Fault Location in Transmission Line using Distributed Parameter Line Model based on Unsynchronized Measurement at Two ends of Line

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ABSTRACT
The article deals with transmission line fault location using an algorithm based on Distributed parameter line model. The discussed algorithm makes use of unsynchronized voltage and current measurements from two ends of the transmission line. Initially derivation of Algorithm is carried out, based on Distributed Parameter Line Model, and then the simulation is performed in SIMULINK with some standard System to obtain the fault voltages and currents at both ends of a transmission line. Following this, a iterative method mainly based on Newton-Raphson approach is used for estimating the fault location and synchronising angle. Lastly, an error based on the estimated location and Actual location will be calculated. Further, in order to test the accuracy of algorithm over the different types of faults and for different fault resistances, an evaluation study based on SIMULINK have undertaken. Lower the value of percentage error, better the accuracy of algorithm.

General Terms
Fault location algorithm, two end measurement.

Keywords
distributed parameter line model, unsynchronized, fault location.

1. INTRODUCTION
As we know, the significance of Transmission lines in Electrical Power System is to transmit the Electrical power over long distances. But due to various reasons like physical constraints (geographical locations, birds, tress, etc.) and technical errors (faults) interruption of power takes place. Hence it is very much important to safeguard the transmission lines from such faults. As faults are unavoidable, it is very much necessary to at least accurately locate the faults in long lines, so that line repair crew members can fix the fault or perform some maintenance task. Hence in a complex Electrical System it is necessary to locate the fault accurately so that the reliability of Power System can be maintained [1].

As faults leads to interruption of power supply, it is very much essential to restore power quickly, for that fault location plays a vital role [2]. Hence Public Utilities have to know the exact fault location. Fault location estimation and restoration of power is necessary, so that Customer grievances and time of breakdown can be reduced. Due to all these reasons, utilities need to have exact fault location, for that various algorithms are being utilised at various levels in such substations. Such algorithms aid in rapid and efficient service restoration.

In this paper, an algorithm estimating fault location is discussed which is based on unsynchronised (without using GPS System) measurements of voltages and currents from two ends of transmission line [3]. Section II describes the different fault algorithms in existence presently. Section III discusses the method of Fault location. Section IV includes results and discussions based on derived algorithm. Later sections involve the conclusion and references of paper.

2. DIFFERENT FAULT ESTIMATION ALGORITHMS
Fault location estimation is a burning issue in today's scenario of Complex Electrical Power System. Hence lot of researches are being going on in this area of power system. Right from the early ninety's, researchers have developed and tested the various fault location estimation algorithms. M. M. Saha, J. Izykowski and others discusses the different techniques in their article [4]. Basically there are various classification of fault estimating algorithms, some of are based on depending upon measurement types like one end [5], two end or multi-end measurement [6]. Few algorithms are based on type of communication link synchronised or unsynchronised measurement. Other techniques involve travelling wave, wavelet, ANN etc. approaches to estimate fault location [7].

But most of the algorithms are based on Impedance based principle which is most commonly used method involving one end, two end and multi end approaches [8].

One-end (single terminal) algorithms make use of data (local voltages and currents) from just one end of the transmission line. But the accuracy of this type of algorithm is normally affected by fault resistance, and a compensation technique is needed to alleviate this effect. Such a technique is simple and does not require communication channel with the distant end. Hence, it is appealing and is vividly incorporated into the microprocessor-based protective relays. However, it is subject to several errors, such as the effect of reactance, shunt capacitance of line, and the fault resistance value [9]. Two terminal algorithms processes signals from both the ends of transmission line which provides utilization large amount of information. From performance point of view the two-end algorithms is generally superior compared to the one-end approaches [10].

The traveling wavebased methods time-tags the arrival of the first high-frequency pulse due to a fault, at each end of the line. From knowledge of the surge impedance of the line, the length of the line and the difference between the time of arrival of the first pulse at each line end, the fault location can be determined. Some papers proposes the use of wavelets [11] to decompose the sampled voltage and current data to determine the time of arrival of the high frequency fault pulse. The papers propose fault location techniques based on artificial neural networks [12]. Online fault detection techniques employing GPS [13] make use of synchronised sampling of data. It also provides higher accuracy in estimating fault location but the drawback is that malfunctioning in this may lead to inaccurate fault location. Hence unsynchronised sampling of two end data is considered to be sound method of fault location. Recently many methods based on Distributed Parameter Model are proposed in detecting the location of fault as in [14, 15].

This paper discusses a fault location algorithm based on unsynchronised measurement of Currents and Voltages from two ends of transmission line [16] involving Distributed Parameters.

3. FAULT LOCATION ESTIMATION METHOD

Consider a Transmission line between Buses A and B, as shown in Figure 1, where EA and EB represent the Thevenin equivalent sources.

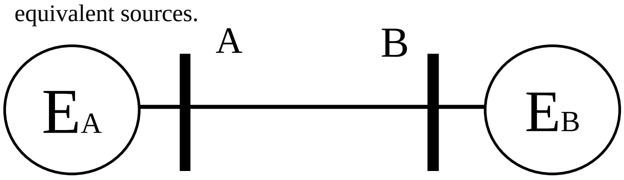

Figure1: Line considered for analysis

Figure 2 depicts the mode 2 equivalent π circuit of the line during the fault [11]. C indicates the fault point.

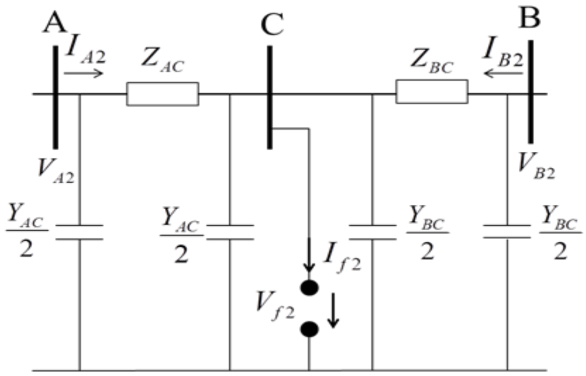

Figure2: Negative sequence network of the system during the fault

Based on Figure 2, we obtain

$$V_{A2} - Z_{AC}\left(I_{A2} - V_{A2}\frac{Y_{AC}}{2}\right) = \left[V_{B2} - Z_{BC}\left(I_{B2} - V_{B2}\frac{Y_{BC}}{2}\right)\right]e^{j\delta} \quad (1)$$

Where,

Z_{AC} and Z_{BC} equivalent series impedance of the line segment AC and BC. Y_{AC} and Y_{BC} are equivalent shunt admittance of the line segment AC and BC. V_{A2} and I_{A2} mode 2 voltage and current during the fault at A. V_{B2} and I_{B2} mode 2 voltage and current during the fault at B. δ is the synchronizing angle.The equivalent transmission line parameters depending on the distributed model are as follows:

$$Z_c = \sqrt{\frac{z_2}{y_2}} \quad (2)$$

$$\gamma = \sqrt{z_2 y_2} \quad (3)$$

$$Z_{AC} = Z_c \sinh(\gamma l_2) \quad (4)$$

$$Z_{BC} = Z_c \sinh[\gamma(l - l_2)] \quad (5)$$

$$Y_{AC} = \frac{2}{Z_c}\tanh\left(\frac{\gamma l_2}{2}\right) \quad (6)$$

$$Y_{BC} = \frac{2}{Z_c}\tanh\left[\frac{\gamma(l - l_2)}{2}\right] \quad (7)$$

Where

Z_c	Characteristic impedance of the line;
γ	Propagation constant of the line;
l	Length of the line in km or mile;
l_2	Fault distance from A to C in km or mile

Substituting (2) to (7) in (1) results in

$$f(x) = V_{A2} - Z_c \sinh(\gamma l_2)\left[I_{A2} - V_{A2}\frac{1}{Z_c}\tanh\left(\frac{\gamma l_2}{2}\right)\right] - V_{B2}e^{j\delta}$$
$$+ Z_c \sinh[\gamma(l - l_2)]\left[I_{B2} - V_{B2}\frac{1}{Z_c}\tanh\left(\frac{\gamma(l - l_2)}{2}\right)\right]e^{j\delta} = 0$$

(8)

where $x = [l_2 \quad \delta]^T$,T represent vector transpose operator. There are two unknown variables in (8), solution of which is presented as follows.

Equation (8) is a complex equation and can be separated into two real equations corresponding to its real and imaginary part as

$$f_1(x) = \mathrm{Real}(f(x)) = 0 \quad (9)$$

$$f_2(x) = \mathrm{Imag}(f(x)) = 0 \quad (10)$$

where Real(.) and Imag(.) yield the real and imaginary part of its arguments, respectively. It follows that

$$\frac{\partial f_1(x)}{\partial l_2} = \mathrm{Real}\left(\frac{\partial f(x)}{\partial l_2}\right) \quad (11)$$

$$\frac{\partial f_1(x)}{\partial \delta} = \mathrm{Real}\left(\frac{\partial f(x)}{\partial \delta}\right) \quad (12)$$

$$\frac{\partial f_2(x)}{\partial l_2} = \mathrm{Imag}\left(\frac{\partial f(x)}{\partial l_2}\right) \quad (13)$$

$$\frac{\partial f_2(x)}{\partial \delta} = \mathrm{Imag}\left(\frac{\partial f(x)}{\partial \delta}\right) \quad (14)$$

Now define

$$J(x)=\begin{bmatrix}\frac{\partial f_1(x)}{\partial l_2} & \frac{\partial f_1(x)}{\partial \delta}\\ \frac{\partial f_2(x)}{\partial l_2} & \frac{\partial f_2(x)}{\partial \delta}\end{bmatrix} \qquad (15)$$

$$F(x)=\left[\, f_1(x) \quad f_2(x)\right]^T \qquad (16)$$

Then the unknown variable x can be obtained using the Newton-Raphson approach iteratively as follows:

$$x_{n+1}=x_n-J^{-1}F(x_n) \qquad (17)$$

Where

$x_{n+1}=$ Solution of x after n_{th} iteration;

$n=$ Iteration count starting from one.

Below steps shows the Newton-Raphson approach with the help of algorithm.

1. Start the Program
2. Enter the polynomial F(x), Jacobian Matrix J(x), Initial X(o)=[l_2 delta]’
3. Set the tolerance epsilon=10e-10 with Initial Approximation $X_x=X_0$
4. JJ=J(X_x)
5. Check that absolute value of Determinant should not be less than JJ, if it is then go to step 2, it not then go to next step
6. $X_n=X_x$-inv(JJ)*$F_n(X_x)$
7. Absolute value of $F_n(X_x)$ should be less than epsilon, if not then considering $X_n=X_x$ go to step 4
8. X=X_n
9. Stop the Program

3.1 Evaluation Study using Simulink

To obtain the voltage and current measurement data at both ends of transmission line after the fault, a simulation model using the SIMULINK has been developed initially for a fault at 150km. A 500kV, 300km long transmission-line is considered throughout the simulation. For testing the algorithm, initially fault is assumed to be at a distance 100km from terminal A.

Per-unit system has been undertaken with a voltage base of 500kV and an apparent power base of 100 MVA. Firstly, the voltage and current values from both source side A and B are obtained from SIMULINK model for line-to-ground fault (L-G) for per phases.

Since we have used the Negative Sequence Mode, hence convert the voltages and currents values from phase value to mode 2 values using below formulae.

$$I_{R2}=\frac{1}{3}\left(I_R+\alpha^2 I_Y+\alpha I_B\right) \qquad (18)$$

$$V_{R2}=\frac{1}{3}\left(V_R+\alpha^2 V_Y+\alpha V_B\right) \qquad (19)$$

Obtaining the values of voltages and currents for both the ends A and B, and after substituting these values in MATLAB based program[16] , we get the values of fault location and synchronising angle for given fault location at SIMULINK Model. Similarly for different fault locations, the accuracy and affectivity of algorithm can be check.

The accuracy of above algorithm is measured by the percentage error calculated as

$$\%Error=\frac{|Actual\ location-Estimated\ location|}{Total\ line\ length}X\,100 \qquad (20)$$

Value of Z_C and γ required in (1) is calculated using (2) and (3) for a particular transmission line module considered in SIMULINK.

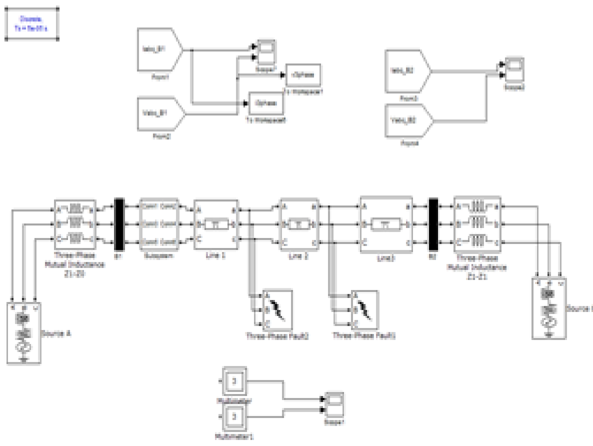

Figure3: Model of Transmission line connected with two end sources.

Fault is taken during the period 0.2 sec to 0.3 sec. Total Simulation time is 0.5 sec. Measurement units are used to collect the data of voltage and current at both ends of line. Fig. 3 above shows a SIMULINK model for the system considered.

The voltage and current waveforms at terminal P obtained from SIMULINK model during L-G fault are shown in Fig. 6. Similarly, the voltage and current waveforms at terminal Q are shown in Fig. 7. Before fault, the voltage and current waveforms are depicted in Fig. 4. As can be seen from waveforms, value of voltage and current observed to be 0.7 per unit and current nearer to 0.7 per unit. Change in values has been observed after the occurrence of fault at 100 km.

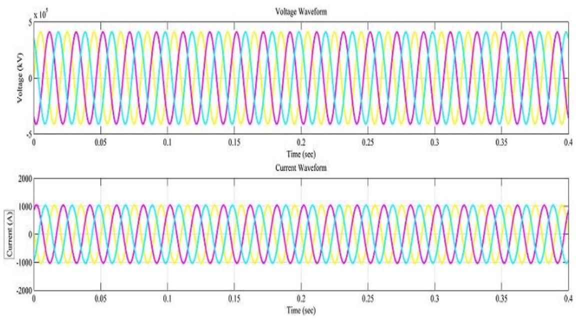

Figure 4: Voltage and Current prior to the Fault

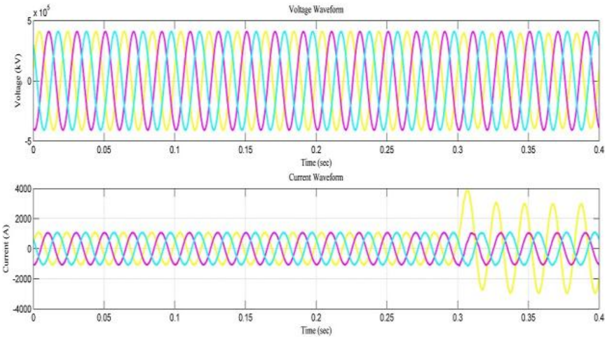

Figure5: Voltage and Current at Bus A with fault at 100 km

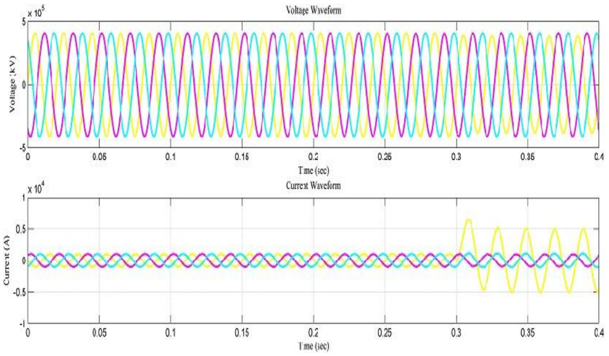

Figure 6: Voltage and Current at Bus B with fault at 100km

4. RESULTS AND DISCUSSION

For estimating the fault location Newton-Raphson based MATLAB code is written which requires six parameters (V_{A2}, I_{A2}, V_{C2}, I_{C2}, Z_C, γ) at initial stage as inputs. After substituting the values, code will demand initial inputs for Newton Raphson based algorithm. Starting value for δ is chosen to be zero in all the cases. Initial fault location can be taken as 0 or half of fault location [17]. Taking the values of voltages and currents at both buses A and B for the fault at 100km, algorithm finds the value of fault location and synchronizing angle.

By giving the intial input arguments to the program it evaluates the fault location and synchronising angle. Iteration counter limit is set at 30. Value of percentage Error is calculated using (18).

Table 1. Parameters of System Considered in Simulink

Sr. No	System Parameters	Value
1	Sources A and B Module	500kV
2	Transmission Line (Pi Section) Module	300 km
3	Powergui Module	-
4	Voltage and Current Measurement Modules	-
5	Scope Module	-
6	Fault Module	-

Table2.Determination of Fault Location with use of Negative Sequence Quantities (Rf=0 ohm)

Fault Types	Actual Location (km)	Estimated Location (km)	Error (%)
LG	50	47.91	0.006
	100	97.60	0.075
	150	140.8	0.028

5. CONCLUSION

In this paper a fault location algorithm based on unsynchronised measurement of Currents and Voltages from two ends of transmission line involving Distributed Parameters is discussed. Only LG type of fault is taken under study and it is observed that for the fault at 100km the percentage of error comes to be very less. It is also observed that convergence of Newton Raphson based code takes place within few iterations. The algorithm can be tested for various fault resistance (5 ohm, 10 ohm etc.) and for various other types of faults in order to validate the accuracy and sensitivity of an discussed algorithm.

Here we have considered the Negative Sequence Components (Mode 2 components), but Positive Sequence Components can also be consider.

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