Artificial Neural Network for Detection and Location of Faults in Mixed Underground Cable and Overhead Transmission Line

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Abstract: Power grid in India is laid almost with the overhead lines (OH). With the capacity of XLPE cables to transmit high voltages has led power system engineers to take keen interest in mixing OH lines with underground (UG) cables where the environmental effects, increasing population or the areas where right of way is a constraint for connecting the grid line. Faults in mixed system require broader aspects of consideration and analysis as the UG cable and OH lines both exhibits different characteristics. Conventional tracer and terminal methods are time consuming therefore computer based methods are emerging as a solution to remove their drawbacks and to provide more accurate results for fault detection, classification and location faster. This paper deals with use of ANN for protection of mixed line taking into account the parameters at each point for cables and sequence components for OH line. In MATLAB/SIMULINK software simulation is carried out for verification of results.

Keywords: Artificial Neural Network, Discrete Fourier Transform, Cable Parameters.

Introduction

In present scenario when the demand for power is increasing along with the increase in the population the hybrid transmission will be the solution when there is constraint of right of way in densely populated area. This combination can also be implemented to connect the existing grids with the off-shore wind farms with better reliability. To make the system operate successfully the response to the fault for the detection and location purpose should be minimal. This helps to reduce the time required to restore the system back to normal condition. Thus with the advancement in the technologies future power grids can be implemented with relays employing the knowledge based techniques.

For protective relaying of mixed systems generally two methods are used for finding fault location in UG cable and OH line [1].1. Phasor based method also called as impedance based method which uses fundamental component of signals [2, 3, 4]. 2. Travelling based method [5]. Travelling based method are sensitive to reflected waves when fault occurs in nearby lines and even to noise. Combination of these two methods has been used in [6, 7]. Unequal impedance is the major problem of the mixed system. Adaptive Network based Fuzzy Inference System is also been used for fault location of ground faults and line faults in mixed lines [8]. Discrete wavelet transformation and Support Vector Machine for hybrid transmission line where DWT is used to extract transient information from measured voltages and SVM to identify faulty section has also been proposed [9]. A new single-ended travelling wave fault location algorithm in which samples just from voltage transients generated by fault clearing action of circuit breaker are taken from the sending end of cable line has been proposed for fault location in mixed line [10].

Researches based on ANN for the protection of power system have taken up the interest of researchers. ANN which works on the learning ability of human from its surroundings, adapting itself to it and responding accordingly is utilized for the protection purpose by training the network with past records, measurements, available data and observations [2]. ANN imitates the biological capability of solving linear [11] and non-linear problems. ANN is been implemented for complete protection scheme for fault detection, classification and location in Transmission lines [12]. ANN is also applied for fault analysis in distribution networks [13]. However there are few researches done considering shunt faults in hybrid underground cable and overhead transmission line using ANN. This paper presents an Artificial Neural Network approach to simulate the hybrid model for distance protection. Simulation is done to detect and locate the faults. Fig. 1 shows the single line diagram of a three-phase mixed transmission line connected with source and Fig. 2 shows the process flow chart of the proposed model.

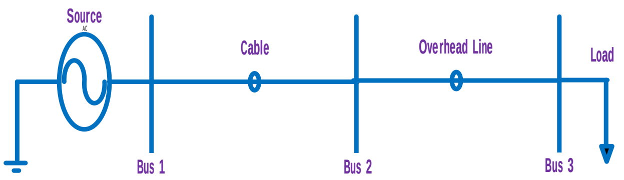


Figure 1. Single line diagram of a three-phase mixed transmission line connected with source

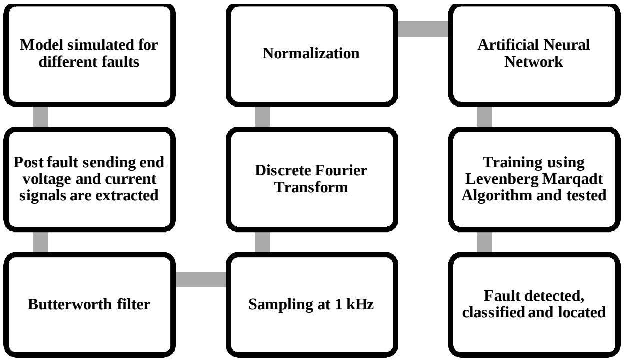


Figure 2. Process flow chart of the proposed model

Mixed Underground Cable and OH Transmission Line Single Line Diagram

A single line diagram of mixed underground cable and overhead transmission line is shown in Fig. 3 and during fault condition at cable in Fig 4, at junction in Fig 5 and at overhead line in Fig. 6.

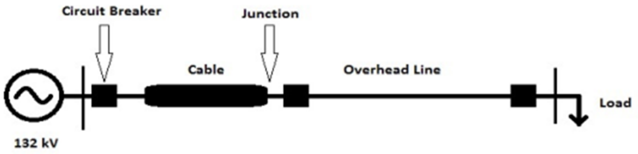


Figure 3. No fault

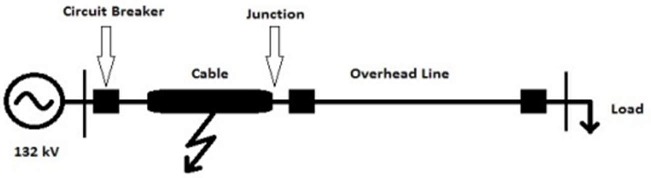


Figure 4. Fault at UG cable section

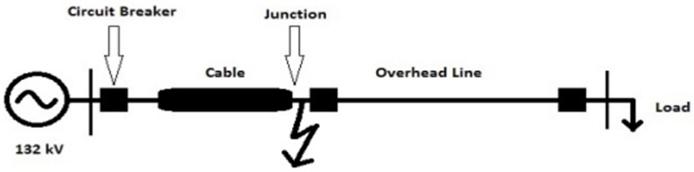


Figure 5. Fault at junction

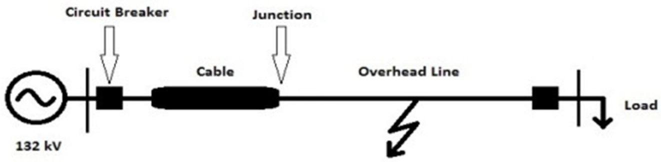


Figure 6. Fault at OH line

System under Study

The system simulated for single line to ground fault is composed of 132 KV, 50 Hz, 15 km mixed transmission lines with 3 km UG cable and 12 km OH line section, connected to a source at one end and to three-phase series RLC load, as shown in Fig. 7. All components are modeled by the MATLAB R2013a Simulink and SimPowerSystem toolbox. Short circuit capacity of the equivalent Thevenin source of the line is considered to be 1250 MVA. *X*/*R* ratio is 10. The cable is simulated using 3 core cable with screen (pi-model) where cable parameters are taken into consideration and can be calculated using power_cableparam command in MATLAB. This command open cable geometry dialog box where according to requirement we can give various specifications. This data is then fed as preloadFcn in callbacks of model properties of the simulation model. Then in initFcn the R, L and C matrix in Ohm, Henry and Farad per km respectively is defined. The overhead line is simulated using three phase pi-section line model. Sequence components are used for line pi-section . The cable specifications used is shown in Fig. 8. Various transmission line parameters are shown in Table 1 [10].

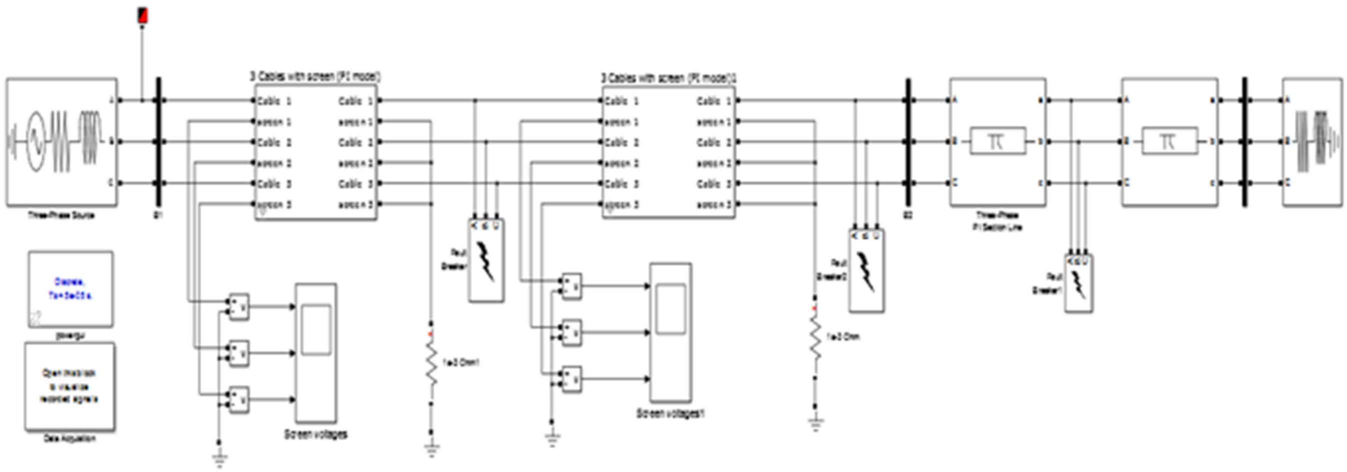


Figure 7. Power system model simulated in MATLAB Simulink software

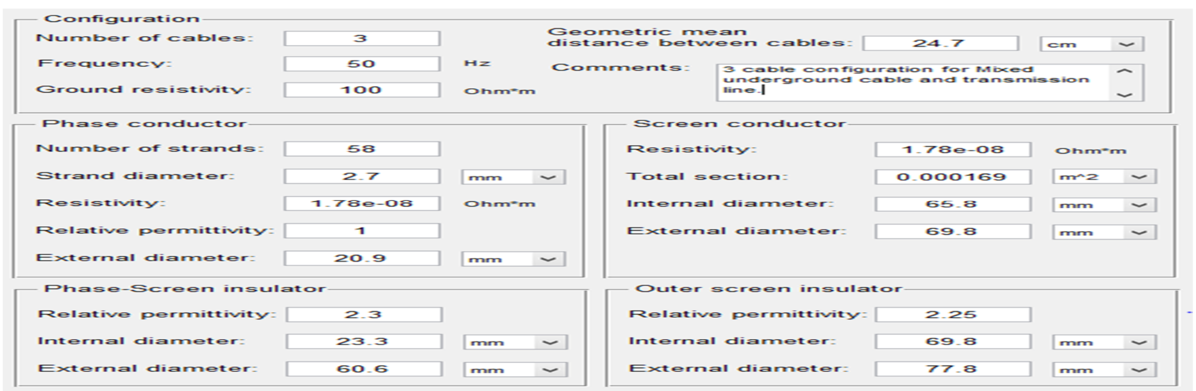


Figure 8. Cable Specifications

Table 1. Line Parameters

Positive sequence resistance R1, Ω/km	0.3317
Zero sequence resistance R0, Ω/km	0.4817
Positive sequence inductance L1, H/km	1.326e-3
Zero sequence inductance L0, H/km	4.595e-3
Positive sequence capacitance C1, F/km	0.008688e-6
Zero sequence capacitance C0, F/km	0.00476e-6
Line length, km	12

Data Generation

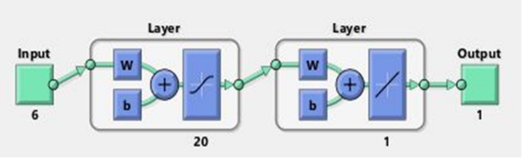
The sending end voltage and current values for single line to ground fault are passed through filter having cut-off frequency of 400 Hz. Then by using sampling frequency of 1 kHz it is passed to Discrete Fourier Transform block to extract the fundamental values. The obtained values are then separated into training inputs six in number (V_{af}, V_{bf}, V_{cf}, I_{af}, I_{bf}, I_{cf}) and testing inputs and fed to the Artificial Neural Network for training purpose. Being knowledge based algorithm target is provided for learning the various features. The algorithm used by the Artificial Neural Network is Levenberg Marquardt.

Sequence of Simulation and generation of input data

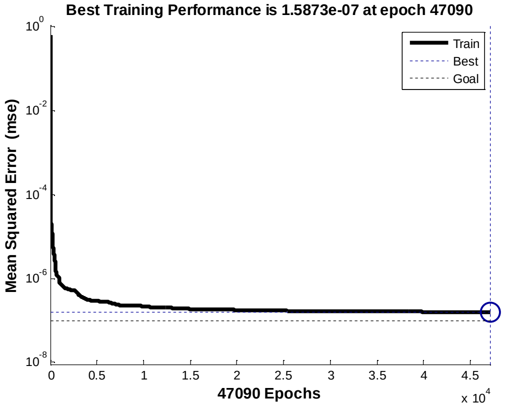
- Single line to ground fault for fault location and all types of fault for fault detection is applied for various fault resistances (FR) and fault inception time (FIT) at different section of cable keeping the line parameters and length of line fixed. Fundamental values are obtained.
- Single line to ground fault for fault location and all types of fault for fault detection is applied for various fault resistances and fault inception angle is then applied at different section of overhead line keeping the cable parameters and length of cable fixed. Obtain the fundamental values.
- Similarly keeping cable and line parameters and length constant fault is applied at junction.
- To create input set merge the cable data, junction data and overhead line data.
- Set the target values for fault detection and fault location.

Fault Detection

Fault detection is done by giving target for faulty data as input 1 and non-faulty data as input 0 and this logic is shown in table 2. The Artificial Neural Network is then trained using one hidden layer having 20 neurons with tansig as activation function and one output layer showing presence or absence of fault with purelin activation function. The ANN architecture and performance plot is shown in Fig. 9(a) and (b) respectively.



(a)



(b)

Figure 9. (a) ANN architecture, (b) Performance index and

Training and testing pattern for fault detection used in the proposed work

The training has been done with FIT= 40 ms, FR= 0, 50, 100 Ω for all types of ground fault. The testing has been done for all types of fault. Results of simulation for AG fault at 2.5 km, FR=20 Ω, FIT=43.333 ms in UG cable, ABG fault at junction, FR=40 Ω, FIT=45 ms and ABC fault at 11 km, FR=60 Ω, FIT=50 ms in OH line is shown in simulation results.

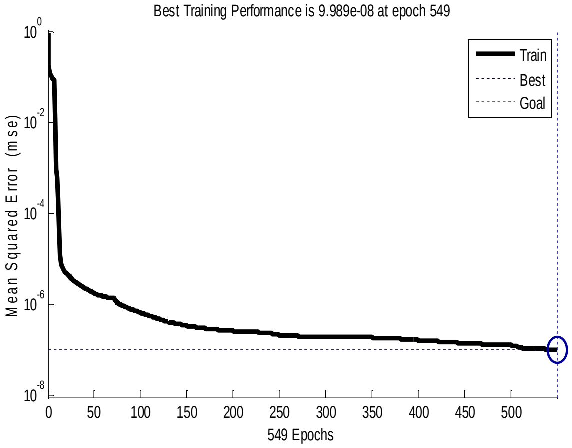
Table 2. Logic for fault detection

Fault Detection	Logic Output
Healthy Condition	0
Faulty Condition	1

Fault Location

Fault location is done by giving input data set (V_{af}, V_{bf}, V_{cf}, I_{af}, I_{bf}, and I_{cf}) and trained and tested with target as location of fault with 2 hidden layers with activation function as tansig and one output layer with purelin and giving output as location to the fault. The ANN architecture and performance plot is shown in Fig. 10(a) and (b) respectively.

(a)



(b)

Figure 10. (a) ANN architecture, (b) Performance index

Training and testing pattern for fault location used in the proposed work

Training and testing pattern for fault resistance variation is shown in Table 3 and Table 4 respectively and inception angle variation is given in Table 5 and Table 6. Voltage and Current waveforms for phase A to ground fault is shown in Fig. 11. Voltage and Current Fundamental Values for phase A to ground Fault is shown in Fig. 12(a) and (b) respectively.

Case I. Variation in fault resistances

- Training
  The training is done keeping the fault inception time 40 ms and the fault resistance values as 0,50 and 100 for various lengths.
- Testing
  The testing is done keeping the fault inception time constant and changing the fault resistance values and lengths which are not used for training purpose.

Case II. Variation in Fault Inception Angle

- Training
  The training is done keeping the fault inception angle 0, 60,120,180 degree 40 ms and the fault resistance values as 0,50 and 100 for various lengths.
- Testing

The testing is done keeping the fault inception 30, 90,150 and the fault resistance values as 2,48,52,98 and lengths which are not used for training purpose.

The relative error for the location purpose is given in equation (1) and the absolute error w.r.t. total line length is given in equation (2):

$$\text{Relative Error for Location} = E = \frac{\text{Actual Distance} - \text{Calculated distance}}{\text{Actual Distance}} \quad (1)$$

$$\text{Absolute Error w.r.t total length} = \frac{\text{Actual Distance} - \text{Calculated distance}}{\text{Total length of the mixed transmission line(15 km)}} \quad (2)$$

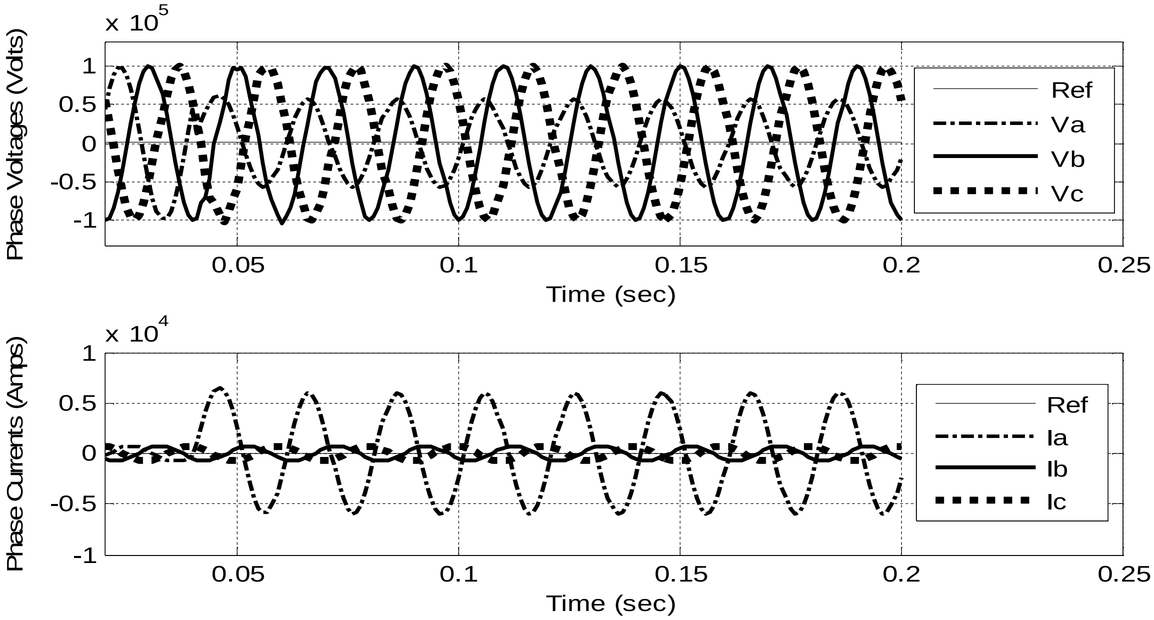


Figure 11. Phase voltages and currents for fault at phase A and Ground

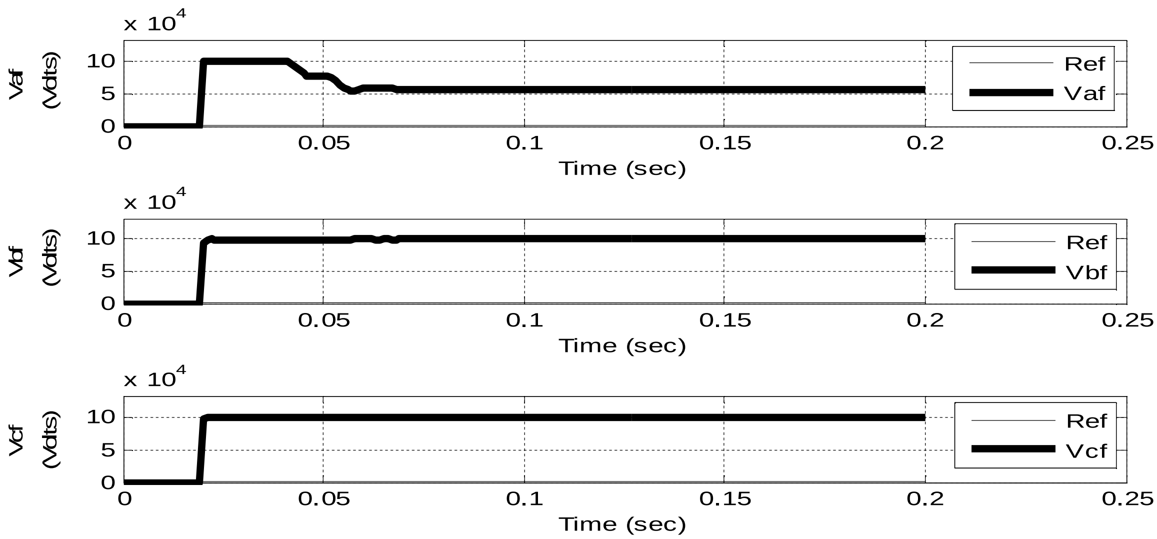


Figure 12. (a) Voltages Fundamental Values for phase A to ground fault

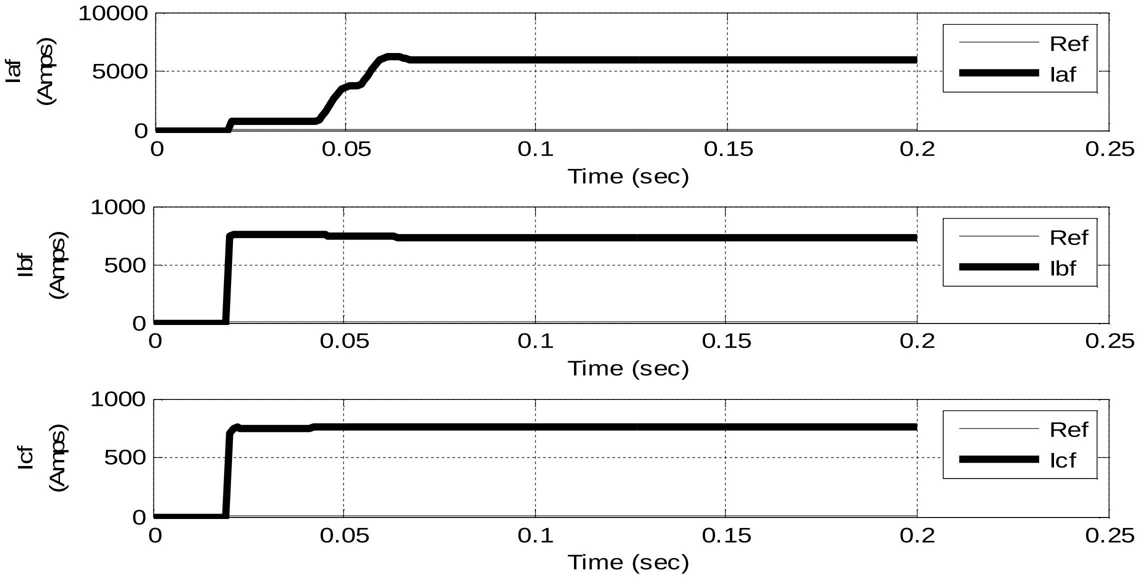


Figure 12. (b) Current Fundamental Values for phase A to ground Fault

Table 3.Variation in fault resistance (train pattern)

1.	Fault Inception Angle		40 ms (0 degree fault inception angle)
2.	Fault Resistance		0,50,100 (in Ohms)
3.	Fault Location	Underground cable	0.05, 0.15, 0.25,… 2.95 (in km)
		Overhead line	0.5, 1.5, 2.5,… 11.5 (in km)

Table 4.Variation in fault resistance (test pattern)

1.	Fault Inception Angle		0 degree fault inception angle
2.	Fault Resistance		2,48,52,98 (in Ohms)
3.	Fault Location	Underground cable	0.1,0.2,0.3,… 2.9 (in km)
		Junction	3.01 (in km)
		Overhead line	1,2,3,4,5,6,7,8,9,10,11 (in km)

Table 5.Variation in fault inception angle (train pattern)

1.	Fault Inception Angle		0,60,120,180 (in degrees)
2.	Fault Resistance		0, 50, 100 (in Ohms)
3.	Fault Location	Underground cable	0.05,0.15,0.25,... 2.95 (in km)
		Overhead line	0.5,1.5,2.5,… 11.5(in km)

Table 6.Variation in fault inception angle (test pattern)

1.	Fault Inception Angle		30,90,150 (in degree)
2.	Fault Resistance		2,48,52,98 (in Ohms)
3.	Fault Location	Underground cable	0.1,0.2,0.3,… 2.9 (in km)
		Junction	3.01 (in km)
		Overhead line	1,2,3,4,5,6,7,8,9,10,11 (in km)

Simulation Result

The proposed scheme for fault detection and location has been designed using ANN and tested with wide variation in fault parameters which are discussed in detail as below:

Fault detection

In Fig. 13 AG fault at 2.5 km, FR=20 Ω, FIT=43.333 ms in UG cable has been detected in 1.67 ms, in Fig. 14 ABG fault at junction, FR=40 Ω, FIT=45 ms has been detected in 2.00 ms and in Fig. 15 ABC fault at 11 km, FR=60 Ω, FIT= 50 ms in OH line has been detected in 3 ms.

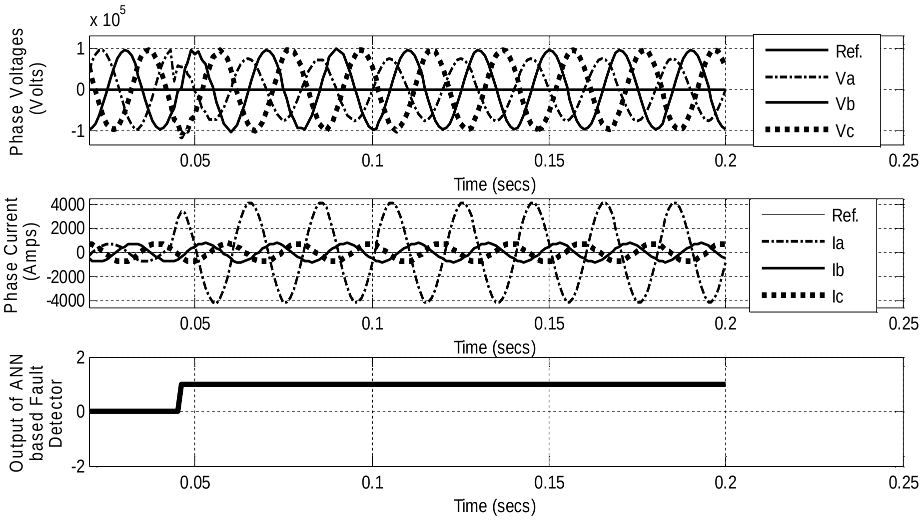


Figure 13. Test Result for AG fault at 2.5 km, FR=20 Ω, FIT=43.333 ms in UG cable

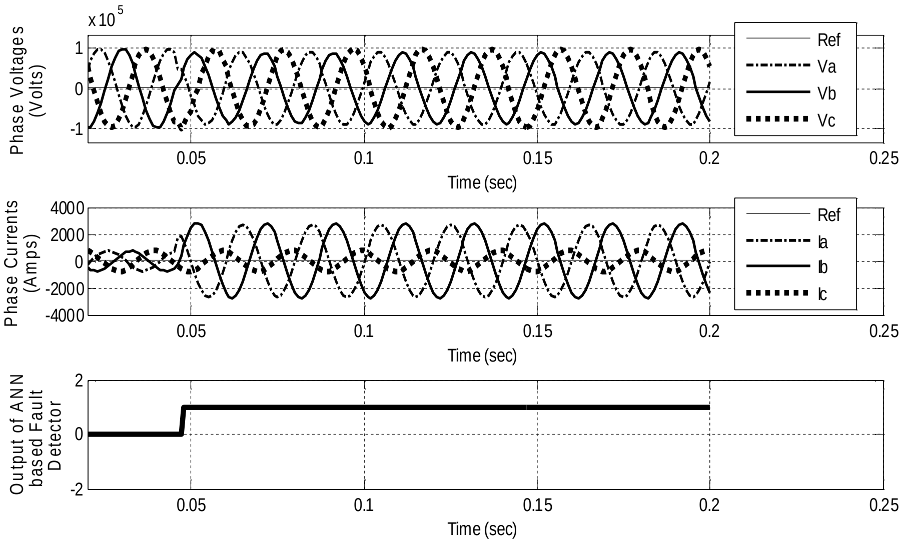


Figure 14. Test Result for ABG fault at junction, FR=40 Ω, FIT=45 ms

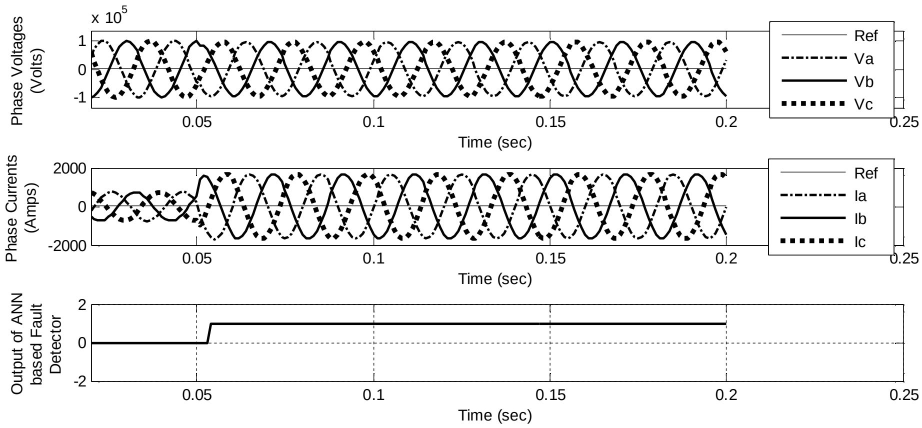


Figure 15. Test Result for ABC fault at 11 km, FR=60 Ω, FIT=50 ms in OH line

Fault location

Test results of simulation for variation in fault resistance and fault inception angle are given in Table 7 and Table 8.

Table 7. Fault Resistance Variation

S. No.	Fault Resistance (in Ohms)	Section of fault	Actual distance (in km)	Calculated distance (in km)	Error w.r.t. total length
1.	2	Cable	1.8	1.789	0.00073
		Junction	3.01	3.009	0.000066
		Line	11	10.87	0.0086
2.	48	Cable	1.8	1.810	-0.00066
		Junction	3.01	2.91	0.0066
		Line	11	10.99	0.00066
3.	52	Cable	1.8	1.799	0.000066
		Junction	3.01	2.981	0.00193
		Line	11	10.88	0.008
4.	98	Cable	1.8	1.67	0.0086
		Junction	3.01	3.35	-0.0226
		Line	11	10.37	0.041

Table 8. Fault Inception Angle Variation

S. No.	Fault Inception angle (in degree)	Section of fault	Actual distance (in km)	Calculated distance (in km)	Error w.r.t. total length
1.	30	Cable	1.8	1.76	0.00266
		Junction	3.01	2.99	0.00133
		Line	11	11.06	-0.00400
2.	90	Cable	1.8	1.78	0.1192
		Junction	3.01	2.94	0.00466
		Line	11	11.138	-0.0092
3.	150	Cable	1.8	1.828	-0.00186
		Junction	3.01	3.038	-0.00186
		Line	11	11.14	-0.00955

Conclusion

In this paper, Artificial Neural Network has been used for fault detection and distance location in Mixed Underground Cable and Overhead Transmission Line. For fault detection and distance location, the Fundamental component of voltages and currents measured at only one end of the line has been used. The Supervised algorithm for training of the ANN used is Levenberg Marquardt algorithm. The performance of the proposed scheme has been also investigated for variation in fault resistance and fault inception angle. Detection and location of fault is done correctly with higher rate of accuracy as shown in simulation results.

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