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Enhance Power Quality by HVDC System, Comparison Technique between HVDC and HVAC Transmission Systems

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Abstract—The alternating current is the main power in all industries and other aspects especially for the short and mid distances, but as far as long a distance which exceeds 500 KMs, using the alternating current technically will face many difficulties and more costs because it's difficult to control the current and also other restrictions. Therefore, recently those reasons led to building transmission lines HVDC to transmit power for long distances. This document presents technical comparison and assessments for power transmission system among distances either ways and studying the stability of the system regarding the proportion of losses in the actual power sent and received between both sides in different systems and also categorizing filters used in the HVDC system and its impact and effect on reducing Harmonic in the power transmission. MATLAB /Simulink simulation software is used to simulate both HVAC & HVDC power transmission system topologies.

Keywords—HVAC power system, HVDC power system, power system simulation (MATLAB), the alternating current, voltage stability.

I. Introduction

As economic accomplishment and population increase, the electricity demand of each country also increases quickly. The power generation and transmission system should also increase in order to cover the demand. As a result, the whole power system will experience more difficulty in operation and stability, such as increased active and reactive power losses, higher inherent of voltage and frequency instability, power flow control, interconnection, power swing, collapse prevention and so on.

Over the last decade, High Voltage Direct Current (HVDC) technology has been widely applied for long distances. High Voltage Direct Current (HVDC) transmission line, more efficient and can transfer bulk power with less electrical losses compared to high voltage alternating current (HVAC) transmission line [1]. Lower cost higher efficiency means a lower transmission cost, helping renewable Energy compete against other power sources. Enhanced reliability: HVDC transmission can improve system stability, permits the operator complete control over power flow, and facilitate the integration of wind from various resource areas [2]. HVDC transmission lines need narrower right-of-way Footprints, using less land, than equivalent AC lines. The dominant Advantage of DC power lines are their efficient less energy is lost as it is transmitted and there is no need for reactive Compensation along the line. Because DC flows firmly through the wires without fluctuating track many times each second and through the entire conductor rather than at the surface, DC transmission lines typically lose less power than AC transmission lines. In addition to upgrading and expanding the present alternating Current (AC) grid networks, there will be a rise need to build “electricity highways”, creating a powerful and reliable back bone structure electricity supplies. Direct Current (DC) technology is relevant when considering a long distance overlay net. Europe cable goes after to provide an authoritative source of knowledge about DC underground cable technology. So far, HVDC transmission has mainly been used in Submarine applications, either connecting offshore wind farms to land or transmit electricity over long distance through the sea where Overhead lines cannot be used. The HVDC cables are beginning to be used also for land transmission projects. HVDC has certain benefits over HVAC transmission system as it has very low corona loss, require less insulation, and 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. [3]

High voltage DC (HVDC) Transmission system consists of three essential parts: 1) converter station to convert AC to DC 2) transmission line 3) second converter station to convert back to AC. HVDC transmission systems can be arranged in many ways on the basis of cost, flexibility, and operational requirements. The simplest one is the back-to-back interconnection, and it has two converters on the exact site and there is no transmission line. This type of connection is used as interns tie between two various AC transmissions systems. The mono-polar link connects two converter stations by a single conductor line and earth or sea is used as are turned path. The most common HVDC link is bipolar, where two converter stations are connected by bipolar (±) conductors and each conductor has its own ground return. The multi-terminal HVDC transmission systems have more than two converter stations, which could be connected is series or parallel.

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II. HVAC versus HVDC Transmission

Nowadays the utilizations of the alternating current (AC) in the industrial and domestic market became very famous, but yet for the long transmission lines, AC has some restrictions which have led to the use of DC transmission in some projects. The technical detail of HVDC transmission compare to high voltage AC (HVAC) transmission is discussed to confirm HVDC two significant factors of the high voltage transmission line. The AC resistance of a conductor is higher than its DC resistance because of skin effect, and finally loss is higher for AC transmission. The switching surges are the serious transient over voltages for the high voltage transmission line, in the case of AC transmission the maximum values are two or three times normal peak voltage but for DC transmission it is 1.7 times normal voltage. HVDC transmission has less corona and radio interference than that of HVAC transmission line [4]. The total power loss due to Corona is less than 5 MW for a ±450 kV and 895 kilometers HVDC transmission line [5], [6].

The long HVAC overhead lines produce and absorb the reactive power, which is a serious problem. If the transmission line has a series inductance *L* and shunt capacitance *C* per unit of length and running voltage *V* and current I, the reactive power produced by the line is:

$$Q_c = \omega CV^2 \tag{1}$$

and consumer's reactive power:

$$Ql = \omega LI^2 \tag{2}$$

Per unit length. If $QC = QL$

$$\frac{V}{I} = \left\{\frac{L}{C}\right\} = Zs \tag{3}$$

where Zs is surge impedance of the line. The power in the line is:

$$\boldsymbol{P_n} = \boldsymbol{VI} = \frac{V^2}{Zs} \tag{4}$$

So the power carried by the line depends on the operating voltage and the surge impedance of the line. Table I shows the typical values of a three phase overhead lines [7], [8].

TABLE I
Voltage Rating and Power Capacity

Voltage (kV)	132	230	345	500	700
Natural load (MV)	43	130	300	830	1600

The power flow in an AC system and the power transfer in a transmission line can be expressed.

$$P = \frac{E1E2}{X} \sin\delta \tag{5}$$

E1 and *E2* are the two terminal voltages, δ is the phase difference of these voltages, and *X* is the series reactance. Maximum power transfer occurs at δ= 90º and is:

$$Pmax = \frac{E1E2}{X} \tag{6}$$

P max is the steady-state stability limit. For a long distance transmission system, the line has the utmost of the reactance and very tiny part is in the two terminal systems, consisting of Machines, transformers, and local lines. The inductive reactance of a single-circuit 50 Hz overhead line with single conductor is about 0.8 Ω/mi 0.5Ω/km; with double conductor is about 3/4 as greater. The reactance of the line is proportional to the length of the line, and thus power per circuit of an operating voltage is limited by steady-state stability, which is opposite proportional to length of line [9]. For the reason of stability, the load angle is kept at relatively low value under normal operating condition (about 30°) because power flow disturbances influence the load-angle very quickly. In an uncompensated line the phase angle varies with the distance when the lines operating at natural load and set a limit on the distance. For 30° phase angle the distance is 258 mi at 60 Hz. By using series capacitor, we can increase the line distance, whose reactance compensates a part of series inductive reactance of the line, but the maximum part that can be compensated has not been determined yet [10]. However, D.C transmission has no reactance problem, hence no distance limitation and no stability problem.

III. Advantages and Disadvantages of HVDC

A. Advantages

- Excellent power per conductor.
- Easier line construction.
- Ground return could be used.
- Consequently, each conductor can be run as an Independent circuit.
- No charging current.
- No Skin impact.
- Cables can be operated at a higher voltage gradient.
- Line power factor is constantly unity: line does not need reactive compensation.
- Less corona loss and radio interference, exclusively in soiled weather, for a certain conductor diameter and rms voltage.
- Synchronized operation is not imperative.
- Hence distance is not bounded by stability.
- May interconnect A.C systems of different frequencies.
- Low short-circuit current on D.C line.
- Does not supply to short-circuit current of an A.C system.
- Tie-line power is regularly controlled.

B. Disadvantages

- Converters are high-priced.
- Converters need more reactive power.
- Converters produce harmonic, require filters.
- Multi terminal or network operation is not simple.

IV. System Model and Simulation

A. HVAC Transmission System

The production of electricity takes place in a power plant. Before the power is transmitted, the voltage level of the power should be raised by the transformer. Electric power is Proportionate to the product of voltage and current this is the reason why power transmission voltage levels are used to reduce power transmission losses. [11] Fig. 2 represents a three-phase HVAC transmission system simulation model, transmitting 2000 MVA (50 Hz, 230 kV, 0.8 lagging) power from a power plant consisting of two Portable constant voltage 2000 MVA sub-station through a (200-1000) km transmission line. The system was originally available in MATLAB simulations with one source and (km) transmission lines, but in order to consider more cases or situations in the work, the number of main sources and line distances increased. Also the disturbance applied is three phase fault to ground near receiving end bus and different positions to see the comparison and impact of positions in the system as results, and taking those cases depending on the distances and fault positions in same case for HVAC and HVDC system models.

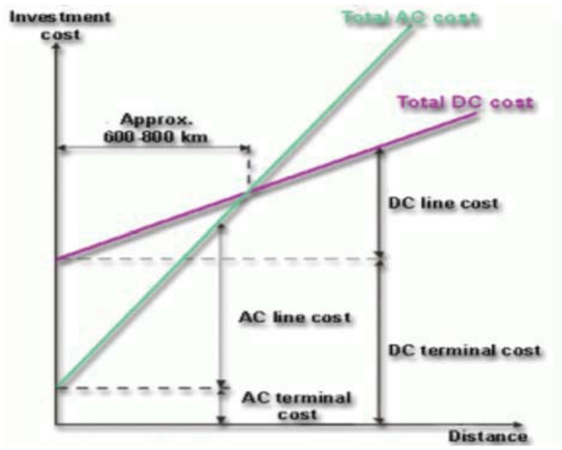

Fig. 1 HVDC and HVAC Transmission systems cost

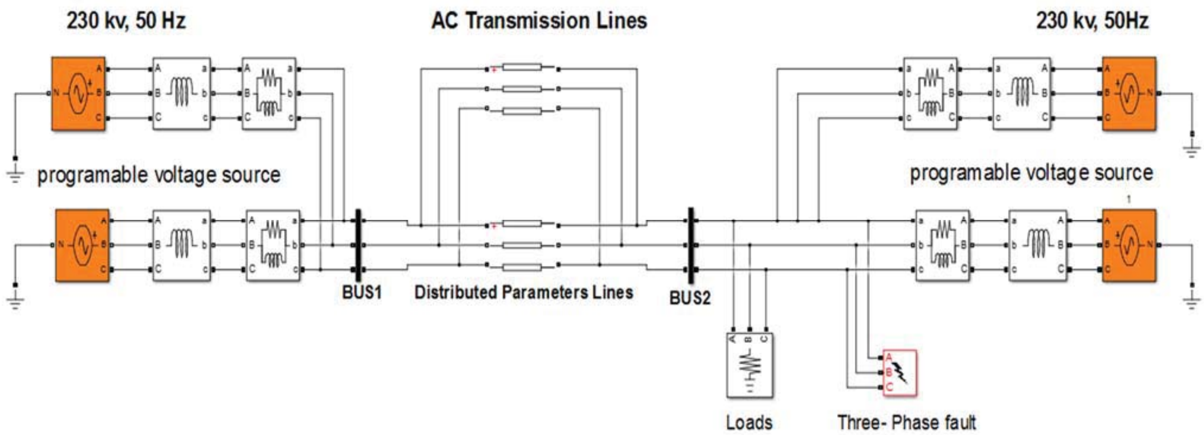

Fig. 2 HVAC Power Transmission System

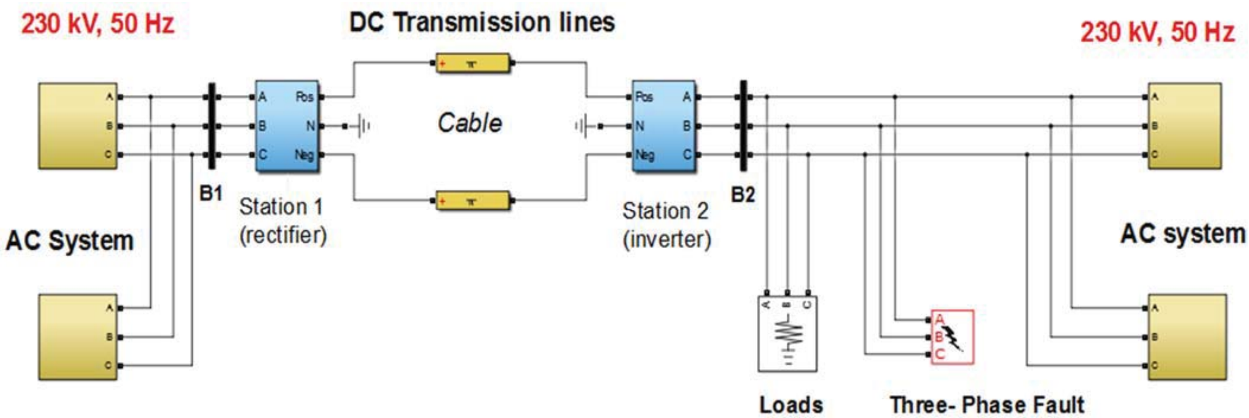

Fig. 3 HVDC Power Transmission System

B. HVDC Transmission System

Now, technological feasibility has been proved for HVDC power transmission system with the improvement of Power electronics devices [12]. These devices make the efficient conversion from AC to DC and thus are the main component of any HVDC power transmission system. [13], [14]

Fig. 3 represents the simulation model of a high-voltage direct current (HVDC) transmission system, transmitting 2000 MVA (50 Hz,230 kV,0.8 lagging) power from a power plant consisting of two 2000MVA Portable constant voltage to a sub-station through a varying distance (200 to 500) km transmission line. The AC systems are represented.

Figs. 2 and 3 show the simulation model of both HVAC and HVDC power transmission system sequentially. For best analysis and observation of cases influence, the parameters for both simulations were kept same.

V. Simulation Results and Study Cases

A. Study Cases When Lengths of Transmission Line Consider (200km) for Both System (HVAC) and (HVDC) Also Kept the All Parameter at Same Value for Evaluate

1. Case 1: Single Line to Ground Faults

When we compare Figs. 4 and 5 in both the two systems for the transfer of power, which can be seen the upper and lower peaks of the two curves, and through this proves to us in the latter that the effect of (fault-current) in (HVAC) system is more than (HVDC) system. Because of the investigations that we have mentioned above in the analysis of the situation.

2. Case 2: Line to Line Faults

The effects of the 'fault current' can be observed through the curves shown in Figs. 6 and 7 attributed to the above mentioned case, where curves analysis of the effects of the 'fault current' on the ability system shows us that the power lines transmission (DC) system is much better than transferring it by (AC) system due to those analyzes, and as a result we propose the transferring of electric power by using (DC) system rather than (AC) system for transferring much possible power(bulk power) especially in the long distances.

3. Case 3: Three-Phase to Ground Faults

In this case the comparison between (HVDC) and (HVAC) system, due to another type of fault called a symmetrical faults occurs in the other side or at 'load side' defined a '3phase to ground' fault types. It is illustrated from Figs. 8 and 9 that, 'fault current' in HVAC transmission system is too high about three times compared to HVDC transmission system this observed are clear when see the figures from output simulations results.

B. Study Cases When Lengths of Transmission Line Consider (500km) for Both System (HVAC) and (HVDC) Also Kept the All Parameter at Same Value for Evaluate

1. Case 4: Single Line to Ground Faults

In this case when apply fault at bus (2) consider the distance (500) km at 0.1 sec. Figs. 10 and 11 show the different situations between two system (HVAC) and (HVDC) in varying distance, also the effects of 'fault current' in the overall power system. This shows us through to watch the top of the wave at the 'fault current' position.

2. Case 5: Line to Line Faults

Fig. 12 and 13 shows the 'fault current' at bus (2). It can be seen that before the fault, the current was (1.0) put. During the fault, the current increased rapidly to (5.8) p.u. Before it dipped down after the fault was cleared, at (500) km can be observed the amplitude of the short current smallest when compare to (200) km transmission line length of system.

3. Case 6: Three-Phase to Ground Faults

In this section or in the study of this case. The (HVAC) and (HVDC) transmission line fixed at (500) km. Figs. 14 and 15 show the results of 'fault current' during the fault time the transmission line length has impact on the shot current at bus (2) during the 3-phase to ground fault on the (HVDC) and (HVAC) transmission line system.

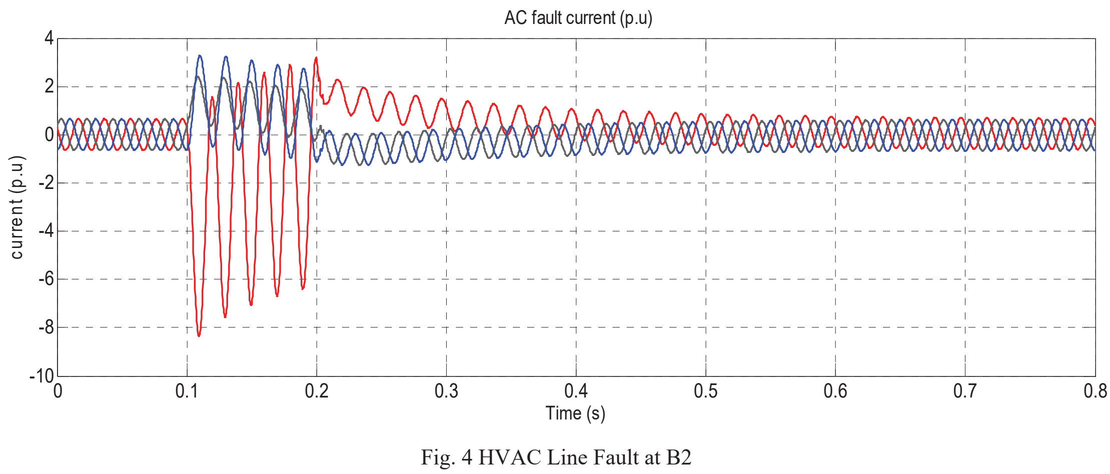

Fig. 4 HVAC Line Fault at B2

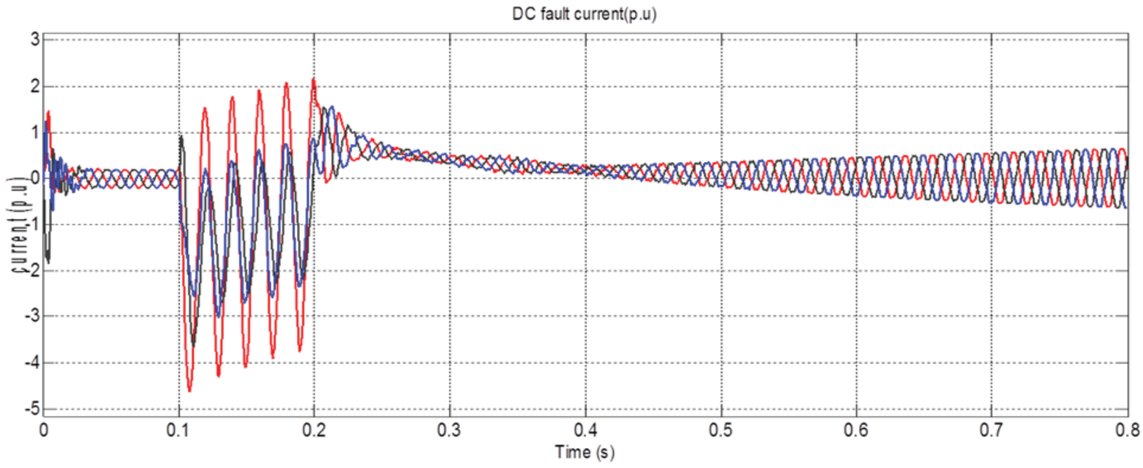

Fig. 5 HVDC Line Fault current at B2

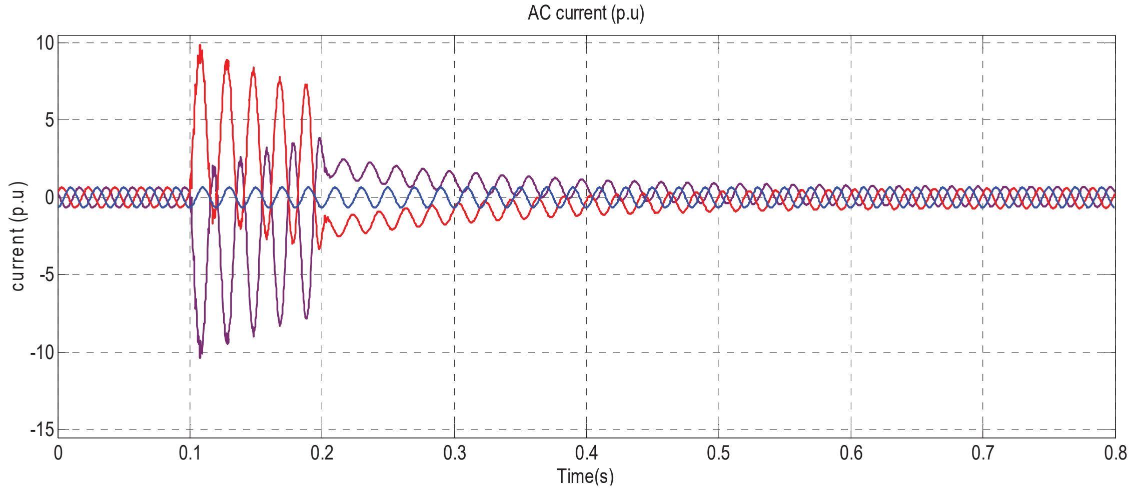

Fig. 6 HVAC Line Fault current at B2

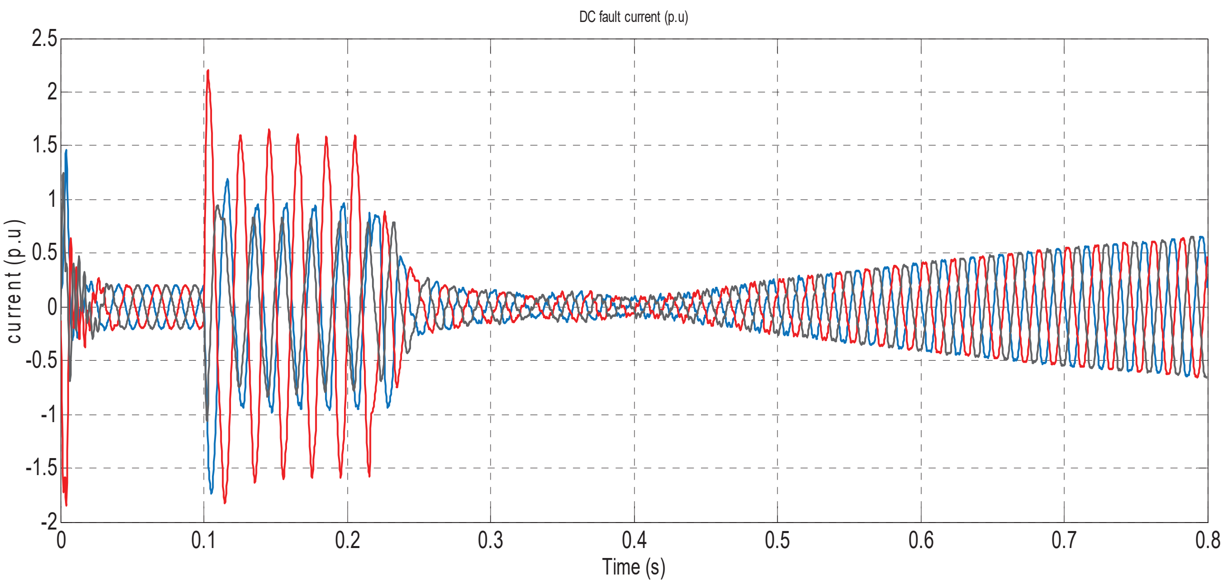

Fig. 7 HVDC Line Fault current at B2

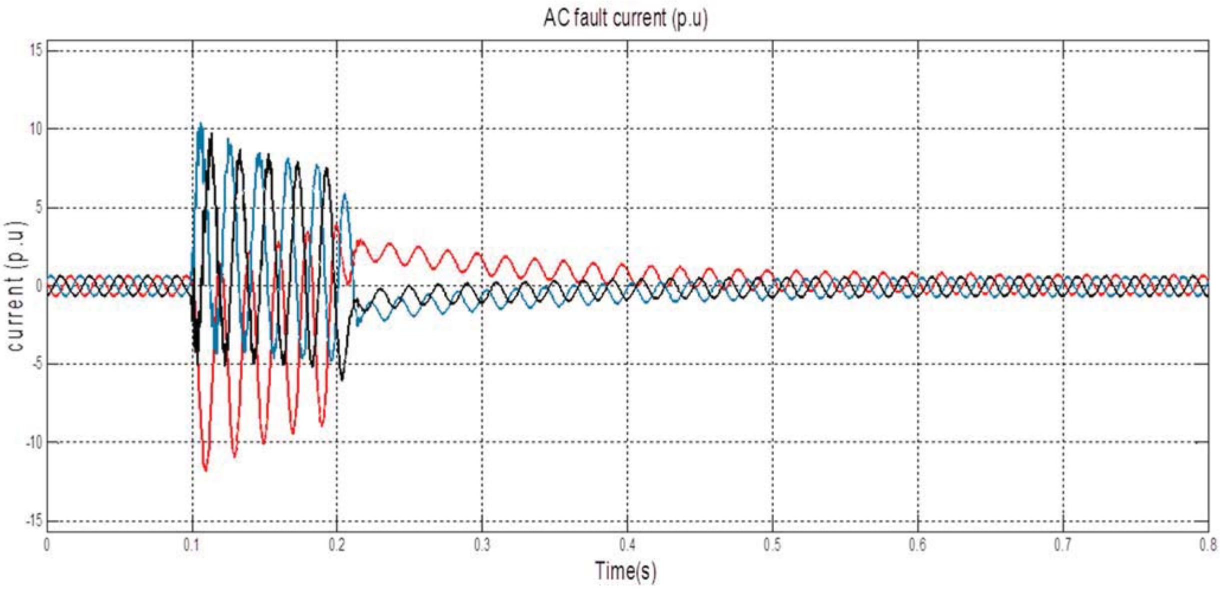

Fig. 8 HVAC Line Fault current at B2

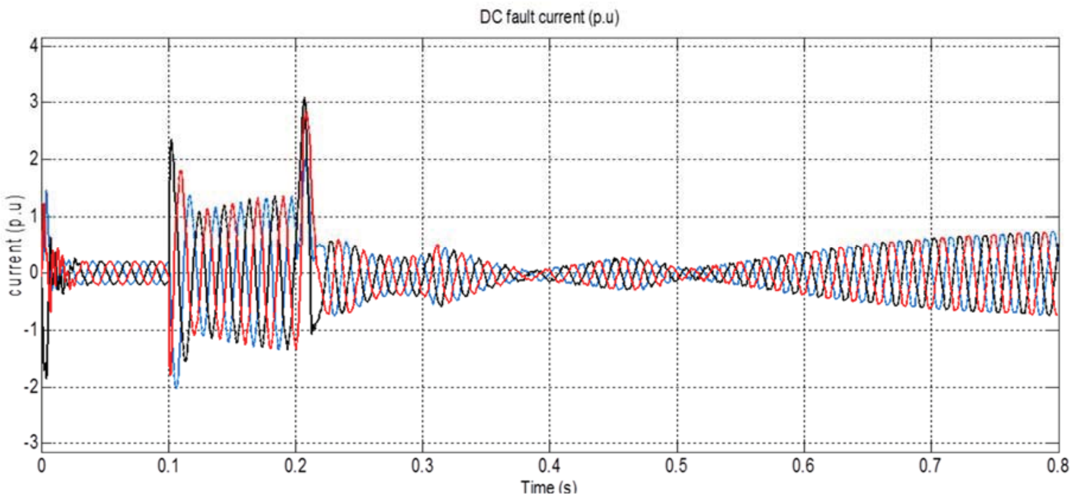

Fig. 9 HVDC Line Fault current at B2

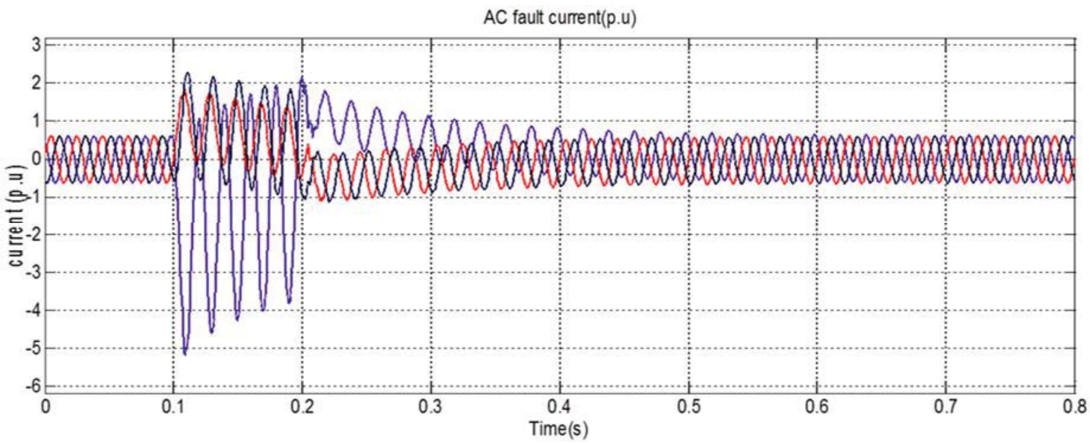

Fig. 10 HVAC Line Fault current at B2

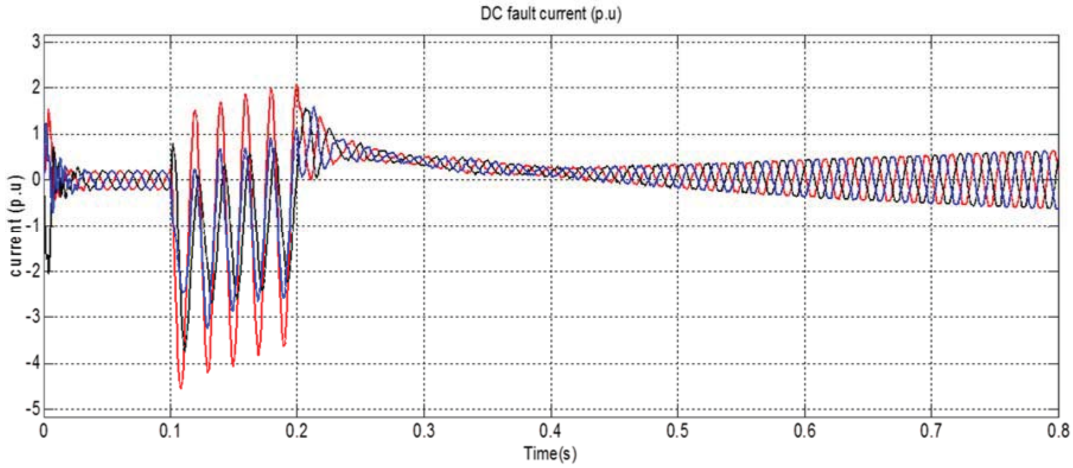

Fig. 11 HVDC Line Fault: current at B2

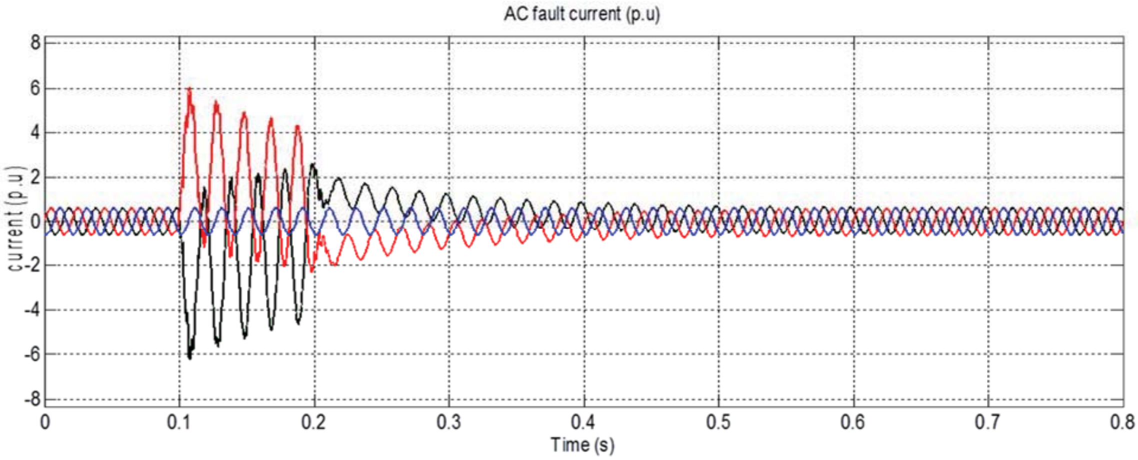

Fig. 12 HVAC Line Fault current at B2

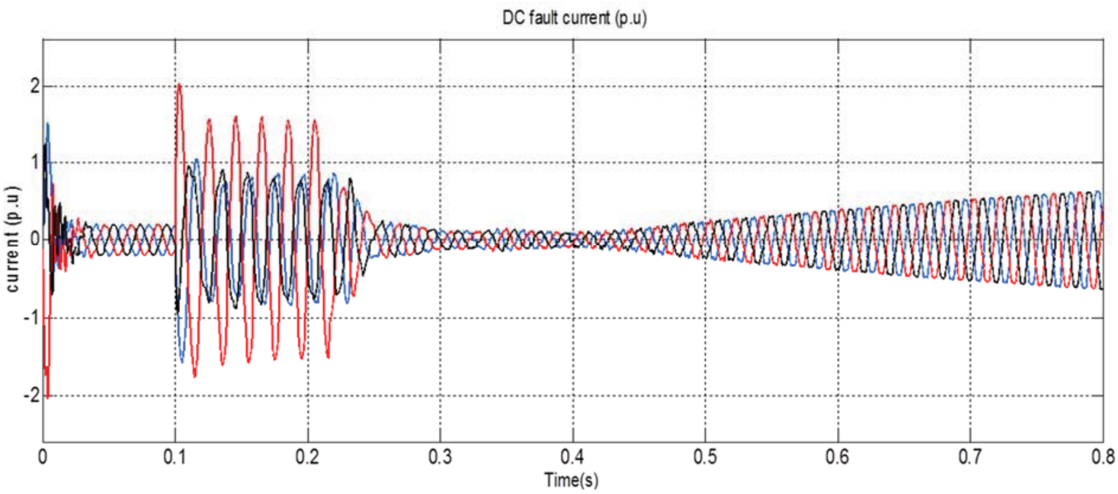

Fig. 13 HVDC Line Fault current at B2

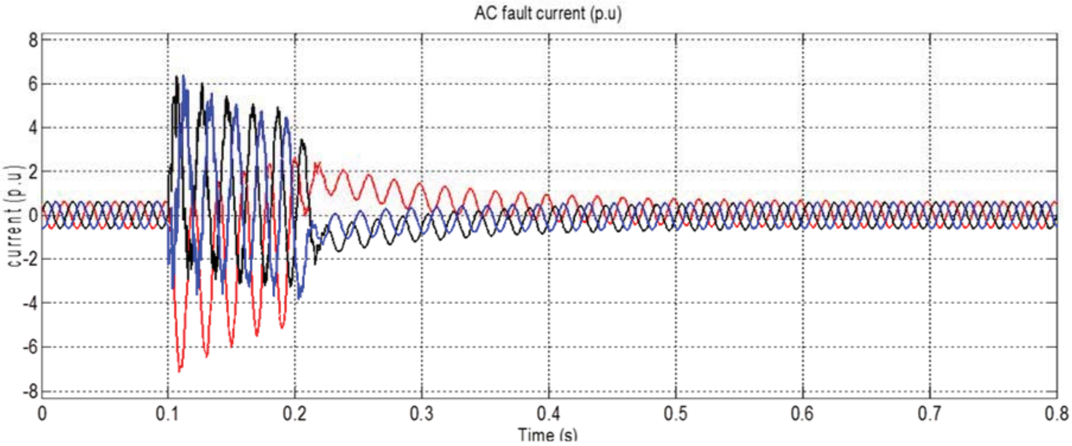

Fig. 14 HVAC Line Fault current at B2

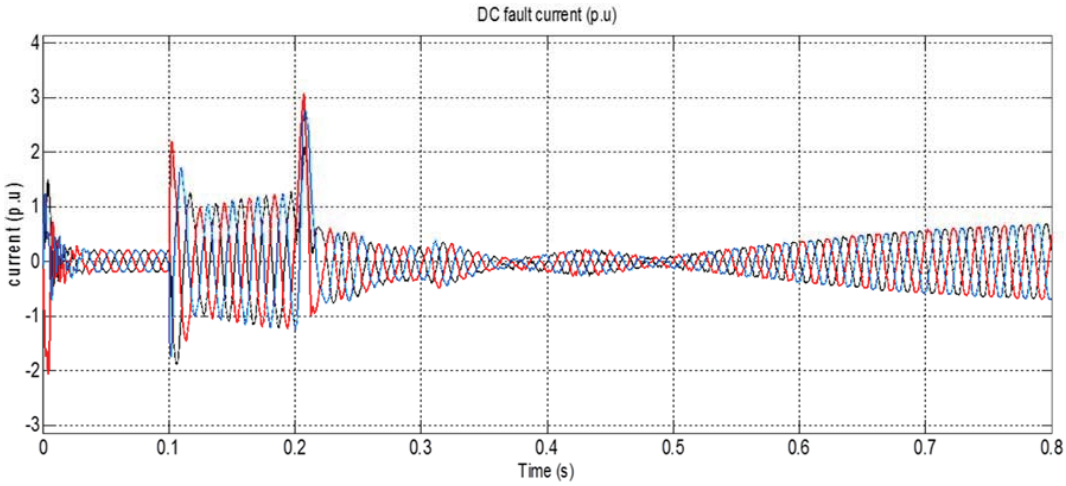

Fig. 15 HVDC Line Fault current at B2

VI. Conclusions

Long distances are technically unreachable by HVAC line without intermediate reactive compensations. The frequency and the intermediate reactive components cause stability problems in AC line. On the other hand, HVDC transmission does not have the stability problem because of absence of the frequency, and thus, no distance limitation. The cost per unit length of a HVDC line lower than that of HVAC line of the same power capability and comparable reliability, the breakeven distance of overhead lines between AC and DC line is range from (450 km to 800 km). 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 '3ph to ground' fault in transmission line for both HVAC and HVDC topologies. For better analysis and comparison, both simulation environments are kept same and the length varying from (200 km to 500 Km, 230 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 and voltage terminal for all types of symmetric, asymmetric faults in different section (sending end, receiving end, and 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.

VII. Result Analysis

TABLE II
Fault Current Comparison at Transmission line Length (200 km)

Fault types		HVAC (put)	HVDC (put)
Single- photo line	Peak up	3.21	2.18
	Peak down	8.15	4.35
Line to line	Peak up	9.84	2.35
	Peak down	9.80	1.85
3ph- ground	Peak up	10.1	3.10
	Peak down	12.08	2.15

TABLE III
FAULT CURRENT COMPARISON AT TRANSMISSION LINE LENGTH (500 KM)

Fault types		HVAC (put)	HVDC (put)
Single- photo line	Peak up	3.21	2.18
	Peak down	8.15	4.35
Line to line	Peak up	9.84	2.35
	Peak down	9.80	1.85
3ph- ground	Peak up	10.1	3.10
	Peak down	12.08	2.15

APPENDIX

A. (A.C) Transmission Lines Data

- Number of phases =3
- Frequency used = 50 Hz
- Resistance per unit length (Ohms/km) = 0.01273
- Inductance per unit length (H/km) = 0.9337e-3
- Capacitance per unit length (F/km) = 12.74e-9
- Line length (km) = 200 and 500

B. (D.C) Transmission Lines Data

- Number of pi sections=2
- Resistance per unit length (Ohms/km) = 1.3900e-002
- Inductance per unit length (H/km) = 1.5900e-004
- Capacitance per unit length (F/km) = 2.3100e-007
- Line length (km) = 200 and 500

C. Source Data

- Voltage Source (base) = 230kv
- Variation timing (s) = [0 0.14] + 1.5

D. Load Data

- Nominal voltage (Vims) = 230 KV
- Active power P (W) = 500MW
- The load is resistive loads.

E. Faults Types

- Switching times (s) = 0.10-0.20
- Fault resistance Ron (Ohm) = 0.001
- Snubber resistance Rest (Ohm)= 1e6
- ‘Single phase to ground’
- ‘Line to Line’
- ‘3ph to ground’

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