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Why And Why Not To Go For HVDC?

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Abstract: *Talking about the expansion taking place in power of electronic apparatus, a noteworthy influence has been put up by the evolution of high-power and high-voltage semiconductor technology. Complete or partial deregulated networks have used this approach in order to carry out management and other efficient operations related to electrical grids. High-Voltage Direct-Current (HVDC) transmission of power as well as the Flexible Alternating Current Transmission System (FACTS) has advanced forward to fit in the futuristic aspects. In this paper, we have presented a brief as well as deep overview of aspects related to HVDC which can help to decide whether to go for HVDC or for any other option. Firstly, history of the HVDC is discussed which is followed by the introduction of different types of links used by HVDC. The key factors which need to focused upon while taking the any decision related to transmission systems is then explained by analyzing and considering the conceptual, economical, environmental and technical perspectives. Reasons for why and why not to go for HVDC are then presented. It squabbles that HVAC can take a back seat in some scenarios whereas HVDC will stand the test of futuristic challenges as the emphasized advantages of HVDC will always turn out to be winners as compared to its disadvantages. Some of major HVDC transmission systems and HVDC application areas are explained. The paper concludes by pinpointing the open future research challenges related to this technology.*
Keywords: *High-Voltage Direct-Current (HVDC),Flexible Alternating Current Transmission System (FACTS), High-Voltage Analog-Current (HVAC).*

I. Introduction

The rural as well as urban areas nowadays are highly dependent on ingestion of electrical energy in order to carry out their basic activities which largely include agricultural, domestic, commercial, social and industrial sectors. Electrical energy is a resource which is heavily consumed all across the world and this large consumption of energy thereby demands for its efficient generation. The generation of electricity is done on a large scale by leveraging thermal, hydro, nuclear and other power generating stations. After successful generation of this electricity, it needs to be transferred to distant locations from where it is further distributed and sent to the consumers. This transfer of electrical energy between distant places is done by means of distributed networks which in turn leverage transmission systems. A transmission system holds the responsibility of transferring the electrical energy unceasingly from one location to another location which can be geographically apart. Some functionalities and responsibilities related to transmission systems are listed as:

- Continuous supply of electricity to consumers which may reside in geographically apart locations.
- Thoroughgoing coverage of area for electricity supply.
- Secure stream of electricity should be provided to consumers.
- It should be fault tolerant to a level.
- Supply should be done in ranged limits of frequency i.e. 49Hz-51Hz and of voltage i.e. variation of ±5%.
- Least conceivable cost should be incurred.

The transmission of electrical energy via transmission lines is an overall expensive process. Transmission costs are by far the higher which force the researchers to work and advance in order to make more improvements in this section. The distribution of electricity in different areas is not that much costly as its transmission to those areas is. Thus transmission becomes an important matter to deal with and it calls for revising the decision of the method which we adopt for transmission. This transmission is done via two ways where one is High Voltage Analog Current and the other is High Voltage Direct Current. HVDC as well as HVAC, both are used as a solution for the transmission but both of these solutions have their own drawbacks and boons. In this paper, we provide the overall conceptual overview of HVDC as well as for HVAC. As per the research conducted in this area, it has been proved that HVDC is better than HVAC in many aspects and hence its use should be enhanced. Still, many organizations prefer HVAC because of business, commercial and industrial reasons. For rest of the organizations, it is still difficult to decide whether they should go for HVAC or for HVDC for their transmissions. This paper tells us the factors and aspects related to why we should go for HVDC and why not we should go for HVDC.

Rest of the paper is organized as: Section 2 explains the history or background related to HVDC. Section 3 explains the types of links we have for DC transmission. Section 4 presents the features of a transmission system which are further divided into technical features, economical features and environmental features. These characteristics are discussed in detail as they lay the foundation for our core decision of HVDC adoption. Section 5 justifies the title of our paperby explaining i.e. Why and why not to go for HVDC. The available HVDC systems in India are summarized in the form of a table in section 6. The future research and open challenges related to this section are presented in the section 7. The last section i.e. section 8 concludes our paper.

II. History Of HVDC

History of HVDC Transmission: The history of one of the key supplements of today's generation i.e. Electricity can be traced back from the year of 1882. Thomas Alva Edison was the first to generate electricity on a commercial level and it was Direct Current i.e. dc electric power. In 1954, the first HVDC transmission task was accomplished which connected Swedish mainland with an island of Gotland in Baltic Sea. It was done by using a submarine cable accompanied by a ground return and its rating was 20 MW, 100 kV. With the advent of mercury arc valves, a subsequent number of HVDC transmission networks were laid all across the world till 1970. For around fifty years, current source converters were used by HVDC transmissions.

With a rated power of 6300 MW and voltage of ±600 kV, Itaipu HVDC transmission system of Brazil has turned out to be the most viable achievement in HVDC transmission. In India, Vindhyachal back-to-back link was the first HVDC transmission project which was commissioned in the year 1989. It connected the western regional grids with the northern regional grids and had a rated power of 176 kV and 500 MW. Between Rihand and Delhi, first long distance HVDC connection was established in 1990. It was 814 km long with rated power of 1500 MW and ±500 kV.

III. Types Of Dc Links

The direct current links can be classified into three types which are briefly explained as:

1) Monopolar link: A single conductor which is of negative polarity is deployed by a monopolar link whereas the positive polarity for monopolar link is provided by ground which also acts as a return path for current flow. This type of DC link is very much beneficial when used to transmit power below the sea level where sea can be used as a second electrode. In presence of corrosion and interference consequences, use of monopolar links is discouraged over long periods of time.
2) Bipolar link: As the name suggests, it has two conductors (with grounded terminal stations) where one is used to provide positive polarity and other for negative polarity. By changing the polarities of conductors, the direction of flow of current can be easily changed. In both the conductors, current remains balanced whereas 1% of current is absorbed by the ground which is almost negligible. It is highly suitable for long distance transmissions of current.
3) Homopolar link: Homopolar links comprises of two or more than two conductors, all of which should be of same polarity. Generally, the polarity of conductors is kept negative and the current flows back via ground which acts as a return path for current. This link is highly fault prone as in absence of failure of one conductor; the others can be easily leveraged so that the flow of current is not disrupted.

IV. Transmission System Features

A major portion of electric power transmissions leverage the three-phase alternating current. Here we discuss the interesting reasons which lead to the choice of HVDC instead of HVAC in order to transmit power. For a particular case, we have numerous reasons which are indeed complex for choosing HVDC and discarding the option of HVAC. Each and every set of transmission projects have their own specifications and requirements and their related reasons and choices thus differ from each other. Viewed from the planning phase, we can make our choice of by considering following mentioned characteristics.

4.1 Technical Characteristics:

Following are the performance parameters concerned with the transmission systems as viewed from technicalperspective:

1) Cost and Reactive power: There are different possibilities which can be considered when dealing with different types of power and voltage ratings. For instance, when we have a transmission line with a rated power of 3500MW and rated voltage of 750kv line then two possibilities can arise:

- When length of transmission line is less than 800 km, then HVAC can turns out to be cost effective whereas reactive power comes out to be nearly same in both transmission lines.
- When length of transmission line is greater than 800 km, then HVDC transmission lines turn out to be efficient as compared to HVAC in terms of cost as well as in terms of reactive power.

General formula for calculating transmission line cost= (n*cost per tower+ s*cost per substation + conductor cost) where n is the number of towers and s is the number of substations. This formula can be used for HVDC as well as for HVAC.

2) DC Reactor: The technical characteristics related to DC reactor are pointed out as:
- It is basically used for controlling the supply of current provided no short circuit occurs.
- It is connected at the converter stations on both the sides of HVDC transmission lines.
- Current flow is continuous.
- Inductance of DC reactor varies from 0.4 to 1H.

3) Substation requirement: the number of substations required can be easily calculated by using the given formula:
For AC transmission: Number of substation required=Total transmission line length (km)/300
For DC transmission: Main substation only at converter side.
4) Reliability: The reliability of system depends on two factors where one is energy availability and other is transient reliability. These two factors can be determined as:

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

Transient reliability= $\left(\frac{\text{Number of times HVDC worked as expected}}{\text{Number of faults observed in working}}\right)$*100
These two factors are used to determine the reliability of the transmission system being deployed.

5) Voltage and current limits: Current and voltage limits referto the voltage and current variation in the transmission line and it holds different values in both the AC and DC transmission. These extreme variations in the transmission lines effect the equipments used in transmission lines and thus in turn causes hazardous effect on the lines. In ACtransmission line sudden increase in voltage due to different switching surges (positive or negative polarity) and heavy lightning can lead to same case. To prevent damage from these effects overhead lines are constructed taking the limits of voltage in the line to 2 - 2.5 times of normal peak working voltages. Whereas, in DC transmission lines sudden voltage changes are very less comparative to the AC transmission and are also less severe.

6) Reactive power control and voltage regulation: The voltage profile is more or less dependent on line loading so as to maintain the constant voltages at terminals of the line surge impedance loading (SIL). This can be attained in two ways:
(i) Line loading greater than SIL: The voltage at the centre point of the line is decreased.
(ii) Line loading less than SIL: The voltage at the centre point of the line is increased.

Shunt capacitive compensation is used to generate power under heavy load conditions. In DC transmission no reactive power is produced or absorbed and the voltage drop is only due to resistive loses. Reactive power plays a significant role only at the terminals of line where convertors are present and synchronous capacitors are placed to absorb the reactive power. A DC transmission line above 400 km requires less reactive power than ac transmission on the same length

7) Circuit breakers and short circuit current: Circuit breakers are use to avoid the possibilities short circuit. When a situation arises where fault can occur, then circuit breaker contacts are opened by the relay. It increases the arc path. However, when a fault occurs in the DC link transmission, it is solved by the temporarily jamming the control grid in the converter valves. Secondly the chance of fault occurrence in dc is less comparative to ac transmission. Due to transitory discharge of the shunt capacitance of the link the transient current is limited to twice the rated current in a short circuit.
8) Harmonics: Voltage and current harmonics are generated in the converters which are positioned at the terminals (the rectifier and invertors) in both sides of AC and DC line due to discrete conduction of valves. These harmonics interfere with the other frequencies like radio and telecommunication. Different filters are used to control this harmonic problem and these filters also help in generating reactive power which is consumed by the converters.
9) Generating stations: Generating stations are also affected by the DC link transmission lines. In order to improve the power stability limit of hydro generating power station, generators are constructed on the basis of transmission line design and specification. In AC transmission line, generator is constructed so as to have very low transient reactance and a high inertia which can turn out to be costly enough to reduce the cost. Thus, we can use dc link transmission as a solution.Also it helps in case of prime mover rotation

as it is controlled in taking the frequency 50 Hz in remind , better frequency which is best in economy is selected.

10) Stability limits: The stability limit is referred to as the all power flow limit which alarms the various factors like voltage drop ,thermal disturbances in line, electrical phase system, cables and various substation systems. The power transmission in the transmission line without any loss dependson the following factors:
(i) Magnitude of the end voltages
(ii) The voltage angle difference at the terminal of the lines
(iii) The reactance of line

Power = $\frac{|Es||Er|}{X}$*sinα
Where, α = voltage angle difference
Es = sending end voltage
Er = receiving end voltage
X = line Reactance

In case of steady state limit occurs when α is 90˙that is when maximum power is calculated as:
Power = $\frac{|Es||Er|}{X}$
Now the power is inversely proportional to reactance (X) and reactance depends directly on distance, as distance increases ,reactance increases and power decreases in the same manner.

4.2. Economic Characteristics:
In order to select the most suitable transmission system from economical view, we have discussed few points below:
1) As compared to ac lines and cables, dc lines and cables are low-priced. As the dc line converters have become expensive, ac terminal equipments on other side turn out to be low-cost as compared to dc terminal equipment. Seeing the bigger picture, we have a low cost of total dc transmission as compared to ac transmission.
2) For same power transmission capability, line losses related to direct current are lesser that the line losses of an alternating current line
3) The towers for direct current transmission are economical, straightforward and slender as compared to alternating current towers.
4) HVDC transmission lines can adjust easily with the futuristic techniques as it is built in stages. For instance, a monopolar link can first be built which can be extended to bipolar and so on.

4.3. Environmental Characteristics:
The choice of transmission system can affect the environmental in numerous ways.
1) Cost of land covered, choice of right-of-way and a lower visual profile are the parameters which need to be focused upon while making the choice of transmission system.
2) Audible noise created by system, visual impact related to system can lead to damage in the nearby environment.
3) It has been observed that HVDC is companionable to any environment and can be amalgamated easily without any negotiation on environmental issues.

V. Why And Why Not To Go For HVDC?

The decision of HVDC or HVAC can vary subsequently based on the specifications as well as requirements of different transmission system objectives. Following are the grounds based on which this decision can be made easier.

5.1 Why To Go For HVDC
1) Power generated per conductor is more in HVDC transmission systems.
2) Construction of HVDC transmission systems is economical because of less number of requirements such as few conductors, petite transmission towers etc.
3) With the use of ground path, each and every single conductor can be used as an independent circuit.
4) It provides bi-directional flow of current.
5) Lower short circuit fault level.
6) Charging current is zero.

7) Tie-line power is easy to control.
8) High availability as well as reliability rate.
9) Companionable with any environment.
10) No constraints on distance due to stability issues.
11) Synchronous operation is not required, thereby eliminating the concerns related to stability.
12) Corona loss and RI is little for a specified size of conductor and RMS voltage.

5.2 Why Not To Go For HVDC

1) The setup requirement is expensive i.e. converter equipment
2) Reactive power requirement on converters is elevated
3) Harmonics are created by converters which in turn necessitates the need of filters
4) Minimal overload capacity
5) Control related complications
6) Complicatedness in breaking current giving rise to expensive dc breakers

VI. HVDC Systems in India:

Following table briefly summarizes the HVDC systems present in India along with their some of their characteristics like power rating, modes and circuit kilometers.

Name of System	Rated Voltage(kV)	Rated Power(MW)	Modes	Length (km)
Rihand-Delhi HVDC System	±500	1500	Bipolar, monopolar with ground or metallic return	810
Vindhyachal HVDC back to back system	176	500	Bipolar	
Talcher-Kolar HVDC System	±500	2000	Bipolar	1367
ChandrapurPadghe	±500	1500	Bipolar	1504
Balia-Bhiwadi	±500	2500	Bipolar	1800
Barsur- Lower Sileru	200	200	Monopolar	162
Biswanath-Agra	±600	4000	Bipolar	3600

VII. Future Work

From the above discussion, it can be firmly concluded that HVDC has given overall ostentatious results in almost every aspect of application. It has turn out to be the best option from operational as well as from economical purposes. The following vibrant factors direct us towards the possibility of adoption of HVDC futuristic schematics:

1) Technology advancement: Transmission of power with rating of 200 Mega Watt can now be easily done with the help of dc cables (polythene) and the developments in VSC based technology has made it even more applicable and approaching. It can transmit power up to 60 km of distance with ease.
2) Power sector reorganization: The private organizations and firms are the new reorganizers of power sector. The requirements of ROW and land acquirement are very much less in HVDC which attracts the private corporate to invest in HVDC. Both of these factors, ROW and land acquirement are included the economic study.
3) Ready for action rim: The flow of HVDC can be bi-directional which opens a opportunistic and competitive perimeter for private sectors. The possibility to change current direction can prove out to be a new aspect to the power market where they can use power reversibly.
4) Prominence on eco-friendly behavior: as the degradation of forests and wild areas is increasing exponentially, HVDC will remain as the only viable option which can save our environment from power connections point of view.

VIII. Conclusion

The work was carried out to sketch down the truthful facts and other information which can help to make the decision of whether to go for HVDC or not easier. The technical, environmental as well as economical characteristics of transmission systems were briefed out which were followed by their detailed discussion. By observing and examining the given features one can decide which option should be adopted, High Voltage Direct Current or for High Voltage Analog Current. The available transmission systems in India are given in tabular form. By examining the specifications and requirements of the transmission system, one can make the decision easily for transmission system. The future research aspects and its ability to cope up with futuristic techniques have winded up our paper in the end.

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