HVDC in Indian Power Sector

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Abstract---* *India is going through a phase of modernization that has given way to growing demand for electrical energy. The wave of modernization has ushered in a emerging industrial sector that has heightened the demand for electricity. In addition, 99.7% of household in India has been electrified which is a remarkable feat considering India has a population of 1.3 billion but it has further elevated the demand. Usually the generation plant is located at a remote area far from the centers of urbanization where the demand as it happens is highest. So a lot depends on transmission which plays a key role in the electrical sector. An expansion in size of the transmission arrange prompts a mind-boggling arrangement of transmission that endures significant obstacles identified with burden stream, control wavering and voltage quality.Conventional AC transmission line had proved inefficient in long distance high voltage transmission. A possible solution to this situation is the use HVDC transmission system. In fact a number of HVDC transmission projects had been planned and constructed throughout India.

Keywords---* *Efficiency,HVDC Transmission,HVAC Transmission,Converter.

I. INTRODUCTION

To meet with the growing demand for electricity different regional grids in India have been interconnected to form "One Nation-One Grid". India had five regional grids – The Northern Grid, The North-Eastern Grid, The Eastern Grid, The Western Grid and the Southern Grid. On 31st December, 2013 the goal of interconnecting the grids was achieved by connecting the Southern Grid with the Central Grid via Raichur-Solapur transmission line. But for such long distance transmission HVAC transmission is not practical due to significant line inductance, switching stations, reactive power compensation and the cost of conductor. Using HVDC on the other hand for such distance reduces the cost significantly and has less losses[1]. India is a pioneer when it comes to the use of HVDC for long distance transmission. Owing to the vast landmass of the country it is cheaper and viable to use HVDC instead of HVAC for transmission across the stretch of the country. As a result multiple schemes are in operation, under commissioning, construction or planning. The following table provides a list of the different HVDC systems across India.

For the creation of a national grid a number of HVDC transmission systems have been constructed and implemented. Multiple HVDC links are also being constructed to connect this national grid to neighboring nations namely Bangladesh, Sri Lanka, Nepal and Bhutan. This goal of these projects are to enable these nations to share the electrical power generated in each country.

Table 1: Bipolar line

Name	Length (km)	Volt (kV)	Power (MW)	Year
Sileru-Barsur	196	200	100	1989
Rihand-Delhi	814	500	1500	1990
Chandrapur-Padghe	752	500	1500	1999
Talcher-Kolar	1450	500	2500	2003
Ballia - Bhiwadi	800	500	2500	2010
Mundra - Haryana	960	500	2500	2012
Champa-Kurukshetra	1365	800	2 x 2000	2016
Biswanath-Agra	1728	800	6000	2016

Existing HVDC Systems in India[10][11]

Table 2: Back-to-Back transmission

Name	Voltage(kV)	Power(MW)	Year
Vindhyachal	176	500	1989
Chandrapur	205	2 x 500	1998
Gajuwaka Block 1	205	500	1999
Sasaram	205	500	2003
Gajuwaka Block 2	176	500	2005

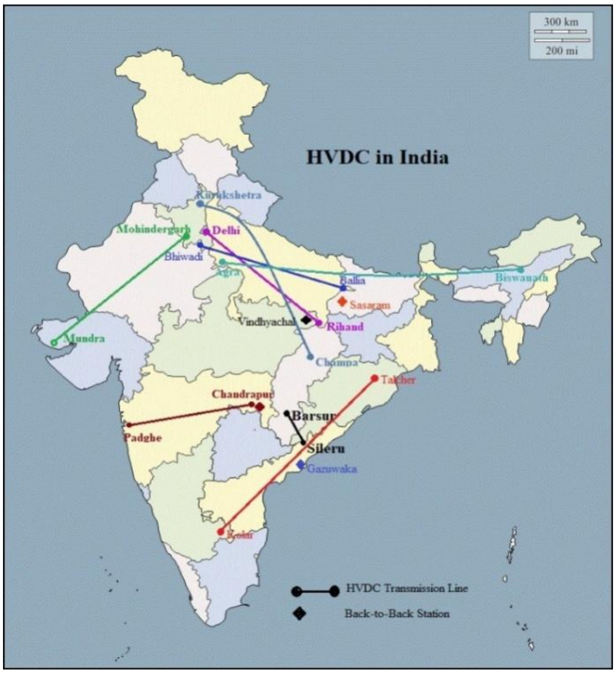

Fig. 1: HVDC in India

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Cross-Border HVDC Connection

HVDC(high voltage direct current) has enabled neighboring countries to connect their grids and import and export power from each other when required. India over the years have interconnected grids with neighboring countries like Bangladesh, Sri-Lanka, Nepal and Bhutan.

A HVDC transmission line that carries 500 MW at 400 kV has been constructed between Baharampur, India and Bheramara, Bangladesh. [11]

Fig. 2: HVDC transmission line between India and Bangladesh

Another HVDC transmission line that will carry 1000 MW at 400 kV between Madurai, India and Sri Anuradhapura, Sri Lanka is under construction. The link would measure approximately 300 km in length including a 50 km of submarine cables between Rameshwaram and Talaimannar.[11]

Fig. 3: HVDC transmission line between India & Sri Lanka

II. FOCAL POINTS OF HVDC OVER HVAC

- Beyond the make back the initial investment remove the expense of HVDC framework is not exactly HVAC even with included costs of terminal station. Meanwhile losses in HVDC line is less compared to a HVAC line of same capacity, which means more power reaches its final destination.
- Compared to conventional HVAC lines with six conductor bundles, a bipolar HVDC overhead line has two conductors and as a result requires less space and has less visual impact.
- Depending on voltage level and development subtleties, HVDC transmission misfortunes are cited to be 3% less contrasted with AC lines, for a similar voltage level. This is on the grounds that DC manages just dynamic power though AC manages both dynamic and responsive power. Between two points, long and bulk power transmission in AC systems in not efficient as AC transmission systems require intermediate tapping for constant power supply, but in case of DC supply all these intermediate tapings are not required.
- Integration of sustainable assets(renewable resources) into the main transmission grid is possible because in DC transmission any amount of voltage levels can be inter connected.
- The conductor cost in DC is also less as compared to AC cables as the size of DC conductors can be smaller as there is no skin effect. Also, the there is no need for neutral conductor in DC transmission.
- Underground or Undersea cable systems have high amount of capacitance. In case of AC transmission the capacitance has to be charged all the time when transmission is being done. But, in case of DC transmission the capacitance has to be charged only in the initial condition when the transmission is started. Considering this, DC transmission is 30% to 40% more efficient than the conventional AC transmission in case of underground or undersea cable systems.
- In case of AC transmission reactive power flow due to large cable capacitance limits the maximum possible distance for transmission. But in case of HVDC there is no such limitation, this is why in some cases HVDC is the only viable alternative[31].
- The power carried per conductor by HVDC is more than that carried by HVAC. The peak voltage for AC determines the actual insulation thickness and conductor spacing. Be that as it may, the power conveyed by an Ac framework is controlled by root mean square(RMS) of air conditioning voltage, which happens to be 70.7% of the pinnacle voltage. HVDC then again works at steady greatest voltage thus requires similarly measured conductor and encasing to convey more power in a territory.
- HVDC can be utilized to expand the limit of a current power matrix in situations where extra wires are troublesome or costly to introduce.
- In case of high powered AC transmission between power plant and major load center, the short circuit current will increment in the accepting framework.But if HVDC transmission is used the problem does not arise as HVDC transmission does not contribute to short circuit current of interconnected AC system.
- In order to connect two AC system that are not synchronous, HVDC is used. This is because HVDC is asynchronous and as a result can adopt to any rated voltage and frequency it receives.
- Both ac and dc transmission system generate coronas. In case of ac transmission, it is due to oscillating particles and in case of dc transmission it is due to consistent wind. However, because of space charge conformed to the conductors, the HVDC framework may have about half misfortune per unit length that that of a HVAC framework conveying a similar measure of influence.
- The land required and the associated right of way for HVDC overhead transmission line is less than that of an AC line[11].

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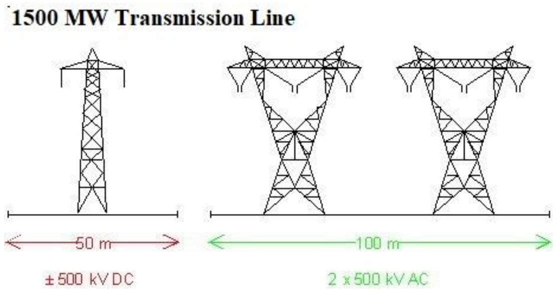

Fig. 4: Right of way for HVDC & HVAC transmission line

III. DISADVANTAGES

- Converter substations needed for HVDC are more complex than HVAC as they not only need additional converting equipment but also more complicated control and regulating systems.
- The converter stations of HVDC creates current and voltage sounds and the transformation procedure is joined by present and receptive power utilization. Accordingly, installation of expensive filter compensation units and reactive power compensation units are necessary.
- In case of a HVDC system a transformer cannot be used to step-up or step-down the voltage levels.
- As the flow of power in a HVDC system must be effectively managed by the control framework rather than the characteristic properties of the transmission line,controlling power flow in such systems require continuous communication between all terminals. This makes operating a multi-terminal HVDC framework morecomplex in contrast to conventional AC systems.
- In instance of a short out in an AC control framework near an associated HVDC substation, a power blame will likewise happen in the HVDC transmission framework for the span of the short out.
- High frequency components in HVDC transmission framework can cause radio clamour in correspondence lines, arranged close to the HVDC transmission line.
- To ground a HVDC transmission system, it is important to build a solid and lasting contact to Earth for legitimate task and furthermore to dispense with the possibility of a dangerous step-voltage being produced.
- Flow of current through earth in case of monopole may cause the electro corrosion of underground metal installations, especially pipelines.

IV. TYPES OF HVDC LINK

1. Monopolar Link

A monopolar link has a single conductor of negative polarity and uses earth or sea for the return path of current. As a result the earth offers less resistance to DC as compared with AC. Also there is no need for the return conductor to be insulated for the full transmission voltage, which makes it less costly.

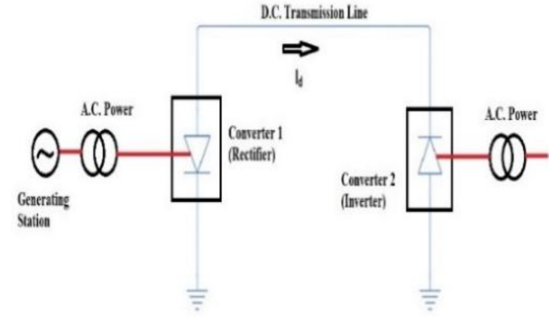

Fig. 5: Monopolar Link

The two converters are set toward the finish of each shaft. Earthing of pole is finished by the utilization of earth anodes put at a separation of roughly 15 to 55 km far from particular terminal stations.[51] But since of the connection utilizes earth as return way it has a few hindrances.As a result the use of monopolar links has reduced over years.

2. Bipolar Link

A bipolar link used two conductors, one positive and the other negative to the earth. There are two converter stations at each end. The midpoint of the converter stations are earthed through electrodes.[1][51] The voltage of the earthed electrode is half the voltage of the conductor used for transmission.

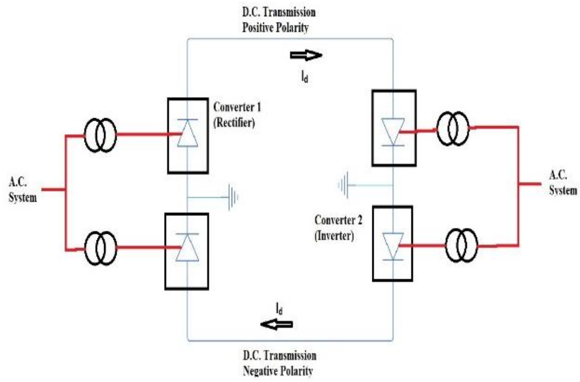

Fig. 6: Bipolar Link

The benefit of utilizing a bipolar connection is that if any of the connections quit working the connection is changed over into Monopolar mode and utilizations the ground for return. Thus 50% of the framework keeps on providing power.Bipolar links7 are the most commonly used links in HVDC system.

3. Homopolar Link

A homopolar interface has two conductors of same polarity, for the most part negative and dependably work with earth or metallic return. If there should be an occurrence of a blame in one conductor, the converter hardware can be associated with solid shaft and it can supply the greater part of evaluated control by over-burdening to the detriment of expanded line misfortune. The poles are worked in parallel, consequently decreasing establishment cost. But a major disadvantage of the system is the large earth return current which has caused significant decline in its use.

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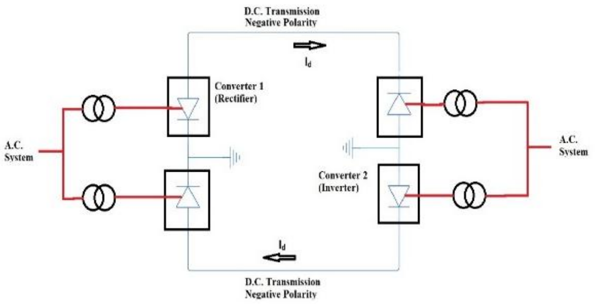

Fig. 7: Homopolar Link

4. Back To Back

A "back to back" framework permits the interconnection of two asynchronous AC systems. In a "back to back" framework two independent neighboring frameworks with various and contradictory electrical parameters like frequency, voltage, cut off dimension, and so on are associated utilizing a DC interface. A HVDC framework takes the electrical power in an AC framework and changes over it into high voltage dc utilizing a changing over station. The dc power is then transmitted to a remote framework where it is changed over back to AC by another HVDC changed over station. A "back to back" framework can be utilized to change over capacity to wanted frequency.It also increases the stability of the system and maintains the power flow within optimal limits.

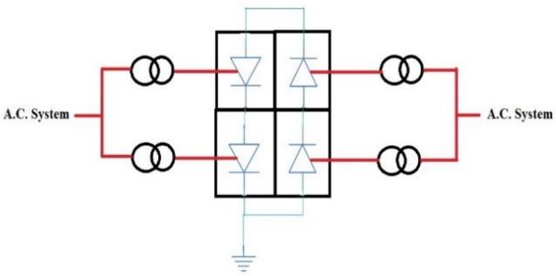

Fig. 8: Back-to-Back

V. COST COMPARISION BETWEEN HVDC AND HVAC

The installation and setup cost of HVDC and HVAC transmission systems differ a lot, As the electrical components used are totally different. HVDC system requires the components that are used in conversion of AC to DC, and also the filters are needed in order to minimize the distortions that are produced in DC transmissions by the means of conversion and also the DC converting stations require the continuous generating of reactive power as DC is only active power[35]. Whereas HVAC systems needs less components comparatively like

AC systems requires the components like transformers. And there are some components that are common in both the systems like circuit breakers, isolators, bus-couplers, and all protection devices. Components in HVDC transmission systems that are not required in HVAC transmission systems[1]:

- Converters
- DC equipment
- Harmonic Filters
- Conversion transformers
- Reactive power

The cost analysis of installation of a power transmission system have been done for same amount of power for equal distance between both HVAC and HVDC systems. Our system is a 1000km transmission line which transmits 1500MW of power. But in HVAC the system is transmitting 440KV where as in HVDC the system is transmitting ±500KV in the transmission line.

Table 3: Cost estimations for setting up the transmission line in million rupees

INSTALLATIONS	HVAC	VSC based HVDC systems
Substations / Converting Stations	4,770	15,900
Overhead Transmission Cables	424	106
Transformers	1.59	9.01
Circuit Breakers	2.12	7.42
Rectifiers/ Inverters	8.48	8.48
TOTAL	5206.20	16030.73

Now the above data is only for the setup of the transmission system[7]. In the above data the setup of HVDC system is way too costly compared to HVAC system. Then why are we showing our interest in HVDC than HVAC, the answer to this question is every point mentioned in advantages of HVDC systems. Are these advantages really worth the difference of cost between the setup of? The answer to this is yes, installation cost may be higher but in economic point of view the HVDC systems are way too profitable in long span but not in short span. Explanation for above statement goes as follows

- Transmission losses in HVAC systems are the sum of Corona losses, Leakage current losses, Dielectric losses, Ohmic losses, Inductive losses, Open circuit losses, losses by the continuous load on measuring and control equipment which totals to the sum of 7% of power transmitted in 1000km line.
- Whereas in HVDC systems the transmission losses do not include Corona losses, Leakage Current losses, Dielectric losses and Inductive losses. HVDC transmission line includes only Ohmic losses, Open circuit losses, losses by continuous load on measuring and control equipment which totals to the sum of 3% total power transmitted in 1000km line.

Therefore, in our 1500MW transmission line which is 1000km long the amount of power lost is[7]:

- In HVAC transmission line7% of 1500MW is 105MW
- In HVDC transmission line3% of 1500MW is 45MW

As per above calculations the HVDC system transmits is 60MW more than HVAC system. Now the cost comparison is done between different mediums of power generation and HVAC/HVDC systems for transmission losses.

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Table4: Transmission loss in INR for different modes of generation

Medium of Generation	Cost of generation for 1MW annually	Amount of money saved in HVDC system with above parameters.
Coal	7.1Cr	7.1*60 = 426Cr
GAS	5.0Cr	5.0*60 = 300Cr
Wind	8.8Cr	8.8*60 = 528Cr
Hydro	7.9Cr	7.9*60 = 474Cr
Nuclear	9.2Cr	9.2*60 = 522Cr

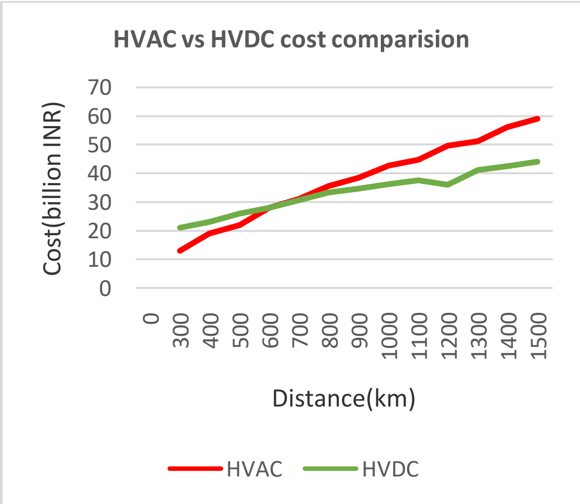


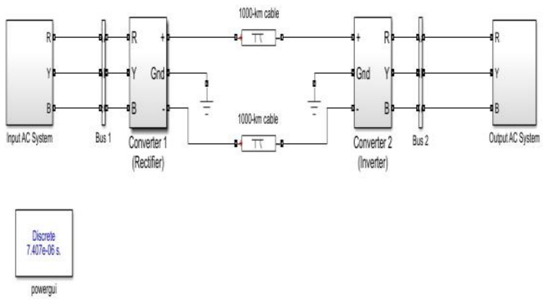
Fig. 9: HVAC vs HVDC cost comparison[8]

VI. SIMULATION& RESULTS

A bipolar HVDC link has three parts:

1. A converter station to convert ac to dc.
2. Two conductors one positive and one negative for transmission.
3. A converter station on receiving end to convert dc to ac.

In the fig10 we have simulated a bipolar HVDC line of 1500MW and a transmission line length of 1000 km[23],[21]. Fig11 and fig12 shows the input and output side power and voltages.



Fig, 10: Bipolar HVDC Transmission line simulation

Table 5: Simulation Parameters and Results

Simulation Parameters:				Simulation Results:		
Input Ac System	R=13.8Ω	L1=62.6mH	L2=31.4mH	MVA	Actual	Simulated
Output Ac System	R=13.8Ω	L1=62.6mH	L2=31.4mH	Input	1500	1459
Transmission Line	R=0.014Ω/km	L=1.7mH/km	C=23nF/km	Output	1455	1432

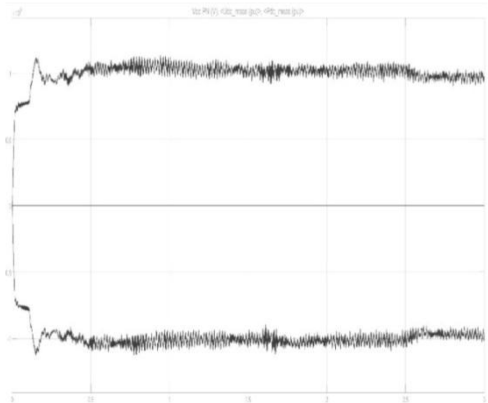


Fig. 11: Converter 1 input voltage

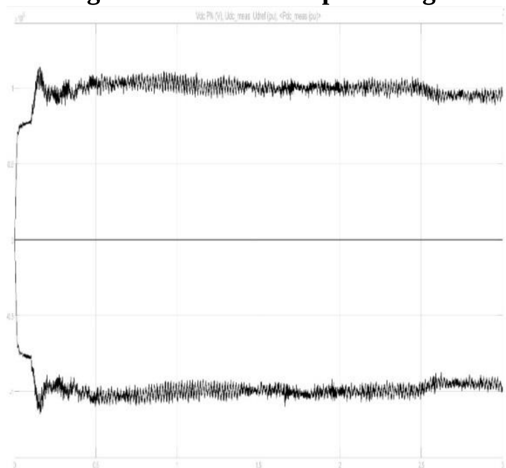


Fig. 12: Converter 2 output voltage

The following simulation of bipolar HVDC link has been done using Simulink and it connects two equivalent ac systems of 1500MW at a frequency of 50Hz. Based on the simulation the loss in a HVDC transmission line is found to be about 3% which is less than that of a HVAC system which has a transmission loss of about 7%.

VII. CONCLUSION

In a developing nation like India availability of power plays a major role. Reducing the losses involved in transmission can play a major role in providing power to everyone efficiently.The importance of implementing HVDC technology is well understood by the Indian power sector and has been implemented to connect the different grids in the country. Today HVDC is used to transmit power across the length and breadth of this country and most new long distance transmission projects are constructed using HVDC technology.

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