CHAPTER 5
MANAGEMENT OF HIGH VOLTAGE DC POWER
AND ITS ECONOMICS

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5.1 INTRODUCTION
The power grid system planner must consider introducing DC transmission lines as an alternative in the grid expansion. The factors to be considered here are 1) Economics of transmission, 2) Technical performance, 3) Reliability. Generally the minimum cost option is primarily selected over technical performance and reliability for high voltage transmission.

In the future expansion planning two applications can be considered vital factors for deciding the choice of DC or AC power transmission:
1. Long distance bulk power transmission
2. Interconnection between two power systems
In the first application, the DC and AC alternatives for the same level of system security and reliability are likely to have the same power carrying capability. Thus the cost comparisons would form the basis for the selection. HVDC technology is flexible to interconnect two asynchronous networks, reduce fault currents, utilize long cable circuits, bypass network congestion, share utility right-of-way without degradation of reliability, and mitigate environmental concerns.

5.2 THE ADVANTAGES OF HVDC POWER TRANSMISSION:
1) Greater power per conductor. 2) Simpler line construction and smaller transmission towers (see figure 5.1) 3) A bipolar HVDC line uses only two insulated sets of conductors, rather than three. 4) Narrower right-of-way. 5) Low short-circuit current on D.C line. 6) Requires only one-third the insulated sets of conductors as a double circuit AC line. 7) Approximate savings of 30% in line construction. 8) Lower line losses. 9) Line power factor is always unity. 10) Line does not require reactive compensation.

![Diagram of AC and DC towers](image)

Fig. 5.1 Shows Tower Lines shape & size of AC compared to DC for the same transmission of power

5.3 STABILITY LIMITS OF DC POWER TRANSMISSION
The power transfer in AC lines is dependent on the angle difference between the voltages Phasor at the two ends. For a given power level, this 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 as a function of distance to cost is shown in Fig 5.2. Fig. 5.3 shows the power carrying capability of DC lines which is unaffected by the distance of transmission and is limited only by the current carrying capacity of the conductors termed as “thermal limit”.

\[ d^* = \text{break-even distance} = 600 \text{ Km} \]

Fig 5.2. Shows the costs versus distances  
Fig. 5.3 Power transfer capability vs. distance between AC and DC

5.3.1. Voltage Control
AC voltage regulation is affected by charging of capacitance in a transmission line and also due to inductive effect, whereas in DC the voltage regulation is affected due to only resistance of the line.

5.3.2. Reliability
The reliability of DC transmission systems is superior to that of AC systems. An exhaustive record of existing HVDC links in the world is available from which the reliability statistics have been computed.
HVDC PROJECT IN INDIA

<table>
<thead>
<tr>
<th>S. No</th>
<th>Projects</th>
<th>Year</th>
<th>Supplier</th>
<th>Power (MW)</th>
<th>Voltage (kv)</th>
<th>Line Length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NHVDC Stage – I</td>
<td>1989</td>
<td>BHEL</td>
<td>100</td>
<td>100</td>
<td>196</td>
</tr>
<tr>
<td>2</td>
<td>NHVDC Stage – II</td>
<td>2000</td>
<td>BHEL</td>
<td>100</td>
<td>200</td>
<td>196</td>
</tr>
<tr>
<td>3</td>
<td>Rihand – Delhi</td>
<td>1992</td>
<td>ABB / BHEL</td>
<td>1500</td>
<td>500</td>
<td>814</td>
</tr>
<tr>
<td>4</td>
<td>Chandrapur – Padghe</td>
<td>1998</td>
<td>ABB / BHEL</td>
<td>1500</td>
<td>500</td>
<td>736</td>
</tr>
<tr>
<td>5</td>
<td>Talcher – Kolar</td>
<td>2003</td>
<td>Siemens</td>
<td>2000</td>
<td>500</td>
<td>1400</td>
</tr>
<tr>
<td>6</td>
<td>Balia – Bhiwadi</td>
<td>2009</td>
<td>Siemens / BHEL</td>
<td>2500</td>
<td>500</td>
<td>780</td>
</tr>
</tbody>
</table>

Table no. 5.1 Existing Project of HVDC in India

MUNDRA – MOHINDERGARH TRANSMISSION LINE
± 500 kV HVDC (989 km)

This has created the benchmark for the fastest completion of India's first private ± 500 kV HVDC (High Voltage Direct Current) transmission system, Mundra - Mohindergarh transmission line (989 kms.). This HVDC transmission project is the largest of its kind, traversing three states that is, Gujarat, Rajasthan and Haryana. This line carries affordable electricity from our Mundra power plant to Mohindergarh in Haryana. An HVDC line can transmit bulk power over long distances in a single hop over a single transmission line. Besides being economical over long distance, this technology also minimizes the transmission losses.

5.3.3. Conversion of Existing AC Lines
Utilities are looking into the operation of converting existing AC circuits to DC in order to increase the power transfer limit. An experimental project of converting a
single circuit of a double circuit 220 kv line was commissioned in 1990 in India between lower Sileru and Barsoor.

5.3.4. UHV DC Transmission
Ultra High Voltage DC transmission at about 800 kv is being considered for transmission of large blocks of power above 3000 MW for distances beyond 1500 km, in China, India, South Africa / Congo and Brazil, where large hydro power resource is available in remote areas.
A bipolar HVDC line operating at 800 kV can transmit power in the range of up to 5000 or 6000 MW with two 12 pulse converters per pole.

5.4 MANAGEMENT OF HVDC TECHNOLOGY
The economics is a primary consideration but life span of the components and their technical performance cannot be ignored. Likewise reliability of the technology and the period during which it is likely to become obsolete, when replacement becomes essential is also in the interest of system performance and competitive market for delivery of goods. While selecting the crucial components of the HVDC system, study of certain elements listed below is made. Particularly converter units, converter transformer, filters, smoothing reactors and dc switch gear. Hence, the management of HVDC conversion would have to study the following aspects:
1) Economics 2) Technical Viability 3) Life span 4) Technology of HVDC System 5) Reliability 6) ROI (Return on Investment) period 7) Redundancy 8) obsolete period

5.5 HVDC SYSTEM TECHNOLOGY
The HVDC transmission systems are point-to-point configurations where a large amount of energy is transmitted between two regions. Converter Unit consists of two 3 phase converter bridges connected in series to form a 12 pulse converter unit. The total number of valves in such a unit is twelve. The valves can be packaged as a single, double or in quadric arrangements. Each valve is used to switch in a segment
of an AC voltage wave form. The converter is fed by converter transformers connected in star/star and star/delta arrangements. The valves can be cooled by air, oil, water or Freon. Liquid cooling using de-ionized water is more efficient and results in the reduction of substation losses.

5.5.1. Converter Transformer
The converter transformer can have different configuration - 1. Three phases, two winding, 2. Single phase, three winding 3, Single phase, two winding See fig. 5.4. The valves side windings are connected in star and delta with neutral point underground. The converter transformers are designed to withstand DC voltage stresses and increased current losses due to harmonic currents.

5.5.2. Filters
Filters are important.
AC filters are passive circuits that are used for providing low impedance and shunt paths for AC harmonic currents.

1. DC filters are similar to AC filters and are used for filtering of DC harmonics.

2. High frequency filters are connected between the Converter Transformer and the station AC bus to suppress high frequency currents.
5.5.3. Reactive Power Source
Converter stations require power supply that is dependent on the active power loading (about 50-60% of the active power). 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 the control.

5.5.4. Smoothing Reactor
A large series reactor is used on the DC side to smooth DC current and provide for DC protection. The reactor is designed as a linear reactor and is connected on the line side, neutral side.

5.5.5. DC Switchgear
This is modified AC equipment for interrupting small DC currents. DC breakers or Metallic-Return Transfer Breakers (MRTB) are used if required for interruption of rated lower currents.

5.5.6. Design and advantages of HVDC Transmission Line
The designs of AC Transmission Lines which are laid through the towers are of three phase and an earth core for is provided protection against lightning flash over.
In the fig. 5.1 of both AC and DC Transmission Lines it can be seen that the DC transmission line is a single phase core running tower to tower therefore cost would decrease to 1/3 on cost of conductor cores. Besides the 3 phases in AC Transmission Lines certain height has to be maintained depending upon high voltage ratings, whereas DC Transmission Lines does not require such tower height. Another factor in AC Transmission Lines is the losses caused due to inductance, resistance and (Y / 2) natural capacitance. In DC Transmission Lines the only loss is caused due to resistance. Factors of inductance and Y / 2 are not affecting during transmission.

5.6 FINANCIAL ANALYSIS
In general, basic parameters such as power to be transmitted, distance of transmission, voltage levels, temporary and continuous overload status of the network, environmental requirements are to be considered in designing a HVDC
system. The cost of a HVDC transmission system depends on management factors, such as power capacity to be transmitted, transmission medium, environmental conditions and safety regulatory requirements. A typical cost structure for the converter stations is shown below:

5.6 FINANCIAL ANALYSIS

![Cost Difference between AC and DC transmission lines](image)

Fig. 5.5 Cost Difference between AC and DC transmission lines
(The graph in figure 5.5 shows that DC transmission for more than 600 km is economical as compared to AC)

<table>
<thead>
<tr>
<th>Items</th>
<th>Expenditure %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Valves</td>
<td>20%</td>
</tr>
<tr>
<td>2. Converter Transformer</td>
<td>15%</td>
</tr>
<tr>
<td>3. AC Filters</td>
<td>10%</td>
</tr>
<tr>
<td>4. Control</td>
<td>8%</td>
</tr>
<tr>
<td>5. Other Equipment</td>
<td>10%</td>
</tr>
<tr>
<td>6. Civil Works, Buildings</td>
<td>12%</td>
</tr>
<tr>
<td>7. Erection</td>
<td>10%</td>
</tr>
<tr>
<td>8. Engineering</td>
<td>10%</td>
</tr>
<tr>
<td>9. Freight &amp; Insurance</td>
<td>5%</td>
</tr>
</tbody>
</table>
5.7 A REVIEW OF COMPARISONS: HV DC & AC TRANSMISSION

D.M. Larruskain et al. [1] has provided the following comparison:

1) More than certain distance, the so called “break-even distance”, the HVDC alternative give the lowest cost. The break-even-distance is much smaller for submarine cables (typically about 50 km) than for an overhead line transmission. The distance depends on several factors, to choose as transmission medium. Different local aspects (permits, local labor etc.) and an analysis must be made for each individual case.

2) Long distance water crossing. In a long AC cable transmission, the reactive power flow due to the large cable capacitance will limit the maximum transmission distance. With HVDC there is no such limitation that is why for long cable links, HVDC is the viable technical alternative.

3) An optimized HVDC transmission line has lower losses than AC lines for the same power capacity. The losses in the converter stations have of course to be added, but since they are only about 0.6 % of the transmitted power in each station, the total HVDC transmission losses work out lower than the AC losses.

It is technically feasible to achieve a substantial power transmission enhancement of existing AC lines through their conversion for use with DC power, by using the same conductors, tower bodies and foundations, but with changes in tower head and insulation assemblies. The distribution networks cost is lower than the transmission ones because of the lower voltage level applied to the conductor.

5.8 INTERDISCIPLINARY TEAM WORK

Management is not just the control and plan of finance, HR, marketing, but also technology. The principles are vital in managing engineering systems.
Technology of Automation plays strategic role in the economic and efficient management of an organization, innovation or industry. An efficient system can optimize the resources and minimize wastages. As we know the present becomes obsolete in near future. One has to keep updated with advancing technologies. Management of Technology is an interdisciplinary activity which requires group efforts of management experts and electrical, electronic, software engineers.

Efficient and economic management of power transmission, control and maximum power utilization requires:
(a) Maximum utilization of existing resources
(b) Incorporating automation
(c) Storing the unused power in the off-peak time.

5.9 ELECTRICAL POWER SYSTEM MANAGEMENT
The power industry is often mismanaged because of old methods and technologies and ineffective utilization of the generated power. There is a necessity to adopt new technologies and management techniques like Supervisory Control and Data Acquisition and High Voltage DC Transmission to study and achieve:

1. Efficient utilization
2. Decrease cost of transmission
3. Economic dispatch and delivery of power
4. Control on the power loss
5. System planning for higher flow of power.

The Tables 5.2 shows the power transfer capability in different sizes of transmission lines and benefits from DC over AC Transmission.
Table 5.2 shows the Transmission capability of AC and DC

5.9.1. Importance of Management Planning
The demand of power is increasing whereas supply is inadequate in most countries even to meet the present demand. This would hamper industrialization, agriculture and domestic requirements of the future. The power consumption has increased over the years but the number of power generation units in the country has not increased proportionately due to high capital investment resulting in power cuts and failures which is hampering the industrial growth. This would affect the country’s economy and development. Management Planning of power system network is required which would give economical and efficient solution with least investment by implementing available new technologies by which power industries can supply power at lesser rate to consumers.

5.9.2. Economic Operation of Energy Management Systems
Economic operation is important for a power system to return a profit on the capital. Rates fixed by regulatory bodies and the importance of conservation of fuel put pressure on power companies to achieve maximum efficiency that can minimize the cost of power. Operational economy of power generation and delivery can be subdivided into two parts – one dealing with minimum cost of power production called economic dispatch and the other dealing with minimum loss delivery of the generated power to the loads. For any specified load condition economic dispatch determines the power output of each plant and each generating unit within the plant which will minimize the overall fuel cost and loss of delivery through HVDC.

To avoid major system failures and regional blackouts, electric utilities can install a number of supervisory control and data acquisition (SCADA) throughout the network to support computer based data systems, for energy control.

5.10 DISCUSSIONS
This chapter presents techniques of management of technology with reference to HVDC transmission. Comparisons between AC and DC power transmission have been studied highlighting what would result in power economy, efficiency and maximum utilization of the existing system of transmission and distribution. AC transmission of power is economical up to certain length of transmission. The data shows beyond 500 km length HVDC transmission is profitable.

Operational factors of AC and DC have been compared and benefits highlighted for changing over from existing AC to DC system. The same tower line can be utilized for higher voltage transmission of DC than AC with certain modifications. The cost of DC conversion is offset by single conductor and tower height (right of way) usage as compared to AC.
For a very long length of transmission line, applications of DC transmission have been made stretching the limit to 800 kV and 5000 MVA.
The progress in high voltage transmission is advancing development in power electronics to support economic and efficient management of electrical power grid. HVDC technology has scope of future research in integrating various generating stations and management strategies have to be studied for smooth system operation and formation of Grid networks.