HVDC over HVAC Power Transmission System: Fault Current Analysis and Effect Comparison

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Abstract—**'*Fault current*' is the flow of abnormal current through an improper path due to electric faults which causes enormous damages. In HVAC transmission system, Fault current due to electric faults is too large which affects the overall power system including - Receiving & Sending end bus, Transmission system, Load and even also the Power Generation Unit. HVDC transmission system dramatically reduces these effects, as the fault current due to electric faults is much lower, and only affects the individual faulty section of the overall transmission system. In favor of HVDC system, this paper presents a '*fault current*' (due to asymmetric faults) analysis and comparisons between HVAC and HVDC transmission system. MATLAB (Simulink) simulation software is used to simulate both HVAC & HVDC power transmission system topologies. From the comparison of the simulation output –lower fault current, less fault effect, better performance & higher reliability is demonstrated for HVDC transmission system.**

Keywords— Electric faults, Fault current, HVAC power system, HVDC power system, Power system simulation.

I. INTRODUCTION

HVDC transmission system is considered as the newest method of bulk power transmission, which has reemerged in an advanced form to possibly replace major AC high-voltage routes. At present, HVDC is attracting more researches as it provides greater operational flexibility. [1]

HVDC has certain advantages over HVAC transmission system as it has very low corona loss, required less insulation, lower voltage drop. The cost of light Towers& Poles, Insulators, cables and conductors are low so the system is economical. Most importantly, the concept of skin effect, dielectric losses, Inductance and Surges, Communication signal interference, synchronizing and stability problems are not found in HVDC transmission system. [2]

Electric Faults can be defined as the flow of a massive current through an alternative path which leads to cause serious equipments damage, interruption of power, personal injury or death. [3]

In a polyphase system, a fault may affect all phases equally which is a "*symmetrical fault*". In transmission line faults, roughly 5% are symmetric. If only some phases are affected, the resulting "*asymmetrical fault*" becomes more complicated to analyze due to the simplifying assumption of equal current magnitude in all phases being no longer applicable. [4-5]

There are three common types of '*asymmetric faults'*. A *'line to line'* fault is a short circuit between lines, caused by the lines come into physical contact. Again, a'*line to ground'*fault is a short circuit between one line and ground, very often caused by physical contact, for example due to lightning or other storm damage. In a *'double line to ground'* fault, two lines come into contact with the ground (and each other), also commonly due to storm damage. [6-7]

II. 'FAULT CURRENT' EFFECT IN POWER SYSTEM

When a fault occurs in transmission system, a '*fault current'* (also known as '*short circuit current'*) arises. A'*fault current'*is a flow of massive current through an electric circuit. This high level *'fault current'* can largely damage the equipment insulation system, lead to power surges that damage equipment that is powered by the current, or possibly charge the devices so that when they are touched, an electric shock is administered. Depending on the nature of the fault current, that shock can be sufficient to cause death. [8]

In case of *asymmetric fault'* in HVAC power transmission system, the high level '*fault current'* can largely affect the transmission line, sending end bus section and also the power generation unit. Generators are frequently subjected to high level '*fault current'* [9]. Faults in particular subject the generator to stress beyond its design limits and cause high temperature increase, amplify and distort air gap torques, and create unbalanced flux densities. Even more stressful as a consequence of faults are sudden loss of load, fault clearance and reclosing. Mechanically, the abnormal forces that are generated excite the rotor and as a result, amplify the shaft's normal mode of oscillation. [10]

As the'*fault current'*on the power system is cleared by circuit breakers, hence the magnitude of '*fault current'* determines the types, settings and the size of the circuit breakers. The lower the '*fault current*', the size and cost of circuit breaker is reduced. In turn, the flexibility of operation of circuit breaker is increased. [11-12]

III. Simulation

A. HVAC Transmission System :

The generation of electric power takes place in a power plant. Then the voltage level of the power is raised by the transformer before the power is transmitted. Electric power is proportional to the product of voltage and current this is the reason why power transmission voltage levels are used in order to minimize power transmission losses.[13]

Fig 1.1 represents a three-phase HVAC transmission system simulation model, transmitting 1680 MW (50 Hz, 500 kV, 0.8 lagging) power from a power plant consisting of six 350 MVA generators to a sub-station through a 300 km transmission line.

To increase the transmission capacity and power quality, each line is series compensated by capacitors representing 40% of the line reactance and is shunt compensated by a 330 Mvar shunt reactance. Shunt capacitive compensation is widely employed to reduce the active and reactive power losses and to ensure satisfactory voltage levels during excessive reactive loading conditions. Series compensation reduces the transfer reactance between buses to which the line is connected, increases the maximum power that can be transmitted, and reduces the effective reactive power losses [14].Sub-station receives 1645 MW power at the very final stage of this HVAC power system simulation model.

B. HVDC Transmission System :

Technical feasibility has been already proved for HVDC power transmission system with the development of Power electronics devices [15]. These devices make the efficient conversion from AC to DC and thus are the main component of any HVDC power transmission system. [16-17]

Fig 1.2 represents the simulation model of a high-voltage direct current (HVDC) transmission system using 12-pulse Thyristor converters, transmitting 1680 MW (50 Hz, 500 kV, 0.8 lagging) power from a power plant consisting of six 350 MVA generators to a sub-station through a 300 km transmission line. The AC systems are represented by damped L-R equivalents with an angle of 80 degrees at fundamental frequency and at the third harmonic. The rectifier and the inverter are 12-pulse converters using two Universal Bridge blocks connected in series. The converters are interconnected through a 300-km line and 0.9 H smoothing reactors. The Smoothing reactor provides the prevention of the intermittent current, Limits the fault current, Prevents resonance in the DC circuits [18]. The tap position is rather at a fixed position determined by a multiplication factor applied to the primary nominal voltage of the converter transformers (0.90 on the rectifier side; 0.96 on the inverter side). Sub-station receives 1645 MW power which is same as that of HVAC power transmission system.

Fig 1.1 and Fig 1.2 shows the simulation model of both HVAC and HVDC power transmission system sequentially. For better analysis and observation of fault current effects, the parameters for both simulation were kept same.

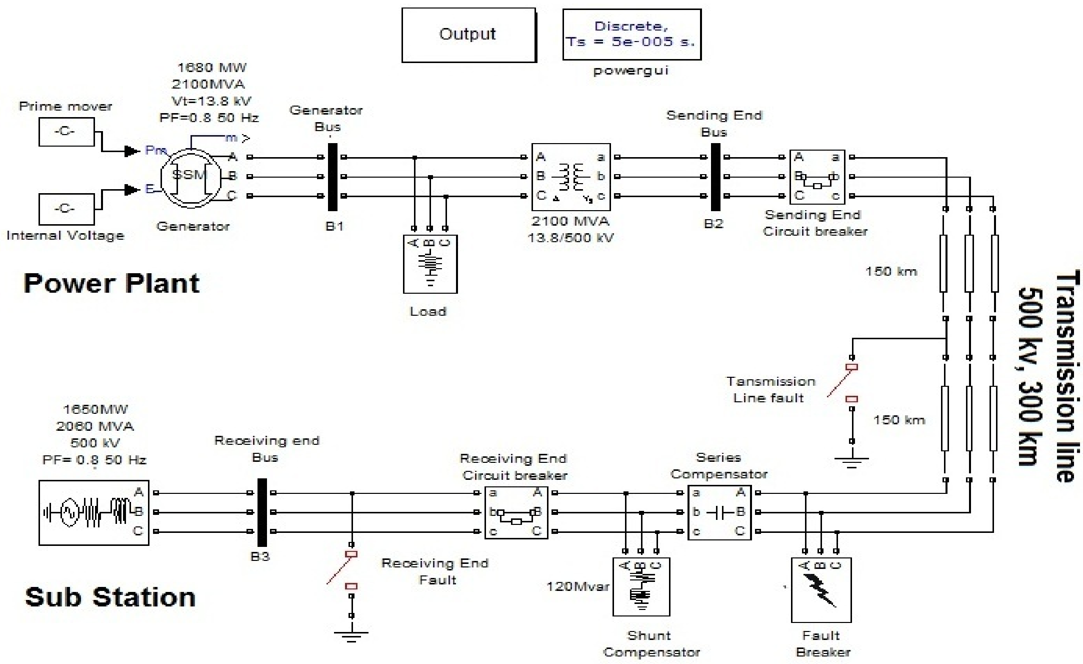

Fig 1.1. HVAC Power Transmission System.

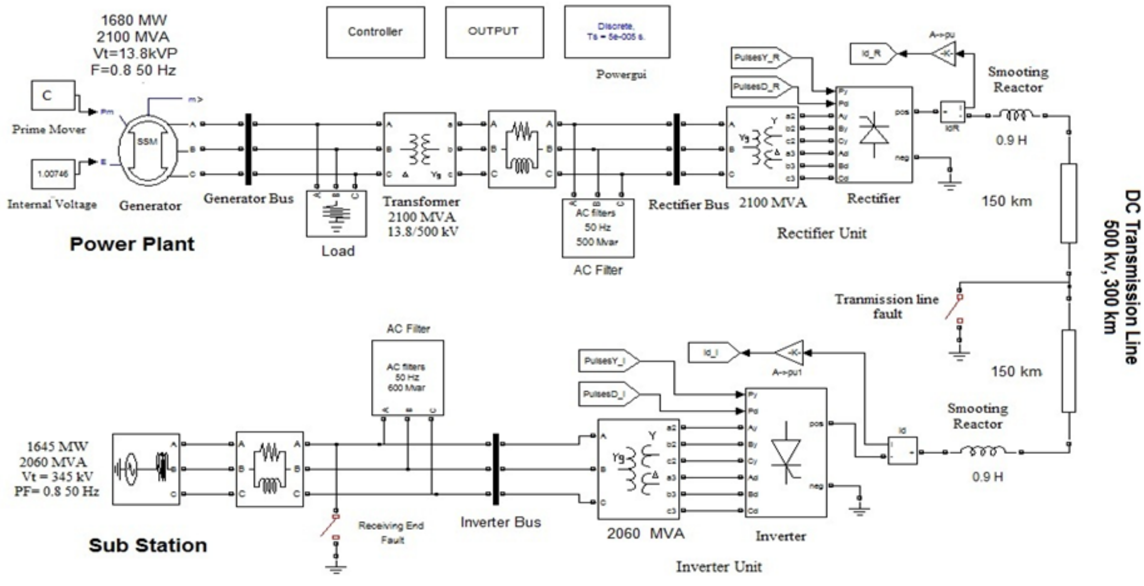

Fig 1.2. HVDC Power Transmission System.

IV. SIMULTION OUTPUT

A. Condition 01: Single line to Ground Fault

Fig 2.1 shows a very high '*fault current'* in HVAC transmission system (37000 A) compared to '*fault current'* in HVDC transmission system (29000 A) due to '*Single line to ground'* fault at receiving end (Fig 2.2).

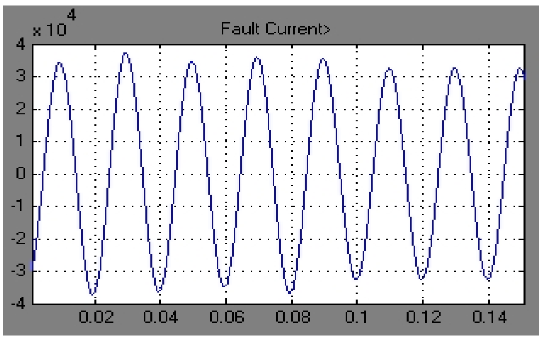

Fig 2.1: Fault current (HVAC system).

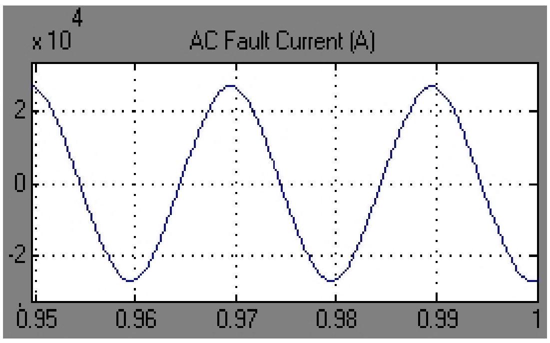

Fig 2.2: Fault current (HVDC system).

The '*Fault current'* effects can be observed from the following figures. Fig 3.1 shows that, due to '*Single line to ground'* fault, sending end voltage and current waveforms of HVAC system are no longer in proper position but highly distorted even if the fault is occurred at the receiving end of the total power system. The phase angles between the phases are highly disturbed.

For the same fault condition Sending end voltage and current waveforms (Fig: 3.2) of HVDC transmission system are in approximate proper position. The current waveforms (Fig 3.2) look like distorted because of 12 pulse converter but doesn't affect the overall power transmission system.

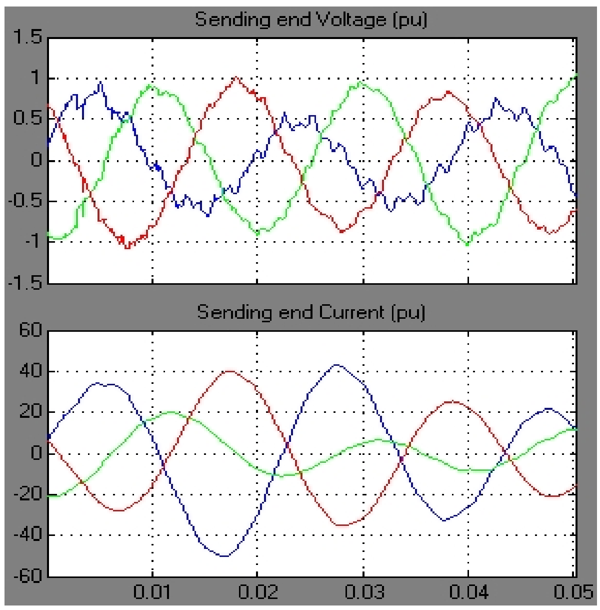

Fig 3.1: Sending end bus (HVAC system).

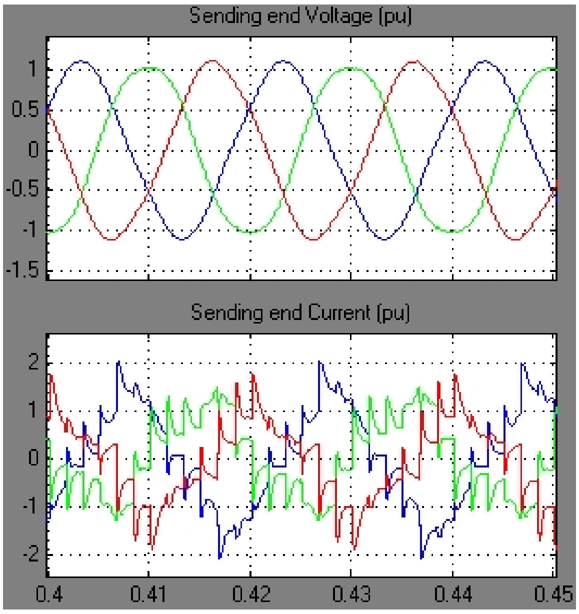

Fig 3.2: Sending end bus (HVDC system).

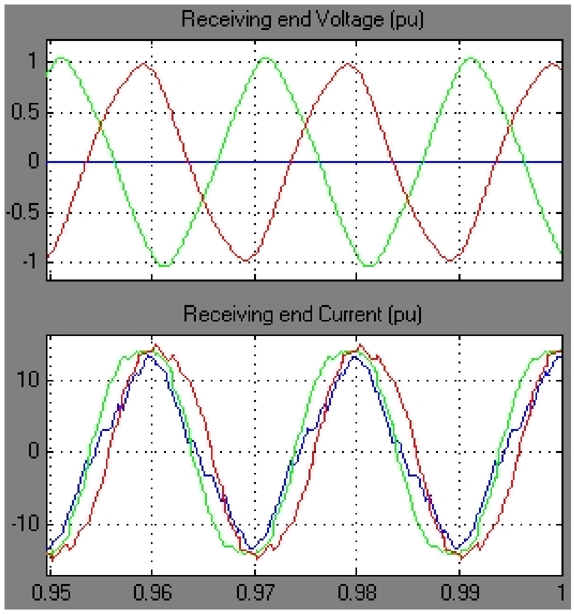

Fig 4.2: Receiving end bus (HVDC system).

Fig 4.1 and Fig 4.2 describe the receiving end voltage and current waveforms for the both HVAC and HVDC transmission system.

A fault in HVDC transmission system only affects the corresponding section. As the '*Single line to ground*' fault was occurs at the receiving end, the faulty phase is grounded; Voltage and current waveforms are affected for the both HVAC and HVDC transmission system. Specifically, only this section of HVDC system is affected.

In case of HVAC transmission system, a fault in receiving end section can affect the total power system, even also the generator section. Fig 5.1 depicts the distorted generator bus section of HVAC transmission system for *'Single line to ground'* fault at receiving end. This distortion can cause a massive destruction in the overall HVAC power system.

But, from Fig 5.2, there is no effect found at generator bus section in HVDC transmission system for the same fault condition.

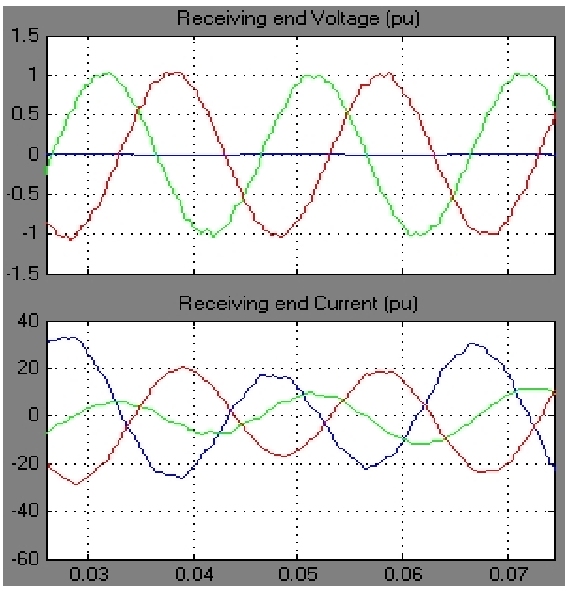

Fig 4.1: Receiving end bus (HVAC system).

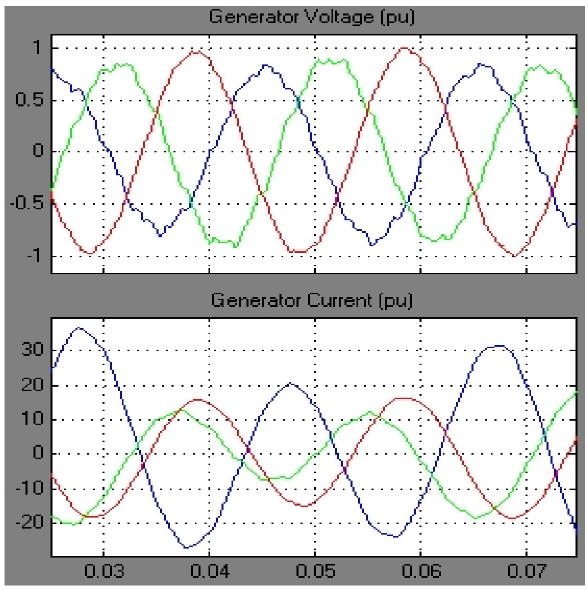

Fig 5.1 : Generator bus (HVAC system).

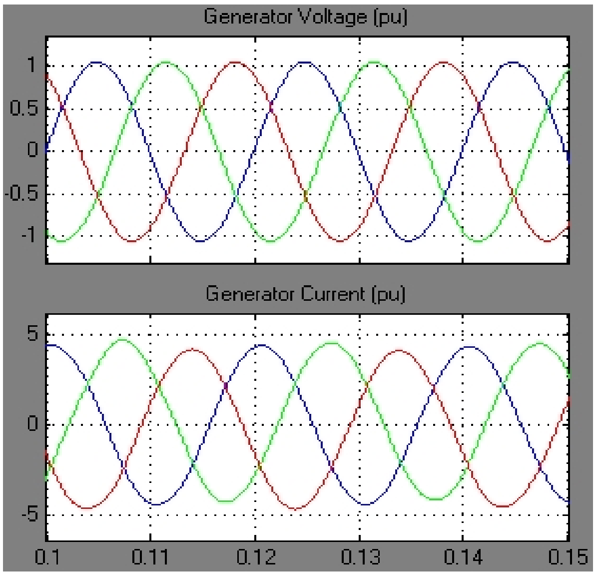

Fig 5.2 : Generator bus (HVDC system)

B. Condition 02: Line to line Fault

'Line to line' Fault is another type of asymmetrical fault. Fig 6.1 shows a very high fault current (almost 34000A) due to '*Line to line'* Fault at receiving end of HVAC transmission system, while fault current is much lower (20000A) in case of HVDC transmission system under same fault condition shown in Fig 6.2.

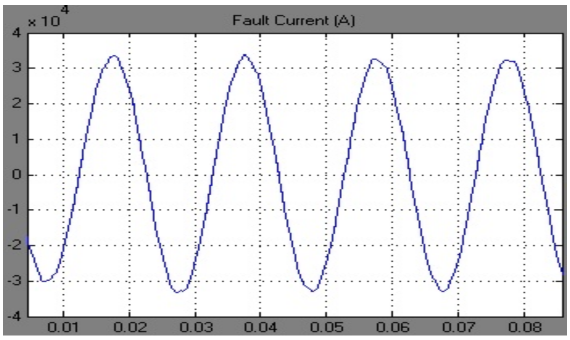

Fig 6.1: Fault Current (HVAC system)

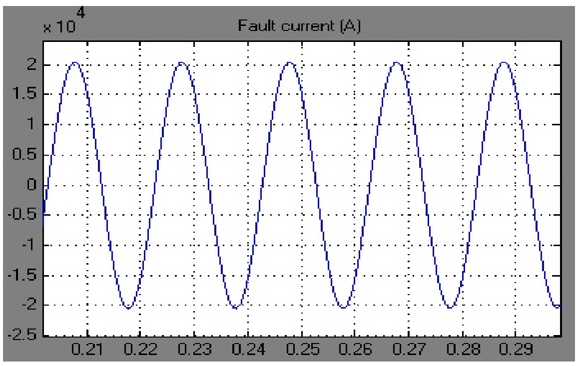

Fig 6.2 : Fault Current (HVDC system)

C. Condition 03: Fault in Transmission line

In case of HVAC transmission system, '*Fault in transmission line'* is similar to that of '*Single line to ground fault'*, but the previous '*Single line to ground'* fault occurred in receiving end section while '*fault in transmission line'* occurred in transmission line section. And, in case of HVDC transmission system, '*fault in transmission line'* occurs in DC transmission line section. It is illustrated from the Fig 7.1 and & Fig 7.2 that, '*fault current'* in HVAC transmission system for '*fault in transmission line'* is too high (12000 A) compared to HVDC transmission system (700 A).

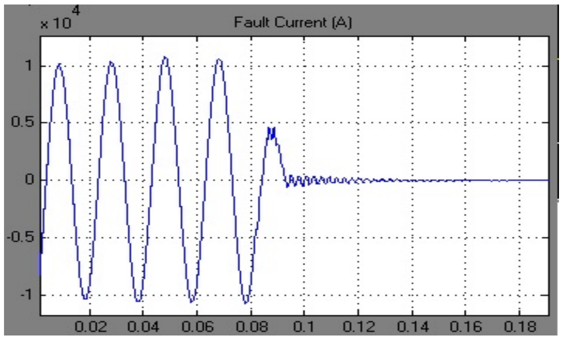

Fig 7.1 : Fault Current (HVAC system)

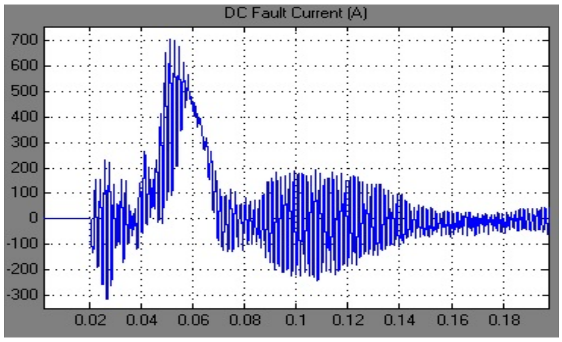

Fig 7.2 : Fault Current (HVDC system)

V. RESULT ANALYIS

Fault current comparison for different types of fault for both HVAC and HVDC transmission system can be illustratedfrom the following table (Table 01) -

Table -01: Fault Current Comparison

Fault	***HVAC* *(Peak value)***	***HVDC* *(Peak value)***
Single line to ground fault	37000 A	29000 A
Line to line fault	34000 A	20000 A
Transmission line fault	12000A	700 A

VI. CONCLUSION

This paper shows a *'fault current'* analysis and comparison between HVAC and HVDC power transmission system. This is done under '*Single line to ground'* fault, '*Line to line'* fault and *'Fault in transmission line'* for both HVAC and HVDC topologies. For better analysis and comparison, both simulation environments are kept same (300 km, 500 KV).The results show that for each and every given fault condition; '*Fault current'* in HVAC transmission system is much higher than HVDC transmission system. Also, the effects of '*fault current'* in HVAC transmission system are highly destructive while effects are gentle, negligible and less harmful in HVDC transmission system.

As a part of future work, fault current for all types of symmetric, asymmetric faults in different section (sending end, receiving end, transmission line) can be analyzed. A complete comparative study of HVAC and HVDC grid system can be performed along with their cost analysis to check the feasibility of HVDC transmission system over HVAC transmission system.

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