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Transmission and Distribution

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D.C. power Transmission Technology

Introduction

The industrial growth of a nation requires increased consumption of energy, particularly electrical energy. This has led to increase in the generation and transmission facilities to meet the increasing demand. System interconnections lead to a search for efficient power transmission at increasing power levels. The increase of voltage levels is not always feasible. The problems of AC transmission particularly in long distance transmission has led to the development of DC transmission.

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However, as generation and utilization of power remain at alternating current the DC transmission requires conversion at two ends from AC to DC at the S.E. and back to AC at the R.E. This conversion is done at converter stations – rectifier station at the S.E. and inverter station at the R.E.

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The converters are static – using high power thyristors connected in series to give the required voltage ratings. The physical process of conversion in such that the same station can switch from rectifier to inverter by simple control action, thus facilitating power reversal.

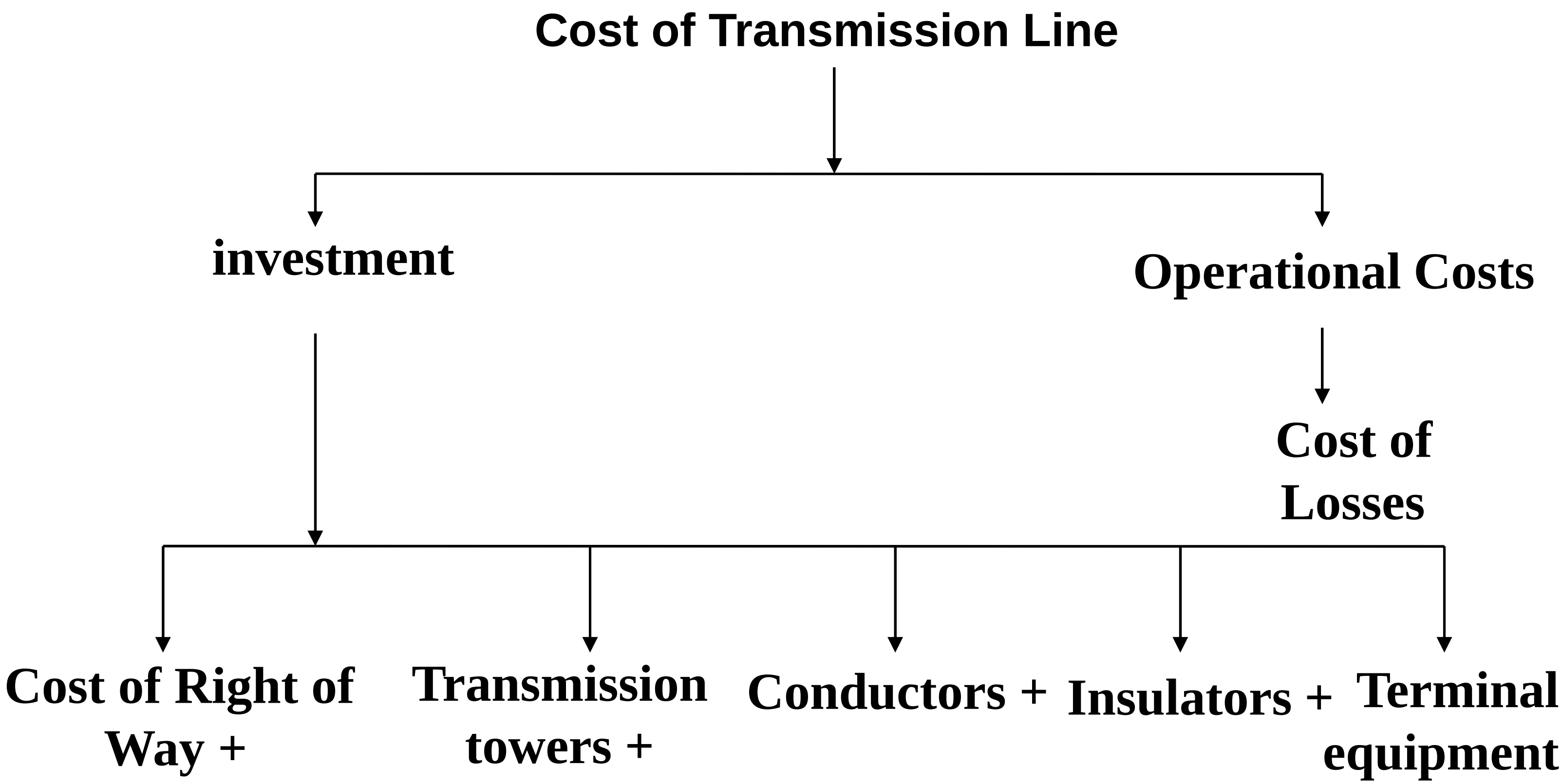
Comparisons of AC and DC Transmission

The comparison between the two modes of transmission (AC & DC) which need to be considered by a system planner are

based on the following factors:

1. Economics of Transmission.
2. Technical performance.
3. Reliability.

Economics of power Transmission



This implies that for a given power level, DC line requires – less (Row) & simple-cheaper towers – and reduced conductor and insulator costs.

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The power losses are also reduced with DC, as there are only two conductors. That absence of skin effect with DC is also beneficial in reducing power losses marginally. Also the dielectric losses in case of power cables is also very less for DC transmission.

Technical Performance

The DC transmission has some positive features, which are lacking in AC transmission. These are mainly due to the fast controllability of power in DC lines through converter control. The following are the advantages;

a) Full control over power transmitted.

b) The ability to enhance transient and dynamic stability in associated AC network.

c) Fast control to limit fault currents in DC lines. This makes it feasible to avoid DC breakers in two terminals DC link.

Also DC overcomes some of problems of AC transmission:

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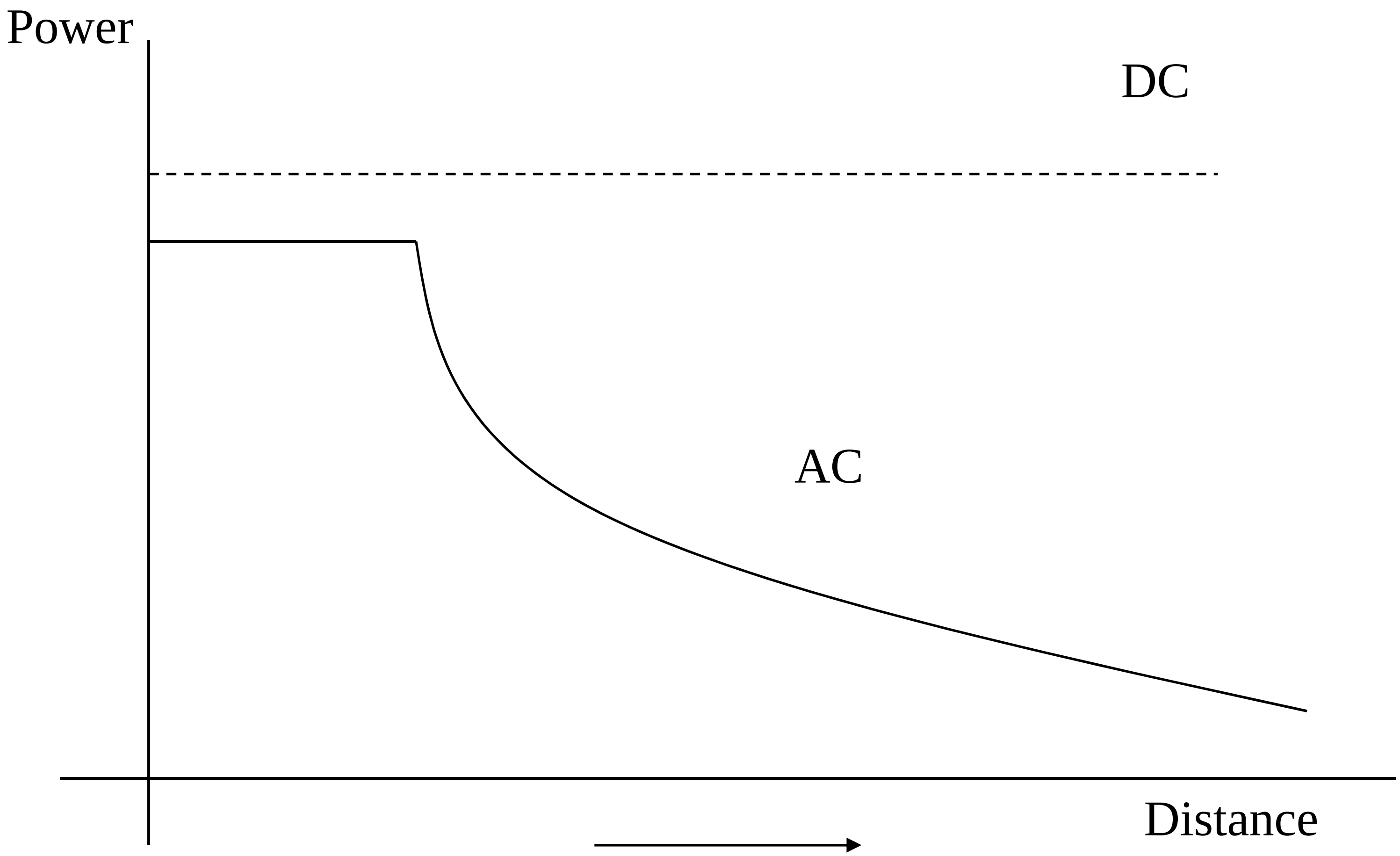

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(a) Stability Limit:

The power transfer in AC is dependent on (the Voltage and current at both sending and receiving ends.) as the distance increases, the angle increases, and the power transfer

decrease.

Figure 1 shows the power carrying capability of DC lines which is unaffected by the distance of transmission.

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(b) Voltage Control:

The reactive power requirements increase with the increase in line length (AC). Although DC converter stations require reactive power, related to the line loading, the line itself does not require reactive power.

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(C) Line Compensation:

AC line requires shunt and series compensation in long distance transmission, mainly to overcome problems of line charging and stability limitations. Series capacitors and shunt inductors are used for this purpose.

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(d) Problems of AC interconnection:

When two power systems are connected through AC ties, the automatic generation Controls of both systems have to be coordinated using tie line power and frequency signals. Even with coordinated control of interconnected systems, the operation of AC ties can be problematic due to:

1) The presence of large power oscillations, which can lead to frequent tripping.

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2) Increase in fault level.

3) Transmission of disturbances from one system to the other.

The controllability of power flow in DC lines eliminates all the above problems. In addition, for asynchronous ties, there is no need of coordinated control.

Disadvantages of DC transmission

1. The difficulty of breaking DC currents, which results in high cost of DC breakers.
2. Inability to use transformers to change voltage levels.
3. High cost of conversion equipment.
4. Generation of harmonics, which require AC & DC, filters, adding to the cost of converter stations.
5. Complexity of control.

Reliability

The reliability of DC transmission systems is quite good and comparable to that of AC systems.

An exhaustive record of existing HVDC links in the world is available from which the reliability statistics can be computed.

It must be remembered that developments in devices, control and protection is likely to improve the reliability level.

There are two measures of overall system reliability – energy availability and transient reliability.

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(a) Energy availability:

$$Energy\ availability = 100\left(1 - \frac{equivalent\,outage}{total\,time}\right) \times 100$$

(b) Transient reliability

This is a factor specifying the performance of HVDC systems during recordable faults on the associated AC systems

$$TR = \frac{100 \times \text{No.of times HVDC systems performed as designed}}{\text{No. of recordable AC faults}}$$

Application of DC Transmission

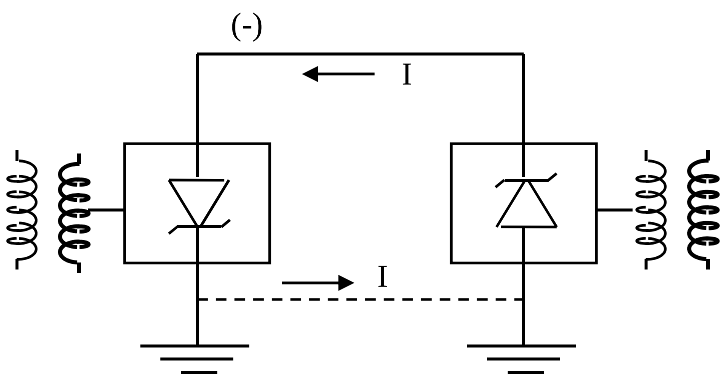
1. Long distance bulk power transmission.
2. Underground or underwater cables.
3. A synchronous interconnection of AC systems operating at different frequencies or where independent control of systems is designed.
4. Control and stabilization of power flows in AC ties in integrated power system.

Description of Transmission System

Types of DC Links

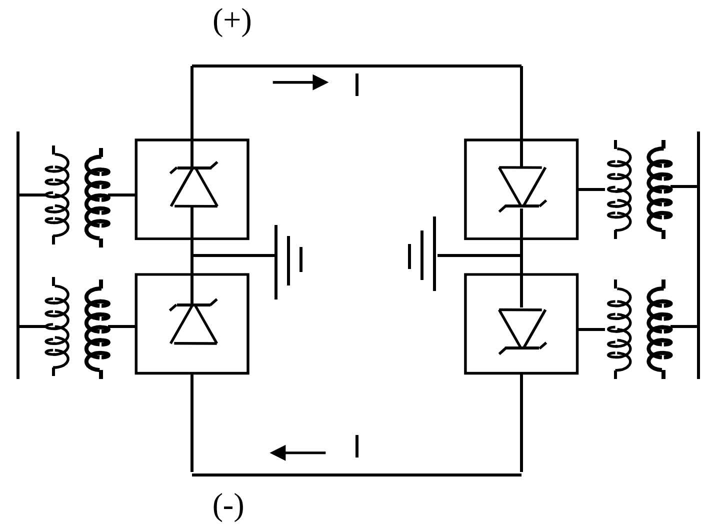
(a) Monopolar:

It has one conductor of – ive polarity, and uses ground or sea return.



(b) Bipolar:

It has two conductors one + ive and the other – ive.



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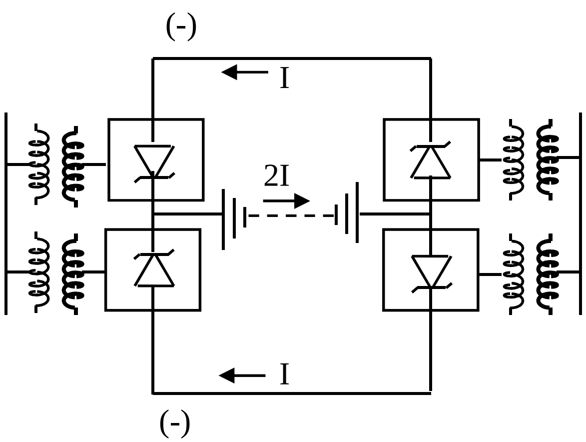
Each terminal has two sets of converter of identical ratings in series on the DC side. The junction between the two sets of Conductors is grounded at one or both ends.

(c) **Homopolar**:

It has two or more conductors all having the same polarity (usually –ive) and also operated with ground or metallic return.



Converter Station

The major components of HVDC transmission systems are converter stations where conversions from AC to DC (Rectifier station) and from DC to AC (Inverter station) are performed.

Converter Transformer

The winding transformer can have different configuration:

a) 3-phase, 2-winding.

b) 1-phase, 3-winding.

c) 1-phase, 2-winding.

The converter transformers are designed to withstand DC voltage stresses and increased eddy current losses due to harmonic currents.

Filters

There are 3- types of filters used:

1. AC filters: There are passive circuits used to provide low impedance. Shunt paths for AC harmonic currents. Both tuned and damped filter arrangements are used
2. DC filter: These are similar to AC filters and are used for the filtering of DC harmonics.
3. High frequency filters: These are connected between the converter transformer and the station AC bus to suppress any high frequency currents. Sometimes such filers are provided on high- voltage DC bus connected between the DC filter and DC line and also on the neutral side

Reactive power source

Converter stations require reactive power supply that is dependent on the active power loading. Part of this reactive power requirement is provided by AC filters. In addition, shunt capacitors, synchronous condensers and static VAR systems are used depending on the speed of control desired.

Choice of voltage level

For long distance bulk power transmission, the voltage level is chosen to minimize the total cost for a given power level (P).

The total costs include investment (c_1) and cost

of losses (c_2).

The investment costs per unit length are modeled as;

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$C_1 = A_0 + A_1 nV + A_2 nq$

V: is the voltage level with respect to ground.

N: is the number of conductors.

q: is the total cross-section of each conductor.

A_0, A_1 and A_2: are constants.

The cost of losses per unit length is given by;

$$C_2 = \left[n(P/nV)^2 \rho TLP \right] / q$$

p: conductor resistivity.

T: total operation time in a year.

L: loss load factor.

P: cost per unit energy.

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C_2 can be simplified as; $C_2 = \left[A_3 (p/V)^2 p\right] / nq$

The total cost $C = C_1 + C_2$

By minimizing the sum of C_2 and the 3rd term in C_1, we have,

$$nq = \sqrt{(A_3 / A_2) p}$$

$A_3 = T\ L\ P$

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Current density,

$$J = p/(nqV) = \sqrt{A_2/A_3 \, p}$$

$$\therefore C = C_1 + C_2 + A_0 + A_1 nV + \sqrt[2]{A_2 A_3 p}\,\left(\frac{p}{V}\right)$$