

Analysis of HVDC Power Transmission Line with Unique Power Control Room

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Abstract: *A high-voltage, direct current (HVDC) electric power transmission system (also called a power super highway or an electrical super highway) uses direct current for the bulk transmission of electrical power, in contrast with the more common alternating current (AC) systems. For long-distance transmission, HVDC systems may be less expensive and suffer lower electrical losses. For underwater power cables, HVDC avoids the heavy currents required to charge and discharge the cable capacitance each cycle. For shorter distances, the higher cost of DC conversion equipment compared to an AC system may still be justified, due to other benefits of direct current links. HVDC allows power transmission between unsynchronized AC transmission systems. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows transfer of power between grid systems running at different frequencies, such as 50 Hz and 60 Hz. This improves the stability and economy of each grid, by allowing exchange of power between incompatible networks.*

Keywords: Power Transmission Line, Flexible AC Transmission Systems (FACTS), High Voltage Direct Current (HVDC), power system

1. Introduction

High voltage is used for electric power transmission to reduce the energy lost in the resistance of the wires. For a given quantity of power transmitted, doubling the voltage will deliver the same power at only half the current. Since the power lost as heat in the wires is proportional to the square of the current for a given conductor size, or inversely proportional to the square of the voltage, doubling the voltage reduces the line losses per unit of electrical power delivered by a factor of 4. While power lost in transmission can also be reduced by increasing the conductor size, larger conductors are heavier and more expensive. High voltage cannot readily be used for lighting or motors, so transmission-level voltages must be reduced for end-use equipment. Transformers are used to change the voltage levels in alternating current (AC) transmission circuits. Because transformers made voltage changes practical, and AC generators were more efficient than those using DC, AC became dominant after the introduction of practical systems of distribution in Europe in 1891 [2]

Practical conversion of power between AC and DC became possible with the development of power electronics devices such as mercury-arc valves and, starting in the 1970s, semiconductor devices as thyristors, integrated gate-commutated thyristors (IGCTs), MOS-controlled thyristors (MCTs) and insulated-gate bipolar transistors (IGBT). The modern form of HVDC transmission uses technology developed extensively in the 1930s in Sweden (ASEA) and in Germany. Early commercial installations included one in the Soviet Union in 1951 between Moscow and Kashira, and a 100 kV, 20 MW system between Gotland and mainland Sweden in 1954. The longest HVDC link in the world is the Rio Madeira link in Brazil, which consists of two bipoles of ± 600 kV, 3150 MW each, connecting Porto Velho in the

state of Rondônia to the São Paulo area. The length of the DC line is 2,375 km (1,476 mi) [4]

Flexible AC Transmission Systems (FACTS) technology is based on the use of power electronic controlled devices for allowing transmission circuits to be used to their maximum thermal capability. In particular the FACTS devices aim principally to control the three main parameters directly effecting AC power transmission namely voltage, phase angle, and impedance. High Voltage Direct Current (HVDC) transmission is parallel technology using power electronics and is not normally included as a FACTS technology. [2]

1.1 Motivation and Objective

A transmission line basically consist two or more parallel conductors to connect the source to the consumer or the load. Uniform transmission line is that whose parameter doesn't change with per unit length. Transmission line parameters are R-L-C-G. the HVDC system has followings objectives-

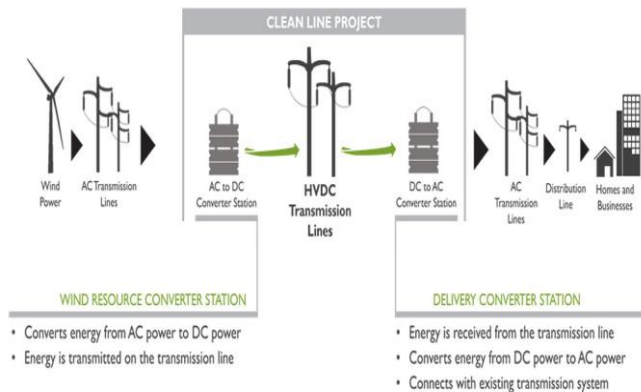
- Losses is occurs in all the stages of the generation transmission and distribution. The losses at the transmission level can be mitigate by the hvdc system.
- It can interconnect the different power system having different frequency.
- For long distance high power transmission by over head line and underground line and for frequency conversion 60-50 hz and 50-25hz.

2. Planning for HVDC Transmission Line

HVDC projects for long-distance transmission have two (or rarely, more) converter stations and a transmission line interconnecting them. Generally overhead lines are used for

interconnection, but important classes of HVDC projects use submarine power cables. A back-to-back station has no transmission line and connects two AC grids at different frequencies or phase counts. Historical HVDC systems used the Thury system of motor-generators but these have all been made obsolete by later developments such as mercury-arc valves, thyristors, and IGBT power transistors.

DELIVERING RENEWABLE ENERGY WITH HVDC



3. Design and Modeling of Transmission Line

3.1 Introduction

An Electrical transmission line can be represented by a series combination of resistance, inductance and shunt combination of conductance and capacitance. these parameters are symbolized as R, L, G and C respectively, of these R and G are least important in the sense that they do not effect much the total equivalent impedance of the line and hence the transmission capacity.[1] They are of course very much importance when transmission efficiency and economy are to be evaluated as they completely determine the real transmission line losses. The resistance of a conductor is given by

$$R = \text{power loss in conductor} / I^2 \text{ ohms} \quad 3.1$$

Where R is the effective resistance of the conductor and I the current flowing through the conductor. The effective resistance is equal to the D.C resistance of the conductor only if the current is uniformly distributed throughout the section of the conductor. Difference in the D.C resistance and effective resistance to frequencies less than 50 Hz is less than 1 percent for copper conductors of section less than 350,000 circular mils. The loss on the overhead transmission line is due to

- 1) Ohmic loss in the power conductors
- 2) Corona loss
- 3) Leakage at the insulators which support the lines at the towers

The performance of lines is meant the determination of efficiency and regulation of lines

$$\% \text{ efficiency} = \text{power delivered at the receiving end} / \text{power sent from the sending end} * 100 \quad 3.2$$

Regulation of a line is defined as the change in the receiving end voltage, expressed in percent of full load voltage, from no load to full load, keeping the sending end voltage and frequency constant. Expressed mathematically,

$$\% \text{ regulation} = (V_r' - V_r) / V_r * 100 \quad 3.3$$

Where V_r' is the receiving end under no load condition and V_r the receiving end voltage under full load condition. It is to be noted here that V_r' and V_r are the magnitudes of voltage.[9]

3.2 Representation of transmission lines

A transmission line is a set of conductors being run from one place to another supported on transmission towers. Such lines, therefore, have four distributed parameters, series resistance and inductance and shunt capacitance and conductance.[15] it is to be noted that the electrical power is being transmitted over the overhead lines at approximately the speed of light. In order to get one full wave variation of voltage or current on the line, the length of the line for 50 Hz supply will be given by

$$f * \lambda = v \quad 3.4$$

where f is the frequency of supply, λ is wavelength i.e the length of the in this case and v the velocity of the wave i.e the velocity of light

$$\lambda = v / f = 6000 \text{ Km} \quad 3.5$$

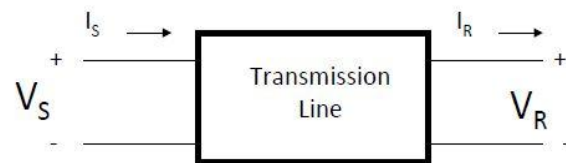


Figure: Transmission Line

This means that if the length of the line is 6000 Km the voltage or current wave at the two ends of the line Transmission lines have been classified as lang and medium and short lines depending on the length of the lines. These are

Upto 80km---short line

80 to 160km-----medium line

Above 160km----long transmission line

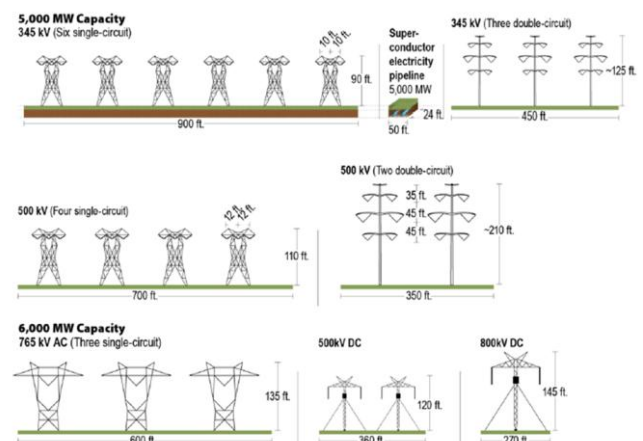


Figure: different types of tower for transmission line

3.3 Cable systems

Long undersea / underground high-voltage cables have a high electrical capacitance compared with overhead transmission lines, since the live conductors within the cable are surrounded by a relatively thin layer of insulation (the dielectric), and a metal sheath. The geometry is that of a long co-axial capacitor. The total capacitance increases with the length of the cable. This capacitance is in a parallel circuit with the load. Where alternating current is used for cable transmission, additional current must flow in the cable to charge this cable capacitance. This extra current flow causes added energy loss via dissipation of heat in the conductors of the cable, raising its temperature. Additional energy losses also occur as a result of dielectric losses in the cable insulation.[15]

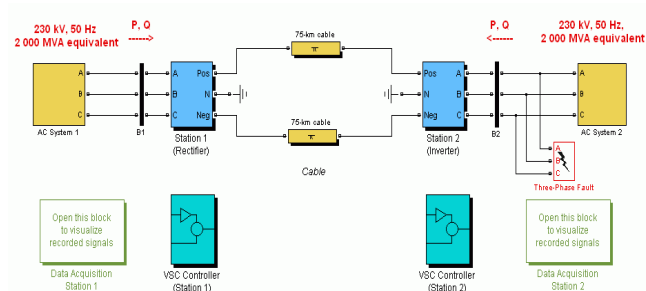


Figure: Cable systems

3.4 Overhead Line Systems

The capacitive effect of long underground or undersea cables in AC transmission applications also applies to AC overhead lines, although to a much lesser extent. Nevertheless, for a long AC overhead transmission line, the current flowing just to charge the line capacitance can be significant, and this reduces the capability of the line to carry useful current to the load at the remote end. [6] Another factor that reduces the useful current carrying ability of AC lines is the skin effect, which causes a non-uniform distribution of current over the cross-sectional area of the conductor. Transmission line conductors operating with direct current do not suffer from either of these constraints. Therefore, for the same conductor losses (or heating effect), a given conductor can carry more current to the load when operating with HVDC than AC.[11]



Figure: Overhead line systems

3.5 Asynchronous Connections

Because HVDC allows power transmission between unsynchronized AC distribution systems, it can help increase system stability, by preventing cascading failures from propagating from one part of a wider power transmission grid to another. Changes in load that would cause portions of an AC network to become unsynchronized and to separate, would not similarly affect a DC link, and the power flow through the DC link would tend to stabilize the AC network. The magnitude and direction of power flow through a DC link can be directly controlled, and changed as needed to support the AC networks at either end of the DC link. This has caused many power system operators to contemplate wider use of HVDC technology for its stability benefits alone.[4]

4. Components of HVDC Transmission System

Following components are used in HVDC system:

- a) Convertors
- b) Smoothing reactors
- c) Harmonics filters
- d) DC link
- e) Electrodes
- f) Circuit breaker
- e) Reactive power source

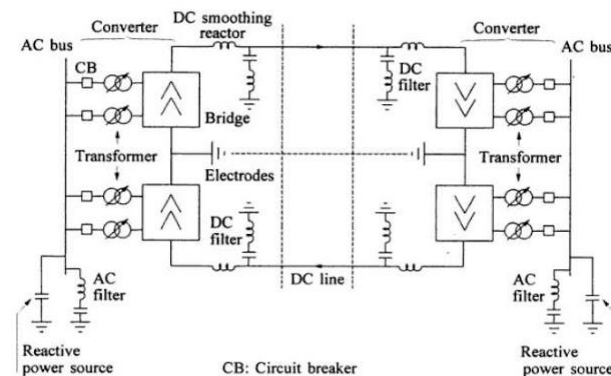


Figure: main components of HVDC system

4.1 Converter

At the heart of an HVDC converter station, the equipment which performs the conversion between AC and DC is referred to as the converter. Almost all HVDC converters are inherently capable of converting from AC to DC (rectification) and from DC to AC (inversion), although in many HVDC systems, the system as a whole is optimized for power flow in only one direction. Irrespective of how the converter itself is designed, the station which is operating (at a given time) with power flow from AC to DC is referred to as the rectifier and the station which is operating with power flow from DC to AC is referred to as the inverter.[7]

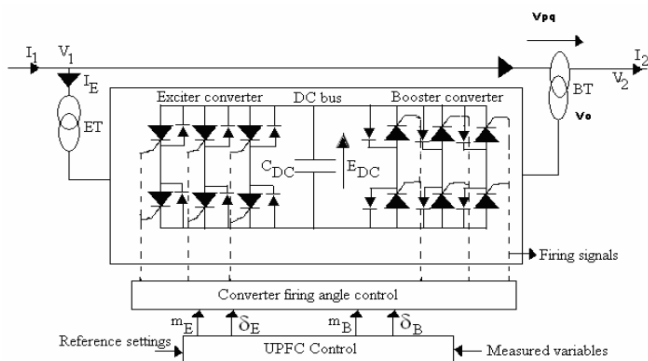


Figure: back-to-back voltage sourced converters.

4.2 Harmonic Filter

All power electronic converters generate some degree of harmonic distortion on the AC and DC systems to which they are connected, and HVDC converters are no exception. With the recently developed Modular Multi Level Converter (MMC), levels of harmonic distortion may be practically negligible, but with line commutated converters and simpler types of voltage source converters, considerable harmonic distortion may be produced on both the AC and DC sides of the converter. As a result, harmonic filters are nearly always required at the AC terminals of such converters, and in HVDC transmission schemes using overhead lines, may also be required on the DC side.[14]

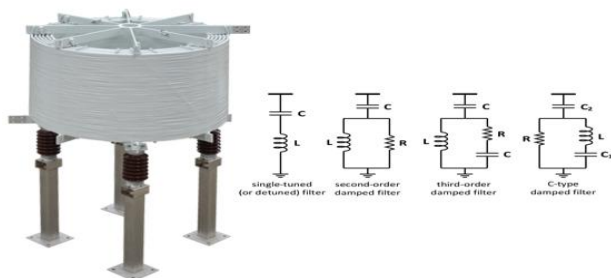


Figure: Harmonic Filter

4.3 DC Link

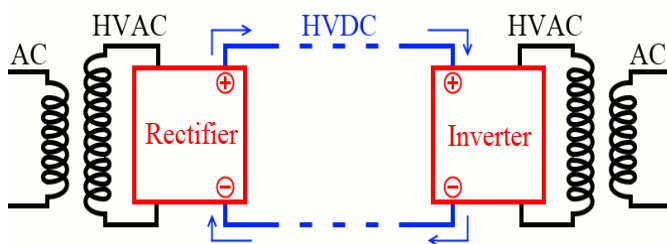


Figure: DC link

4.4 Electrodes

Electrodes are conductors that provide connection to the earth for neutral. They have large surface to reduce the current densities and surface voltage gradients.

4.5 Circuit Breaker

They use to clear the fault in the transformer and disconcert to the DC link. They not use to clear the DC fault in circuit. DC fault is removed by the convertor control more rapidly. HVDC circuit breakers are difficult to build because some mechanism must be included in the circuit breaker to force current to zero, otherwise arcing and contact wear would be too great to allow reliable switching.



Figure: Circuit Breaker

4.6 Reactive Power Source

Under the steady state condition the convertor consume the i^2x power about the 50% of the active power transferred. Under the transient condition it will very huge. reactive power is therefore achieves near about the convertors. In strong power system this power is provides by the shunt capacitors.[16]

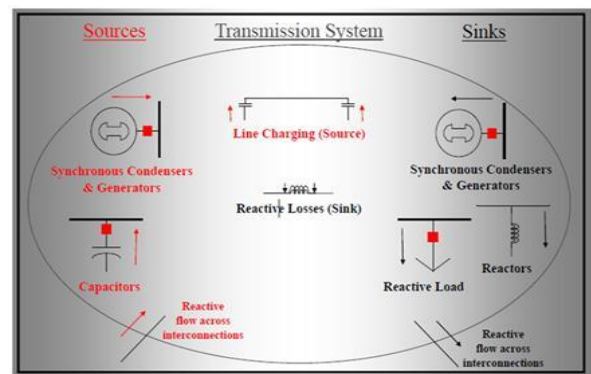


Figure: Reactive Power Source

4.7 Smoothing Reactor

It is used to remove the ac component exist in the HVDC transmission system. It offer the reactance path for the AC component of the power transmitted through the circuit.

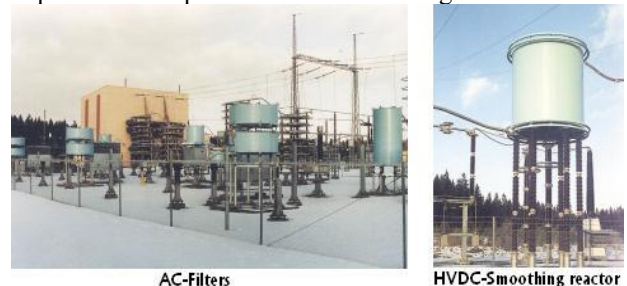


Figure: HVDC Smoothing Reactor

5. Configurations of HVDC Transmission System

5.1 Monopolar link

Monopole In a common configuration, called monopole, one of the terminals of the rectifier is connected to earth ground. The other terminal, at a potential high above or below ground, is connected to a transmission line. The earthed terminal may be connected to the corresponding connection at the inverting station by means of a second conductor.

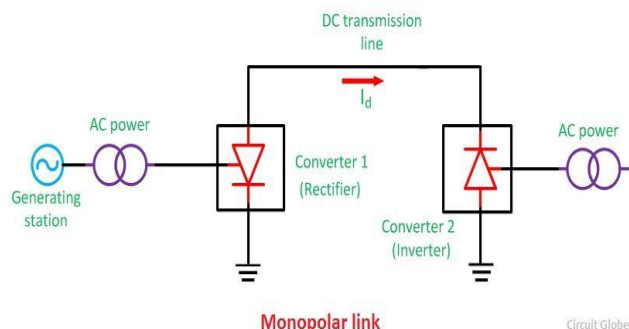


Figure: Monopolar link

5.2 Bipolar Link

In bipolar transmission a pair of conductors is used, each at a high potential with respect to ground, in opposite polarity, one positive and another is negative with respect to earth. Currents in two poles are equal there is no ground current. Since these conductors must be insulated for the full voltage, transmission line cost is higher than a monopole with a return conductor. However, there are a number of advantages to bipolar transmission which can make it an attractive option.

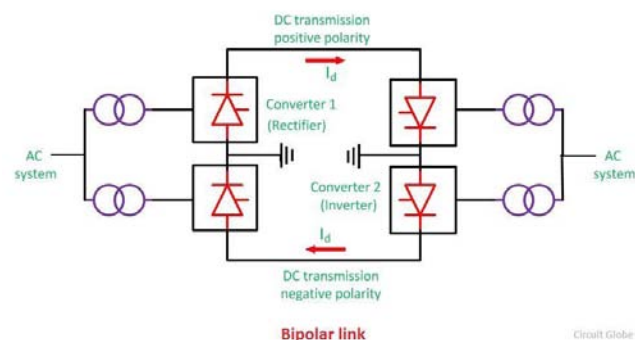


Figure: bipolar link

5.3 BACK TO BACK

Back to back a back to back station (or b2b for short) is a plant in which both converters are in the same area, usually in the same building. The length of the direct current line is kept as short as possible.

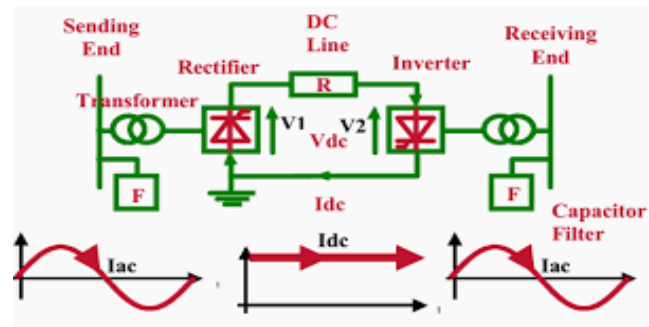


Figure: back to back link

6. Cost of HVDC Transmission System

Generally, providers of HVDC systems, such as Alstom, Siemens and ABB, do not specify cost details of particular projects. It may be considered a commercial matter between the provider and the client. Costs vary widely depending on the specifics of the project (such as power rating, circuit length, overhead vs. cabled route, land costs, and AC network improvements required at either terminal). A detailed comparison of DC vs. AC transmission costs may be required in situations where there is no clear technical advantage to DC, and economical reasoning alone drives the selection. However, some practitioners have provided some information: For an 8 GW 40 km link laid under the English Channel, the following are approximate primary equipment costs for a 2000 MW 500 kV bipolar conventional HVDC link (exclude way-leaving, on-shore reinforcement works, consenting, engineering, insurance, etc.).[2]

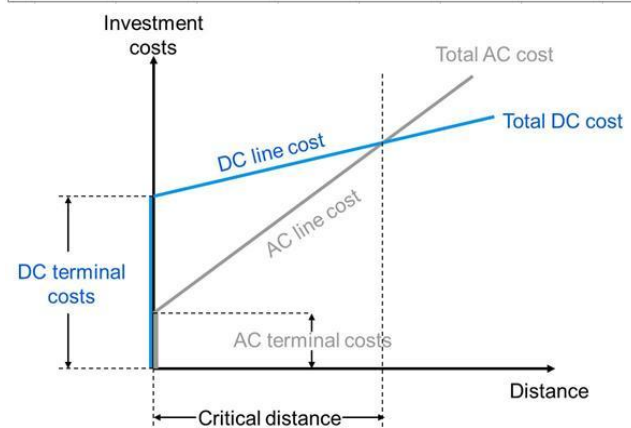
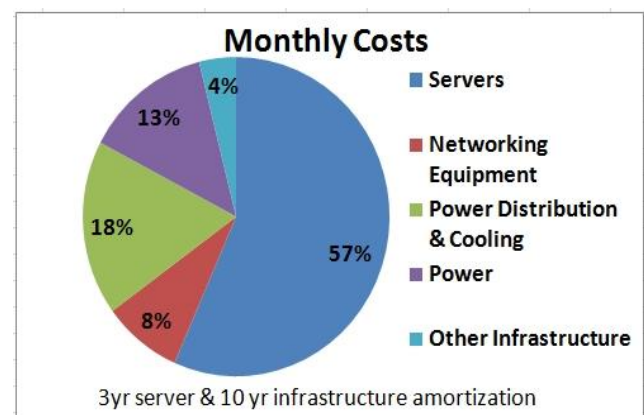


Figure: Cost analysis of AC and DC transmission system

7. Control Room

A control room, operations center, or operations control center (OCC) is a room serving as a central space where a large physical facility or physically dispersed service can be monitored and controlled. A control room will often be part of a larger command center. Control room means the location at which asset owners have facilities to receive operational instructions from the system operator and to act on those instructions. Control rooms are usually equipped with elaborate fire suppression and security systems to safeguard their contents and occupants, and to ensure continued operation in emergencies.[8] In hazardous environments, the control room may also serve as an area of refuge for personnel trapped onsite. The rooms are typically crammed with equipment, mounted in multi-function rack mount cabinets to allow updating. The exits equipment often requires special electrical uninterruptible power supply (UPS) feeds and air conditioning.

Since the control equipment is intended to control other items in the surrounding facility, these (often fire-resistance rated) service rooms require many penetrations for cables. Due to routine equipment updates these penetrations are subject to frequent changes, so that a control room maintenance program must include vigilant fire stop maintenance for code compliance.



Figure: HVDC control room

8. Merits of HVDC Transmission System

HVDC transmission may also be selected for other technical benefits.

- A long distance HVDC transmission approach generally has lower overall investment cost and lower losses than an equivalent AC transmission scheme.
- HVDC conversion equipment at the terminal stations is costly, but the total DC transmission line costs over long distances are lower than AC line of the same distance. HVDC requires fewer conductors per unit distance than an AC line, as there is no need to support three phases and there is no skin effect.
- According to voltage level and construction details, HVDC transmission losses are analyzed about 3.5% per 1,000 km, which are 30 – 40% less than with AC lines, at the same voltage levels.

- Allowing power transmission between unsynchronized AC distribution systems, no frequency matching is required.
- Mitigate the needs of wiring and insulations for a given power transmission capacity.

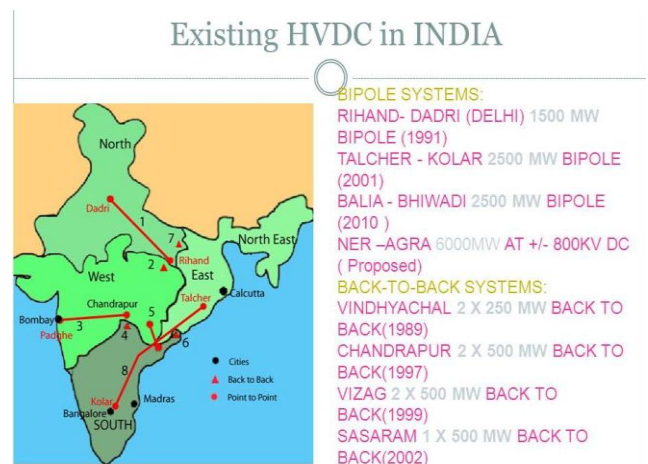
9. Demerits of HVDC Transmission System

The disadvantages of HVDC are in conversion, switching, control, availability and maintenance.

- HVDC is less reliable and has lower availability than alternating current (AC) systems, mainly due to the extra conversion equipment. Single-pole systems have availability of about 98.5%, with about a third of the downtime unscheduled due to faults. Fault-tolerant bipolar systems provide high availability for 50% of the link capacity, but availability of the full capacity is about 97% to 98%. HVDC system required converter stations are expensive HVDC system having limited overload capacity. 4. At smaller transmission distances, the losses in the converter stations may be bigger than in an AC transmission line for the same distance. The cost of the converters may not be offset by reductions in line construction cost and lower line loss.

10. Conclusion

Finally, depending upon the environmental conditions and the performance of overhead line insulation operating with HVDC, it may be possible for a given transmission line to operate with a constant HVDC voltage that is approximately the same as the peak AC voltage for which it is designed and insulated. The power delivered in an AC system is defined by the root mean square (RMS) of an AC voltage, but RMS is only about 71% of the peak voltage. Therefore, if the HVDC line can operate continuously with an HVDC voltage that is the same as the peak voltage of the AC equivalent line, then for a given current (where HVDC current is the same as the RMS current in the AC line), the power transmission capability when operating with HVDC is approximately 40% higher than the capability when operating with AC. according to voltage level and construction details, HVDC transmission losses are analyzed about 3.5% per 1,000 km, which are 30 – 40% less than with AC lines, at the same voltage levels.



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