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# LOSS EVALUATION OF HVAC AND HVDC TRANSMISSION SOLUTIONS FOR LARGE OFFSHORE WIND FARMS

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***ABSTRACT: This paper shows a correlation of transmission system losses in percent for wind farm power creation. Three specialized arrangements are investigated, i.e. HVAC, HVDC Line Commutated Converter (LCC) and HVDC Voltage Source Converter (VSC). Wind power, as a renewable power source delivering no eminations and with an adequate wind asset in numerous parts of the world, is drawing in expanding interest and developing quickly. Offshore wind quality is generally substantially more stronger than onshore levels and some extensive scale wind farms (more than 1GW) are intended to be built in offshore and must transmit power over long separations. Long separation control exchange is a noteworthy issue for renewable power sources situated far from the significant load centers . This issue includes examining the cost of venture and activity and sorts of interconnection utilized for transmitting the huge power from a remote region to a noteworthy load centers . As the level of intensity exchange and the transmission separate builds, the power loss of the transmission line tends to increment. Thus, it is basic to deliberately investigate the effect of interconnection on the aggregate loss of a power system, subject to changes in working conditions and fluctuating transmission distances. The regular approach for long transmission lines is to utilize high voltage (HV) in view of either DC or AC. . In principle, the HVAC line has higher obstruction and reactance, along these lines, it has a high loss in the line contrasted with the HVDC alternative. Then again, the HVDC conspire has a noteworthy extent of loss in its converter/inverter stations. Up to a specific separation called the "breakeven distance", HVAC is predominant regarding the aggregate cost, loss and the stability edge. Over this separation, HVDC is the most good alternative. The principle undertaking in this paper is deciding this "breakeven distance" for a specific power system in light of static power flow investigation. . The losses for every innovation are computed for various size of the wind resourse, different separations to shore. Furthermore, arrangements with blends of two and the three arebroke down and compared. From these analysis encourage examination with respect to reliability quality and financial issues can be considered so as to characterize best answers for wind power transmission.***
***Keywords: HVAC; HVDC; LCC; VSC;***

## I. INTRODUCTION

The present introduced offshore wind farms have moderately smaller evaluated powers and are put at shorter separations from shore than future arranged projects [1]. The average approach for long transmission lines is to utilize high voltage (HV) in view of either DC or AC. In principle, the HVAC line has higher resistance and reactance; in this way, it has a high loss in the line contrasted with the HVDC choice. Then again, the HVDC scheme has a significant extent of loss in its converter/inverter stations. Up to a specific distance called the "breakeven distance", HVAC is superior as far as the total cost, loss and the stability edge. Over this separation, HVDC is the most great alternative. the aggregate system losses because of the effect of HVAC, Line-Commutated Converter (LCC) HVDC and Voltage Source Converter (VSC) based HVDC associated with a. huge offshore wind farm (from 100 to 1000 MW) with shifting distances up to 200km. Paper [4] inferred that the HVAC arrangement is better for distance more than 70km. LCC HVDC is favored regarding lessened system losses over this separation. The "breakeven distance" for VSC HVDC in a loss perspective is around 200km. As indicated by their outcomes, the mix of various transmission systems never enhances the aggregate loss in the system. Paper [5] showed that the HVDC arrangement is more costly than the HVAC alternative with 100MW, 200MW and 500MW wind farms at the association a distance of 60km because of higher venture cost and higher power loss. Be that as it may, the HVDC choice has all the earmarks of being less expensive than the HVAC alternative while associated with a 100MW wind farm with a distance more noteworthy than 90km. The utilization of High Voltage Direct Current (HVDC), i.e. voltages over the most noteworthy being used, 600 kV, has been observed to be monetarily appealing for power obstructs 6000 MW for separations over 1000 km, Furthermore the utilization of 800 kV as transmission voltage will be achievable inside the not so distant future with a restricted measure of improvement work. None of the AC equipment, auxiliary or control and security will be influenced by the expansion of DC voltage. Likewise a large portion of the DC voltage is effortlessly adjusted for 800 kV, for example, thyristor valves and DC filter capacitors. Station outside insulation and line insulation must be considered with care

Contrasted with HVAC, VSC HVDC transmission can flexibly control dynamic and responsive power, and can ease the propagation of voltage and frequency changes because of wind variations in wind strength. The way that HVDC transmission lines can be directed underground wiping out accidents, for example, corona makes HVDC appealing and ecologically friendly. Thus, they are once in a while known as ―the invisible transmission lines [2]. DC can likewise transport moderately more power at a similar voltage/insulation level as AC. Along these lines, HVDC transmission is viewed as a viable method for interfacing offshore wind farms to the principle grid.

Two strategies, the traditional line commutated converter (LCC) and the voltage-source converter (VSC), have been utilized for HVDC applications. Contrasted and the LCC HVDC, VSC HVDC has numerous focal points [3][4]. It can control the dynamic and receptive power autonomously and supply a passive system. Moreover, power flow inversion can be acknowledged by turning around DC current direction without switching DC voltage polarity. There is no requirement for interchanges between the converters at every node, and this is an important favorable position that can encourage the formation of a multi-terminal HVDC system. A VSC multi-terminal HVDC (MTDC) system has dominance over a two-terminal HVDC system, in that it encourages progressive extension of distributed systems, the input and output power can be controlled adaptably with a specific end goal to expand the total power transportation limit. At first, a double-input single-output HVDC was proposed, which would interface two wind farms to the AC grid through one DC connection, and this has been examined as far as system control and stability [5]. MTDC systems have likewise been proposed for urban sub-transmission [6], oil and gas stages [7], and ―premium quality power parks‖ [8].

## II. LOSS EVALUATION

First, The test framework utilized as a part of this paper is a 2-zone system appeared in Fig. 2, which contains 4 generators and 2 extensive loads. The two zones are associated with each other by two interconnection lines. In the first system, the interconnections are two 220km, 230 kV HVAC lines in parallel.

The line parameters are:

R = 0.0529 (Ohms/km)

X = 0.529 (Ohms/km)

B = 33.1 x $10^{-6}$ (S/km)

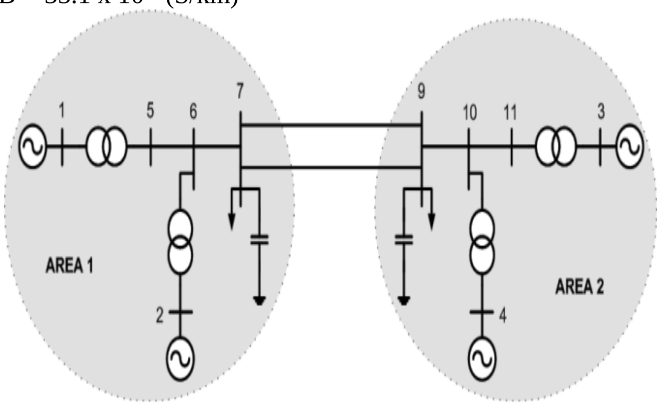


Fig. 1 System diagram [8]

The active and reactive power at system buses are presented in Table 1.

| Bus | VM (pu) | $V_{base}$(kV) | $P_G$(MW) | $Q_G$(MVAr) | $P_L$(MW) | $Q_L$(MVAr) |
|---|---|---|---|---|---|---|
| 1 | 1.03 | 22 | 700 | 0 | 0 | 0 |
| 2 | 1.01 | 22 | 700 | 0 | 0 | 0 |
| 3 | 1.03 | 22 | 700 | 0 | 0 | 0 |
| 4 | 1.01 | 22 | 700 | 0 | 0 | 0 |
| 7 | 1.00 | 230 | 0 | 200 | 967 | 100 |
| 9 | 1.00 | 230 | 0 | 350 | 1767 | 100 |

Table 1. System data bus, including voltage magnitude (VM), base voltage ($V_{base}$), active and reactive power generated ($P_G$, $Q_G$) and consumed ($P_L$, $Q_L$) at all buses in thesystem.

We tried the first system with HVAC interconnections changed by HVDC interconnections. The load stream results for the changed system are contrasted with that of the first system. The line resistance for the HVDC system is been the same as that of the HVAC system. In the HVAC case, bus 3 is the slack bus for the entire system; in HVDC interconnection case, bus 1 is the slack bus for area 1 and bus 3 is the slack bus for zone 2. The HVDC appraised voltage is 230kV, the information of which is taken from [9]. The rectifier and inverter commutating reactance are 0.07 and 0.055 pu, in reference to an evaluated power of 890MW and an appraised voltage of 230kV. The tap proportion at the converter transformer is kept upat 1.0 pu. The inverter is worked in steady extinction angle mode with γ=220. The greatest and least terminating angle at the rectifier side is 120 and 80, separately. Table 2 condenses load stream results got from utilizing PSSE with HVAC and HVDC interconnection systems.

| **Bus** | **HVAC** | | **HVDC (constant +)** | |
|---|---|---|---|---|
| | **VM (pu)** | **Ang. (deg)** | **VM (pu)** | **Ang. (deg)** |
| **1** | 1.03 | 20.98 | 1.03 | 24.79 |
| **2** | 1.01 | 11.22 | 1.01 | 14.9 |
| **3** | 1.03 | -6.8 | 1.03 | -6.8 |
| **4** | 1.01 | -16.93 | 1.01 | -16.82 |
| **5** | 1.0066 | 14.51 | 1.0008 | 18.27 |
| **6** | 0.9785 | 4.43 | 0.9645 | 8.01 |
| **7** | 0.9618 | -3.98 | 0.9367 | -0.68 |
| **9** | 0.9751 | -31.33 | 0.9604 | -31.38 |
| **10** | 0.987 | -22.98 | 0.9793 | -22.92 |
| **11** | 1.0114 | -12.74 | 1.0086 | -12.7 |

Table 2.Voltage profile of the system, including voltage magnitude and voltage angle of all buses after solving load flow.

  

The dynamic power exchange from bus 7 to bus 9 was kept at 400 MW, bringing about 200MW dynamic power moved in each line. The load flow results are shown in Table 3 below.

| | **HVAC** | | **HVDC (constant +)** | |
|---|---|---|---|---|
| | **P (MW)** | **Q (MVAr)** | **P (MW)** | **Q (MVAr)** |
| **Gen. 1** | 700 | 184.05 | 635.78 | 180.19 |
| **Gen. 2** | 700 | 231.94 | 700 | 258.28 |
| **Gen. 3** | 718.74 | 164.93 | 772.30 | 202.10 |
| **Gen. 4** | 700 | 191.54 | 700 | 255.79 |
| ***Total*** | *2818.74* | *772.46* | *2808.07* | *896.36* |
| **L7** | 967 | 100 | 967 | 100 |
| **L9** | 1767 | 100 | 1767 | 100 |
| ***Loss*** | *84.74* | *572.46* | *74.07* | *696.36* |

Table 3. Power flow data, including active and reactive power generated at generator buses and consumed at load buses. See text below for loss calculation

Table 3 gives an underlying examination of the two interconnection choices: HVDC and HVAC, with a similar dynamic power exchange level. Both dynamic and responsive power losses are figured by subtracting the aggregate dynamic/responsive power expended at the loads from the aggregate created dynamic/responsive power. The dynamic power loss is specifically identified with working expense. The responsive power loss speaks to the extra responsive power the generators need to give to the grid to keeping up the system voltage to a desired level. Responsive power generation is an essential subordinate administration in a power control market, and along these lines, likewise relates nearly to the working expense. As can be found in Table 3, the dynamic power loss in the HVDC system is lighter than that of the HVAC system. Notwithstanding, the HVDC system requires more responsive power than the HVAC system. In the accompanying areas, dynamic/responsive power loss of the HVDC and HVAC systems are thought about at various power exchange levels and transmission lengths.

## III. IMPACT OF DISTANCE ON SYSTEM LOSS

The length of the two interconnections is differed from 200 km to 350 km. The HVDC is worked in the power control mode. The power exchanged from the rectifier station (bus 7) to the inverter station (bus 9) is kept equivalent to the power moved in the HVAC case. The voltage magnitude and angle of bus 1 in the HVDC system is kept up equivalent to that in the relating HVAC case. The outcome is appeared in Fig. 3.

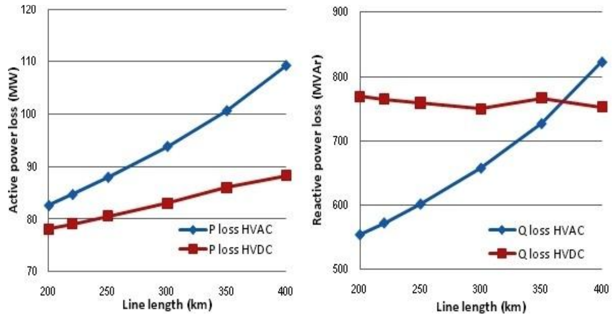


Fig. 2 Total system losses relating to transmission length

It can be seen from Fig. 3 that dynamic and responsive power losses in the HVAC case consistently raise with the expansion of the interconnection length. This is not out of the ordinary, as dynamic/responsive lossses on the interconnection line is a critical piece of the aggregate AC system dynamic/responsive loss. Then again, dynamic/responsive loss in the HVDC system depends basically on the losses in converter stations. The dynamic power loss in the HVDC system is hence smaller than that in the HVAC sytem. Also, the dynamic power loss system in the HVDC case does not increment as steeply as does the dynamic influence loss in the AC interconnection situation when the transmission length increments. The reason is that the voltage profile diminishesfundamentally for the HVAC case while the voltage profile of the HVDC system is marginally enhanced as the length of the line increments.

The length of the interconnection line since the DC line does not expend responsive influence. Also, in the HVDC plot, the inverter is worked in steady γ mode, which keeps voltage at the inverter transport consistent at 0.9604 pu (bus 9). Therefore, when the transmission length is expanded, the The responsive power loss in the HVDC system is somewhat diminished with the expansion in bus voltage at the rectifier bus will be expanded keeping in mind the end goal to keep up the bus voltage at the inverter bus because of the relationship in condition (6). The voltage profile of the entire system, subsequently, will be enhanced somewhat bringing about lower responsive power loss.

At the point when the line length is expanded to 350km, to keep the power exchanged on the HVDC line equivalent to that on the HVAC case, the HVDC should be worked in consistent extinction angle mode γ=230 so as to build the dc (voltage at bus 9 is kept at 0.9581 pu). Along these lines, we can see a slight increment in responsive loss of the HVDC line. At the point when the length goes up to 400km, the extinction angle was kept at 230, in this manner the responsive power loss in the HVDC case keeps on diminishing marginally and ends up smaller than that in the HVAC case. Consequently, from both dynamic power and responsive power loss perspectives, the HVDC would be better than HVAC after a separation of 360km.

  

## IV. IMPACT OF POWER TRANSFERRED IN TRANSMISSION LINE ON THE "BREAKEVEN DISTANCE"

The power exchange level is progressively expanded from 150MW to 300MW for every line. This is finished by differing the load at the sending end (bus 7), from 1067MW to 767MW. Load streams are figured for both AC and DC systems at each power exchange level. The outcomes are displayed in Fig. 4.

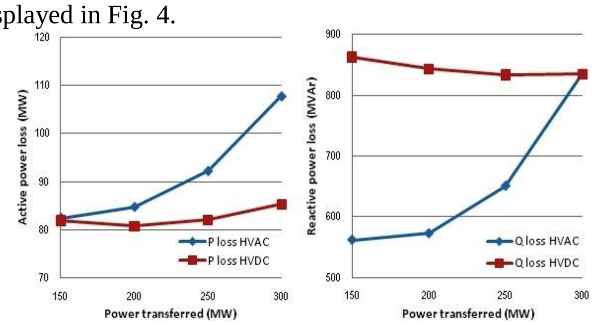


Fig. 3 Total system losses relating to power transferred in the interconnection

The loss in the HVAC system increments fundamentally as the dynamic influence exchange is expanded. Then again, the responsive power loss in the HVDC system remains generally unaltered (or even somewhat diminishes) as the influence exchange is expanded. Indeed the slight lessening of responsive power loss does not identify with the DC interface for this situation. As the load at bus 7 is diminished, the current hanging in the line 6-7 is decreased, accordingly, the aggregate responsive power loss in area 1 is lessened marginally.

The "breakeven distance" for this case happens around 600MW of power exchange (300MW for each line). At this power exchange level, the responsive power loss in the AC system begins to outperform the responsive loss in the HVDC system. It is to be noticed that the two shunt capacitors at bus 7 and 9 help to diminish the responsive power move in the two areas. The aggregate responsive loss in the HVDC system could be additionally enhanced on the off chance that one upgrades the responsive influence pay at the two sending/accepting ends. By and large, responsive power remuneration is to be done locally, deliberately putting shunt capacitors may help to incredibly enhance the productivity of the HVDC system.

## V. CONCLUSION

This fundamental work thinks about the DC and AC interface alternatives for a straightforward power system at different transmission lengths, load levels. All through the paper, it is watched that the dynamic power loss in the DC connect constitutes an irrelevant piece of the aggregate system loss. Besides, the required responsive power for the HVDC system is very independent of the interconnection quality and power exchange level. Then again, the AC system losses change extensively with the above parameters. In this way, as the power exchange level and the interconnection length increment, the DC interface step by step demonstrates its predominant execution. It is to be noticed that key position of responsive power pay can enormously enhance the effectiveness of a HVDC system. For the examined system in this paper, responsive power areas are clear as there are just two critical loads. In this work, the "breakeven distance" is controlled by contrasting just the responsive/dynamic power loss, which is firmly identified with the working expense. In the event that one considers the capital cost, the "breakeven distance" would be higher, because of the mind-boggling expense of building HVDC systems.

One potential preferred standpoint of the HVDC system is its ability to upgrade the aggregate system dynamic stability. A similar investigation of system security with/without HVDC system is along these lines required, and will be the subject of our future research.

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