World’s first Ultra High Voltage Direct Current (UHVDC) system
Siemens’ 5th HVDC transmission project in China

In the last decades many HVDC projects have been realized for power rating up to 3000 MW at ±500 kV voltage levels. Currently world-wide existing HVDC schemes are limited to maximum voltage levels of 600 kV. However in future bulk power transmission exceeding 4000 MW and covering about 2000 km is necessary. Therefore it was important for Siemens to develop HVDC for voltage levels above ±600 kV – Ultra High Voltage Direct Current (UHVDC). Several UHVDC projects, with preferred operating voltages of ±800 kV have been identified in China and India with power transmission requirements up to about 6400 MW using a single bipolar DC line. Finally in June 2007 Siemens Power Transmission and Distribution has won an order from China’s Southern Power Grid Company, to construct world’s first Ultra High Voltage Direct Current (UHVDC) transmission system between the provinces of Yunnan and Guangdong. This link will be Siemens’ 5th HVDC system in China (Fig. 1) and with Tian-Guang (1800 MW, June 2000), Gui-Guang I (3000 MW, September 2004) and Gui-Guang II (3000 MW, commissioning end of 2007) Siemens’ 4th HVDC system to supply China’s most populous province Guangdong (all in all 110 million) with energy. The UHVDC system will transmit up to 5000 MW, generated by hydroelectric power plants in Yunnan, at a voltage level of ±800 kV to Guangdong, with its megacities Guangzhou and Shenzen, both among the four most important cities in China.

Specific requirements on equipment for UHVDC
As the power rating compared to state-of-the-art HVDC systems is increased, some limits on equipment may be reached and thereby require changes as follows:

Converter transformer and pulse group arrangement
In a conventional HVDC scheme a single 12-pulse group is the state-of-the-art solution (Fig. 2a). In case of a 5000MW UHVDC system the required single phase two winding transformers might already be approaching the limits of transportation. Hence, for the Yunnan-Guangdong UHVDC Project the converters are arranged in two 12-pulse groups connected in series (Fig. 2b).
For other applications parallel arrangement of 12-pulse groups may be an adequate solution especially if the following advantages can be used:
- different locations for each group are possible (i.e. multi-terminal configuration)
- highly adaptable to stage wise development
Insulation of the Equipment

One important factor for designing UHVDC equipment is adequate external insulation, this means to take care of proper clearances and creepage distances of the equipment housings. Required flash distances determine the axial length of the equipment. For UHVDC equipment the nonlinear behavior of the flashover phenomenon for large switching impulse levels will become the dimensioning factor for the flash distance.

As far as equipment will be installed outdoors the external insulation with respect to creepage distances is even more complex compared to the flash distance as it severely depends on degree of pollution collected on the equipment, wetting conditions of the polluted housing surfaces and shed profile. However proven mitigation methods exist:

- silicone rubber housings with hydrophobic abilities
- coated porcelain housings with hydrophobic material (significantly improved in recent years)
- insulators with porcelain core equipped with silicone rubber sheds (under investigation)
- indoor installation of UHVDC yard equipment (so-called DC hall)

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 existing projects.

Converter Transformer and Transformer Bushings

Due to the combined AC and DC stresses the internal insulation system design of a converter transformer comprise of considerable amount of paper insulation in addition to oil. As a result the size and weight of converter transformer is large compared to normal AC transformer of equivalent rating. The valve windings of the converter transformers connected with the upper six pulse group would see maximum rated dc voltage of transmission which may be $\pm 800$ kV plus the allowed tolerances. These windings may also see overvoltages originating from DC as well AC side. Thus the bushings, leads and winding insulation shall have to be rated for high voltage resulting in large dimensions for these equipment.
**DC Wall Bushings**

Doubtless, the existing technology of wall bushings provides the best solution 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 have been thoroughly investigated. Further, it has been observed that the wall bushings require particular attention in their mounting since these are particularly prone to uneven wetting during rain which increases the risk of flashovers. Based on excellent experiences gained at operation levels up to 500 kV insulators of hydrophobic silicon material will be used for UHVDC applications as most effective mitigation measure against flashovers.

**Fig. 3: UHVDC transformer bushing in test facility**

**DC Switchyard Equipment**

The main DC yard equipment that would require special attention is the following:

- Smoothing Reactor
- DC Switchgear

For the Yunnan-Guangdong Project a smoothing reactor inductance of 300mH has been selected for each pole at each station. Air-type smoothing reactors have been identified as preferred solution for such UHVDC applications. The operating DC current determines the largest smoothing reactor coil size which can be manufactured. For this application a series connection of four coils of 75 mH each is needed (similar as shown in Fig. 4). Half of the inductance will be installed at the neutral bus.
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. For UHVDC applications disconnect switches as well as bypass breakers are designed using composite insulators with silicone housings in order to improve external insulation for highly polluted environments.

CONCLUSIONS
The most suitable configuration of an UHVDC project is selected based on rating and system considerations which influence converter transformer size and overload capability of the project. Main equipment for UHDC systems of up to 800 kV is designed and manufactured based on existing technology and know-how. Besides of improvements of internal insulation of converter transformers and bushings required for covering the increased insulations levels, also external insulation of UHVDC equipment has been thoroughly investigated. Especially for outdoor installations use of silicone housing insulators is a key issue for UHVDC applications.