Introduction of HVDC Transmission System

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Evolution of Power System

Late 1870s	Commercial use of electricity
1882	First Electric power system (Gen., cable,fuse,load) by Thomas Edition at Pearl Street in Newyork. -dc system, 59 customers, 1.5 km in radius -110 V load, underground cable, incandescent Lamps
1884 1886	Motors were developed by Frank Sprangue Limitation of dc become apparent -High losses and voltage drop. -Transformation of voltage required. Transformer and ac distribution(150 Lamps)developed by William Stanley of Westinghouse
	N. Tesla developed polyphase system and had patents of generator, motors, transmission, transmission Lines. Westinghouse bought it.

Evolution of Power System.........

1889	First ac transmission system in USA between Willamette Falls and Portland, Oregon. -1 phase, 4000V, over 21 km
1890	Controversy on whether industry should standardize ac or dc. Edison advocated dc and Westinghouse ac -voltage increase, simpler and cheaper generator and motors
1893	First 3-phase line, 2300 V, 12 km in California. *AC was chosen at Niagra Falls(30 km)*
	Early Voltage (Highest)
1922	165 kV
1923	220kV
1935	287kV
1953	330kV
1965	500kV
1966	735kV
	765kV
	1100kV
	Standards are 115, 138,161,230kV,-HV
	345,500,765kV -EHV

Evolution of Power System.........

	Earlier Frequencies were 25,50,60,125 and 133 Hz; USA -60 Hz and some countries-50 Hz
1880-1911	HVDC Transmission System A system of HV DC transmission was designed by a French engineer, Rene Thury when the ac system was in their infancy. At least 11 Thury system were installed in Europe. The prominent was Mounteirs to Lyons(France) in 1906. 180 km(4.5 km underground cable), 4.3 MW,57.6kV,75 A. -DC Series generator were used -Constant control current mode of operation

Evolution of Power System.........

1938 1920	All Thury system were dismantled. Transverter were developed. It is poly-phase transformer commutated by synchronously rotating bus gear. But not used commercially.
1950s 1954	Mercury Arc Valve First HVDC transmission between Sweden and Gotland island by cable(70 km)

Limitations of HVAC Transmission

- Reactive Power Loss
- Stability
- Current Carrying Capacity
- Skin and Ferranti Effect
- Power flow control

Comparison of AC and DC Transmission

The two modes of transmission can be compared based on following aspects:-

1. Economics of transmission

2. Technical Performance

3. Reliability

1. Economics of transmission

The cost of transmission line include the investment cost and operational costs. The investment cost includes costs of Right of Way (RoW) transmission towers, conductors, insulators and terminal equipment. The operational costs include mainly the cost of losses.

To transmit same power level, the number of conductors required to transmit DC is two (with positive and negative polarities with respect to ground).But AC transmission requires three conductors. This implies that for a given power level DC line requires less Row, simpler and cheaper towers and reduced conductors and insulator costs.

The power losses are also reduced with DC as there are only two conductors. The skin effect, corona loss and radio interference are lower for a DC line. The dielectric losses in case of power cables [illegible]ry low for DC transmission.

Economics of transmission……

The other factors that influence the line costs are the costs of compensation and terminal equipment. DC lines do not require compensation but the terminal equipment costs are increased due to the presence of converters and filters.

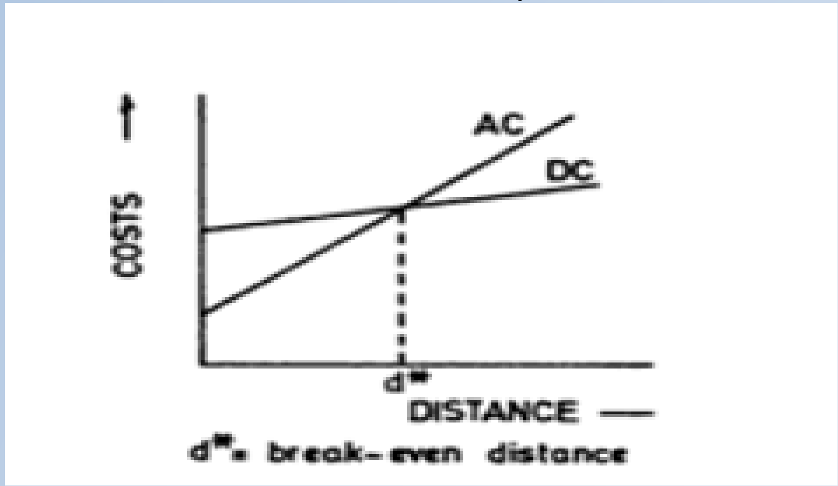


Fig 1 Variation of costs with line length

Fig.1 shows the variation of costs of transmission with distance for nd DC transmission. AC tends to be more economical than DC distances less than 'break even distance' and costlier for longer nces. The break even distances can vary from 500 to 800 km erhead lines depending on the per unit line costs.

2.Technical Performance

The DC transmission has 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:

1.Full control over power transmitted.

2.The ability to enhance transient and dynamic stability in associated AC networks.

3.Fast control to limit fault current in DC lines. This makes it [illegible]ble to avoid DC breakers in two terminal DC links.

Technical Performance…….

In addition, the DC transmission overcomes some of the problem of AC transmission. These are described below:

Stability Limits:-

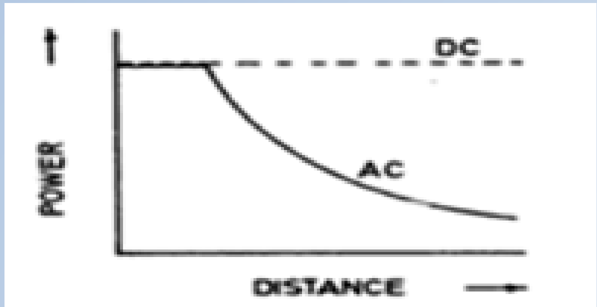


Fig 2. Power transfer capability Vs distance

The power transfer in AC lines is dependent on the angle difference between the voltage phasors at the two ends. For a given power level, the angle increases with distance. The maximum power transfer is limited by the considerations of steady state and transient stability. The power carrying capability of an AC line ...ction of distance is shown in figure 2. The same figure also ... the power carrying capability of DC lines which is ...ted by the distance of transmission.

Voltage Control

The voltage profile in a AC line is relatively flat only for a fixed level of power transfer corresponding to surge impedance loading. For constant voltage at the line terminals, the midpoint voltage is reduced for line loading higher than SIL and increased for loadings less than SIL.

The maintenance of constant voltages at two ends require reactive power control from inductive to capacitive as the line loading is increased.

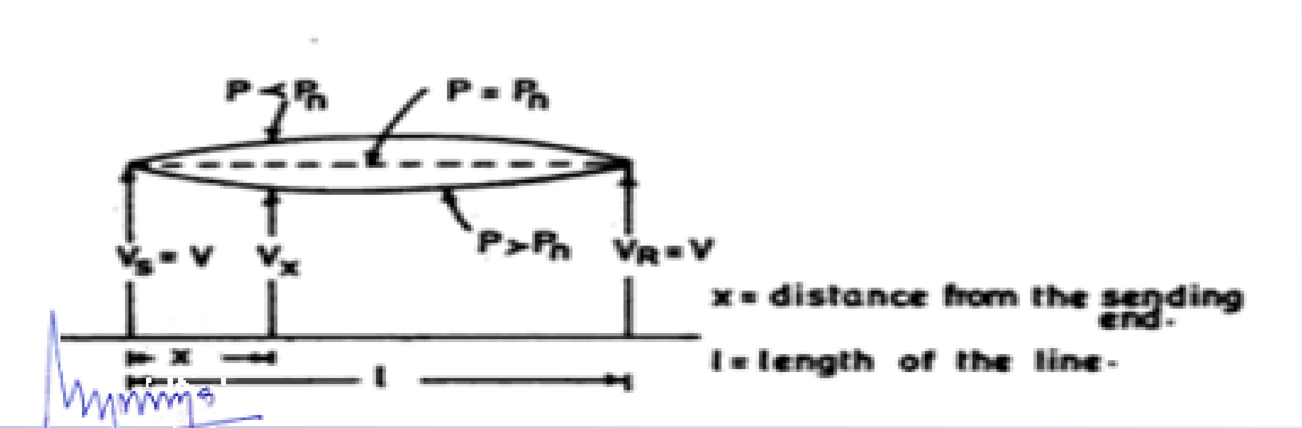


Fig. 3 Variation of voltage along the line

Line compensation

In AC line, the reactive power generated by the line capacitance equals the reactive power absorbed by the line inductance only when the load impedance is equal to SIL.The power transmitted will be maximum(Pn)called natural loading power .Since the loads vary with time, the voltage profile will change as shown in fig.3 If the load is greater than natural load (P>Pn),the reactive power absorbed by the line inductance is more and must be supplied from one or both ends. Since $Qr \; \alpha \; \Delta v$, voltage profile falls down. At light load (P<Pn),the reactive power absorbed by the line inductance is less than reactive power generated by the line capacitance and voltage profile is above the SIL. Thus reactive power must be absorbed during light load periods and must be supplied during high load periods.

In dc, no reactive power is transmitted, voltage drop is resistive drop. So in AC, reactive power compensations are provided series capacitors and shunt inductors.

Problems of AC interconnection

When two power systems are connected through AC ties, the automatic generation control of both systems have to be coordinated using tie line power and frequency signal. It has problems like

- Presence of large power oscillations which can lead to frequent tripping.
- Increase in fault levels.
- Transmission of disturbance from one system to the other.

The controllability of power flow in DC lines eliminates the above problems. In addition asynchronous DC ties, there is no need of coordinated control. Hence DC ties are used to interconnect two AC systems with different frequencies.

Disadvantages of DC transmission

- The difficulty of breaking DC currents which results in high cost of DC breakers
- Inability to use transformers to change voltage levels
- High cost of conversion equipment
- Generation of harmonics, which requires AC and DC filters, adding to the cost of converter stations
- Complexity of control of converters

Over the years, there have been significant advances in DC transmission, which have tried to overcome the disadvantages listed above. These are

- Development of DC breakers
- Modular construction of thyristor valves
- Increase in ratings of thyristor cells that make up a valve
- Twelve pulse operation of converters
- Use of metal oxide gapless arresters
- Application of various control techniques and fibre optic in control of converters

3. Reliability of HVDC System

The reliability of DC transmission system is quite good and comparable to that of AC systems. The performance of thyristor valves is much more reliable than mercury arc valves. Further developments like direct light triggered thyristor (LTT) and new techniques of control and protection have improved reliability levels.

There are two measures of overall system reliability-**Energy availability** and **transient reliability**.

Energy Availability

This is defined as

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

Where equivalent outage time is the product of the actual outage time and the fraction of system capacity lost due to outage.

Transient Reliability

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

Transient reliability =

$$\left(\frac{100 * No. of\ times\ HVDC\ systems\ performed\ as\ designed}{No. of\ recordable\ AC\ faults}\right)\%$$

Recordable AC system faults are those faults which cause one or more AC bus phase voltages to drop below 90 % of the voltage prior to the fault. It is assumed that the short circuit level after the fault is not below the minimum specified for satisfactory converter operation.

Both energy availability and transient reliability of existing DC systems with thyristor valves is 95 % or more.

The average failure rate of thyristors in a valve is less than 0.6 % per operating year. It is common practice to provide redundant thyristors in [illegible]s string composing a HVDC valve, so that failed thyristors can be [illegible] during scheduled maintenance (once or twice a year). The [illegible]nce of the thyristor valves is also much simpler than the earlier [illegible]arc valves.

Outage statistics of HVDC is given in the following table indicating mean time to failure(MTTF) and mean time to repair(MTTR)

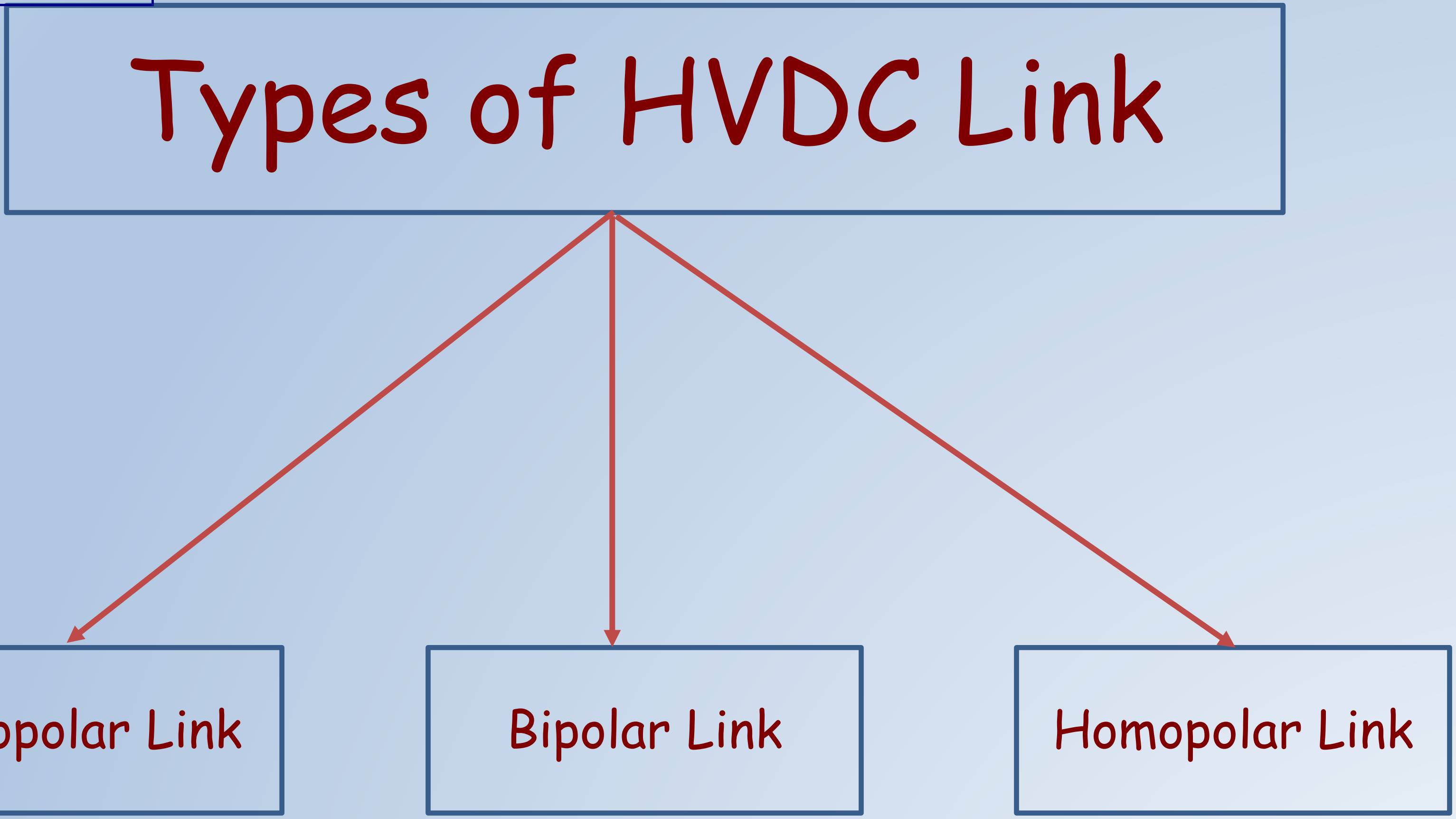
Equipment	MTTF (years)	MTTR (hours)
Thyristor group	13.7	6.1
Converter transformer	16.1	1700.0
Smooothing reactor	76.8	1700.0
DC filter	19.7	7.9
AC filter	12.6	9.3
Master control	25.0	6.9
Pole control	9.0	8.6
Pole of transmission line	1.25/100 km	1.5
DC line switch	147.2	7.8

While comparing the reliability of various alternatives, it must be ...red that the bipolar DC line can be as reliable as a double circuit ...ith the same power capability. This is because of the fact that ...ent of failure of one pole of DC system, the other pole can ... least 50 % energy with ground return.

Application of DC transmission

The detailed comparison of AC and DC transmission in terms of economics and technical performance, leads to the following areas of application for DC transmission:

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


Types of HVDC Link
Monopolar Link
Bipolar Link
Homopolar Link

1. Monopolar Link

This link has only one conductor as shown in fig.4 usually negative polarity and uses ground or sea water as the return conductor. The -ve polarity is preferred on overhead lines due to lesser radio interference.

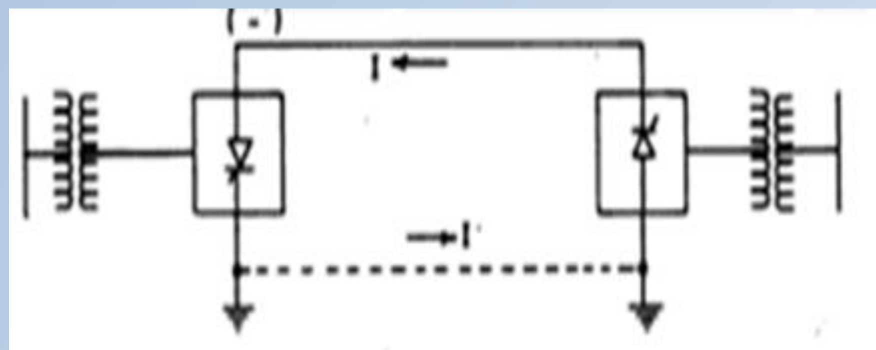


Fig. 4 Monopolar Link

The ground return means return path through ground or sea. Most of dc transmission lines use ground return for reason of economy and reliability. The resistance is low ... erefore low power loss as compared to metallic ... or path provided the ground electrodes are ... y designed.

2.Bipolar Link

This DC link has two conductors one positive and other negative. Each terminal has two set of converter of identical ratings, connected in series on dc side as shown in fig.5. The junction between the two sets of converters is grounded at both ends. Both poles operates at equal current and hence there is zero ground current flowing under these condition. Whenever fault occurs in any one pole, the other pole continue to supply power to the load with ground return.

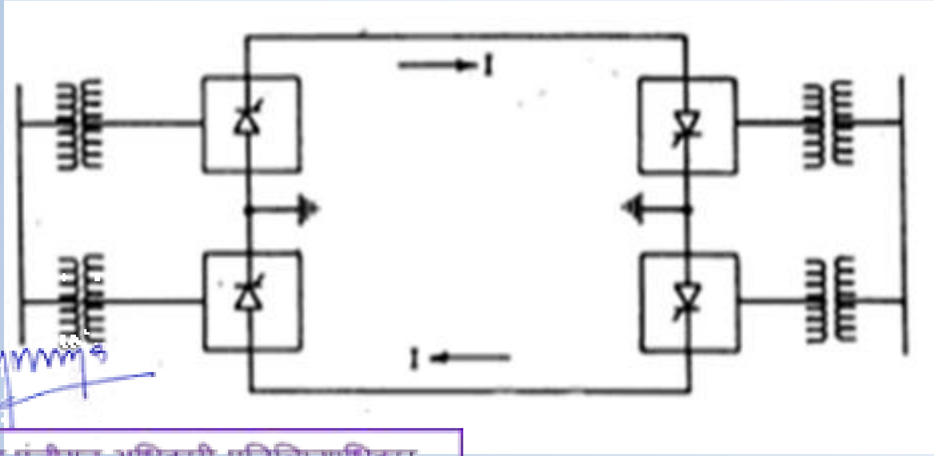


Fig. 5 Bipolar Link

3.Homopolar Link

This DC link has two or more conductors having same polarity (usually – ve)as shown in fig.6 and always operated with ground or metallic return. If any fault occurs in one pole, the other pole continue to supply half the power to the load with ground return. The difference between bipolar and homopolar under fault condition is that, bipolar require control over the converter station to reverse or reconnect the converter which is complicated. Hence homopolar and monopolar uses ground return permanently and bipolar use it under fault condition only.

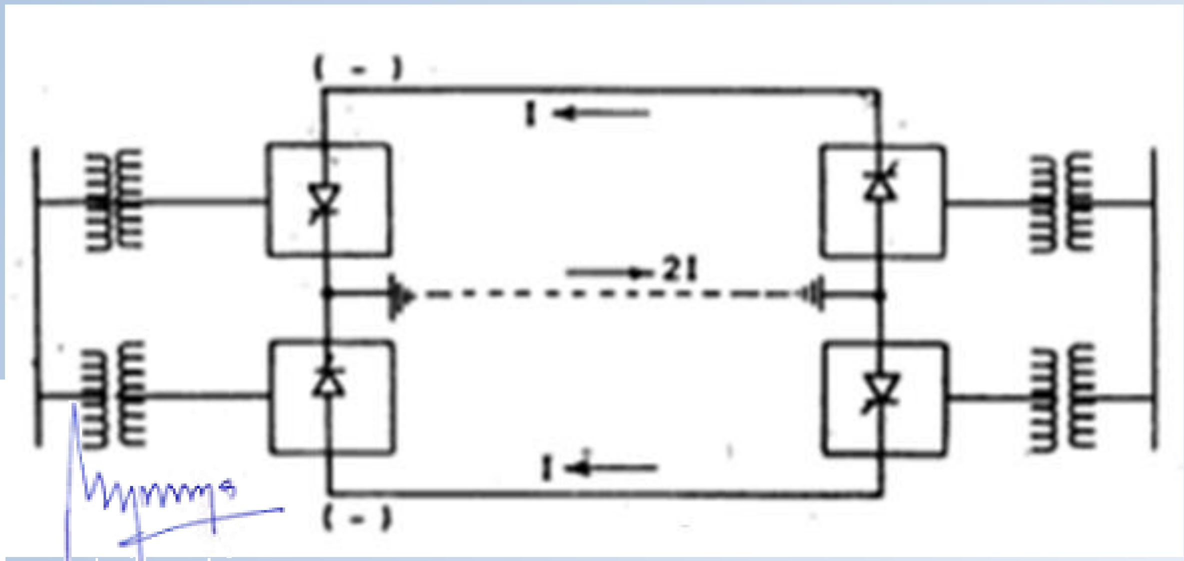


Fig. 6 Homopolar Link

Main Components of HVDC Converter Station System

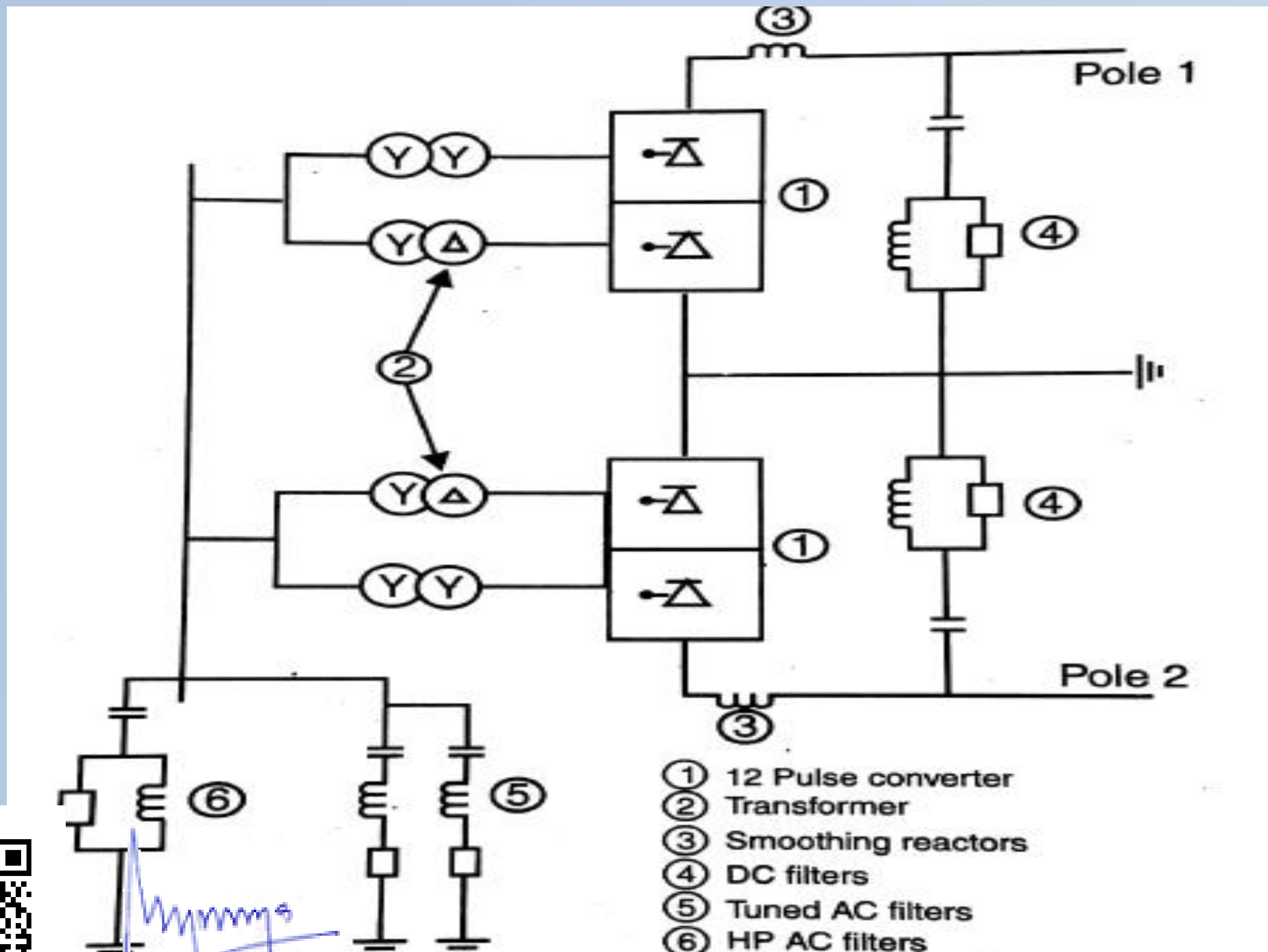
- Converter Unit
- Converter Transformer
- Filters
- Reactive power source
- Smoothing Reactor
- Switchgear

Main Components of HVDC Converter station System ......

The major component s of a HVDC transmission system are converter stations where conversions from AC to DC (Rectifier station) and from DC to AC(Inverter station) are performed. A point to point transmission requires two converter stations. The role of rectifier and inverter station can be reversed (resulting in power reversals) by suitable converter control.

A typical converter station with one 12 pulse converter unit per pole, is shown in fig. 7

Schematic diagram of a typical HVDC Converter Station



. 7 Schematic diagram of a typical HVDC converter station

Converter Unit

This usually consists of two three converter bridges connected in series to form a 12 pulse converter unit as shown in figure 8. The total number of valves in such unit are twelve. The valves can be packaged as a single valve, double valve or quadrivalve arrangements. Each valve is used to switch in a segment of an AC voltage waveform. The converter is fed by converter transformers connected in Y / Y and Y /Δ arrangements.

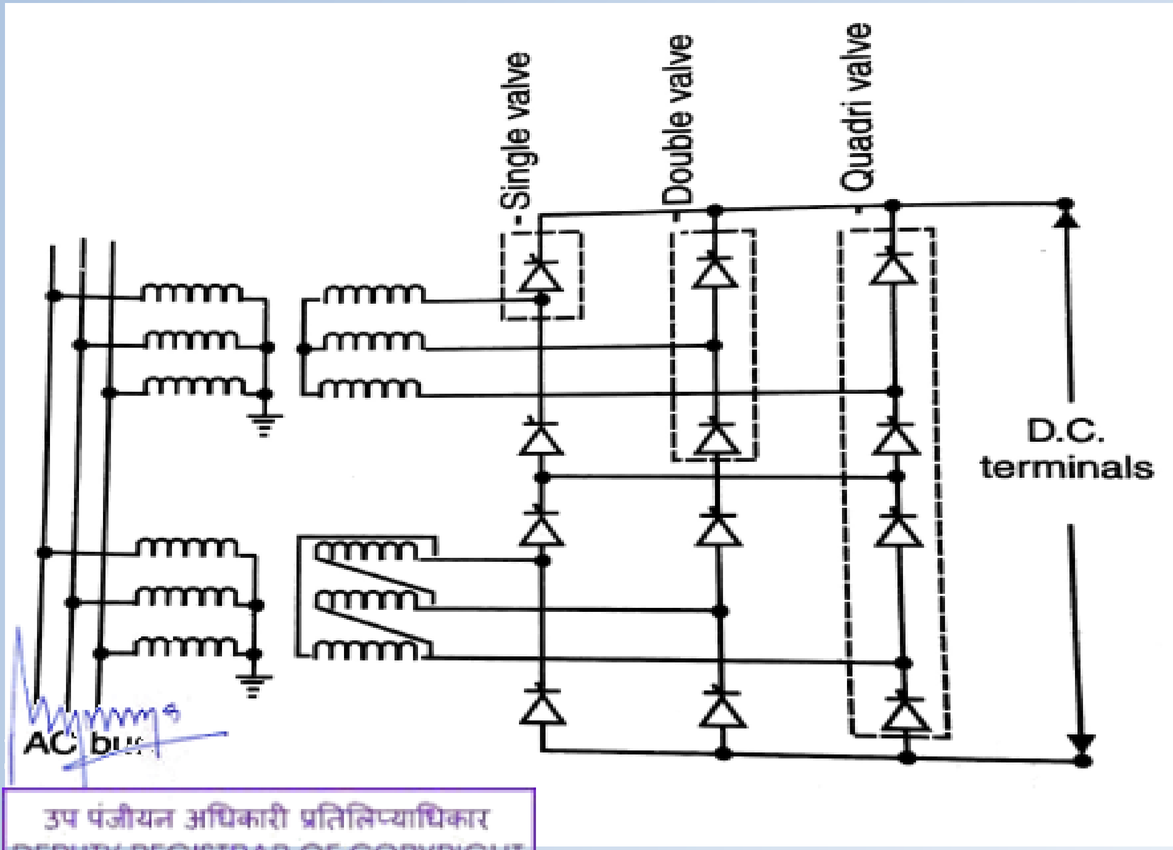


Fig 8. Twelve pulse converter unit

Converter Unit……

The valves can be cooled by air, oil, water or feon. Liquid cooling using deionized water is more efficient and results in the reduction of station losses. The ratings of a valve group are limited more by the permissible short circuit currents than steady state load requirements. The design of valves is based on the modular concept where each module contains a limited number of series connected thyristor levels.

Valve firing signals are generated in the converter control at ground potential and are transmitted to each thyristor in the valve through a fiber optic light guide system. The light signal received at the thyristor level is converted to an electrical signal using gate drive amplifiers with pulse transformers.

The valves are protected using snubber circuits, [illegible]rive firing and gapless surge arresters.

HVDC Converter Transformers & Filters

Fig 9. HVDC Converter Transformers & Filters

Converter Transformer

The converter transformer can have different configurations- (i)three phase, two winding(ii)Single phase, three winding (iii)Single phase, two winding. In fig. 10 the valve side windings are connected in star and delta with neutral point ungrounded. On the AC side, the transformer are connected in parallel with neutral grounded. The leakage reactance of the transformer is chosen to limit the short circuit currents through any valve.

The converter transformer are designed to withstand DC voltage stresses and increased eddy current losses due to harmonic currents. One problem that can arise is due to the DC magnetization of the core due to unsymmetric firing of valves.

In back to back links, which are designed for low DC voltage levels, an extended delta configuration can result in identical transformers being used in twelve pulse converter units. This ... in the reduction of the spare capacity required. However, ... formance of extended delta transformers in practice is still ...sted.

Converter Transformer…….

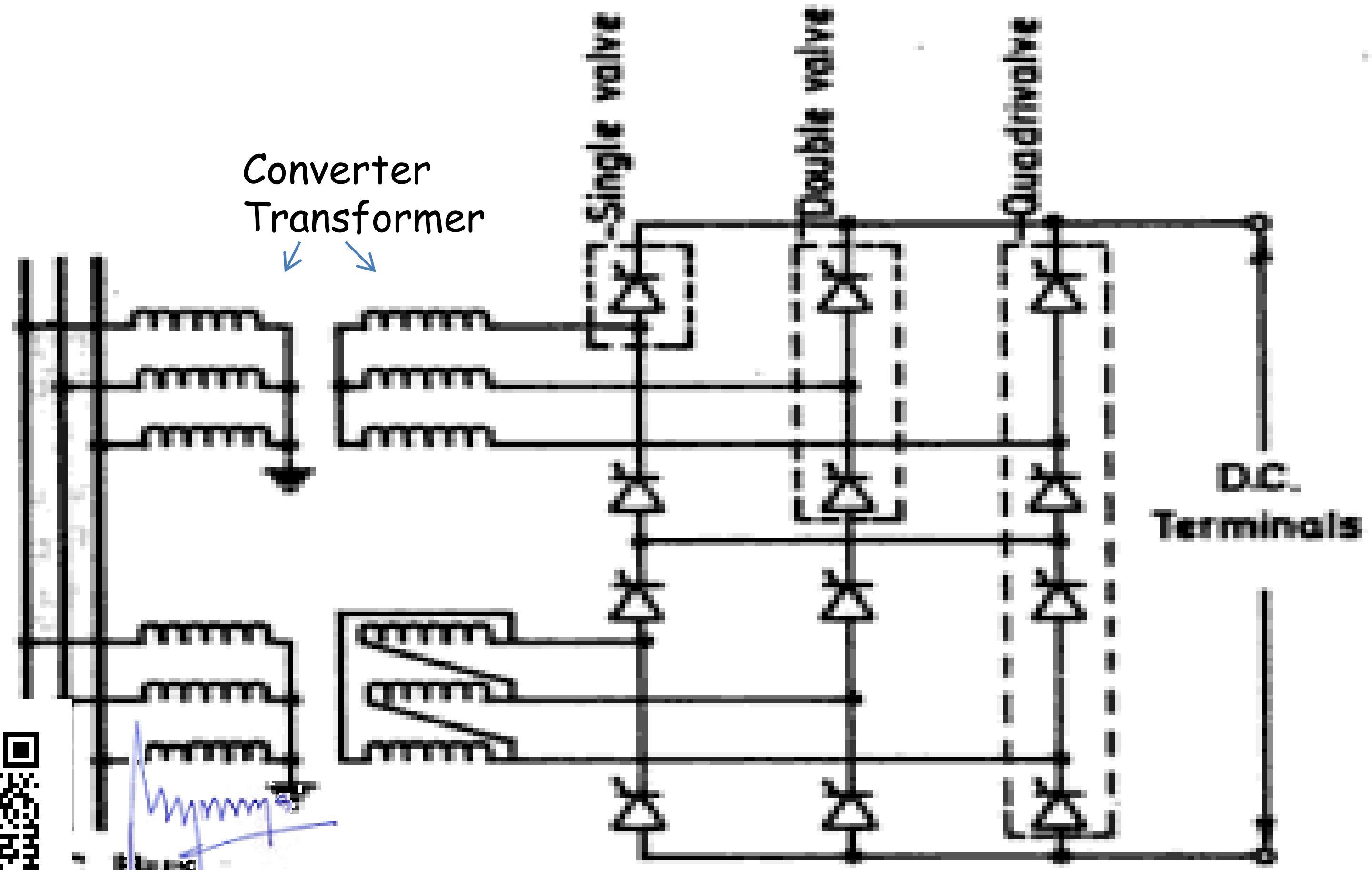


Fig. 10 Converter Transformer

Filters

There are three types of filters used:

1.AC filters : These are passive circuits used to provide low impedance, shunt paths for AC harmonic currents. Both tuned and damped filter arrangements are used.

2. DC filters: These are similar to AC filters and are used for the filtering of DC harmonics.

3.High frequency (RF/PLC) filters: These are connected between the converter transformer and the station AC bus to suppress any high frequency currents. Sometimes such filters are provided on high voltage DC bus connected between the DC filter and DC line and also on neutral side.

Reactive Power Source

Converter stations require reactive power supply that is dependent on the active power loading (about 50 to 60 % of the active power). Fortunately, part of this reactive power requirement is provided by AC filters. In addition, shunt (switched) capacitors, synchronous condensers and static var systems are used depending on the speed of control desired.

Smoothing Reactor

A sufficiently large series reactor is used on DC side to smooth DC current and also for protection. The reactor is designed as a linear reactor and is connected on the line side, neutral side or at intermediate location.

DC Switchgear

This is usually a modified AC equipment used to interrupt small DC currents (employed as disconnecting switches). DC breakers or metallic return transfer breakers (MRTB) are used, if required for interruption of rated load currents.

In addition to the equipment described above, AC switchgear and associated equipment for protection and measurement are also part of the converter n.

References

1. HVDC Power Transmission Systems: K. R. Padiyar, Wiley Eastern L.
2. NPTEL Lectures.

Thank You !