HVDC Transmission Line Faults Analysis

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***Abstract*— Today's world relies mostly on the utilization of electrical energy for industrial, commercial, agricultural, domestic and social purposes. However, for the present HVDC system, proper protection instruments and logic are not yet much developed as the AC system. This paper presents the fault analysis for the HVDC (110 kV) transmission line, using MATLAB. Faults occurring in the DC transmission line are analyzed. This paper also looks into the response of the system to different kind of faults. It is seen that the AC and DC faults have different characteristics allowing us to differentiate them apart.**

Keywords—HVDC, fault analysis, converters, transmission line, MATLAB Simulink.

I. INTRODUCTION

Electrical energy is generated basically in the form of alternating current (AC). After the generation, the electrical energy sent out as AC[1]. Power is transmitted to different locations and distributed to the consumers as AC.

In some circumstances, it is more preferable to implement direct current (DC) scheme for distributing electrical energy and is the future trend in heavy power transmission[1]. The transmission losses and the capital investments are in due course higher for AC systems above certain distance, e.g., usually about 700 KM for overhead and 40 KM for ug lines [6]. Direct connection between two AC systems with different values of frequencies is very difficult. HVDC is preferred in these cases[2]. Furthermore, the HVDC systems cause less impacts on the environment compared to the HVAC. Connection of renewable energy sources to the grid is easier using the HVDC system [4].

II. BACKGROUND OF STUDY

As the world is evolving very fast the electrical energy necessity to assist the development also peaks up and the systems have to enlarge. This has led to the mutual connection of all types of power systems all over the world. The rising rate of industrialization all over the world makes a huge demand for the consumption of electrical energy. More requirement for electrical energy has led to the search of more efficient methods of electrical energy transmission at higher power and voltage levels. High voltage AC (HVAC) used across the world tends to be fussy over longer distances and it creates various environment issues. Therefore, HVDC use is been propound.

III. LITERATURE REVIEW

Literature review deals with the different types of HVDC system configurations and the components that are used in the HVDC system.

A. *Types of HVDC Systems*

The different types of HVDC systems are:

1) *Mono polar HVDC system*: This system mostly made of more than one units of six-pulse converters, in which they are either arranged in the parallel or series manner through the end paths[1]. It has a single conductor in it and the return can be through the earth or ocean.

2) *Bi polar HVDC system*: Bi-polar dc lines system as the name says it has two different polarities or conductors in the system[2]. The conductors are of the same rated voltage and have been connected in a series at the end of dc lines[1].

3) *Homo-polar HVDC system*: Homo-polar, comprises of more than two conductors that are connected together having the same polarity which can either be the negative or positive electrodes and they also operate in parallel a connection[1].

B. *Components of HVDC*

HVDC system is made of many various sections of units or components that are connected with each other in the whole system, so as to operated efficiently[2].

A simple representation of HVDC system is as shown below in Fig. 1 [7].

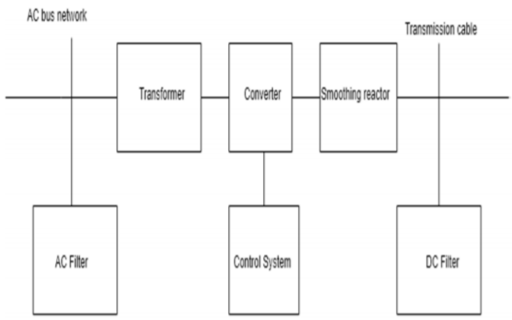

Fig. 1. Components of HVDC

1) *AC harmonic filter system:*

Harmonics are unwanted signals in the system that may causes any obstruction or changes in waveform[5]. Converters are mainly said to create harmonics that are linked to the AC bus [3][16].

It has two main purpose to effect which are below.

• To take up harmonic currents created by the HVDC system

• To give or produce the reactive power to system

2) *Converter Transformer :*

The converter transformer is the link between two components i.e. the thyristors or IGBT(insulated gate bipolar transistors) and the AC network and provide proper phase difference of 30° for two six pulse converters, and other purposes of the converter transformer are[2] ;

• It gives separations between the systems.
• It gives the required amount of voltage and phase difference.

3) HVDC smoothing reactor systems:
HVDC network for the transmission of power it needs a smoothing reactor and main reasons are[2] ;

- Limiting the specific fault current in the DC movement
- Reduction of unwanted ripples that are present in the DC lines.

4) HVDC protection system:
Since there is no zero crossing in the DC current the protection of the system becomes tedious in order to eliminate fault, we have to create a zero crossing and then cut down the current but different approaches are being used in the protection scheme at the converter station[4].

IV. METHODOLOGY

A) Rectifier Mode of Operation

Rectification is the conversation of AC to DC by the use of the constant dc voltage value. The on and off device is the "semiconductor diode" in the network circuit[3]. The valve system basically operates in one direction to which it is flowing from positive (+) points of the system to the negative (-) points in the circuit [10]. If the three-phase rectifier's median DC voltage output is calculated if it is operating with a zero (0) angle delay, by using expression (1)[3].

$$Vo = 3 * \sqrt{3} * \sqrt{2} * Vrms \div \pi \qquad \text{…….. (1)}$$

V. MATLAB MODEL

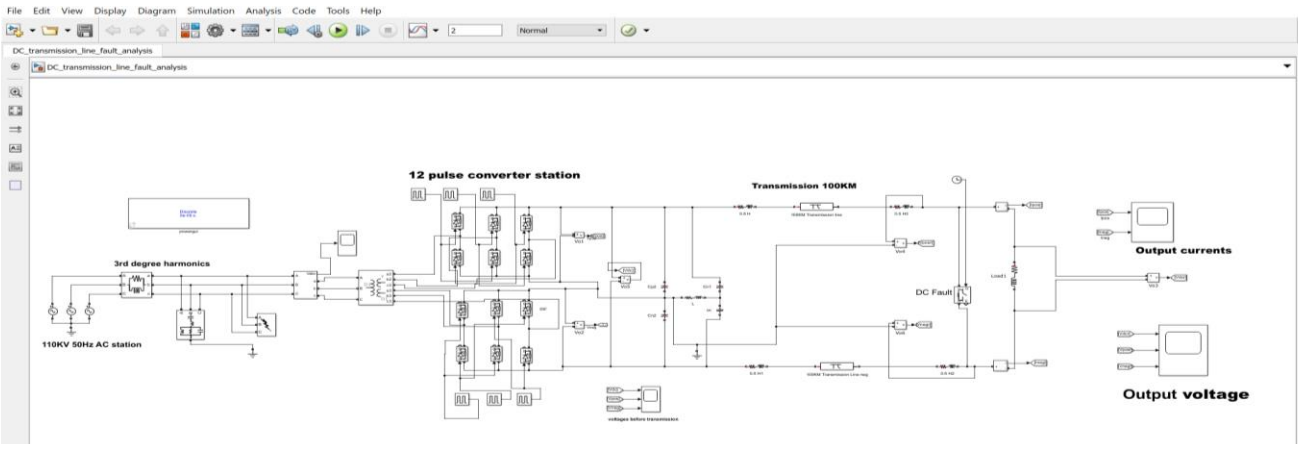

Fig.3 MATLAB simulation model of HVDC transmission

$$Id = Vda - Vdb/Rdc \qquad \text{….. (2)}$$

And the power transmission to the voltage B will be expression as

$$Pd = Vdb * \frac{Vda - Vdb}{Rdc} \qquad \text{….. (3)}$$

where, R_{dc} is the dc resistance for the positive transmission line conductor. Theoretically, the R_{dc} is very less and its Id becomes as an output to the low difference between the two huge voltages in the above expression (3). Therefore, one side of the converter is being monitored and control the transmission line voltages and also monitors Id[5]. Since we know that the inverter is operating at a constant extinction angle, it is ideally to select the inverter to monitor the V_d, therefore the power level to be monitored by the rectifier. In Fig. 2, rectifier and the inverter control characteristics in the V_d - I_d plane is shown [3].

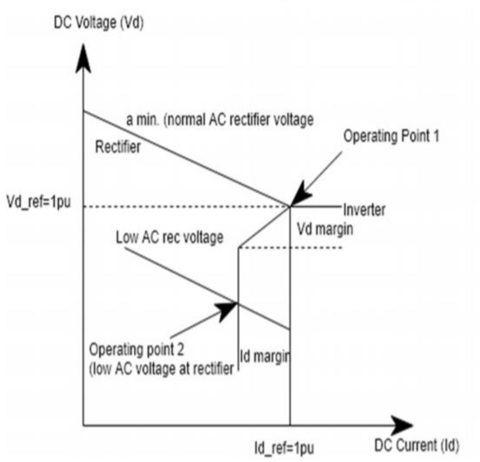

Fig.2 Rectifier and converter control charateristics

Parameters	Value
Frequency	50Hz
Grid Voltage (V_{p-p})	110kV
DC Voltage	9.2 kV
DC Current (for RL load)	1800A
Switching frequency	1500Hz
Cable length	100km

Table. 1. Parameters of HVDC model

1. *HVDC TRANSMISSON (NORMAL CONDITION)*

In the normal steady state, the bi-polar link transmits the voltage being converted by 12 pulse converter which is being fed by an AC grid voltage of 110kV, 50Hz. The voltages at normal conditions are pole to pole 9.2kV, positive pole 4.6kV and negative pole -4.6kV as shown in the scope outputs in Fig. 4.

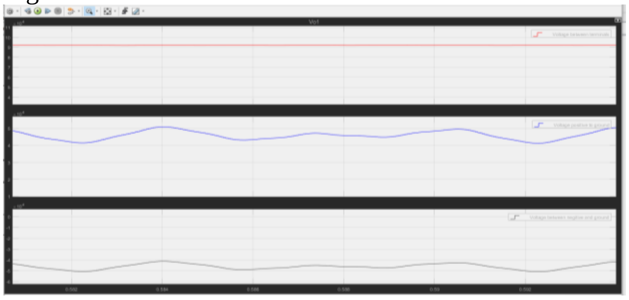

Fig. 4. Normal output Voltages

2. *DC POLE TO POLE FAULT*

DC pole to pole faults arise due to direct contact or insulation breakdown between positive and negative conductors of the bipolar DC transmission line. This type of fault is not usual but it can result in serious damage on the system such as annihilate the power electronic devices and power interruption. In the carried-out simulation the fault is created at 1sec by short circuiting the positive pole to negative pole, the scope outputs can be seen in the Fig. 5.

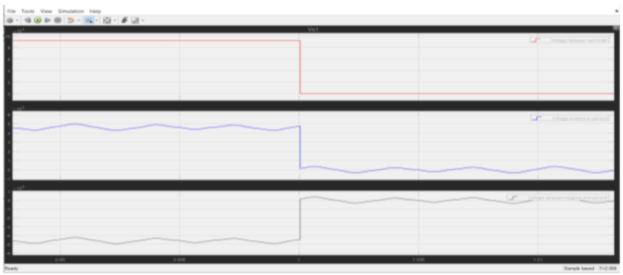

Fig. 5. Pole to Pole fault output Voltages

3. *DC POSITIVE POLE TO GROUND FAULT*

DC Positive pole to ground fault occur when the positive pole of the transmission line comes in direct contact with ground, touches the structure or falls on the ground. The fault in the simulation is being created at 1sec and we can observe that the positive voltage becomes zero at 1sec but the negative pole continues to transmit power as shown in the Fig. 6.

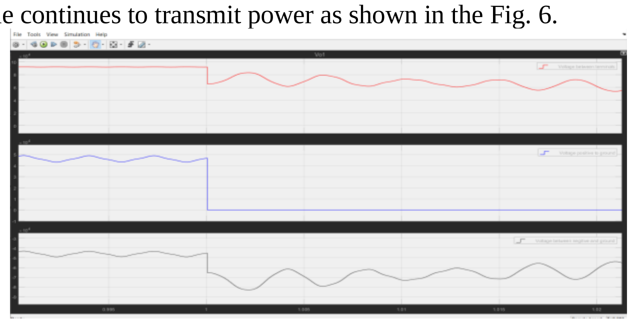

Fig. 6. Positive Pole to ground fault output Voltages

4. *DC NEGATIVE POLE TO GROUND FAULT*

DC Negative pole to ground faults occur when the negative pole of the transmission line comes in direct contact with ground, touches the structure or falls on ground. The fault in the simulation is being created at 1sec and we can see that the negative pole voltage becomes zero at 1sec but the positive pole continues to transmit power as shown in the Fig. 7.

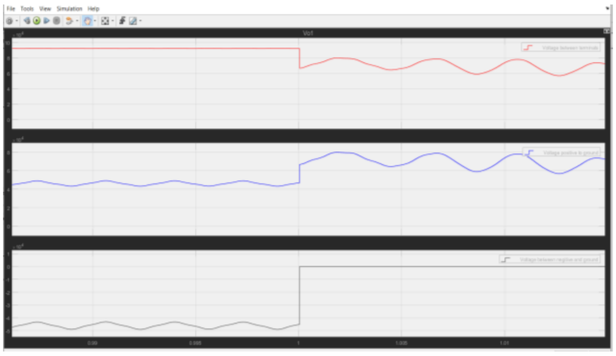

Fig. 7. Negative Pole to ground fault output Voltages

5. *DC CURRENT VARIATION DURING STEADY STATE AND POLE TO POLE FAULTS*

The Current in the normal steady state condition for the load RL load is 1800A at each pole as shown in the fig.8 when the fault occurs the current peaks for a time period up to 11000A as shown in the fig. 9 the current falls to zero on 1.1sec and the fault in the circuit is being created at 1sec this is same for all fault conditions like pole- pole or pole-ground faults.

Fig.8. DC output current steady state

As we can observer that during the fault the current ramps to 8000A that is when the fault is being created at 1sec, current does increase to very high value that is from 1800A to 8000A in the both poles as shown in fig.9.

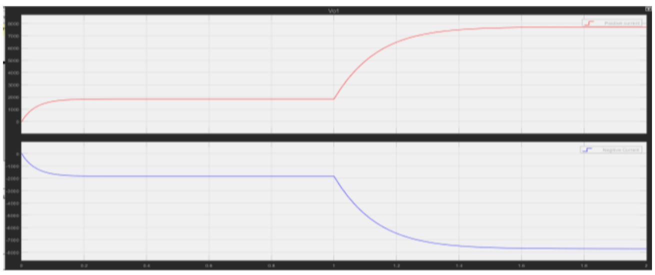

Fig. 9. DC output currents

6. *CURRENT DURING POLE TO GROUND FAULTS*

- POSITIVE POLE TO GROUND FAULT

As we can observe the fault current in the positive pole ramps up to 11000A and the negative voltage decreases to a certain limit as seen in Fig.10

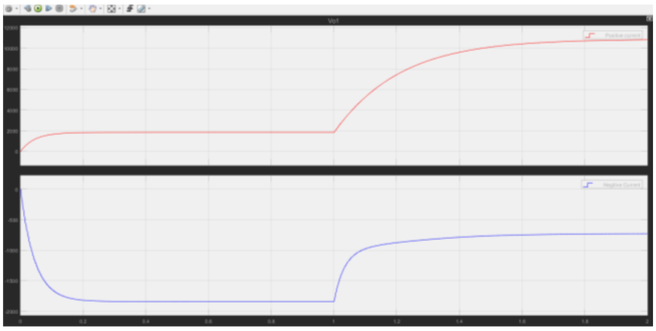

Fig.10 Positive to ground faults

- NEGATIVE POLE TO GROUND FAULT

As we can observe the fault current in the positive pole ramps up to -4500A and the negative voltage decreases to a certain limit as shown in Fig.11.

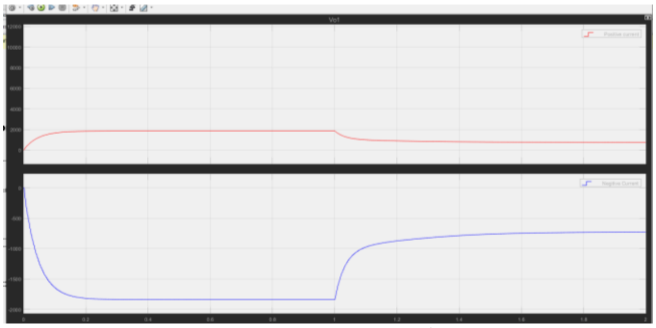

Fig.11 Negative to ground faults

7. *STEADY STATE VALUES OF THE HVDC SYSTEM*

Supply Grid AC Voltage	DC Voltage pole to pole in kV	Voltage in Positive Pole in kV	Voltage in Negative pole in kV	DC Current in amps
110kV	9.2kV	4.6kV	-4.6kV	1800A

Table 2. Steady state values of the HVDC model

8. *PARAMETER VARIATION FOR VARIOUS FAULTS*

Fault Type	Voltage Pole-Pole in kV	Voltage Positive Pole in kV	Voltage Negative Pole in kV	Positive Pole Current in amps	Negative Pole Current in amps	Settling Time in seconds
Pole-Pole	0	0	0	8000	-8000	1.1
Positive-Ground	8.8 - 5.5	0	8.8 - 5.5	12000	-1200	1.4
Negative-Ground	8.8 - 5.5	8.8 -5.5	0	1200	-4500	1.4

Table 3. Changes in parameters for different faults

The result obviously shows that the DC fault results in the transient at the rapid rate. All three types of DC faults have been analyzed and this analyzation can be further used for the development of protection techniques for HVDC systems.

The following remarks are cited on the simulation results.

- The main objective is to know the different fault characteristics. This would in return be helpful to develop a strong and promising protection system in future.
- We can also observe that if fault occurs in any one pole of the Bi-polar HVDC transmission system the other system will continue working normally as a monopolar system.

Using the analysed data from this paper the protection scheme for the HVDC transmission line can be implemented in a more reliable, efficient and robust manner. By, this we can prevent losses, predict the future faults and control the faults easily and eradicate them.

The major drawback of the system is the inverter station is not shown and have not analysed the condition of converter stations when operating during faulty conditions.

VII. CONCLUSION

The HVDC transmission is perpetually developed and widely used in renewable power applications, so it has a wide outlook. This paper presents the study and analysis of HVDC transmission system at the time of DC transmission pole to pole short circuit fault and pole to ground faults. The system configuration has been shown. DC pole to pole fault is choose to be analysed because it is observed as one of the most dangerous faults in any transmission system. The fault characteristics has been studied starting from the instant of fault moment and until it reaches its steady state condition. It is seen that during this type of faults the system configuration changes in time. A HVDC transmission system has been simulated by using MATLAB Simulink and the system has been tested in normal and fault conditions.

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