The energy consumption in the world is growing, and distant energy resources are needed. The use of renewable resources such as hydropower, wind and sun is normally not possible without the use of electric transmission, since these resources, at least new ones, are often located far away.

In many cases, there is a need to transfer bulk high voltage power through areas and countries with comparatively little consumption, and it is not obvious how to supply power to customers along the transmission route, especially when HVDC is used. This paper describes the state of the art of bulk power transfer, and how supplies can be arranged for those living along the line.

**AC transmission**

AC is by far the most widely used way of transmitting electric power, and has been so since very early in the development of the electrical transmission technology. Typical actions to make AC more suitable for transmission of power over long AC lines is to use series compensation of the lines. This works quite well when the power is transmitted from one point to another, but is normally not used inside a meshed net.

In developing countries, AC is not only used to build grids as in other countries, but is also to a certain extent used for transmission of power from distant generation sources.

If the task is to transfer power to far away places, one has to design the system to be stable and to survive faults on the AC lines.

AC lines may have quite high power transfer capabilities if they are short. This capability depends on the voltage used and the thermal rating of the conductors. Longer lines have higher impedance and this reduces the power transfer capability. See the Eqn. 1 for the transfer of active power:

\[ p = \frac{U_1 U_2 \sin(\delta)}{X} \]  

where

- \( p \) is the active power transferred;
- \( U_1 \) and \( U_2 \) is the voltage of the sending and receiving ends of the line respectively;
- \( \delta \) is the phase angle between \( U_1 \) and \( U_2 \) the two ends; and
- \( X \) is the line impedance.

Fig. 1 shows transmission capability in MW of AC lines with 50% compensation.

Power supplies for communities close to a HVDC transmission line

This article describes a novel approach to providing on-route power supplies to rural and urban communities in close proximity to the extra high voltage DC transmission line, in addition to on-route country bulk transfers and country point-to-point bulk transfers.

HVDC transmission

HVDC is presently used for transmission of power up to 3000 MW per bipolar with voltages up to ±600 kV. Development now being completed for 800 kV HVDC for transmission of bulk power up to at least 6000 MW per bipolar.

Power supplies for communities close to a HVDC transmission line by Gunnar Asplund and Andrew Williamson, ABB

This article describes a novel approach to providing on-route power supplies to rural and urban communities in close proximity to the extra high voltage DC transmission line, in addition to on-route country bulk transfers and country point-to-point bulk transfers.
When designing an 800 kV HVDC station with a power of 6000 MW, it is important to design the station so that a failure of a single critical component results in a loss of only a fraction of the power. Fig. 10 shows a station with four power blocks. This can be made by using the following configurations:

- Two poles each consisting of two series connected groups
- Two poles each consisting of two parallel groups

The layout could look something like that indicated in Fig. 10.

Cost of AC and DC

A cost comparison has been made of transmitting 6000 MW over a distance of 3500 km with AC and with DC. Fig. 11 shows the cost of stations, lines and losses as a function of the line losses. This makes it possible to see which line loss gives the lowest total cost. As can be seen, 800 kV HVDC gives the lowest overall cost and at the lowest losses in the lines.

System aspects

DC transmission is made by converting AC to DC in a rectifier station, transmitting the power in a DC bipolar line, and converting the power back into AC in an inverter station. From a system point of view, DC is for transmission over long distances. The rectifier and inverter stations can control the current and voltage very fast, and thereby control the power. The phase angle difference between the sending and receiving end is of no importance if the interconnection is DC only. Also, asynchronous networks can be connected without causing any problems, as DC has no phase angles and is not depending on the frequency. Disturbances in the sending end where generation is lost and the frequency deviates from nominal will not influence the DC transmission.

HVDC configurations

For 800 kV HVDC, several converter configurations are possible as can be seen in Fig. 3. Also, different line configurations can be considered as shown in Fig. 4.

With 800 kV HVDC, power transfer of up to 18 000 MW could be made on one single right-of-way.

Technical challenges

The highest voltage of HVDC today is 600 kV. The Itaipu project was commissioned more than 20 years ago, and is operating with two bipoles of ±600 kV and transmitting 6300 MW over a distance of 800 km. 800 kV HVDC transmission has required development of the following new equipment:

- Transformers
- Transformer bushings
- Valve hall wall bushings
- Thyristor valves
- Arresters
- Voltage dividers
- DC filter capacitors
- Support insulators

Development in this regard has been ongoing at ABB for several years, and all the 800 kV equipment has been designed, manufactured and tested. Some examples are given below.

**Transformer prototype**

A simplified transformer prototype (Fig. 5) has been manufactured, including all the insulation details for an 800 kV converter transformer. Initial tests passed on the transformer prototype so far includes:

- DC withstand: 1250 kV
- AC withstand: 900 kV

**Transformer bushing**

A prototype of the transformer bushing for the highest 6-pulse group has been produced (Fig. 6). The bushing has passed all type and routine tests, including:

- DC withstand: 1450 kV
- AC withstand: 1050 kV

**Valve hall wall bushings**

The wall bushing design is also based on the well proven design that is used for the recent installations at 500 kV. Besides the electrical requirements, the 18 m length of the wall bushing (Fig. 7) has been a mechanical challenge. However, all electrical and mechanical type and routine tests have passed successfully. Also the seismic withstand has been verified by calculations. The design and manufacturing of the 800 kV wall bushing is completed, and the completed bushing is installed in the 800 kV test circuit, including:

- DC withstand: 1250 kV
- AC withstand: 910 kV

**Long term test station**

As a final proof that everything works, a long term test station has been built where all equipment is tested at 855 kV for at least six months.

**Development status**

The present status is that 800 kV HVDC is now fully developed and available for commercial transmission applications.
Providing on-route power supplies

Combined AC and DC

As was mentioned above, the main disadvantage with HVDC is the high cost of tapping power along the line. However, a combination of HVDC transmission in parallel with a lower voltage AC network could in many cases be the optimal solution. This can give both low cost and high flexibility to supply customers along the route.

HVDC tapping

Tapping of bulk transmission HVDC has been seen as quite costly. The reason is that using tapping stations of the same type as the main transmission inverter will cost almost the same as the full-size inverter. Feeding into networks without own generation will require synchronous machines.

However, by using voltage source converters (VSC) in the tapping stations, much smaller stations can be built, and the influence on the main transmission will be very small. There is no need for generation in the network as VSC converters create their own voltage.

Fig. 12 shows a VSC tapping on an HVDC transmission. Fig. 13 shows the VSC converter. By connecting the phases in series, high voltage can be achieved at low power. Fig. 13 shows VSC converter using series connected phases to reduce the number of semiconductors.

Table 1 shows the power and voltage that can be achieved by using the present standard VSC with series connected phases.

A preliminary layout is shown in Fig. 14 (note that outdoor valves are proposed in order to drastically reduce the size).
Use of HVDC on isolated shield wire

If less power is needed, the shield wires could be insulated and voltage source converter (VSC) HVDC could be used to supply multiple smaller loads along the line at a comparatively low cost.

Fig. 15 shows shield wires of a bulk power HVDC bipole.

Fig. 16 shows an arrangement where power is fed into the line in each end via rectifiers and distributed along the line via inverters.

Assume three tapings along 3000 km line with two shield wires of aluminium with 500 mm² area. Fig. 17 shows the voltage profile of the 130 kV line up to 400 km from the tapping station.

If the taps are evenly distributed, and with the same power in each, we could get at least 120 MW anywhere along the line. In the tapping stations themselves, the power is only limited by the tapping station rating.

Conclusion

Even if we still produce most of our electric power by fossil fuels, there will come a day when this is no longer possible. Then sustainable energy generation will be needed. Characteristic of such generation is that it is often located in very sparsely inhabited areas and normally very far from the place where the energy will be consumed. Here it will be very important to find efficient ways to transport large amounts of electricity over long distances. Transmission of bulk power over long distances can now be made economically in large scale using 800 kV HVDC. One of the drawbacks with HVDC has been the difficulty of providing power supplies along the route. This can be solved either by parallel AC transmission or by tapping of the HVDC with VSC converters and/or supplying power by VSC converters from isolated ground wires.

References


