I. INTRODUCTION

The modern society has come to depend heavily upon continuous and reliable availability of electricity and high quality of electricity too. No power system can be designed in such a way that it would never fail. So one has to live with failures, if no fast fault locator used and identify the fault position and take quick restoration process. For quick restoration process require a fast and accurate fault location algorithm that provide a quick and reliable solution of this problem. So, that fault locating algorithms gains a growing interest among protective device in recent few years. Transmission lines commonly experience a variety of faults resulting in disconnecting the power delivering to loads nearby it. Therefor the restoration process can be archive easily, if the fault location of the fault is either known or can be predicted with reasonable accuracy. Many benefits are achieved by using fault locator in power systems, including reducing maintains times, improving power quality, increasing the power availability, and avoid future misfortunes.

Fault location algorithms may be classified on the account of available data at measured terminals and line parameters. On the basis of available data for measured terminal, one end, two end and multi-end methods are available. The two end methods are giving good results for locating faults in transmission system for any type of transmission line modeling(lumped or distributed parameters) [1], [2]. Similar is the case for multi end method as in [3]. The requirement for these methods in order to generate accurate fault location are line parameter and fundamental phasor synchronization. Two end method is more accurate and faster than the one end method. However two end method require synchronizing measure data that require data acquisition process which makes it more complex and costly. There are several methods used to calculate fault location. Some of them are presented here, impedance based methods, travelling wave based methods, artificial intelligence technique. There are various impedance based methods that may use one-end, two-end data. These impedance based method calculate fault location by modeling a network which consider faulty condition by the use of synchronized phasor measurement. In travelling wave based method transient signals or travelling surge are used at power frequency or high power frequency [4]–[10]. However some of the issues relevant to travelling wave based methods are wavefront detection, timing accuracy, multiple reflections and noise filtering etc. Therefore this method needs more computation time along with costly instruments. Some of the algorithm are based upon Artificial intelligence technique but it requires accurate features identification and maximum possible fault test cases [11]–[13]. One of the Intelligence techniques uses Artificial neural networks (ANN). ANN used for fault identification, classification and location [14]. Other intelligence like techniques such as Support vector Machine or a combination of ANN and wavelet transform [15] and many other combinations are also used for fault identification and location.

Some of the algorithms are proposed to located fault with unsynchronized measured data [16], [17] and some without using line parameters [18]–[21]. By taking synchronization angle and line parameter as unknown some of the method calculate fault location using iterative method like Newton Raphson. Though
the iterative method requires a good initial guess therefore solution is sensitive to that value. Most of 
the algorithm requires type of fault along with its 
representation for each symmetrical and un- 
symmetrical fault component.

In this work, a fault location algorithm is proposed 
without using line parameters. This algorithm is 
equally applicable to any type of fault along with 
synchronized and un-synchronized measured data. 
The algorithm formulation based upon two end 
measurement data using Least squares Technique 
(LSQ) for locating fault point. This algorithm works 
in two steps. First, calculate synchronization angle 
based on the three sample moving window technique. 
Second, evaluate fault distance 
for different types of 
faults. The reminder of this is as follows. Section-II 
describe system modeling with line simulation with 
line configuration. 
Section-III gives the problem formulation, and 
simulation results with discussion are provided in 
section-IV for the given transmission system.

II. SIMULATED SYSTEM

Fig.1 show the single line diagram of 200 km, 230 kV 
transmission line simulated in the PSCAD transient 
program. MATLAB software interface is used to 
implement the algorithm. Thevenin’s Equivalent 
Impedance of voltage sources at bus j and k are given 
as using mutual coupled R-L circuit as: the positive 
sequence is $Z_{j1} = 52.9 \angle 83^\circ \Omega$, $Z_{k1} = 52.9 \angle 83^\circ \Omega$ 
and zero sequence is $Z_{j0} = 52.9 \angle 83^\circ \Omega$, $Z_{k0} = 52.9 \angle 83^\circ \Omega$ respectively.

The locators are estimated using low and high 
resistive faults as well as using arcing faults [22]. 
This transmission line is represented using frequency-
dependent model [23]. Trans- 
mision line impedance 
are given as: the positive sequence is $R_{abc1} = 1.787240475 \ \Omega$, $L_{abc1} = 25.3881338 mH$, $G_{abc1} =5.0 \ \mu mho$, $B_{abc1} = 0.163558973 mH$, and zero sequence is $R_{abc0} = 18.15761005 \ \Omega$, $L_{abc0} = 
66.3236615mH$, $G_{abc0} = 5.0 \ \mu mho$, $B_{abc0} = 
033049.1161mH$.

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identification and location. From Fig.3 shows the equivalent circuit diagram of faulted transmission system. The three-phase voltage to the fault point are computed based on Kirchhoff’s Voltage Law from both end are taken and the equations are given as:

\[
V_{abc} = mZ_{abc}I_{abc} + (I_{abc} + I_{kabc})R_f \tag{1}
\]

\[
V_{kabc} = (1 - m)Z_{abc}I_{kabc} + (I_{abc} + I_{kabc})R_f \tag{2}
\]

\[
V_{abc} - V_{kabc} = (1 - m)Z_{abc}I_{abc} + (I_{abc} + I_{kabc})R_f \tag{3}
\]

Where, \( m \) is per unit fault distance of transmission line. \( Z_{abc} \) is total transmission line impedance \( I_{abc} \), \( I_{kabc} \), \( V_{abc} \), \( V_{kabc} \) are the three phase currents and voltage measured at concerning fault section buses as shown in Fig.3. If data are not synchronized then it can be calculated synchronized angle of other bus with reference bus, here it have been taken as \( e^{j\theta} \). It can facilitate estimate of the correct fault location. Now with synchronization angle equation (3) is rewritten for un-synchronized data set as:

\[
V_{abc} - V_{kabc} e^{j\theta} = (1 - m)Z_{abc}I_{abc} + (I_{abc} + I_{kabc} e^{j\theta})R_f \tag{4}
\]

Where, \( e^{j\theta} \) is written for the synchronization angle. Correctly identifying \( e^{j\theta} \) with the help of three sample moving window method. Finding accurately angle is much important because it effect on the accuracy of fault location calculation. If it find \( e^{j\theta} \) correctly then it easily the solve fault location from equation (4).

For solving equation (3) and (4) we rewrite it’s in equation (5) and (6) respectively as:

\[
\Delta V_{abc} = m Z_{abc}(I_{abc} + I_{kabc}) - Z_{abc}I_{kabc} \tag{5}
\]

\[
\Delta V_{abc} = m Z_{abc}(I_{abc} + I_{kabc} e^{j\theta}) - Z_{abc}I_{kabc} e^{j\theta} \tag{6}
\]

Where, \( \Delta V_{abc} = V_{abc} - V_{kabc} \) or \( V_{abc} - V_{kabc} e^{j\theta} \) for synchronized or un-synchronized data equation (3) or (4) respectively.

\[
m = |X^{-1} Y| \tag{7}
\]

Fault location
\[
m \times \text{Length of Transmission Line} \tag{8}
\]

From equation (8), it can easily computed the fault location of transmission line without knowing line parameter. Overall step of the proposed algorithms is shown in the Fig.4

**IV. SIMULATED RESULTS AND DISCUSSIONS**

Proposed algorithm is based on two end measured data, the all derived equation is rewritten using the symmetrical transformation using its positive sequence component for further calculation. We generate all possible permanent and transient faults to check the feasibility of the algorithms in fault location. We also take un-synchronized measured data in this section for further calculation because we easily see from algorithms it equally applicable for any type of measured voltage and current data of buses. Equation (4) can be rewritten for un-synchronized measured data.
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\[ V_{012} - V_{0k12} e^{j\delta} = (1 - m)Z_{012} + \left( I_{012} + I_{0k12} e^{j\delta} \right) R_f \]  

(9)

Where, \( V_{012} - V_{0k12} e^{j\delta} = [T] \left( V_{012} - V_{0k12} e^{j\delta} \right) \) and \([T] \) is transformation matrix \([22]\). Equation (5) is rewritten as,

\[ \Delta V_{012} = m Z_{012} (I_{012} + I_{0k12}) - Z_{0k12} I_{0k12} \]  

(10)

Now taken the phasor measurement at instant \( t = t_1 \) then equation (8) is rewritten as,

\[ \Delta V(t_1)_{012} = m Z_{012} (I(t_1)_{012} + I(t_1)_{k12}) - Z_{0k12} I_{t1} \]  

(11)

Now proceed for the \( N \) number of sample with constant interval \( \Delta t \) above equation is rewritten as,

\[ \begin{bmatrix} \Delta V(t)_{012} \\ \Delta V(t)_{021} \\ \Delta V(t)_{021} \end{bmatrix} = \begin{bmatrix} \Delta V(t)_{012} \\ \Delta V(t)_{021} \\ \Delta V(t)_{021} \end{bmatrix} \begin{bmatrix} m Z_{012} \\ Z_{012} \end{bmatrix} \]  

(12)

Equation (12) can be rewritten as,

\[ [V_n] = [I_n] \begin{bmatrix} m Z_{012} \\ Z_{012} \end{bmatrix} \]  

(13)

Equation (13) should be solve for finding the ratio between unknown variables \( m Z_{012} \) and \( Z_{012} \) rather than computing the value of these variables. So that this ratio can be enumerated easily for available \( N \) number of equations, thus solving equation (13) as,

\[ \begin{bmatrix} m Z_{012} \\ Z_{012} \end{bmatrix} = [V_n] [I_n]^{-1} \]  

(14)

Then the fault location \( L_f \) of line length \( L \) is calculated as,

\[ L_f = m \times L = \begin{bmatrix} m Z_{012} \\ Z_{012} \end{bmatrix} \]  

(15)

From equation it can easily found fault location with reasonable accuracy. With algorithms it have been calculated fault location of different cases and result are given in the Table-I. In Table-I it calculated fault location with respect of all types of permanent faults and shown in Table-I and error variation of actual location to calculated location is shown in Fig.4. For showing clear variation we take ten test cases for each type of faults that may affect the technique accuracy including fault resistance, line loading and line transposition. The voltage and current data calculated at sampling frequency at 1.6 MHz. The proposed algorithms based on fundamental phasors, the recursive Discrete Technique (DFT) is utilized to find out those phasors for each test cases, find out the resulted estimated error is given as a percentage of total line length.

\[ \text{Presentage Error} = \frac{(L_f)_{\text{actual}} - (L_f)_{\text{calculated}}}{\text{Total Line Length}} \times 100 \]  

(16)

Where, \( (L_f)_{\text{actual}} \) \( (L_f)_{\text{calculated}} \) and \( L \) are the actual fault location, calculated fault location and transmission line length respectively.

From the above Table-I and Fig.4 it seen that algorithms provide fault location with the maximum percentage error 0.1859 that is equal to in length 0.3718 Km or 371.80 m that is within the permissible limit provided in IEEE standards \([1]\). It also seen that when the fault location within 40 Km percentage error is negative but above this length percentage error is positive with respect to the reference bus. This algorithms require less than one cycle data to providing location of fault that accelerate the restoration process by reducing the search area and increased transfer capability of transmission line in specific time.

| TABLE I | RESULT OF CALCULATED FAULT LOCATION WITH DIFFERENT FAULTS TYPES |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Fault Type | Actual FL | Calculated FL | Error in FL | Error in FL |
| Phase to Grounds (A-G) | 20 | 19.8752 | -0.1218 | -0.0609 |
| 40 | 39.7754 | -0.2246 | -0.1122 |
| 60 | 60.1699 | 0.1869 | 0.0849 |
| 80 | 80.2384 | 0.1884 | 0.0942 |
| 100 | 100.0046 | 0.0466 | 0.0023 |
| 120 | 120.0474 | 0.0474 | 0.0023 |
| 140 | 140.5852 | 0.0502 | 0.0024 |
| 160 | 160.1578 | 0.0525 | 0.0024 |
| 180 | 180.1256 | 0.0546 | 0.0024 |
| Phase to Phase (A-B) | 20 | 19.8244 | -0.1750 | -0.0878 |
| 40 | 39.7957 | -0.2122 | -0.1061 |
| 60 | 60.2355 | -0.2444 | -0.1272 |
| 80 | 80.2096 | 0.0926 | 0.0463 |
| 100 | 100.0068 | 0.0968 | 0.0484 |
| 120 | 120.0126 | 0.0984 | 0.0513 |
| 140 | 140.2008 | 0.1026 | 0.0535 |
| 160 | 160.8502 | 0.1047 | 0.0556 |
| 180 | 180.1917 | 0.1068 | 0.0577 |
| Phase to Grounds (A-B-G) | 20 | 19.8371 | -0.1269 | -0.0683 |
| 40 | 39.7916 | -0.2084 | -0.1042 |
| 60 | 60.1183 | 0.1183 | 0.0592 |
| 80 | 80.2226 | 0.1262 | 0.0613 |
| 100 | 100.2734 | 0.0074 | 0.0037 |
| 120 | 120.0685 | 0.0094 | 0.0042 |
| 140 | 140.0909 | 0.0099 | 0.0049 |
| 160 | 160.0884 | 0.0084 | 0.0044 |
| 180 | 180.0247 | 0.0074 | 0.0042 |
| Phase to Grounds (A-C-G) | 20 | 19.8162 | -0.1818 | -0.0910 |
| 40 | 39.8500 | -0.1614 | -0.0821 |
| 60 | 50.2708 | 0.0718 | 0.0393 |
| 80 | 80.2004 | 0.0094 | 0.0042 |
| 100 | 100.0728 | 0.0728 | 0.0364 |
| 120 | 120.0112 | 0.0066 | 0.0034 |
| 140 | 140.2056 | 0.0536 | 0.0268 |
| 160 | 160.0886 | 0.0886 | 0.0443 |
| 180 | 180.0563 | 0.0563 | 0.0282 |

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CONCLUSION

A simplest technique for fault location in transmission lines has been introduce without using line parameter on the least error square estimate principle. Simple formulas have been define that suitable for any type of faults. The describe algorithms has also suitable for different types of transmission lines. It also follow the guide line of two end fault. The describe algorithms has also suitable for different types of transmission lines. It also follow the guide line of two end fault location describe in the IEEE standers. Its performance evaluated based on nonlinear resistance such as the arcing faults has been calculated here. It has provide in a simple form and not used the line parameters but provide accurately location of the fault point within specify range.

REFERENCES