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POWER TRANSFER ENHANCEMENT OF EXISTING EHVAC TRANSMISSION LINE WITH HVDC CONVERSION - INDIAN SCENARIO

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ABSTRACT

This paper analyses the feasibility of converting the existing 400kV and 765 kV Double circuit AC Transmission line available in Indian scenario to HVDC line without altering the tower structure, line insulators and conductors. It has been observed that though line losses are more in HVDC system compared to AC Transmission line, there has been substantial increase in Net power transfer capability i.e. 2.84 times and 2.75 times increase in power transfer with +/-200kV HVDC and +/-400kV HVDC configuration respectively by using the existing conductors close to their thermal limits. Moreover, the benefits of all the advantages of HVDC are obtained by adapting this conversion.

Keywords: high voltage directs current, extra high voltage alternative current, flexible AC transmission system, right of way, independent power producers.

INTRODUCTION

There has been steep increase in Power demand in recent years in India during the recent years which forces utilities and IPP's to operate more or less their full capacities. The demand in Electricity is mainly subjugated by Industrial Sector followed by residential, commercial, agriculture and transport sector (recently with introduction of Metros in cities). With increase in Generating capacity, India's transmission network also requires parallel growth to cope up with this demand. However, there are environmental and economic constraints to build new generating plants and further evacuation by transmission lines due to ROW (Right of Way) constraints. The locations of generating stations are largely determined by regulatory policies, environmental clearances and availability of coal, water etc. The amount of electric power that can be transmitted between two locations through a transmission network is restricted by security and stability constraints as per St. clair's curve. Thus, these lines are not loaded to their thermal limit to keep sufficient margin against transient instability.

There has been increasing difficulties faced in finding suitable corridors for new overhead transmission lines. This results in many electric power utilities to look for other alternatives like going for up rating / up gradation of existing transmission lines to avoid right-of-ways (ROW) problems which is still far cheaper than going to underground transmission as most of the stretch falls in rural areas. Efforts have been made in recent years in studying and analyzing various possibilities like:

- Converting HVAC to HVDC lines by making suitable modifications in the existing tower structures
- Connecting FACTS devices to the existing HVAC transmission lines to upgrade it.

Conversion of existing AC transmission line to HVDC line requires certain modifications to be carried out in the tower, insulators etc. Moreover, tower modification requires proper analysis of civil foundation and tower structures to cross check whether all required criteria are met and certain minimum amount of down-time is required during up gradation period. The proposed scheme requires no modification and down-time.

The flexible AC transmission system (FACTS) concepts, based on applying state-of-the-art power electronic technology to existing AC transmission system, improve stability to achieve power transmission close to its thermal limit [4]. Such devices are installed by utilities and by many private entities in India. In order to achieve this identical goal other way is by converting existing 400kV / 765 kV double circuit HVAC line to HVDC line without any modifications in the existing tower structure, insulators and conductors considering heavy pollution as the worst case.

NEED FOR CONVERSION

In India, 400kV Double circuit Transmission line is predominant with Twin Moose / Quad Moose configuration. Similarly 765kV Double circuit Transmission line with Hexa zebra conductor configuration is predominant taking care of bulk power Transfer from remote generating stations and connecting various regional grids. However these lines are under utilized due to stability constraints. Clerici [1] suggested conversion of existing AC line to HVDC line with some modification in the tower structure cross arm and conductor stringing is required once again after modification. This requires certain amount of shut down time and alternate feeders are required to be identified to feed the existing load. This paper proposes literally no modification in existing tower structure, insulators and existing conductors will be utilized for HVDC power transmission.

Figure-1 depicts the schematic drawing for conversion of HVDC line from an existing double circuit 400kV / 765kV AC transmission line. Conventional HVDC bi-polar line is connected to the existing double circuit AC transmission line. One of the important aspects

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of this conversion is that there is no modification envisaged in tower structure, insulator and conductor. One pole of the DC line is connected to one of the AC circuit and another pole is connected to second circuit. DC current can be allowed to flow through the circuit and the only constraint being the thermal limit of the conductor. In this paper, two cases after HVDC conversion have been analyzed. First case will be with 400kV double circuit twin moose and quad moose transmission line. Second case will be with 765kV double circuit with hexa zebra conductor configuration.

CRITERIA FOR EXISTING HVAC TO HVDC LINE

As there is no change made in the conductors, the total continuous rated current remains the same i.e. the power transmitted increases proportionally to the newly adapted DC line to ground voltage.

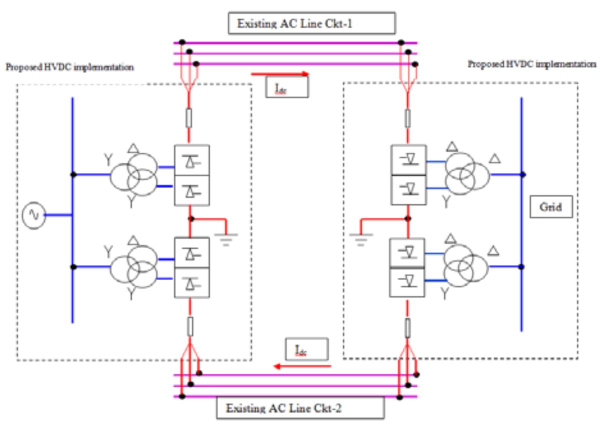

Figure-1. Basic scheme for HVAC to HVDC conversion.

Case-1: 400kV transmission line

i) As insulators remain unchanged, the peak voltage in both cases should be equal

$$V_{max} = \sqrt{2}\, V_{ph} = V_d \qquad (1)$$

Considering existing 400kV AC line, HVDC transmitting voltage shall be restricted to +/-200kV.

ii) Each conductor is to be insulated for Vmax in case of AC line. However for DC line, conductor-to-conductor separation distance within the circuit of each line is not required since the entire circuit is used for one pole. The available clearances in existing double circuit AC line and required clearance for Bipolar DC line is compared as per Figure-2 in conjunction with Table-1 and found sufficient with above voltage level.

iii) In case of AC line considering heavy pollution, existing lines containing 23 nos of disc insulator per string and individual disc insulator having creepage of 430mm total creepage arrived at 9890mm. However with DC lines even by considering heavy pollution as the worst case, 47mm/kV and the same disc insulator arrangement with 200kV DC works out to be 9870mm considering 210kV as highest voltage. From the above it is evident that creepage requirement of HVDC is getting satisfied with the existing insulator string.

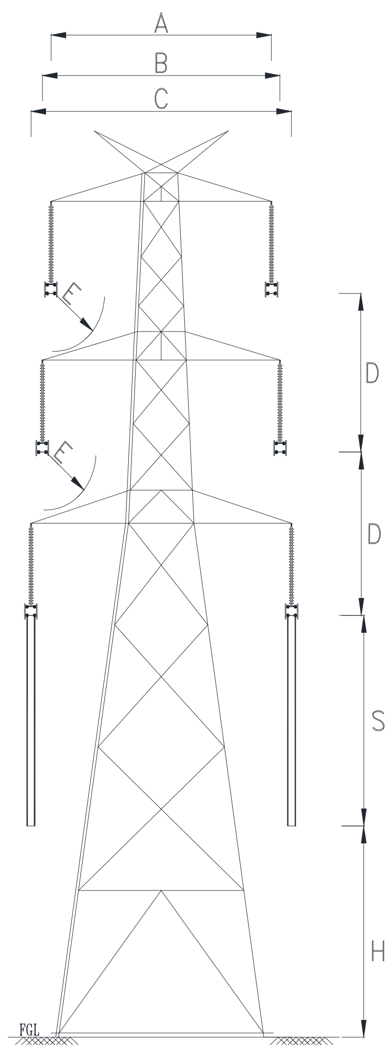

Figure-2. Tower clearance drawing.

iv) Corona losses of converted DC line are very much lower in the range of 1kw/km compared to original AC lines in 400kV which is in the range of 17kw/km.

v) Since the conversion scheme adapted does not involve any modification in tower structure and conductor, there is no need to check the adequacy of mechanical strength of tower and its civil foundation.

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Table-1. AC and DC clearance comparison check.

Reference	Voltage	Cond	D	E	S	H
400kV Line			(Dimensions in mm)			
Std Tower	420kV AC	Quad	8600	3050	13412	9065
	420kV AC	Twin	8000	3050	13412	9065
Min. Clearance as per CBIP	420kV AC		4200	3050	-	8950
	+/- 200kV DC		-	620	-	6810
765kV Line						
Std Tower	800kV AC	Hexa	15000	4400	13641	15225
CBIP	800kV AC		9400	4400	-	12550
	+/- 400kV DC		-	1960	-	8720

Case-2: 765kV double circuit transmission line

i) Using Equation (1) considering existing 765kV AC line, HVDC transmitting voltage shall be restricted to +/-400kV.

ii) Similarly the available clearances in existing double circuit AC line and required clearance for Bipolar DC line is compared as per Figure-2 in conjunction with Table-1 and found sufficient with above voltage level.

iii) In case of AC line considering heavy pollution, existing lines containing 47 nos of disc insulator per string and individual disc insulator having creepage of 430mm, total creepage arrived at 20210mm. However with DC lines even by considering heavy pollution as the worst case, 47mm/kV and the same disc insulator arrangement with 400kV DC works out to be 19740mm considering 420kV as highest voltage. From the above it is evident that creepage requirement of HVDC is getting satisfied with the existing insulator string.

iv) Corona losses of converted DC line are very much lower in the range of 3kw/km compared to original AC lines in 765kV which is in the range of 45kw/km.

v) In this case also, there is no need to check the adequacy of mechanical strength of tower and its civil foundation as the conversion scheme adapted does not involve any modification in tower structure and conductor.

CASE STUDY - ANALYSIS

A) Before conversion - AC System

The loadability of ACSR Moose, twin bundle conductor and quad bundle conductor, 400-kV, double circuit line and ACSR Zebra, Hexa bundle, 765kV, 50-Hz, 300-km has been analyzed. The Line parameters [7] (per unit / km / circuit, at 100 MVA base) are given in Table-2.

Table-2. AC Line parameters.

Line configuration	Positive sequence (per unit / km/ckt)		
	R	X	B
400kV Twin moose D/C	1.800E-5	1.923E-4	6.02E-3
400kV Quad moose D/C	9.177E-6	1.582E-4	7.33E-3
765kV Hexa zebra D/C	2.096E-6	4.360E-5	2.66E-2

The total power transfer through the double circuit line before conversion is as follows:

$$P_{AC} = 3V_{ph}^2 \sin \partial_1 / X \quad (2)$$

where X is the transfer reactance per phase of the double circuit line, and ∂1 is the power angle between the voltages at the two ends. To keep sufficient stability margin, ∂1 is generally kept low and it does not exceeds 30. With the increasing length of line, the loadability of the line is decreased [5]. An approximate value of ∂1 may be computed from the loadability curve by knowing the values of Surge Impedance Loading (SIL) and transfer reactance X of the line.

$$P_{AC} = 2 \text{ M SIL} \quad (3)$$

where M is the multiplying factor and its magnitude decreases with the length of the line. The value of M can be obtained from loadability curve [5].

Transfer reactance X of twin moose D/C and quad moose D/C line is estimated as 46.15 and 37.968 ohms respectively for 400kV line. Similarly for 765kV Line, Transfer reactance X of Hexa zebra D/C line is estimated as 38.27 ohms. Current carrying capacity of each ACSR Moose sub-conductor = 0.8kA for 400kV line. In case of 765kV line, Current carrying capacity of each ACSR Zebra sub-conductor = 0.65kA

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I_{ther}=1.6kA and SIL= 515 MW/Ckt; 400kV twin bundle (4)

I_{ther}=3.2kA and SIL=650 MW/Ckt; 400kV quad bundle (5)

I_{ther}=5.2kA and SIL=2250MW/Ckt; 765kV hexa bundle (6)

Even though power transfer rating is much higher, the values are restricted due to limitations in SIL as indicated above. Approximate value of AC current per phase per circuit of the double circuit line may be computed as

$I_a = P_{AC} / \sqrt{3}\ V_L \cos\varphi$ (7)

Power loss for each line = $P_{Loss} \approx 3I^2R$ (8)

B) After HVDC conversion

Using equation (1), we are choosing

Vd=+/- 200kV for 400kV Tower and +/- 400kV for 765kV Tower. Now, allowing the net current through the conductor equal to its thermal limit Ither. Thus DC current (Id) obtained is as follows.

Id = 1.6kA - for twin bundle (9)

Id = 3.2kA - for quad bundle (10)

Id = 5.2kA - for hexa bundle (11)

The total power transfer through the double circuit line after conversion is as follows:

$P_{DC} = 6V_d\ I_d$ (12)

Power loss for each line = $6\ I_d^2\ R$ (13)

The analysis after HVDC conversion is made for all three phases per circuit utilized for one DC pole and the configuration will be HVDC Bi-pole arrangement with conventional ground return path. The arrangement will be as shown in Figure-3.

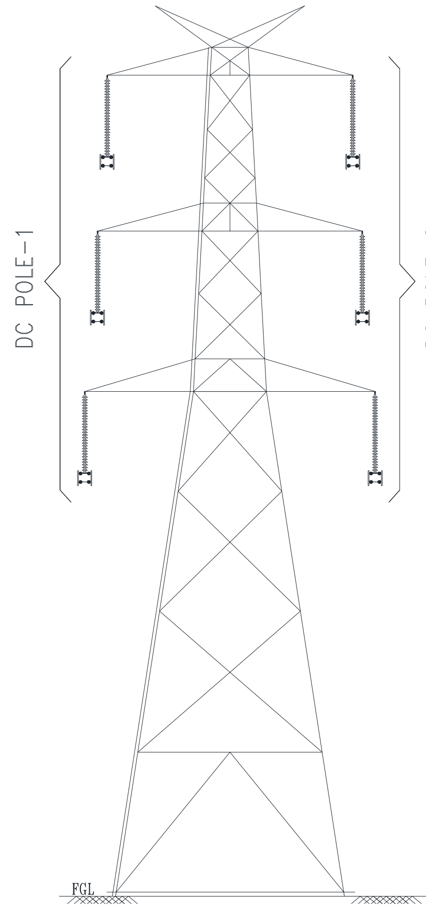

Figure-3. Tower with HVDC configuration.

COMPARISON ON TRANMSSION LINE CAPACITY

The details tabulated in Table-3 shows the comparison on transmission line capacity and losses for 400kV double circuit twin moose / quad moose line converted to +/- 200kV HVDC line by applying the above equations discussed with all three phases in one circuit utilized for one DC pole and another three phase circuit for other DC pole.

Table-3. AC / DC line capacity comparison - HVAC 400kV to HVDC +/- 200kV Conversion.

Parameter	Twin Moose D/C line		Quad Moose D/C line	
	HVAC 00kV	HVDC +/- 200kV	HVAC 400kV	HVDC +/- 200kV
Power transfer capability (MW)	1030	1920	1300	3840
Line loss (MW)	47.5	127.9	37.8	255.8
Net power transfer (MW)	982.5	1792.1	1262.2	3584.2
Increase in power transfer	**1.82**		**2.84**	

The details tabulated below are the comparison on transmission line capacity and losses for 765kV double circuit Hexa zebra line converted to +/- 400kV HVDC line by applying the above equations discussed with all three phases in one circuit utilized for one DC pole and another three phase circuit for other DC pole.

Table-4. AC / DC line capacity comparison - HVAC 765kV to HVDC +/- 400kV Conversion.

Parameter	**Hexa Zebra D/C line**	
	HVAC 765kV	**HVDC +/- 400kV**
Power transfer capability (MW)	4500	12480
Line loss (MW)	47.3	254.92
Net power transfer (MW)	4452.7	12225.1
Increase in power transfer	2.75	

CONCLUSIONS

The feasibility to convert existing AC transmission line to a HVDC line has been discussed. For the particular transmission line studied, there is substantial increase in the loadability of the line. The line can also be loaded to its thermal limit without any restriction due to HVDC current. There is no need for any modification in the size of conductors, insulator strings, and towers structure of the original line and it is also evident from the above Tables 3 and 4 that conversion with 400kV quad moose line has got more advantage as more power can be transferred compared to conversion with other lines. Such an arrangement of conductor configuration can be looked into, while designing new HVDC transmission lines instead of going for more number of conductors per bundle per pole.

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