DISTANCE PROTECTION OF HVDC TRANSMISSION LINE WITH NOVEL FAULT LOCATION TECHNIQUE

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Abstract

This paper presents a novel method for locating faults using setting point voltage and current data. The line model used is based on the frequency dependent parameter model and it is distributed in to two parts: Distributed Parameter model and Compensation matrix. Finite Impulse Response filters are used to fit the Compensation matrix. So by using local Sampling data, voltage and current at the setting point are calculated accurately. Then, the line model equations are solved in time domain to calculate the fault distance. The proposed method is able to enhance the accuracy of the measurement of fault at far end. Simulation results have shown the effectiveness of proposed method and is capable of locating the faults occurring on HVDC Transmission lines accurately and quickly.

Key Words: *fault distance, frequency dependent parameter, distributed parameter model, HVDC transmission lines*

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1. INTRODUCTION

The HVDC transmission system has advantages of transmitting large amount of power over long distances with lower capital cost, lower losses and enhancing the stability and economy of the overall grid [1]. HVDC lines are mostly used for transmitting power over long distances, certainly passing through complex terrain, influenced by the weather and geographical conditions, occurrence of fault is quite often which may cause a major HVDC outage. So, it is very necessary to find the location of the fault accurately and employing protective measures for clearance of the fault.

Various methods are employed for the protection of HVDC transmission lines [3]-[7]. Travelling wave protection is used as a primary protection and is unable to detect the line faults with high transition resistance. Under voltage protection and differential protection serves as a back up for the travelling wave protection but because of longer delay time, differential protection loses its back up function. Under voltage protection is also not reliable for high impedance faults.

Currently travelling wave based method [3] is used for locating the fault in line but it is unable to detect the wave head when the fault has occurred with high transition resistance. Distributed parameter model technique [2],[8] is also used, but it neglect the effect of frequency dependent nature of the parameters, as during initial period of the fault plentiful harmonics are present in the transient voltages and current and using only constant parameters for the calculation of voltage and current at the setting point will lead to inaccuracy in the calculation of location of fault. To reduce the inaccuracy, the frequency dependent line parameter model is used and has been successfully implemented in Electromagnetic Transients program and electromagnetic transients in DC system [9]-[12]. This paper proposes a method to remove the inaccuracy in the operating parameter estimation and improve the operating behavior of line protection.

2. MEASUREMENT ACCURACY IN LOCATION OF FAULT

Determination of fault location is necessary to distinguish whether the fault is internal or external to protection zone, especially for the end zone faults. Therefore, in distance protection some degree of measurement error is acceptable as relay will operate only when the fault lies in the protection zone and if the measured fault distance is not more than the setting distance.

Assume relay is installed at point M as shown in fig.1 and K is the setting point. Fault has occurred at F. So, the condition for protection method to operate correctly is that the measurement error in the location of fault should be less than the difference between the fault distance and setting distance [2] that is given as below

$$Em < |l_f - l_{set}| \tag{1}$$

where E_m is the measurement error, l_f and l_{set} is the fault distance and the setting distance respectively.

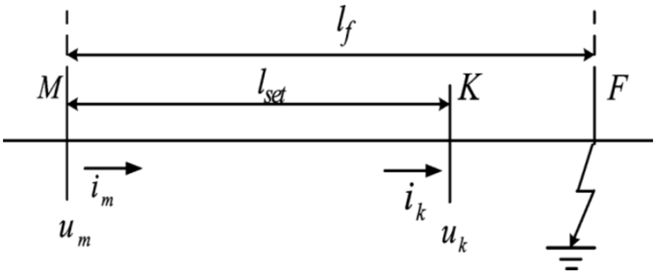

Fig 1: Proposed protection principle

Hence for protection method to operate correctly, accuracy should be high for far end faults and comparatively low for close up faults. For that we are calculating setting point voltage and current using local sampling data. The following proposed method depends mostly on the accurate calculation of setting point voltage and current.

3. PRINCIPLE OF PROPOSED TECHNIQUE

The proposed technique is based on the frequency dependent nature of the line parameters. Hence, by considering frequency dependent parameter line model transformation matrix is separated into two parts (1) Constant parameter model known as distributed parameter model (2) Compensation matrix consisting of frequency dependent parameters.

From Fig 1. Voltage and current at relay point M and setting point K, is given as

$$\begin{bmatrix} U_K(S) \\ I_K(S) \end{bmatrix} = J(s) \begin{bmatrix} U_m(S) \\ I_m(S) \end{bmatrix} \tag{2}$$

J(s) is the line transformation matrix given by

$$J(s) = \begin{pmatrix} \cosh(\gamma(s) l_{set}) & -\sinh(\gamma(s) l_{set}) Z(s) \\ -\sinh(\gamma(s) l_{set}) / Z(s) & \cosh(\gamma(s) l_{set}) \end{pmatrix} \tag{3}$$

Where l_{set} is the setting distance, Z(s) is the characteristic impedance and ϒ(s) is the propagation constant and all the line parameters are dependent on frequency (R in Ώ/Km , L in H/Km, C in F/Km and G in S/Km).

The line transformation matrix for the given frequency f_0 can be obtained from

$$J_0(s) = \begin{pmatrix} \cosh(\gamma_0(s) l_{set}) & -\sinh(\gamma_0(s) l_{set}) Z_0(s) \\ -\sinh(\gamma_0(s) l_{set}) / Z_0(s) & \cosh(\gamma_0(s) l_{set}) \end{pmatrix} \tag{4}$$

Equation (2) can be rewritten as

$$\begin{bmatrix} U_K(S) \\ I_K(S) \end{bmatrix} = J(s).J_0^{-1}.J_0(s) \begin{bmatrix} U_m(S) \\ I_m(S) \end{bmatrix} \tag{5}$$

The matrix in the above equation is splitted in to distributed parameter model $J_0(s)$ and compensation matrix H(s) given by

$$H(s) = J(s) . J_0^{-1}(s) \tag{6}$$

It is observed that the compensation matrix is independent of the voltages and current and is related to frequency dependent parameters. The proposed technique can be written in two steps:

Step I: Determination of distributed parameter model which is indicated as below

$$\begin{bmatrix} U_{K0}(S) \\ I_{K0}(S) \end{bmatrix} = J_0(s) \begin{bmatrix} U_m(S) \\ I_m(S) \end{bmatrix}$$

Step II: The frequency dependent parameter model which is given as below

$$\begin{bmatrix} U_K(S) \\ I_K(S) \end{bmatrix} = H(s) \begin{bmatrix} U_{K0}(S) \\ I_{K0}(S) \end{bmatrix}$$

Where U_{k0} and I_{k0} are setting point voltage and current respectively

4. FREQUENCY DOMAIN TO TIME DOMAIN

Calculations are being carried out in time domain to enhance the measurement accuracy and calculation speed.

4.1 Distributed parameter model

Bergeron transmission line model is adopted to simulate the HVDC transmission line. The voltage and current distributions along the line can be obtained according to[13] Equations (10) and (11) gives the setting point voltage and current, where r is resistance per kilometer, Z_0 and v_0 are characteristic impedance and wave speed respectively. For obtaining the setting point voltage and current $u_{k0}(t)$ and $i_{k0}(t)$ linear interpolation in [15] can be used .

$$\begin{aligned} u_{ko}(t) = {} & \\ & \left(Z_0 + \frac{rl_{set}}{4}\right)^2 \frac{1}{2Z_0{}^2}\left[u_m\left(t+\frac{l_{set}}{v_o}\right) - \left(Z_0 + \frac{rl_{set}}{4}\right) i_m\left(t+\frac{l_{set}}{v_o}\right)\right] + \\ & \left(Z_0 - \frac{rl_{set}}{4}\right)^2 \frac{1}{2Z_{co}^2}\left[u_m\left(t-\frac{l_{set}}{v_o}\right) + \left(Z_0 - \frac{rl_{set}}{4}\right) i_m\left(t-\frac{l_{set}}{v_o}\right)\right] - \\ & \frac{rl_{set}}{4Z_0^2}\left[\frac{rl_{set}}{4} u_m(t) - \left(Z_0 + \frac{rl_{set}}{4}\right)\left(Z_0 - \frac{rl_{set}}{4}\right) i_m(t)\right] \end{aligned} \tag{10}$$

$$\begin{aligned} i_{ko}(t) = {} & \\ & \left(Z_0 + \frac{rl_{set}}{4}\right) \frac{1}{2Z_0^2}\left[u_m\left(t+\frac{l_{set}}{v_o}\right) - \left(Z_0 + \frac{rl_{set}}{4}\right) i_m\left(t+\frac{l_{set}}{v_o}\right)\right] \\ & - \left(Z_0 - \frac{rl_{set}}{4}\right) \frac{1}{2Z_0^2}\left[u_m\left(t-\frac{l_{set}}{v_o}\right) + \left(Z_0 - \frac{rl_{set}}{4}\right) i_m\left(t-\frac{l_{set}}{v_o}\right)\right] \\ & - \frac{rl_{set}}{4Z_0^2}\left[u_m(t) - \frac{rl_{set}}{4} i_m(t)\right] \end{aligned} \tag{11}$$

4.2 Compensation matrix

Four Finite Impulse Response filters are employed to fit the compensation matrix.

$$H_k(z) = \begin{pmatrix} A_k(z) & B_k(z) \\ C_k(z) & D_k(z) \end{pmatrix} = \begin{pmatrix} \sum_{n=0}^{N-1} a_n z^{-n} & \sum_{n=0}^{N-1} b_n z^{-n} \\ \sum_{n=0}^{N-1} c_n z^{-n} & \sum_{n=0}^{N-1} d_n z^{-n} \end{pmatrix} \tag{7}$$

The filter coefficients a_n, b_n, c_n, d_n are calculated using line parameters and setting distance, so in advance we can calculate this coefficients offline.

The setting point voltage and current in time domain using frequency dependent parameter model is given by:

$$u_k(t)=\sum_{n=0}^{N-1} a_n u_{k0}(t-nT_s)+\sum_{n=0}^{N-1} b_n i_{k0}(t-nT_s) \qquad (8)$$

$$i_k(t)=\sum_{n=0}^{N-1} c_n u_{k0}(t-nT_s)+\sum_{n=0}^{N-1} d_n i_{k0}(t-nT_s) \qquad (9)$$

4.3 Calculation of fault location

A constant parameter RL model between the setting point and the fault point is simulated as shown in fig. 2. fault distance can be calculated using equation (12) and setting point voltage and current.

$$u_k = \left(Ri_k + L\frac{di_k}{dt}\right)(l_f - l_{set}) + R_f i_f \qquad (12)$$

L is in H/Km, R_f is the fault resistance and i_f is the fault component.

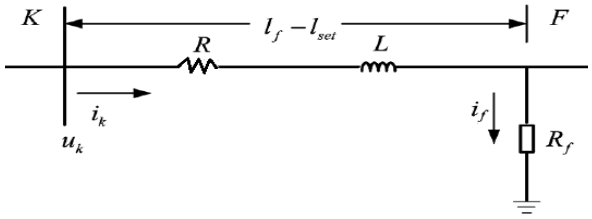

Fig.2 RL transmission line model

5. SIMULATION RESULTS

The schematic diagram of the bipolar HVDC transmission line is shown in fig.3. The CIGRE benchmark system [14] is modified to form the bipolar model. The line length is being changed to 500 Km and the other system data is same as in [14]. PSCAD is running to generate data, sampled at 10KHz. The quantities measured at the relay point are influenced by the coupling between the positive line and the negative line, it is required to transform the sampling value of voltage and current at the relay point to independent mode quantities employed in [13].

For this case, the setting distance is taken as 400 Km and the fault has taken place at 0.9 sec with transition resistance of 0 ohm and 150 ohm.

5.1 *Case I* : Suppose a positive pole to ground has taken place at 460 Km at 0.9 sec. with 0 ohm and 150 ohm fault resistance.

DC voltage and current at the dc side of the converters for both positive and negative poles of DC link is shown in fig. 4 and fig. 5 with x axis as time (milisec) and y axis as voltage or current.

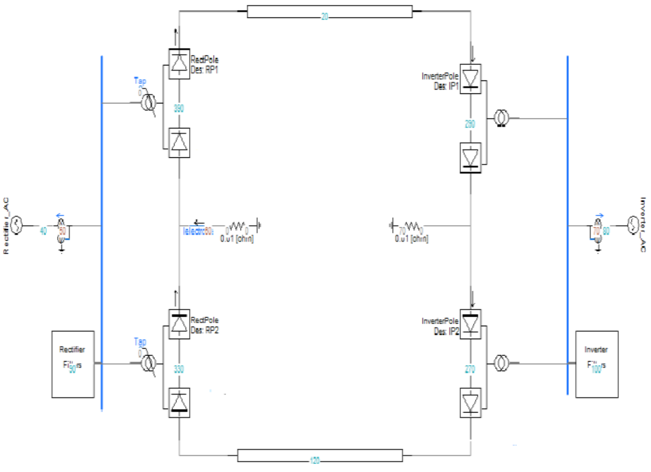

Fig.3 HVDC Bipolar link

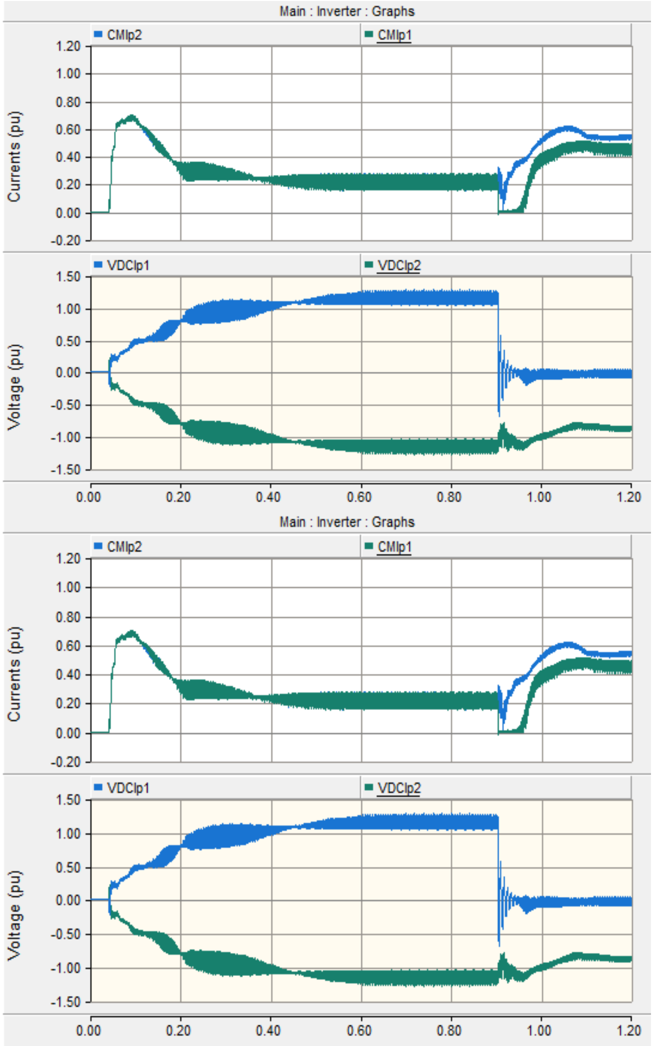

Fig.4 DC voltage and current graph for both the poles at rectifier side and inverter side with transition resistance of 0 ohm

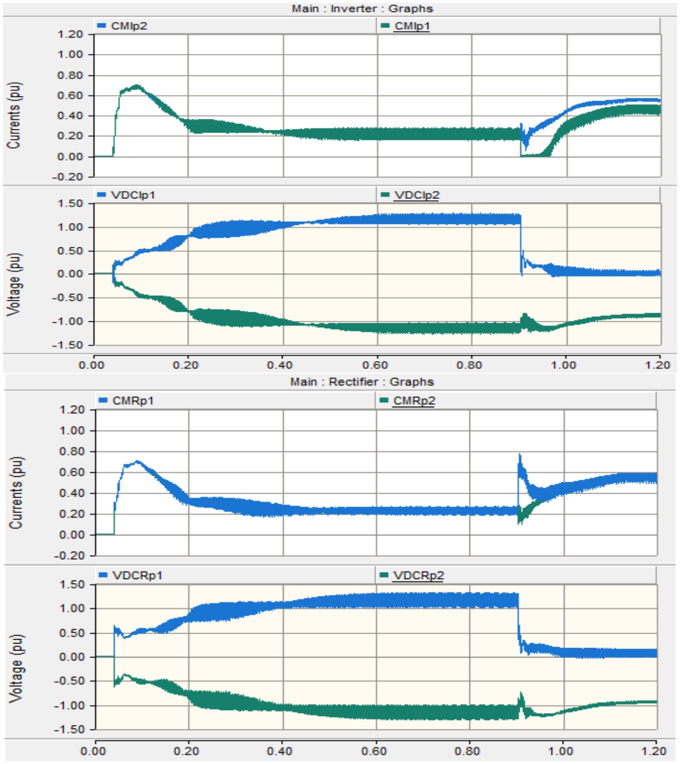

Fig. 5 positive pole to ground fault DC voltage and current at rectifier and inverter with 150 ohm fault resistance.

From Fig. 4 and Fig. 5 it may be concluded that, on occurrence of fault on HVDC line, in the initial period transients or oscillations are present in the faulted pole voltage and current and the line voltage collapses and rectifier current rises while the inverter current tends to fall. With increase in transition resistance faulted current peak also reduces in rectifier. With the help of this figure the setting point voltage and current are determined.

5.1.1 Measured distance results:

After the determination of setting point voltage and current, location of the fault is determined by using the differential equation (12).

Figure 6 gives the error in the location of fault by using distributed parameter model and frequency dependent parameter model. The maximum relative error occurred in frequency dependent parameter model with transition resistance zero ohm is less than 2.7% (13.5 Km) compared to 3.8 % in distributed parameter model. Since the allowable error according to (1) is 40 Km, the presented protection method can operate reliably with frequency dependent parameters With 150 ohm transition resistance also errors are less compared to distributed parameter model.

5.2 ***Case II*** Negative pole to ground fault has occured at a distance of 460 Km at 0.9 sec. with fault resistance of 0 ohm and 150 ohm. Behavior of Voltage and current through the line is shown in fig. 7(a) and 7(b).

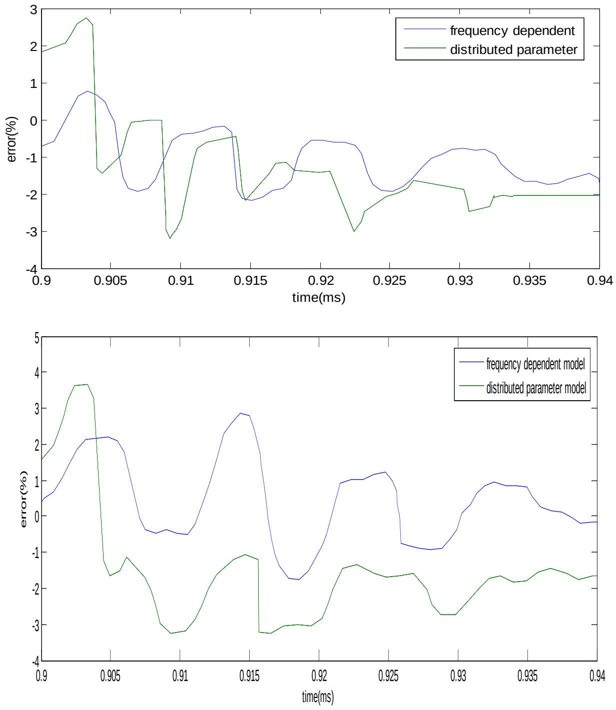

Fig 6. Measured distance Errors when positive pole to ground has occurred with transition resistance 0 ohm and 150 ohm respectively.

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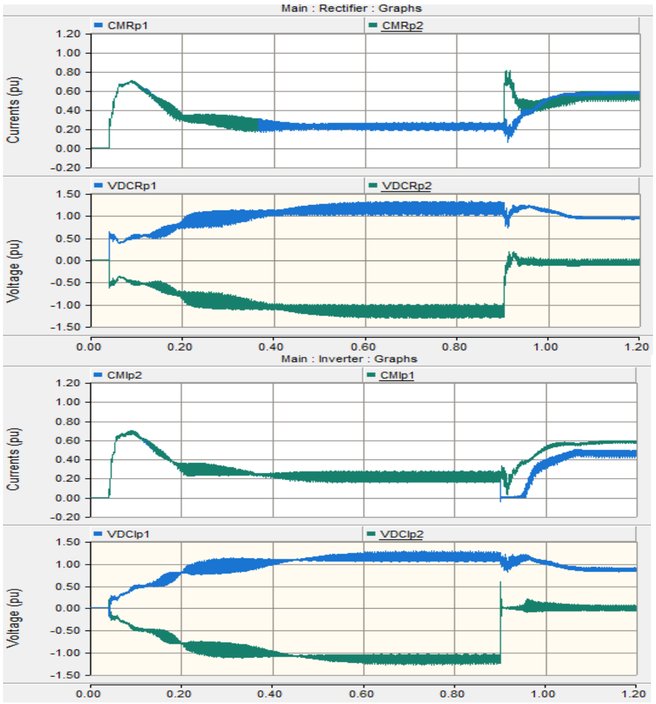
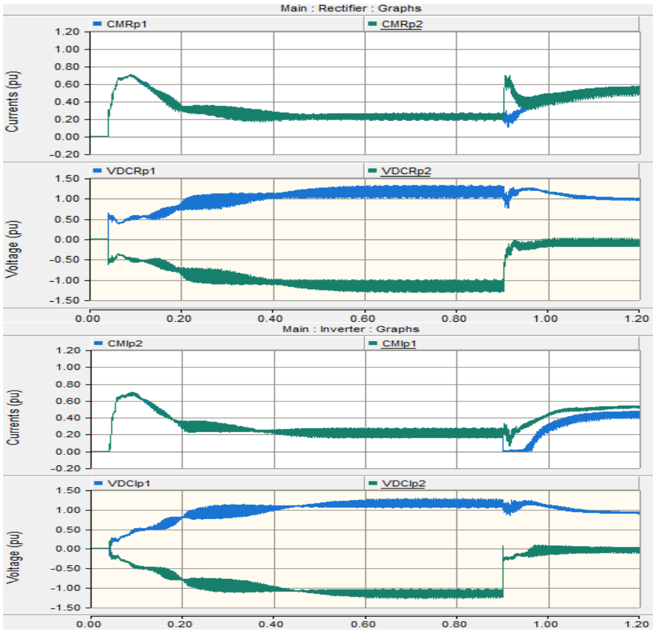


Fig. 7(a) Negative pole to ground fault DC voltage and current at rectifier and inverter side for both the poles with zero ohm transition resistance.



(b)

Fig. 7(b) Negative pole to ground fault DC voltage and current at rectifier and inverter side for both the poles with 150 ohm transition resistance

5.2.1 Measured Distance error

From fig. 8 we concluded that the maximum relative error is more while using distributed parameter model than in frequency dependent parameter model error is 2.2% with 150 ohm transition resistance .
We also observed that the measurement accuracy is not much affected by the transition resistance.

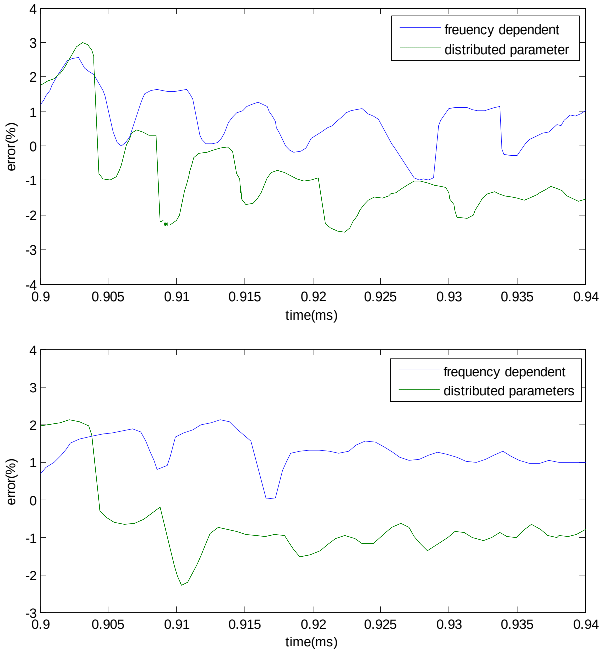


Fig. 8 Measured distance Error with negative pole to ground faults with zero ohm and 150 ohm transition resistance resp.

5.3 ***Case III*** Pole to pole fault has occurred at 0.9 sec with 150 ohm transition resistance.

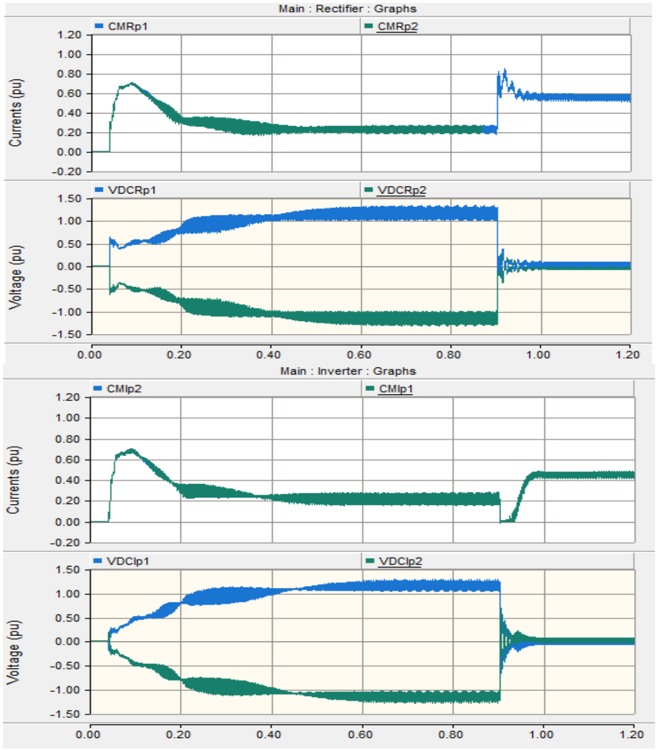


Fig. 9 pole to pole fault DC voltage and current at rectifier side and inverter side for both the poles with 150 ohm transition resistance

From the above figure 9 we observed that the whole system is collapsed due to pole to pole fault

5.3.1 Measured Distance Result:

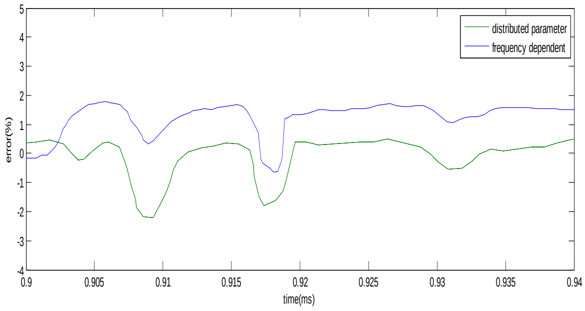


Fig. 10 measured distance error with 150 ohm transition resistance for both the models

From fig 10 it is clearly visible that the maximum relative error due to distributed parameters is about 2.5 % and with frequency dependent parameter model is 1.8%. Hence, it can accurately calculate the location for any type of fault.

6. CONCLUSIONS

In this paper the main purpose of the proposed technique is to determine the location of the fault and to identify whether the fault lies in the protection zone or not. So, the proposed technique is based on the accuracy of calculation of setting point voltage and current using frequency dependent parameter model. It reduces the error in the measurement of distance to a greater extent for far end faults as compared to distributed parameter model. Simulation Results shows that the proposed technique is able to locate the fault accurately at any fault distance and fault type. Hence, it can be used to protect the whole line and will enhance the performance of the line.

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