

Design Aspects of UHVDC Equipment

M. Haeusler, H. Koelsch, V. Ramaswami

Siemens AG, Power Transmission and Distribution, 91056 Erlangen, Germany

Summary: Bulk Power HVDC transmission schemes over distances of up to 2000 km are currently under planning for various large hydropower stations in China. Ultra high dc voltage (UHVDC) in the range of up to 800 kV is the preferred dc voltage level for these applications. Currently world-wide existing HVDC schemes are limited to maximum voltage levels of 500 kV to 600 kV. Therefore the impact of increased steady state and transient voltage stresses on the design of the main equipment for UHVDC stations has to be carefully investigated. Adequacy of existing technologies has to be evaluated taking manufacturing capabilities into account. This paper focuses on specific design aspects for key UHVDC equipment to be taken into consideration.

Key Words: UHVDC, Main Equipment

1. Introduction

HVDC systems have been successfully integrated in transmission networks for many decades. The increasing demand for electric power especially in large countries as China will force this technology to play an even more important role in the future. Bulk power HVDC transmission systems provide technical and economical benefits. Significantly reduced losses compared to ac applications are possible. However, if the dc currents should be limited to moderate values the operating dc voltages have to be further increased. Currently HVDC systems world-wide are limited to operating voltages of 500 to 600 kV. In order to enable bipolar power ratings of up to 6000 MW, the operating dc voltage levels have to be increased to a range of 750 kV to 800 kV.

In this paper focus is drawn on design challenges for converter station main equipment to be connected to this voltage level. If series connection of 12-pulse-groups per pole is an issue some equipment will be connected to an intermediate DC voltage level which however will not be higher than DC voltages of existing schemes. Therefore, reference to such is excluded from this report.

Some main equipment does not require detailed investigations since existing technology basically enables to extrapolate from lower voltage applications. An example for this type of equipment is the thyristor valves which are based on a modular design. Additional thyristor levels to be connected in series are well feasible and do not require any conceptual changes. However, for other equipment it has to be verified how far existing technology and know-how is adequate for design and manufacturing process. This includes the following equipment which will be discussed in more detail in this paper:

- converter transformers including bushings
- dc wall bushings
- dc smoothing reactors
- dc-bypass switches and dc disconnectors

Additional conditions may be important for the design of UHVDC equipment and must be taken into consideration.

The converter stations may be located in areas

- with considerable degree of pollution
- at altitudes of more than 1000 m above sea level
- where transport limitations exist for heavy equipment.

It is quite evident that basic design requirements are not new for UHVDC equipment. They remain just as they had to be considered for the equipment of existing DC voltage levels as follows:

- proper internal design of the equipment
- safe external insulation of the equipment housings
- enough margin with respect to mechanical stresses, including seismic forces
- meeting the dimensions and weights for the transportation of the equipment.

However, in order to fulfill such requirements for the planned ultra-high voltage levels further research and development may be necessary.

It is worthwhile to mention that the above requirements cannot be regarded as independent of each other. Examples for existing interrelations are:

- The design of leads and barrier systems of the valve side bushings of converter transformers will have a decisive influence on the transport dimensions of the transformers.
- In terms of voltage grading the external insulation of equipment housings must be carefully coordinated with the internal insulation of the equipment in order to avoid excessive radial voltage stresses.

- Mechanical requirements e. g. for disconnect switches allow only porcelain type of insulators which results in adverse effects on the performance of external insulation.

It is well understood that mechanical requirements do not only include operational forces but also seismic conditions and wind loads anticipated for the areas where the converter stations will be located. By nature UHVDC equipment, suspension structures etc. are expected to be much higher than equipment for existing voltage levels. Hence, not only electrical properties but also careful consideration of mechanical stresses is required for a proper equipment design.

From experience it can be said that for higher voltages the external insulation becomes more and more a crucial issue. Therefore some basic considerations are given to it in the following, prior to starting with specifics of the equipment in section 3.

2. External Insulation of the Equipment

Designing equipment for correct external insulation means to take care of proper

- flash distances and
- creepage distances

of the equipment housings.

Flash distances

Required flash distances determine the axial length of the equipment. Flash distances can be calculated fairly well based on the specified insulation levels for the equipment. For UHVDC equipment the switching impulse level will become the dimensioning factor. DC voltages are not decisive with respect to the flash distance. Corrections will be included for equipment to be installed at higher altitudes above sea level. Flash distances increase more than linearly with increasing switching impulse voltages. Finally the correct design will be verified by corresponding type tests of the equipment.

Creepage distances

As far as equipment will be installed outdoors the external insulation with respect to creepage distances is more complex compared to the flash distance as it severely depends on environmental and weather conditions, i. e. on the degree of pollution collected on the equipment and wetting conditions (rain, fog etc.) of the polluted housing surfaces. It must be accepted that pollution combined with wetting as it occurs under service conditions can hardly be determined for the purpose of test conditions. Artificial pollution tests as per the standards can only show the capability of a housing to cope electrically with a certain degree of completely wetted pollution.

Another important role concerning the pollution flashover performance of housings plays the shed profile of the insulators. From experience two types of shed forms should be taken into consideration for DC application which are the deep under-rib and the alternate shed profile. A decisive property of a shed profile is the ability to prevent wetting of the pollution, i. e. to maintain the effectiveness of the creepage distance on the surface as much as possible. Publications show that there is no straightforward advantage for one of the shed types. A well designed alternating shed profile can perform as good as a deep under-rib profile. The decisive understanding seems to be that an improvement in pollution performance cannot be achieved by only increasing the creepage distance without increasing the axial length of the housing. In other words: increasing the creepage distance by increasing only the overhang of the sheds and/or reducing the shed spacing is not effective. Hence, increasing the creepage distance must go coincidentally with increasing the axial length of the housing.

This shows that general rules to select the appropriate equipment housing in order to prevent external flashovers resulting from pollution and wetting conditions cannot be established. Site conditions, if available, with respect to amount of pollution collected on the housing and the ability of natural cleaning should be taken into consideration, as well.

Such reflections are mainly applicable for porcelain type equipment housings. Alternative solutions are known and have to be looked at.

From long-term experience also with 500 kV DC outdoor equipment one alternative solution are housings with hydrophobic type of surfaces. The hydrophobic properties need not to be explained in detail here. Hydrophobicity is an intrinsic property of silicone rubber and is not achieved by additives or surface treatment. Elements of the silicone rubber which cause hydrophobicity diffuse into contamination layers on the surface of the housing and thus are transferring this property to the contamination. A further advantage is that hydrophobic material prevents the formation of larger coherent wet zones on the surface under rain and humidity. This is an important precondition in order to maintain the effectiveness of the creepage distance against pollution flashovers. Silicone rubber housings having such advantages are available and successfully in service in DC stations since a very long time. From

experience with existing projects the specific creepage distance of composite insulators can even be reduced by up to 25% compared to that of porcelain insulators.

However, as already mentioned before for some equipment porcelain type insulators are still required because of mechanical reasons. This refers to the support insulators in the DC yard and for air-insulated smoothing reactors and to the insulators of disconnect switches. Without taking remedy measures for such UHVDC equipment pollution flashovers cannot be excluded. Alternatives for improvement need to be found. They are still subject to final investigation and must be pushed thoroughly.

One possibility could be to coat the porcelain housings with hydrophobic material. This technology has been improved quite a lot in recent years. Yet, details need still to be verified especially the long-term behavior of the coating material.

Another alternative for post insulators is under investigation in a very early stage. The idea is to use porcelain as core material providing sufficient mechanical strength and to equip this core with silicone rubber sheds, as it is done with composite housings (silicone rubber sheds on epoxy resin tube, mechanically reinforced with fiber glass).

For completeness sake it should be mentioned that the method of booster sheds is also a well known possibility to improve the performance of porcelain insulators under DC stresses considerably.

As far as converter valves and associated equipment are concerned the design of creepage distance is not a problem as such equipment will be installed indoors in the converter valve hall like in the existing projects. The valve hall provides a controlled environment. For UHVDC equipment inside the valve hall the same specific creepage distance can be selected as for the existing 500 kV DC equipment.

Consistent to this it seems reasonable to consider the installation of UHVDC yard equipment also indoors in a so-called DC hall. If this alternative will be traced the DC hall has to be designed very thoroughly with the objective of achieving defined low pollution and humidity conditions inside the hall, conditions which do not depend on the outside environment. For indoor installation the specific creepage distance can be reduced to some extent compared to outdoor installation.

Relative to existing equipment it can be stated that specific creepage distances neither for outdoor nor for indoor installation need not to be increased for UHVDC equipment in order to ensure safe performance against pollution flashovers. Furthermore, higher altitudes above sea level are no issue for the creepage distance. If the flash distance of the equipment is properly corrected with respect to the altitude above sea level influences of the altitude on the creepage distance, should any exist, will be covered.

3. Main Equipment Design

3.1 Converter Transformer and Transformer Bushing

Converter transformers are one of the very important components for UHVDC application. It is quite understood that the existing technology and know-how of converter transformers can well manage higher DC voltages. Yet, there are critical areas which need careful consideration and further development in order to keep the electrical stresses at a safe level. Above all the windings and the transformer internal part of bushings on the valve side of the converter transformers with the barrier systems and cleats and leads need very careful attention. The design of transformer bushings in principle is identical to the wall bushing design mentioned in the next section.

A typical single phase two winding converter transformer is shown in Fig. 1 as used for 500kV applications.

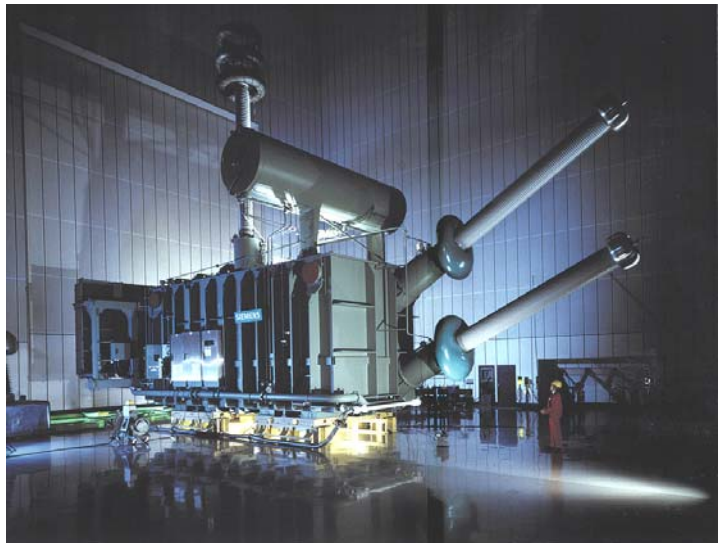


Fig. 1: Single-Phase Two Winding Converter Transformer (500 kV dc)

Increased insulation levels in combination with larger rated power may lead to new solutions for the transformer design. A possible approach may be splitting up of the secondary windings and a new design of the connections

between windings and bushings on the valve side as indicated in Fig. 2. This part of the transformer will be crucial for its transportation data.

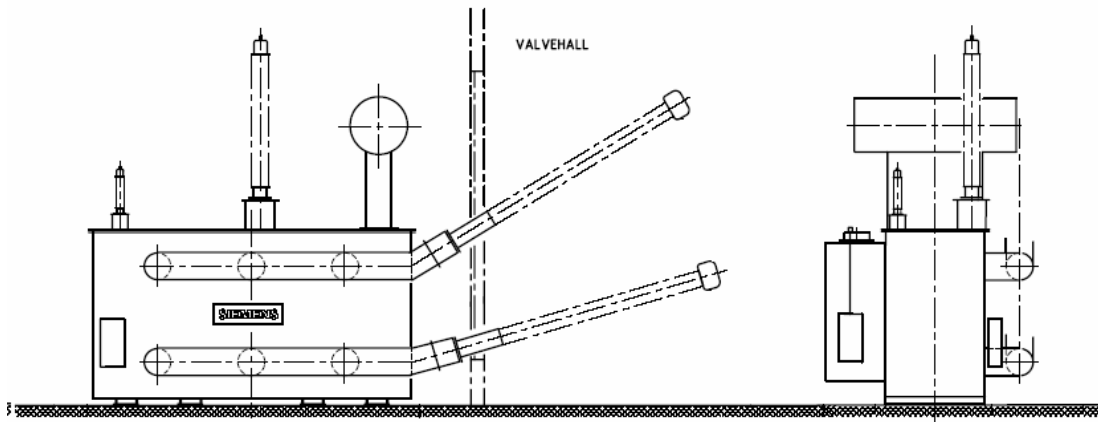


Fig. 2: Preliminary Outline Drawing UHVDC Converter Transformer

As an example transformer rating and preliminary shipping data for a system rating of 5000 MW with 800 kV DC are as follows:

	one 12p-group per pole	two 12p-groups per pole
rating (MVA)	506	253
length / width / height (m)	13.3 / 4.3 / 5.0	9.4 / 4.0 / 4.9
weight (t)	480	300

These data refer to the unit of the highest DC voltage level at the sending end; all other units of the system will not exceed such dimensions and weights. With respect to typical limits which might exist in case of railway transportation it is quite evident that improvement is required especially as far as the transformer width is concerned. If railway transportation is the only possibility, then in case of one 12-pulse group per pole arrangement additional investigations have to be done to achieve adequate transport conditions.

3.2 DC Wall Bushing

Doubtless, the existing technology of wall bushings provides the best solution for UHVDC application. Existing technology means composite housing with silicone rubber sheds for external insulation and internally with condenser core of oil-free resin impregnated paper and SF6 for insulation between core and inner surface of the housing. Both parts of the wall bushing, indoors and outdoors, are of the same design and are connected by means of a SF6 filled duct. This type of wall bushing is successfully in operation since more than 15 years under various pollution conditions.

Fig. 3 shows an outline drawing of a wall bushing as suitable for UHVDC applications. Most important for this bushing technology is the appropriate coordination between internal and external insulation. The manufacturing capabilities in terms of length of housings and length of condenser cores play an important part in this context. Another area of concern with wall bushings is the mechanical stresses which needs thorough investigations.

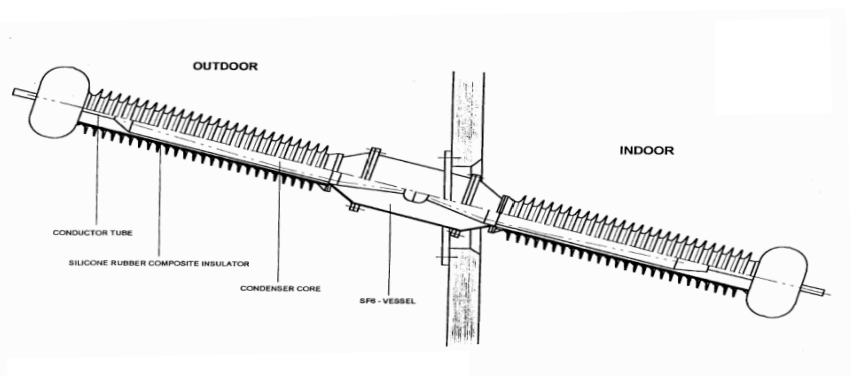


Fig. 3: UHVDC Wall Bushing

3.3 Smoothing Reactor

Both, air- and oil-type smoothing reactors, have to be considered. Know-how and experience for both technologies are available.

Oil-type Smoothing Reactor

Oil-type smoothing reactors face similar challenges as converter transformers. Two different arrangements are shown in Fig. 4 and 5 for indoor/indoor and indoor/outdoor arrangements. For the outdoor part of this smoothing reactor bushing similar requirements as for the wall bushings regarding pollution conditions exist. Preliminary shipping data for a 300 mH, 800 kV smoothing reactor can be given as:

length / width / height (m)	5.5 / 4.0 / 4.8
weight (t)	150.

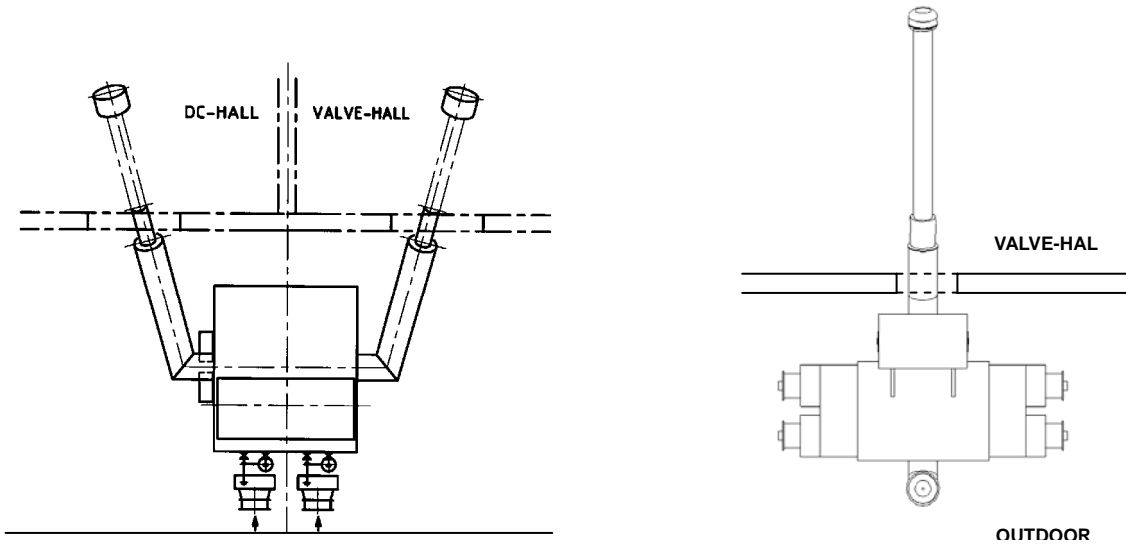


Fig. 4: Oil-type Smoothing Reactor (Indoor/Indoor) Fig. 5: Oil-type Smoothing Reactor (Indoor/Outdoor)

Air-type Smoothing Reactor

The operating dc current determines the largest smoothing reactor coil size which can be manufactured. As an example for a dc current of 3.3 kA a maximum coil size of approx. 100 mH is feasible. Fig. 6 shows the preliminary drawing of such an air-type smoothing reactor suitable for UHVDC application. The available technology and know-how for the coils of existing HVDC schemes can be fully used for UHVDC application.

Assuming typical total smoothing reactor sizes of 250 to 350 mH a series connection of several coils might be needed as illustrated in Fig. 7. For economical reasons parts of the coils might also be installed at the neutral bus.

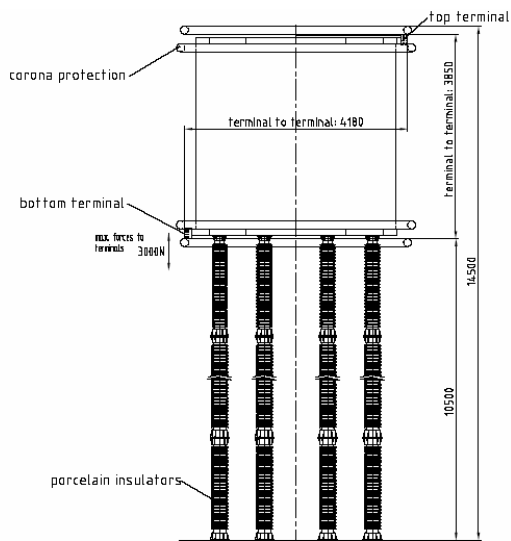


Fig. 6: UHVDC Dry-type Smoothing Reactor Coil

Fig. 7: Example for Series Connection of Dry-Type Smoothing Reactor Coils

Porcelain support insulators are the main issue to be solved for air-type smoothing reactors.

3.4 DC Switchgear

Disconnect Switch

Disconnect switches need to be designed based on porcelain insulators specifically because of mechanical stresses resulting from operation. Such stresses are even increased if grounding switches are directly attached to the disconnect switch. Fig. 8 shows the preliminary drawing of an UHVDC double break disconnect switch.

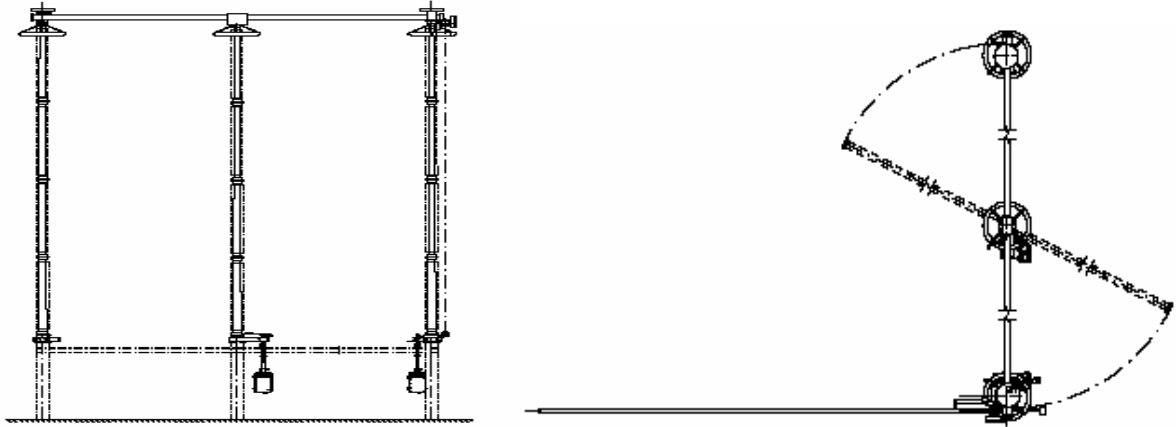


Fig. 8: UHVDC Double Break Bypass Switch

Bypass Switch

If a transmission system consists of two 12-pulse groups per pole breakers and disconnect switches are needed for each 12-pulse group. In case of failures related to a 12-pulse group and its associated equipment this group can be by-passed with the other 12-pulse group of the pole still in operation. Regarding the disconnect switches needed for the by-pass operation the section above is relevant.

The breaker to be used as bypass switch will be a proven standard AC breaker adapted for the DC application. Of course, the housings of current interrupting chambers and support insulators of this breaker are of the porcelain type. It should be kept in mind that for the voltage-wise higher 12-pulse group the voltage between terminals is the group voltage whereas the voltage to ground is the UHVDC bus voltage.

The steady state DC voltage capability between the terminals of the bypass switch, i. e. the DC voltage capability of the interrupting units is another very important subject which needs further investigation. This is part of the modification for DC application mentioned before.

4. Conclusions

Without going into details general conclusions read as follows:

- From the main equipment point of view UHVDC systems of up to 800 kV are technically feasible
- In general UHVDC equipment can be designed and manufactured based on existing technology and know-how
- For most of the station equipment only some or even no R&D is anticipated
- However, converter transformers and bushings need more thorough R&D
- External insulation of UHVDC equipment, especially for outdoor installation has been identified as one of the key issues
- Transportation limitations for converter transformers may dictate the configuration of converter stations in terms of number of 12p-groups per pole

5. Biographies:



Marcus Haeusler

born in 1966, received his Dipl.-Ing. Degree in Electrical Engineering from University of Karlsruhe, Germany, in 1992. Since he joined Siemens AG in 1992, he has been working on HVDC system engineering for many HVDC projects world wide.



Hermann Koelsch

born in 1942 received the Dipl.-Ing. Degree from the University of Darmstadt and the Dr.-Ing. Degree from the University of Bochum, both in Electrical Engineering. He has been working in the field of HVDC since 1975.



Ramaswami Velpanur

born in 1946 received his Bachelors Degree in Electrical Engineering from the University of Bangalore in 1969. He has been working in the HVDC field since 1980, first with Brown Boveri & Cie and then with Siemens AG. Currently he is responsible for HVDC Sales and Marketing at Siemens Power Transmission and Distribution Group