

AVAILABILITY AND RELIABILITY

Due to the large power associated with power transmission at 800 kV HVDC, the society will have exceptional requirements on reliability of the complete system. That means that the reliability of the transmission is a very important issue and has to be a major design parameter.

Line Faults

The frequency of line faults is dependent on the length of the line. Bipolar faults can occur e.g. at tower failures or due to icing at extreme weather conditions, but are rare. The majority of the pole line faults are cleared easily within some periods by retarding and restart. During the retard time the healthy pole compensates the power loss on the failing pole. At rare occasions the line will stay tripped for longer periods, and will recover within a couple of hours. The time needed for dead line maintenance will be added to the line unavailability.

For some DC systems special arrangements have been done to increase the power availability. In the Inga-Shaba HVDC project, the two converters in the bipole can be paralleled and the power can be transmitted on one pole line, however at higher losses. Switching stations along the line allows for simultaneous line faults on different segments along the line. For the Itaipú HVDC project, with two bipoles in parallel, the two converters can be connected in parallel to one bipole, in order to minimize the loss of power at bipole line outage.

Converter Stations

The structure of the present control and protection system, cable routing and auxiliary systems should be revised, reflecting the different requirements on reliability and availability and also the new configuration. It is envisaged that the two poles will be totally independent and that the groups in each pole will have a minimum of interactions. Ideally, the bipole should be built as two separate monopoles. This should also be applied for the AC-yard configuration, with possibility to entirely disconnect the areas that are needed for each separate pole.

Each twelve pulse group will have a separate valve hall with six double valves and six single phase two winding transformers penetrating into the hall, i.e. the same arrangement as for the recent ± 500 kV, 3000 MW projects.

CONVERTER CONFIGURATION

The rating of the transmission, 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. Another reason for dividing into more groups is the transport restrictions (size and weight) of the converter transformers. A scheme with more than one 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. Each group had a by-pass breaker, should one mercury arc valve be out of order. The Itaipu ± 600 kV HVDC project is the only project with thyristor valves that has two groups per pole and the operation experience is excellent.

The arrangement on 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. 3

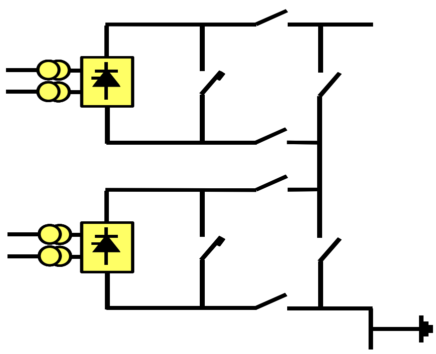

Figure 3. Converter arrangement with two 12-pulse groups in series per pole

INSULATION COORDINATION

General

For 800kVDC stations, the basic ideas for insulation coordination are the same as those applied for lower voltages; i.e. to have equipment with withstand characteristics above the expected stresses. Then, as is normal in medium or high voltage, the expected stresses are controlled by a combination of arresters and shielding. The difference for 800kVDC is that it is economically beneficial to control the expected stresses to an even higher degree, and to revise the steps leading from the expected stresses to the desirable insulation withstand; i.e. the insulation margins.

One has to remember that both aspects aim 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, mainly due to the high non-linearity in the relationship between withstand and necessary clearances, the savings in engineering are far outweighed by the savings in equipment by a judicious choice and application of margins.

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 colleagues, with regard to preliminary design of the equipment expected for such an installation. Further, as the study progresses, it became apparent that one fine adjustments to the configuration would yield significant benefits: Splitting the smoothing reactor function in two equal inductances, one at the neutral, and one at the pole.

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 reason is that even relatively small gains in stresses result in significant savings in equipment. 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
- 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.

Another important aspect comes from the mentioned splitting of the smoothing reactor. By balancing the inductance it is possible to reduce the ripple appearing on the arresters in the upper 12-pulse group, making it possible to lower their protective level.

The third aspect is that controlling the incoming lightning surges is also profitable. Apart from the normal shielding at the station, it is important to optimize the line design for the towers nearest the converter stations.

Still another aspect is the locations of arresters close enough to the protected equipment, so that distance effects will be negligible. The combination of this principle with the natural distances between different pieces of equipment in an 800kVDC station leads to more arresters, even at the same bus, and for the same protective levels.

Insulation Margins (Deriving Withstand from Stress)

At the resulting stresses for 800kVDC equipment it is extremely important to have safety and economy dictated margins. There is no room for additional margins based on subjective appreciations.

Perhaps even more important: there is no rationale 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.

At lower voltages, where high engineering and testing costs cannot be justified, a simplification is often applied by forcing a ratio between the insulation withstands to switching and lightning surges. At the levels necessary for equipment at 800kVDC, the voltage stresses for all kinds of phenomena and transients are carefully calculated. So are the internal stresses for equipment designed to withstand them, and so are the tests that verify them. At UHVDC, the equipment should be designed to withstand the actual stresses. Then, depending on the materials, and the internal configuration of parts of different resistivities and dielectric permitivities, the ratio between withstand capabilities may or may not be close to the traditional factors. Therefore such relationship factors have no reason to exist in 800kVDC insulation coordination. They increase the cost of equipment; yet only give a false sense of security.

Another reasoning taken slightly out of context leads to insulation margin levels that are not quite justified. Specifically, for thyristor valves, by extension, the same insulation margins used for conventional equipment have been required in some HVDC transmissions. There are a couple of important points why the same margins need not be used in the thyristors, and not in the grading circuits. One point is the extremely well controlled voltage grading along the valve, transiently, dynamically, and even as a function of time after application of a dc field, and even as the years pass. Also the ambient conditions are well controlled. This 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, e.g. outdoor equipment.

The insulation margins advocated by the authors are in table 1:

Table 1 Insulation Margins

Insulation type	Oil	Air	Valves[1]
Lightning	20%	20%	10%
Switching	15%	15%	10%

[1] Across single valve

Study Results

From the studied transmission the stresses resulting, or more accurately, the resulting protective levels, for the most important equipment are listed below in table 2:

Table 2 Protective levels (kV)

Location	Switching	Lightning
Converter transformer Valve side	1320	1453
Smoothing reactor. Across	NA	1800
Smoothing reactor. To earth	1345	1625
Thyristor valve. Across	406	386
Thyristor valve. Top to ground	1320	1500

With the results found, as given above, and the margins advocated, the following test voltage levels are proposed for the main components, in table 3:

EXTERNAL INSULATION

General

The study of external insulation is considered as one key topic for the research program related to 800 kV HVDC [3], for the transmission line as well as for the converter equipment. The research project on the external insulation for 800 kV was awarded to STRI in 1992 by ABB. A large numbers of experiments were performed in STRI's laboratory with pollution test ability up to 1200 kV DC. Some of the outcomes of these studies were published successively since 1993 on various international conferences [4]-[8]. As a result of the combined efforts on evaluating existing converter stations, performing laboratory tests and technical achievements on equipment, design rules for HVDC insulators has been established up to 800 kV.

Operational Experience

ABB has performed a review on the operational experience of the existing HVDC stations worldwide. [9][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 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, a very low flashover rate of 0.05 per pole per year has been achieved in total 80 poles (47 stations) around the world supplied by ABB. Good operational experiences with silicone rubber insulators, even with shorter creepage distance than that of porcelain, have also been obtained.

Site Conditions

The most important factor for the design of external insulation is the actual site conditions, as well as what is expected for the future since the specific creepage distance will mainly be decided by the site pollution severity. Also factors such as site altitude must be known

Table 3 Test levels (kV)

Equipment	**SI**	**LI**	**AC_{rms}**	**DC**	**DC** Polarity reversal
Transformer valve side	1518	1744	900	1250	970
Transformer bushing Valve side	1518	1744	900	1250	970
Multiple thyristor valve, top to ground	1518	1800	NA	1040 (3 hs)	NA
Wall bushing	1518	1800	1000 (one minute)	1235	1030
Smoothing reactor:					
Across	NA	2160/n	NA	NA	NA
To earth	1546	1950	NA	NA	NA

to allow for proper atmospheric corrections. It is therefore very important to map the pollution at a future HVDC site. In order to make this possible, ABB can provide a portable test station that measures airborne pollution, collects weather data like wind, rain, humidity and temperature. Also high DC voltage (100 kV) is generated to energize insulators to be set up at the test station, to measure the pollution gathered by the energized insulators. Also the leakage current is continuously measured for each individual insulator. In a joint research activity between BDCC of SGC, EPRI and ABB, this portable test station has been utilized in site pollution measurements for Three Gorges-Shanghai projects. The measurements performed on Huangdo and Guojiagang sites will be presented in a separate publication [11].

Laboratory Tests

Laboratory tests with pollution and with uneven rain have been performed on different type of insulators. Insulators of different shed profiles have also been compared in laboratory tests. It is also clear from laboratory studies that for a SDD level equal to or higher then 0.05mg/cm^2, a linear relationship holds between the required creepage distance and the applied voltage for the same type of insulator. This fact simplifies the dimensioning of the insulation, when the pollution level is known. The effects of various palliative methods, such as hydrophobic coatings and booster sheds have not only been reviewed in the operational experience but also verified in the laboratory tests.

Other Considerations

The most effective way to reduce the risk for flashovers in the converter station is of course to reduce the number of insulators. The state of the art is to have the converter transformer bushings protruding into the valve hall, thus reducing the number of wall bushing. Also the old type of direct current transducers has been replaced with optical current transducers in modern converter stations. When possible, composite silicone rubber insulators, with superior surface properties, are used. The ultimate solution of the external insulation complex is of course to build an indoor DC yard, as has been done at Zhengping converter station. This should be considered at sites with high pollution.

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 realize 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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