

Comparative analysis of HVDC and EHVAC

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Abstract - High voltage direct current (HVDC) technology has characteristics which make it especially attractive in certain transmission applications. The number of HVDC projects accomplished or under consideration globally has increased in recent years reflecting a renewed interest in this field proven technology. New HVDC converter designs and improvements in conventional HVDC design have contributed to this trend. AC is the main driving force in industries and residential areas but for long transmission line AC transmission is more expensive than DC. AC transmission have more complications because of frequency where in DC transmission frequency is absent. This paper provides an overview of HVDC and HVAC transmission system. This provides the basic literature survey for researchers. It also gives comparison between HVDC and EHVAC transmission lines.

Key Words: HVDC, HVAC transmission

1 Historical Background

Power Transmission was initially carried out in the early 1880s using Direct Current (d.c.). With the availability of transformers (for stepping up the voltage for transmission over long distances and for stepping down the voltage for safe use), the development of robust induction motor (to serve the users of rotary power), the availability of the superior synchronous generator, and the facilities of converting a.c. to d.c. when required, a.c. gradually replaced d.c.

1.1 Important milestone in the development of HVDC Technology.

- Hewitt's mercury - vapour rectifier, which appeared in 1901.
- Experiments with thyratons in America and mercury arc valves in Europe before 1940.
- First commercial HVDC transmission, Gotland 1 in Sweden 1954.

- First solid state semiconductor valves in 1970.
- First microcomputer based control equipment for HVDC in 1979.
- Highest DC transmission voltage (+/- 600 kV) in Itaipu, Brazil, 1984.
- First active DC filters for outstanding filtering performance in 1994.
- First Capacitor commutated Converter (CCC) in Argentina- Brazil interconnection, 1998.
- First voltage source converter for transmission in Gotland, Sweden, 1999.[2]

1.2 Projects carried out in HVDC.

There are many different reasons as to why HVDC was chosen. A few of the reasons selected projects are:

In Itaipu, Brazil, HVDC was chosen to supply 50 Hz power into a 60 Hz system and to economically transmit large amount of hydro power over large distances.

In Leyte- Luzon project in Philippines, HVDC was Chosen to enable supply of bulk geo thermal power across an island interconnection. And to improve stability to the Manila AC network.

In Rihand - Delhi project in India, HVDC was chosen to transmit bulk (thermal) power (1500MW) to Delhi, to ensure minimum losses, least amount right-of-way, and better stability and control.

In Garabi, an independent transmission project (ITP) transferring power from Argentina to Brazil, HVDC back-to-back system was chosen to ensure supply of 50 Hz bulk(1000MW) power to a 60 Hz system under a 20- year power supply contract.

In Gotland, Sweden, HVDC was chosen to connect a newly developed wind power site to the environmental sensitivity of the project area and improve power quality.

In Queensland, Australia, HVDC was chosen in an ITP to interconnect two independent grids to: enable electricity trading between the two systems, ensure very low environmental impact and reduce construction time.[2]

2 Types of HVDC Systems

There are mainly three types of HVDC Links that are use.

2.1 Monopolar Link

A monopolar system has only one conductor with ground as return conductor, and it is usually of a negative polarity. It is suitable in submarine systems where sea water can be used as a return conductor.

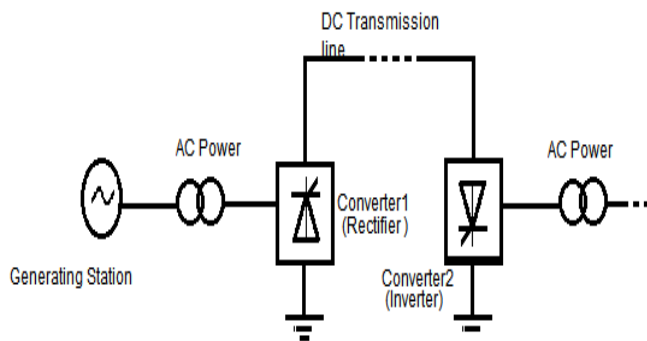


Fig -1: Monopolar link

2.2 Bipolar Link

A Bipolar system has two conductors, one of positive and other of negative polarity. The mutual or ground point is maintained at the mid-potential. Each terminal of a bipolar system has two converters of equal voltage rating connected in series. If both neutrals are grounded then two poles operate at equal current and there is no ground current. In the event of fault in one conductor, the other conductor with ground return can be used up to half the rated load or power with the rated current of the pole.

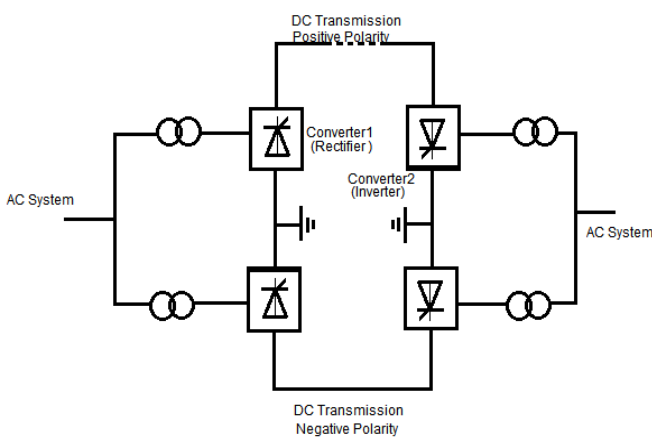


Fig -2: Bipolar link

2.3 Homopolar Link

Homopolar system has two or more conductors with the same polarity, usually negative, and they always operates with ground return. In the event of fault in one conductor, the whole converter can be connected to a healthy pole and can carry more than half the power by overloading but at the expense of increased line losses. However, this is not possible in a bipolar system due to the use of graded insulation for negative and positive poles. When continuous ground currents are inevitable, homopolar system is preferable. The additional advantage is lower corona loss and radio interference due to negative polarity on the lines.[6]

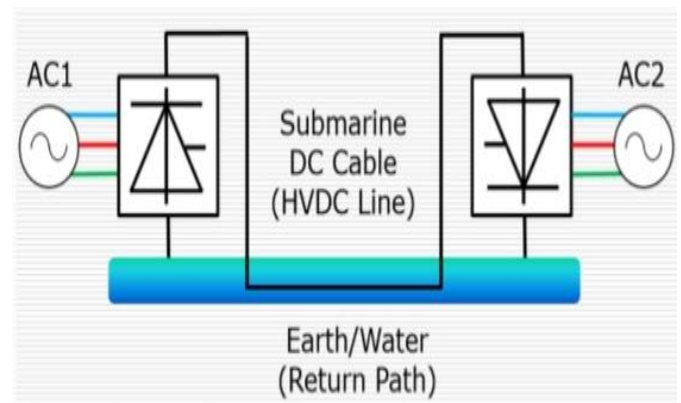


Fig -3: Homopolar link

3 Equipment required for HVDC Systems

Sources and generation of power is usually in AC mode. An essential requirement of a DC system is conversion of AC to DC at one end and inversion back to AC at the other end. This naturally demands rectifiers and inverters of the high power rating. A typical layout of HVDC transmission system is shown in figure.

Essential requirements of HVDC system are

1. 6/12 pulse converters
2. Converter transformer with suitable ratio and tap changing
3. Filters both on the AC side and on the DC side to take care of harmonic generation at the converters and to reduce the harmonics
4. A smoothing reactor in the DC side to reduce the harmonic current in the DC line and possible transient over currents
5. Shunt capacitors to complement reactive power generated by the converters as they operate on lagging power factor and take lagging current
6. DC transmission line or DC cables for power transmission

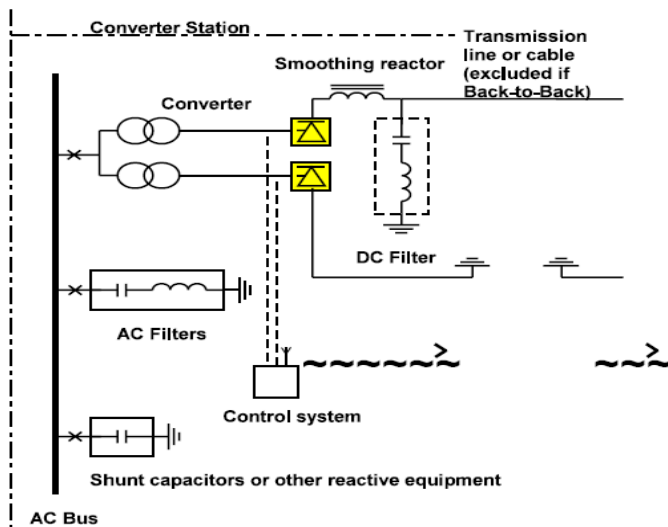


Fig -4: Typical layout of HVDC transmission system

3.1 Converters

The converter provides the transformation from AC to DC or DC to AC as required. The basic building block of the converter is the six-pulse bridge; however, most HVDC converters are connected as twelve-pulse bridges. The twelve-pulse bridge is composed of 12 “valves” each of which may contain many series-connected thyristors in order to achieve the DC rating of the HVDC scheme. For a HVDC power transmission scheme, the valves associated with each twelve-pulse bridge are normally contained within a purpose built building known as a “valve hall”. For back-to-back schemes, where both the sending and receiving end of the HVDC link are located on the same site, it is typical for the valves associated with both ends of the link to be located within the same valve hall.

3.2 Converter Transformer

The converter transformer is the interface between the AC system and the thyristor valves. Typically the HVDC converter transformer is subjected to a DC voltage insulation stress as well as the AC voltage stress normally experienced by a power transformer. These AC and DC stresses are fundamentally different. The AC voltage stress is predominantly in the insulating oil and defined by the geometry and permittivity of the materials, whilst the DC stress is governed by the resistivity of the insulating materials which, in turn, vary with operating conditions. In addition, it is important that the converter transformer be thermally designed to take into consideration both the fundamental frequency load and the AC harmonic currents that will flow from the converter through the converter transformer to the AC harmonic filters. Typically, the converter transformer is arranged as an earthed star-line winding and a floating-star and delta secondary windings. There is normally an on-load tap changer on the line winding.

3.3 AC Harmonic Filters

Converter operation results in both the generation of AC current harmonics and the absorption of reactive power. In order to limit the impact of these AC harmonic currents and the absorbed reactive power, the converter station normally includes shunt connected switchable AC harmonic filters, either connected directly to the converter busbar or connected to a “filter busbar” which, in-turn, is connected to the converter busbar. The AC harmonic filters are automatically switched-on and off with conventional AC circuit breakers when they are needed to meet harmonic performance and reactive power performance limits. The AC harmonic filters are typically composed of a high voltage connected capacitor bank in series with a medium voltage circuit comprising air-cored air-insulated reactors, resistors and capacitor banks. These components are selected to provide the required performance from the AC harmonic filter and to ensure that the filter is adequately rated.

3.4 DC Smoothing Reactor

DC smoothing reactors are normally only required for power transmission schemes; they are not required for Alstom Grid back-to-back schemes. For a HVDC transmission scheme, the DC smoothing reactor provides a number of functions but principally it is used to:

- Reduce the DC current ripple on the overhead transmission line or cable.
- Reduce the maximum potential fault current that could flow from the DC transmission circuit into a converter fault.
- Modify the DC side resonances of the scheme to frequencies that are not multiples of the fundamental AC frequency.
- Protect the thyristor valve from fast front transients originating on the DC transmission line (for example a lightning strike).

3.5 DC filter

The DC smoothing reactor is normally a large air-cored air-insulated reactor and is principally located at the high voltage terminal of the HVDC converter for schemes rated at, or below, 500 kV DC. Above 500 kV, the DC smoothing reactor is commonly split between the high voltage and neutral terminals.

Converter operation results in voltage harmonics being generated at the DC terminals of the converter, that is, there are sinusoidal AC harmonic components superimposed on the DC terminal voltage. This AC harmonic component of voltage will result in AC harmonic current flow in the DC circuit and the field generated by this AC harmonic current flow can link with adjacent conductors, such as open-wire telecommunication systems, and induce harmonic current flow in these other circuits. In a back-to-back scheme, these harmonics are contained within the valve hall with adequate shielding and, with a cable scheme, the cable screen typically provides adequate shielding. However, with open-wire DC

limit the amount of harmonic current flowing in the DC line. The DC filter is physically similar to an AC filter in that it is connected to the high voltage potential via a capacitor bank; other capacitors along with reactors and resistors are then connected to the high voltage capacitor bank in order to provide the desired tuning and damping.

3.6 Transmission line

For bulk power transmission over land, the most frequent transmission medium used is the overhead line. This overhead line is normally bipolar, i.e. two conductors with different polarity. HVDC cables are normally used for submarine transmission. The most common types of cables are the solid and the oil-filled ones. The solid type is in many cases the most economic one. Its insulation consists of paper tapes impregnated with high viscosity oil. No length limitation exists for this type and designs are today available for depths of about 1000 m. The self – contained oil-filled cable is completely filled with low viscosity oil and always works under pressure. The maximum length for this cable type seems to be around 60 km.

The development of new power cable technologies has accelerated in recent years and today a new HVDC cable is available for HVDC underground or submarine power transmissions. This new HVDC cable is made of extruded polyethylene, and is used in VSC based HVDC systems.[5]

3.7 Advantage of HVDC Transmission

- Required less space
- Ground can be used as return conductor
- Less corona loss and No reactive power loss
- Cheaper for long distance transmission
- No skin and Ferranti effect
- Asynchronous operation possible
- No switching transient
- No transmission of short circuit power control possible
- No stability problem[11]

3.8 Disadvantage of HVDC Transmission

- Cost of terminal equipment high
- Introduction of harmonics
- Blocking of reactive power[11]

3.9 Following are the transmission line rates in India

Sr.	From	To	Power	Voltage
1	Rihland (U.P)(from 1990)	Dadri (pehli)	15000 MW	±500 KV (bipolar)

2	Talcher-is the biggest HVDC transmission passes through Orissa(A.P) Tamilnadu & Karnataka	Kolar	2000 MW	± 500 KV (bipolar)
3	Chandrapur-padghe (Maharastra)	Padghe (Maharastra)	1500 MW	± 500 KV (bipolar)
4	Western Region	Northern Region	500MW	-
5	Western Region	Northern Region	100MW	-

4. HVAC Transmission System (Electric Power Transmission Lines)

4.1 Introduction to HVAC Transmission System

The increased demand of electricity needs more generation of electrical power. As the generation takes place at remote places, an efficient distribution system is necessary. The problems of AC transmission particularly in long distance transmission have led to the development of DC transmission.

HVAC Transmission system can be divided into two parts:

- (a) Transmission System
- (b) Distribution System

Each part is again subdivided into two parts:

- 1. Primary Transmission
- 2. Secondary Transmission

Generation and transmission now days is almost three phase. The secondary transmission is also three phase whereas the distribution to the customer may be three phase or single depending on the requirement of the consumer. [10]

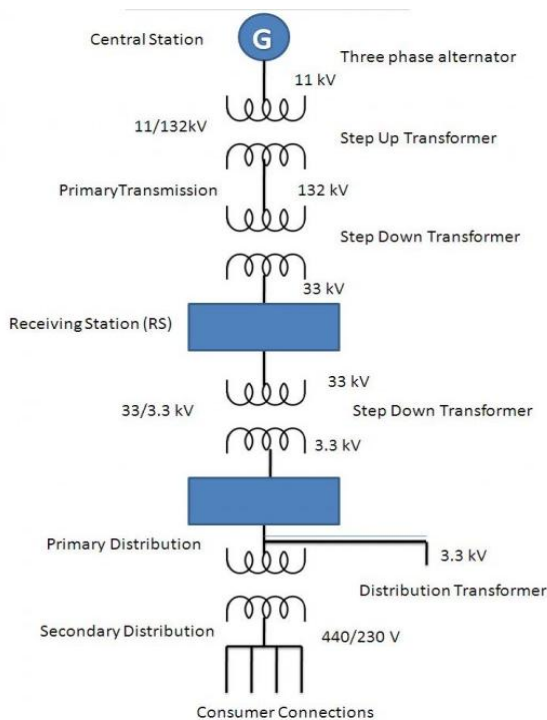


Fig -5: HVAC Transmission System

4.2 Primary Transmission

In fig the central station CS generates power using three phase alternators at 6.6 or 11 or 13.2 or 32 kV. The voltage is then stepped up by suitable three phase transformers, to 132 kV as shown.

Such a high voltage of transmission requires conductors of smaller cross section which results reduction in the cost of copper or aluminium.

However the cost of insulation increases. The transmission voltage is therefore determined by economic considerations. Higher transmission voltage also reduces the line losses and improves the efficiency.

The three phase three wire overhead high voltage transmission line gets terminated in the step down transformers in a substation known as Receiving Station (RS).

Receiving station is usually situated outside the city to ensure safety. Here the voltage is stepped down to 33 kV from 132 kV.[10]

4.3 Secondary Transmission

From The receiving station, power is then transmitted at 33kv by underground cables located at various points in the city. This is known as secondary or low voltage transmission. At substation this is further reduced from 3kV to 3.3 kV, using step down transformers.

4.4 Primary Distribution

The output of substation at 3.3 kV can be directly given to a customer whose demand exceeds 50kVA using special feeders. This is primary distribution.

4.5 Secondary Distribution

The secondary distribution is done at 440 or 230 V. The reduction in voltage level from 3.3 kV to 440/230 V is done by the step down transformers at the distribution substations.

The most common system for secondary distribution is 440/230 V, three phase, four wire system. The single phase residential load is connected between any one line and the neutral where as three phases 440 V, motor load is connected across the phase lines directly. The standard frequency for a.c. working is 50 Hz in India and 60 Hz for U.S.A. For single phase traction applications, frequencies as low as 25 or 16.67 Hz are also used.

Classification of transmission line

A transmission line has three constants R, L, C distributed uniformly along the whole length of the line. The resistance and inductance form the series impedance. The capacitance existing between conductors for 1-phase line or from a conductor to neutral for a 3-phase line forms a shunt path throughout the length of the line. Therefore, capacitance effect introduces complications in transmission line calculations. Depending upon the manner in which capacitance is taken into account: the overhead transmission lines are classified as:

(i) Short Transmission Line: when the length of an overhead transmission line is up to about 50 Km and the line voltage is comparatively low (<20 KV), it is usually considered as a short transmission line. Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected. Therefore, while studying the performance of a short transmission line, only resistance and inductance of the line are taken into account.

(ii) Medium Transmission Line: when the length of an overhead transmission line is about 50-150 Km and the line voltage is moderately high (>20 KV <100), it is considered as a medium transmission line. Due to sufficient length and voltage of the line, the capacitance effects are taken into account. For purpose of calculations, the distributed capacitance of the line is divided and lumped in the form of condensers shunted across the line at one or more points.

(iii) Long Transmission Line: when the length of an overhead transmission line is more than 150 Km and line voltage is very high (.100 KV), it is considered as a long transmission line. For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line and rigorous methods are employed for solution.[10]

4.6 Advantages of HVAC Transmission:

- With increase in the transmission voltage size of the conductors is reduced (Cross section of the conductors reduce as current required to carry reduces).
- As the reduction in current carrying requirement losses reduces results in better efficiency
- Due to low current voltage drop will be less so voltage regulation improves

4.7 Limitations of HVAC:

- With the increase in the voltage of transmission, the insulation required between the conductors and the earthed tower increases. This increase the cost of line support
- With increase in the voltage of transmission, more clearance is required between conductors and ground. Hence higher towers are required.
- With increase in the voltage transmission, more distance is required between the conductors. Therefore cross arms should be long.

4.8 Comparison between EHV A.C and H.V.D.C

Sr.no	points	EHV A.C	H.V.D.C
1	Voltage level	220 KV,400 KV,765 KV	± 500
2	Amount of power delivered	There is limit due to power angle and inductance	No limit
3	Equivalent essential	Step-up transformer and step-down transformer	Step-up transformer, rectifier and inverter, step-down transformer
4	Economical viability	EHVAC is economical for bulk power is to be transmitted over a long distance. 500 KM and above	HVDC is economical to transmit bulk amount of power and above. Over a long distance(800 KM and above)

5. CONCLUSIONS

The detailed introduction of HVDC and EHVAC have been discussed. The comparison between both techniques have been presented. From this it is been proved that for higher voltage levels, HVDC transmission is better up to certain distance. The losses are less and corona, skin effect is not present in HVDC. Thus the advantages of HVDC are presented with proper comparison with EHVAC.

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