High-Voltage Dc Transmission Lines

Introduction

The facilities required for electric power supply comprise three groups: the generating stations, the transmission and interconnection of systems, and the distribution networks. With the increase in requirement of electric power, these facilities have to be increased. Considerations regarding the generation and distribution facilities to suit the requirements are not so difficult. Transmission and interconnection systems. However, have to be properly planned for this purpose. The voltage level of transmission system have increased in a short time from 110 kV to 220k V and 400 kV

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. Higher voltages such as 500 kV and 750 kV are also in operation. In the high range of voltages, it is worthwhile considering whether the three-phase voltage would solve the problems or high-voltage dc would be better.

With the development of mercury are converters handling large currents, and the associated high-voltage dc transmission technology, it has now been possible to use high-voltage dc transmission where large blocks of power are to be transmitted over a long distances. At both ends of a dc

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transmission line, converting plants are used, one of them being operated as a rectifier, converting high-voltage ac to dc and at the receiving-end, the converting plant acts as an inverter changing high-voltage dc to ac. The generation as well as distribution is maintained at ac voltages as transformers facilitate to step up generation voltage to required high-voltage value and also step down to distribution voltage level at various consumers ends.

Limitations of High-Voltage ac Transmission

The factors, which impose limitation on the amount of power to be transmitted over a three-phase line, are:

1. Reactive Loss: An ac line with negligible resistance, inductance L and capacitance C will have lagging reactive VA loss and leading reactive. VA loss due to L and C of the line and the transmission would be economical if these two losses balance each other at all points along the line. This happens at the characteristic impedance of the line, Z_0 . The power transmitted, $VI=V^2/Z_0$. Watts per phase. However, it is not possible to operate the line at characteristic load conditions all the time. Thus, this causes reactive loss in the lines.

2. Stability: The power tr**Continue**

ansmitted over a line of reactance X ohms per phase is

$$P = \frac{V_s V_r \sin \delta}{X}$$

watts per phase where V_s and V_r are sending and receiving-end voltages, respectively and δ is the load angle. The maximum steady-state power occurs when δ = 900 Considering transient conditions, δ is not generally more than 300 for effective stable operation of the system. Stability considerations impose serious limits on the distance of power transmission over ac lines.

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3. Current Carrying Capacity Values of the current carrying capacities of overhead lines are above the corresponding natural loads (surge impedance loads) but with underground cables, the values are much below the natural-load values. The underground cables also have high-charging current. The charging current varies

from 6 A pr km for a 132 kV cable to 16 A per km for a 400 kV cable.

The length of the cable when charging current becomes equal to the thermal-cu Tent limit is known as critical length and limits the distance of power transmission by cables.

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4. Ferranti Effect: The rise of voltage at the receiving-end due to leading reactive VA on the line on no-load may be serious. This again limits the distance of transmission of power over ac lines.

Advantages of HVDC Transmission

1. In the case of dc lines, only two conductors are needed for a single line. Using earth return, only one conductor is enough and with two conductors and earth return, the capacity of the line is doubled, one of the conductors being at potential higher than the earth potential while the other is at potential below earth potential. With two-pole operation, the voltage of the line is also doubled. In the case of ac transmission line, at least three conductors would be necessary and for double-circuit line, six conductors would be necessary.

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2. high-voltage dc line needs less space compared to an ac line of the same voltage rating and size. This reduces the space to be maintained.
3. The electrical field strength at the surface of the conductor can be about 50 % higher on overhead lines and about three times higher on cables in case of dc is compared to ac.

Due to nominal field strength and over voltages as well as due to lack of dielectric space charges and losses, dc cables are less expensive than ac cables.

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4. For transmission rating of about 1000 MW to 2000 MW, costs were equal for a transmission distance of 500 to 1500 km in 1960. If the converter station costs are reduced by 30% to 40% as is expected, the transmission distance for equal cost would be reduced to even about 400 km for the use of high-voltage de transmission in preference to high-voltage ac transmission. In case of transmission by cables, this already applies for a distance of 100 to 200 km

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5. There is no need to maintain the synchronism between the two ac systems connected together by a dc link The supply frequencies on the two sides may or may not be equal. The power flow along the HVDC line can always be maintained as long as the voltage of the systems linked by HVDC transmission is maintained within certain limits.

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6. If transmission is interrupted due to a voltage drop in one of the systems, it is reestablished immediately after the voltage returns, irrespective of synchronism.
7. For ac voltages above 400 Kv, it becomes necessary to limit the possible switching transients due to economic reasons. With HVDC such problems do not occur.

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8. Power flow through a dc line terminal can easily be controlled via grid control of the valves. There being less inertia in a dc terminal due to the distance of rotating synchronous machines, the power control can be fast and accurate
9. HVDC does not transmit short-circuit power in case of faults and disturbances.

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10. Terminals and lines can be built in stages. DC line voltages can be increased gradually by stepwise installation of an increased number of converters and the power capacity of the dc link will also be increased accordingly.

11. Feeding-in power in the medium-voltage part of the system using HVDC results in better utilization of the system and saving of circuit-breakers and transformers.

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12. Two ac power systems having different frequencies can be linked up together by means of the HVDC link.
13. There is no technical limit to the distance over which power may be transmitted by overhead-transmission lines or by cable using HVDC.

Limitations of HVDC Transmission

1. The cost of terminal equipment is high. The voltage and the power to be transmitted should be high to justify the choice economically.
2. There is a possibility of considerable distortion in the waveform of the ac voltages by the use of HVDC link. Special filters will be necessary in the terminal equipment on either side of HVDC
3. DC line blocks the transmission of reactive KVA load. The receiving- end network must be capable of supplying the whole of the reactive component of power required by the loads and the inverters.
4. DC line is restricted to point-to-point transmission.

Principal Parts and Requirements of High-Voltage DC Transmission

Figure 3 shows a single-line diagram of a two-pole HVDC transmission line including the main features of the line this is the representation of HVDC line connecting the South and North island power systems in New Zealand.

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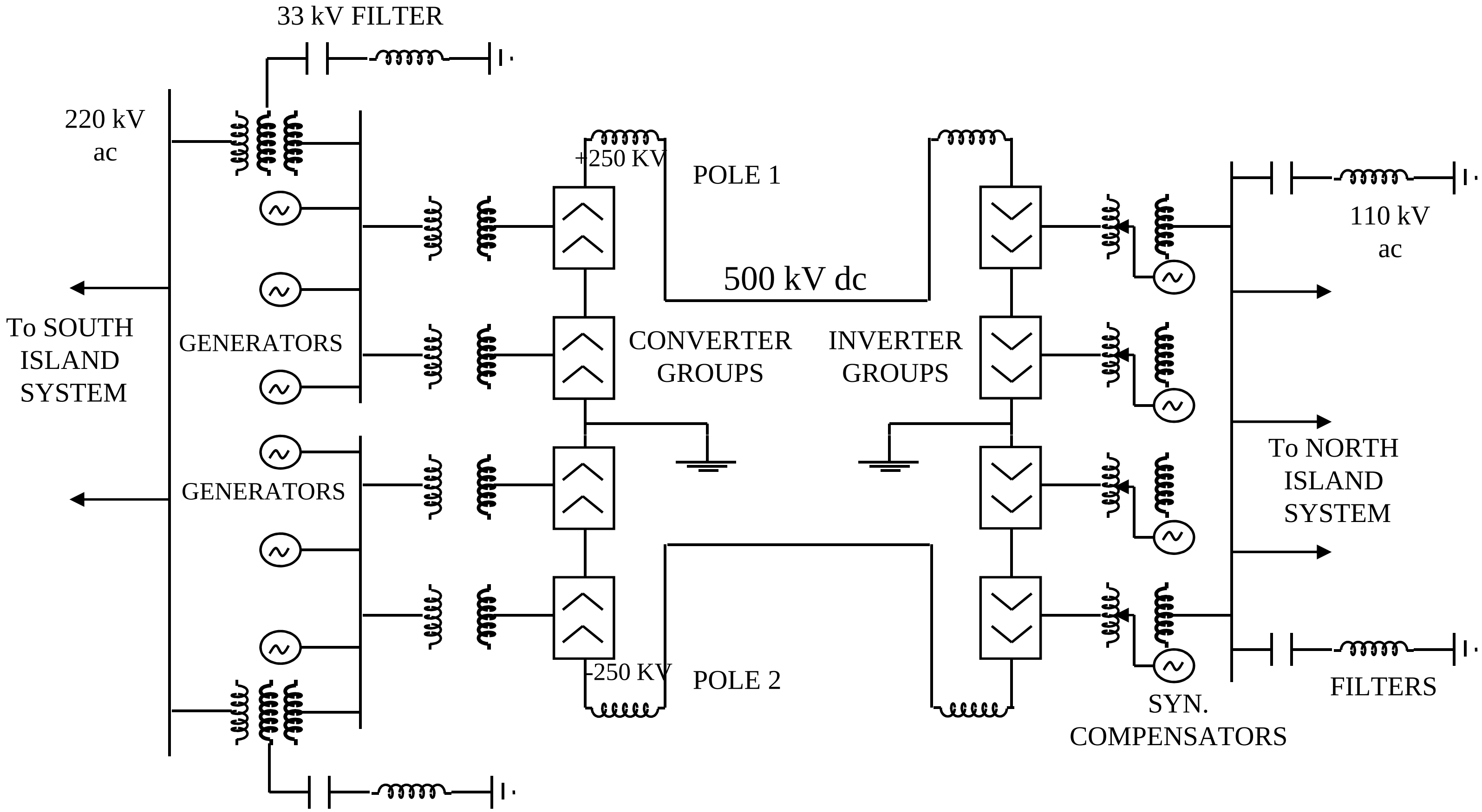

Fig. 3 Single-line diagram showing main connections of HVDC transmission

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The main parts of the HVDC scheme are as follows:

1. Mercury Arc Converter Groups All HVDC transmission stations are present based on three-phase bridge converter circuits consisting of six mercury-arc excitron type valves plus a bypass valve.

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2. Converter Transformers: The converter transformers have line winding, valve winding and tertiary winding between the two windings. The valve windings have to withstand direct voltages in addition to the normal ac voltage. The bridge circuit used gives three-phase two way-full-wave conversion-and, thus, six-pulse operation. For dc schemes, where there are two six-pulse converters per de pole, the two transformer windings on each pole are displaced by 30 so that the operation of both converters connected in series becomes a 12-pulse converter.

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3. Smoothening Reactors: These reactors are used to smoothen the dc current output of a converter and to limit the rate of rise of the fault current in case of short-circuit on the dc lines. An air-cored magnetically shielded reactor is used for this purpose. The windings are of disc coil type and are braced to withstand short-circuit currents. Saturation inductance is not too low under short-circuit conditions. For these reactors, the inductance should be higher under light-load conditions to assist valve operation. This is made possible by providing a partial magnetic-core path in parallel with the air core of the reactor. The partial core becomes saturated when full load current passes through it.

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4. Harmonic Filters: HVDC converter stations inject harmonic currents into ac systems and also draw reactive power from them. In the case of six-pulse Converter bridge, harmonic currents are of the order of $(6n \pm 1)$

   Where n is an integer. The harmonic filter is connected to the converter station terminals. The filter provides a low-impedance path to the earth for the harmonic currents. The use of filters prevents excessive quantities of harmonic currents and voltages from entering the system. The filter also supplies some of the reactive power consumed by the converter station.

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5. Reactive power Requirements of ac Systems and

ac/dc: Converters Mercury-arc valves are used in HVDC transmission schemes for converters. It is necessary to build up a forward voltage across the valve before firing it when it is in rectifier operation and it is necessary to ensure that it extinguishes before any forward voltage can occur across it when it is in inverter operation. As a result of this, there is phase displacement between the current drawn by the converter and the voltage of the ac system. Thus, reactive power is drawn from the ac system. The amount of reactive power required increases with the firing angle α of a rectifier and the extinction angle γ of an inverter. This power requirement is about 50% to 60% of the real power transfer. The reactive power consumption to some extent is provided by capacitors, filters or synchronous compensators associated with the converters.

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A static device consisting effectively of a fixed capacitor in parallel with a transformer-fed ac saturable reactor will give virtually instantaneous control of Mvar for both supply and absorption. The synchronous compensators with their inherent inertia are also used in some cases. In Fig.3, synchronous compensators are used in station on 110 KV side after the inverter for this purpose. Synchronous compensators not only deliver lagging reactive power required by the load and converter but also provide ac voltage for the natural commutation of the inverter circuit.

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The synchronous compensators used for HVDC systems would be laminated salient pole machines-even as 6-pole machines-due mainly to harmonic currents. The impedance of the machines to harmonics depends on subtransient reactance. The damper bar short circuit rings would be completed between the poles so that X_d'' is made approximately equal to X_q''. Damper bars help in reducing transients and harmonics