International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Comparison of Accuracy of various Impedance Based Fault Location Algorithms on Power Transmission Line

Ankamma Rao J[1], Gebreegziabher Hagos[2]

[1]Assistant Professor, Electrical& Computer Engineering Department, Samara University, Ethiopia

[2]Lecturer, Electrical & Computer Engineering Department, Samara University, Ethiopia

Abstract: ***Transmission line protection is important issue in power engineering because 85-87% of power system faults are occurring in transmission lines. This paper presents three developed algorithms: Takagi's method, Ericsson method, Fault sequence component of current method. MATLAB/ Simulink software was used to implement these algorithms. The accuracy of fault location on power transmission line are compared for these three method by varying various parameters like fault type, fault resistance, fault location and fault inception angle, on a given power system model. The simulation results demonstrate the validity of the suitable fault location method in 400KV transmission line.***

Keywords: Power system Faults, Fault location, MATLAB, Fault impedance, Fault resistance, Fault inception angle, Accuracy of fault location.

1. Introduction

Electric power systems are designed to ensure **a** reliable supply of energy with the highest possible continuity. The growing complexity of electrical power system demands performance of protection and control equipment. Faults can occur in any point of the power system, and the most exposed parts are overhead transmission lines. Fault locators are used to pinpoint transmission line faults, and they help in the reduction of maintenance works and quick system recovery from faults. A fault locator is also a very useful tool in evaluating transient faults that could otherwise cause weak spots in transmission and distribution systems, resulting in future problems or faults. During the last **20** years there has been considerable interest in computer relaying of power systems [l] and in the development of microprocessor-based fault locators [l0].The method which uses data from all ends requires synchronized measurement with time stamping and online communication of data to central location [11-13]. This paper describes three impedance based fault location algorithms on 400 KV transmission line.

2. Theory of Impedance Based Fault Location Algorithms

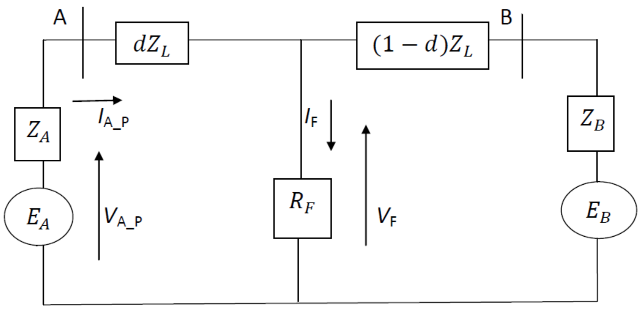

Figure 1: Fault network diagram

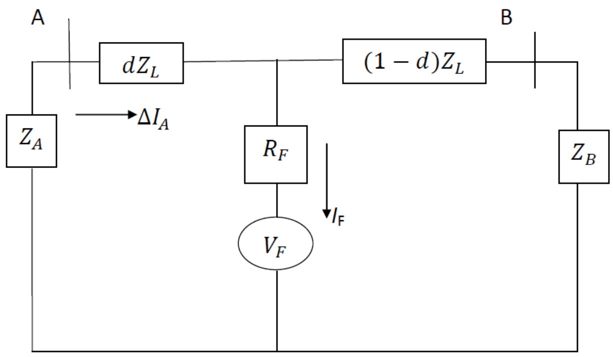

Figure 2: Pure Fault network

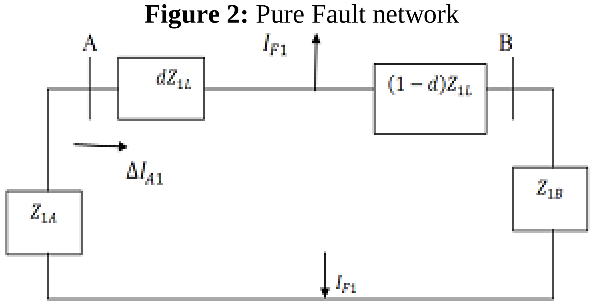

Figure 3: Incremental positive sequence network diagram

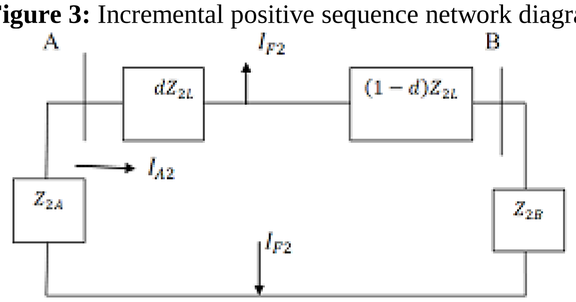

Figure 4: Negative sequence network diagram

3. Nomenclature

d Estimated distance to the fault (units: p.u)
V_{A_P} Protective distance relay voltage at the line end A

I_{A_P} Protective distance relay current at the line end A
I_F Total fault current
Z_L Total line impedance
V_F Fault voltage
Z_A, Z_B Source impedances at terminals A and B respectively
E_A, E_B Source voltages at terminals A and B respectively
ΔI_{A1} Incremental positive sequence current.
I_{A2} Negative sequence current
Z_{1L} Total positive sequence line impedance
Z_{2L} Total negative sequence line impedance
Z_{1A} , Z_{1B} Positive sequence source impedances at terminals A and B respectively
Z_{2A} , Z_{2B} Negative sequence source impedances at terminals A and B respectively.

A. Takagi's Method

To derive the Fault location algorithm, the fault loop composed according to the fault classified type is considered. This loop contains the faulted line segment (between points A and F) and the fault path itself. A generalized model for the fault loop is stated as fallows

$$V_{A\_P} - dZ_L * I_{A\_P} - I_F * R_F = 0 \quad (1)$$

The superimposed circuit (Fig.2) is a current divider of the fault current and thus:

$$\Delta I_A = \frac{(1-d)*Z_L + Z_B}{Z_A + Z_B + Z_L} * I_F \quad (2)$$

$$\text{Let } I_F = \frac{\Delta I_A}{k_F} \quad (3)$$

Where the current distribution factor is

$$k_F = \frac{(1-d)*Z_L + Z_B}{Z_A + Z_B + Z_L} \quad (4)$$

$$k_F = |k_F| * e^{j\Upsilon} \quad (5)$$

Substitute Equation (3) in Equation (1)

$$V_{A\_P} - dZ_L * I_{A\_P} - \frac{\Delta I_A}{k_F} * R_F = 0 \quad (6)$$

Substitute Equation (5) in Equation (6)

$$V_{A\_P} - dZ_L * I_{A\_P} - \frac{\Delta I_A}{|k_F| e^{j\Upsilon}} * R_F = 0 \quad (7)$$

Multiplying Equation (7) by the term $\Delta I_A{}^* e^{j\Upsilon}$ and taking imaginary part yields the following formula for the distance to fault:

$$V_{A\_P} \Delta I_A{}^* e^{j\Upsilon} - dZ_L * I_{A\_P} * \Delta I_A{}^* * e^{j\Upsilon} - \frac{R_F}{|k_F|} = 0 \quad (8)$$

$$d = \frac{Im\left(V_{A\_P} * \Delta I_A{}^* * e^{j\Upsilon}\right)}{Im\left(Z_L * I_{A\_P} * \Delta I_A{}^* * e^{j\Upsilon}\right)} \quad (9)$$

It was assumed that current distribution factor is a real number so $e^{j\Upsilon} = 1$

$$d = \frac{Im(V_{A\_P} * \Delta I_A{}^*)}{Im(Z_L * I_{A\_P} * \Delta I_A{}^*)} \quad (10)$$

B. Eriksson's Method

To derive the fault location algorithm, the fault loop composed according to the classified fault type is considered. This loop contains the faulted line segment (between points A and F) and the fault path itself. A generalised model for the fault loop is stated as fallows:

$$V_{A\_P} - dZ_L * I_{A\_P} - I_F * R_F = 0 \quad (11)$$

The superimposed circuit (Fig.2) is a current divider of the fault current and thus:

$$\Delta I_A = \frac{(1-d)*Z_L + Z_B}{Z_A + Z_B + Z_L} * I_F \quad (12)$$

Where $\Delta I_A = I_A - I_A{}^{Pre}$ -incremental current determined from the moment of the fault-inception occurrence (thus in the fault interval), and obtained by taking the fault current and subtracting the pre-fault current (present before fault inception). Note that the recordings of the pre-fault current have to be available.

This allows the total fault current to be determined as

$$I_F = \frac{Z_B + Z_A + Z_L}{(1-d)*Z_L + Z_B} * \Delta I_A \quad (13)$$

Substitute Equation (13) in Equation (11) and it gives

$$V_{A\_P} - dZ_L * I_{A\_P} - \frac{Z_B + Z_A + Z_L}{(1-d)*Z_L + Z_B} * \Delta I_A * R_F = 0 \quad (14)$$

Expanding the Equation (14) results in

$$V_{A\_P} * \left((1-d)*Z_L + Z_B\right) - dZ_L * I_{A\_P} * \left((1-d)*Z_L + Z_B\right) - (Z_B + Z_A + Z_L) * \Delta I_A * R_F = 0 \quad (15)$$

Dividing the Equation (15) by the term $I_{A\_P} * Z_L$ results in

$$\frac{V_{A\_P}}{I_{A\_P}*Z_L} * \left((1-d)*Z_L + Z_B\right) - d * \left((1-d)*Z_L + Z_B\right) - \left(\frac{Z_B + Z_A}{Z_L} + 1\right) * \frac{\Delta I_A}{I_{A\_P}} * R_F = 0 \quad (16)$$

Dividing Equation (16) by the term Z_L

$$\frac{V_{A\_P}}{I_{A\_P}*Z_L} * \left(1 + \frac{Z_B}{Z_L} - d\right) - d * \left(1 + \frac{Z_B}{Z_L} - d\right) - \left(\frac{Z_B + Z_A}{Z_L} + 1\right) * \frac{\Delta I_A}{I_{A\_P}*Z_L} * R_F = 0 \quad (17)$$

Expanding the Equation (17) results in

$$d^2 - d * \left(\frac{V_{A\_P}}{I_{A\_P}*Z_L} + 1 + \frac{Z_B}{Z_L}\right) + \frac{V_{A\_P}}{I_{A\_P}*Z_L} * \left(1 + \frac{Z_B}{Z_L}\right) - \left(\frac{Z_B + Z_A}{Z_L} + 1\right) * \frac{\Delta I_A}{I_{A\_P}*Z_L} * R_F = 0 \quad (18)$$

Equation (18) can be written in the following form

$$d^2 - d * k1 + k2 - k3 * R_F = 0 \quad (19)$$

Where

$$k1 = \left(\frac{V_{A\_P}}{I_{A\_P} * Z_L} + 1 + \frac{Z_B}{Z_L}\right) \quad (20)$$

$$k2 = \frac{V_{A\_P}}{I_{A\_P} * Z_L} * \left(1 + \frac{Z_B}{Z_L}\right) \quad (21)$$

$$k3 = \left(\frac{Z_B + Z_A}{Z_L} + 1\right) * \frac{\Delta I_A}{I_{A\_P} * Z_L} \quad (22)$$

For eliminating R_F multiply Equation (19) by $k_3{}^*$

$$d^2 * k_3{}^* - d * k_1 * k_3{}^* + k_2 * k_3{}^* - R_F = 0 \quad (23)$$

R_F Can be eliminated by forming Equation with only imaginary parts and results the following Equation

$$B_2 d^2 - B_1 d + B_0 = 0 \quad (24)$$

The solution to the Equation (24) is given by

$$d = \frac{B1 - sqrt\left(B_1{}^2 - 4 * B_2 * B_0\right)}{(2 * B_2)} \quad (25)$$

Where $B_2 = imag\,(k_3{}^*)$; $B_1 = imag\,(k_1 * k_3{}^*)$ and $B_0 = imag\,(k_2 * k_3{}^*)$

The Equation (18) shows the relationship between $V_{A\ P}, I_{A\ P}, \Delta I_A, Z_A$ and Z_B in determining fault location. The absence of line charging capacitance in the equation for fault location, introduces error in estimated fault location when applied for EHV transmission lines. Another limitation of this method is exclusion of the effect of multiple power corridors normally present in any power network. This drawback when coupled with high resistance fault and fault nearer the receiving end (measurements at the sending end) results in erroneous solution.

C. Fault Sequence Component of Current Method

To derive the Fault location algorithm, the fault loop composed according to the fault classified type is considered. This loop contains the faulted line segment (between points AA and F) and the fault path itself. A generalized model for the fault loop is stated as fallows

$$V_{A\ P} - dZ_{1L} * I_{A\ P} - I_F * R_F = 0 \quad (26)$$

Where

$$I_F = a_{F1} * I_{F1} + a_{F2} * I_{F2} + a_{F0} * I_{F0} \quad (27)$$

Fault loop voltages and current can be expressed interns of the local measurements and with using coefficients gathered in Table 1

$$V_{A\ P} = a_1 V_{A1} + a_2 V_{A2} + a_0 V_{A0} \quad (28)$$

$$I_{A\ P} = a_1 I_{A1} + a_2 I_{A2} + a_0 \frac{Z_{0L}}{Z_{1L}} I_{A0} \quad (29)$$

Table 1: Coefficients for determining signals defined in Equations (28) and (29)

Fault Type	a_1	a_2	a_0
AG	1	1	1
BG	a^2	a	1
CG	a	a^2	1
$AB, ABG, ABC, ABCG$	$1-a^2$	$1-a$	0
BC, BCG	a^2-a	$a-a^2$	0
CA, CAG	$a-1$	a^2-1	0
$a = exp(j2\pi/3)$			

Voltage drop across the fault path (as shown in the third term in Equation (26) is expressed using sequence components of total fault current (I_{F0}, I_{F1}, I_{F2}). Determining this voltage drop requires establishing the weighting coefficients. These coefficients can accordingly be determined by taking the boundary conditions for particular fault type. However, there is some freedom for that. Thus, it is proposed firstly to utilize this freedom for avoiding zero sequence quantities. This is well known that the zero sequence impedance of a line is considered as unreliable parameter. This is so due to dependence of this impedance upon the resistivity of a soil, which is changeable and influenced by weather conditions. Moreover, as a result of influence of overhead ground wires, the zero sequence impedance is not constant along the line length. Thus, it is highly desirable to avoid completely the usage of zero sequence quantities when determining the voltage drop across the fault path. This can be accomplished by setting $I_{F0} = 0$ as shown in Table 2, where the alternative sets of the weighting coefficients are gathered. Secondly, the freedom in establishing the weighting coefficients can be utilized for determining the preference for using particular quantities. The negative sequence (Table 2) or the positive sequence (Table 2) can be preferred

For example, considering AG fault one has:

$$\begin{vmatrix} I_{F0} \\ I_{F1} \\ I_{F2} \end{vmatrix} = \frac{1}{3} * \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix} * \begin{vmatrix} I_{FA} \\ 0 \\ 0 \end{vmatrix} \quad (30)$$

Thus, symmetrical components of a fault current are:

$$I_{F0} = I_{F1} = I_{F2} = \frac{1}{3} * I_{FA} = I_F \quad (31)$$

It follows from Equation (31) that the total faults current ($I_F = I_{Fa}$) can be expressed in the following alternative ways, depending on which symmetrical component is preferred:

$$I_F = 3 * I_{F1} \quad (32)$$

$$I_F = 3 * I_{F2} \quad (33)$$

$$I_F = 3 * I_{F0} \quad (34)$$

$$I_F = 1.5 * I_{F1} + 1.5 * I_{F2} \quad (35)$$

Table 2: Alternative sets of weighting coefficients

Fault type	Set I			Set II		
	a_{F1}	a_{F2}	a_{F0}	a_{F1}	a_{F2}	a_{F0}
AG	0	3	0	3	0	0
BG	0	$-1.5+j1.5\sqrt{3}$	0	$-1.5-j1.5\sqrt{3}$	0	0
CG	0	$-1.5-j1.5\sqrt{3}$	0	$-1.5+j1.5\sqrt{3}$	0	0
AB	0	$1.5-j0.5\sqrt{3}$	0	$1.5+j0.5\sqrt{3}$	0	0
BC	0	$j\sqrt{3}$	0	$-j\sqrt{3}$	0	0
CA	0	$-1.5-j0.5\sqrt{3}$	0	$-1.5+0.5\sqrt{3}$	0	0
ABG	$1.5+j0.5\sqrt{3}$	$1.5-j0.5\sqrt{3}$	0	$1.5+j0.5\sqrt{3}$	$1.5-j0.5\sqrt{3}$	0
BCG	$-j\sqrt{3}$	$j\sqrt{3}$	0	$-j\sqrt{3}$	$j\sqrt{3}$	0
CAG	$1.5-j0.5\sqrt{3}$	$1.5+j0.5\sqrt{3}$	0	$1.5-j0.5\sqrt{3}$	$1.5+j0.5\sqrt{3}$	0
$ABC, ABCG$	$1.5+j0.5\sqrt{3}$	$1.5-j0.5\sqrt{3}$	0	$1.5+j0.5\sqrt{3}$	$1.5-j0.5\sqrt{3}$	0

The total fault current (I_F) is expressed as weighted sum of it's the symmetrical components (I_{F1}, I_{F2}, I_{F0}) , which can be determined with use of fault current distribution factors:

$$I_{F1} = \frac{\Delta I_{A1}}{k_{F1}} \quad (36)$$

$$I_{F2} = \frac{I_{A2}}{k_{F2}} \quad (37)$$

$$I_{F0} = \frac{I_{A0}}{k_{F0}} \quad (38)$$

Taking into account a set of weighting coefficients that for zero sequence: $a_{F0} = 0$ and expressing the symmetrical components of total fault current with use of fault current distribution factors and one obtains:

$$I_F = a_{F1}\frac{\Delta I_{A1}}{k_{F1}} + a_{F2}\frac{I_{A2}}{k_{F2}} \quad (39)$$

Considering that for the fault current distribution factors for positive- and negative-sequence, with respect to their magnitude and angle, we have

$$k_{F1} = k_{F2} = |k_F|e^{j\gamma} \quad (40)$$

$$\gamma = angle(k_{F1}) = angle(k_{F2}) \quad (41)$$

The Equation (39) can be rewritten as

$$I_F = \frac{a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2}}{|k_F|e^{j\gamma}} \quad (42)$$

Substitute Equation (42) in the basic Equation (26)

$$V_{A\_P} - dZ_{1L} * I_{A\_P} - \frac{a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2}}{|k_F|e^{j\gamma}} * R_F = 0 \quad (43)$$

Multiplying the Equation (43) by the term$\left(e^{j\gamma}(a_{F1}\Delta I_{A1} + a_{F2}I_{A2})^*\right)$ yields

$$V_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma} - dZ_{1L} * I_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma} - \frac{R_F}{|k_F|} = 0 \quad (44)$$

Eliminating the term $\frac{R_F}{|k_F|}$ by taking imaginary parts of the Equation (18) and then rearranging, the resultant formula for the sought distance to fault (d (p.u.)) is obtained as follows:

$$d = \frac{Im\left(V_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma}\right)}{Im\left(Z_{1L} * I_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^* * e^{j\gamma}\right)} \quad (45)$$

$$d = \frac{Im\left(V_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^*\right)}{Im\left(Z_{1L} * I_{A\_P} * (a_{F1} * \Delta I_{A1} + a_{F2} * I_{A2})^*\right)} \quad (46)$$

In formula (45), the angle of the current distribution factor (for the positive or negative-sequence) is involved. It is proposed to assume that this angle equals zero ($\gamma = 0$), i.e., that the fault current distribution factor is a real number. In practice, this assumption is not completely fulfilled and thus there is a certain error due to this.

4. Power System Model

Table 3: Comparison of Impedance based algorithms for R_F=64 ohms and FIA=36^0 for 400KV Transmission line

Fault Type	Actual fault location	Takagi's Method		Ericsson's Method		Fault sequence Method	
		d_{esti}	Error%	d_{esti}	Error%	d_{esti}	Error%
AG	10	9.6817	0.3183%	9.6880	0.312%	9.7584	0.241%
BG	20	19.7033	0.2967%	19.7087	0.2913%	19.661	0.338%
CG	30	29.36	0.639%	29.363	0.636%	29.334	0.665%
AB	40	40.0723	0.0723%	40.0749	0.0749%	39.317	0.682%
BC	50	49.20	0.793%	49.207	0.793%	49.220	0.779%
CA	60	59.18	0.812%	59.185	0.814%	59.179	0.820%
ABG	70	69.23	0.766%	69.227	0.772%	69.224	0.775%
BCG	80	79.36	0.637%	79.351	0.648%	79.357	0.64%
CAG	85	84.364	0.636%	85.032	0.032%	84.678	0.322%
ABC,ABCG	90	89.96	0.039%	89.940	0.059%	89.988	0.012%

The SimPowerSystem which is an extension to the simulink of MATLAB software was used to simulate the double end fed power system. The 100 km, 400 kV transmission line was modeled using distributed parameter model as shown in Fig.5.

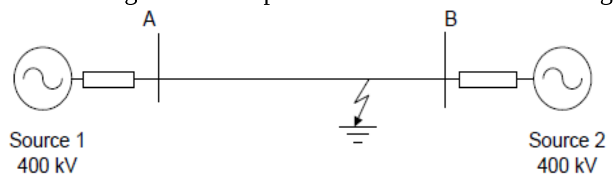

Figure 5: Power System model

The transmission line parameters are as follows:
Positive Sequence Resistance, R_1 : 0.0275 Ω / km
Zero Sequence Resistance, R_0 : 0. 275 Ω/km
Zero Sequence Mutual Resistance, R_{0m} : 0.21 Ω/km
Positive Sequence Inductance, L_1 : 0.00102 H/km
Zero Sequence Inductance, L_0 : 0.003268 H/km
Positive Sequence Capacitance,C_1 : 13 $e^{-0.009}$ F/km

5. Simulation Results

The simulation is carried out for these algorithms by varying various fault parameters like fault inception angle, fault resistance, fault type, fault location. The various measurements processed for various types of faults during implementation of algorithm are shown in table.4. The accuracy of fault location of these three algorithms are compared and shown in Table.3.

The fault location error is calculated as

$$Error(\%) = \frac{|Calculated\ Fault\ Location - Actual\ Fault\ Location|}{Total\ Line\ Length} * 100 \quad (47)$$

Table 4: Measurement processed for various types of faults for 400KV power transmission line for impedance based fault location algorithms

FAULT TYPE	V_{A_P}	I_{A_P}	ΔI_A
AG	V_A	$I_A + K_N I_N$	$\frac{3}{2}(\Delta I_A - I_{0A})$
BG	V_{BA}	$I_B + K_N I_N$	$\frac{3}{2}(\Delta I_B - I_{0A})$

CG	V_C	$I_C + K_N I_N$	$\frac{3}{2}(\Delta I_C - I_{0A})$
ABC AB ABG	$V_A - V_B$	$I_A - I_B$	$\Delta I_A - \Delta I_B$
BC BCG	$V_B - V_C$	$I_B - I_C$	$\Delta I_B - \Delta I_C$
CA CAG	$V_C - V_A$	$I_C - I_A$	$\Delta I_C - \Delta I_A$

Where

$$K_N = \frac{Z_{0L} - Z_{1L}}{3Z_{1L}} \qquad I_N = 3I_{0A} \tag{48}$$

6. Conclusion

In this paper, three impedance based fault location algorithms: Takgi's Method, Ericsson's Method, Fault sequence component of current Method was implemented using Matlab Simulink and programing.The accuracy of fault location of these three algorithms are compared by varying various fault parameters like fault inception angle, fault type, fault location, fault resistance. The simulation results show that all ten types of faults are correctly located with fault location error less than 1%.

References

[1] IEEE Tutorial Course, "Computer relaying," IEEE Pub. No. 79EHO148-7 PWR, 1979.
[2] M. Aucoin and B. D. Russell, "Detection of distribution high impedance faults using burst noise signals near 60 Hz," ***EEE** Trans.* ***Power Del.,*** vol. PWRD-2, no. 2, pp. 342-348, April 1987.
[3] B. D. Russell, K. Mehta, and R. P. Chinchali, "An Arcing Fault Detection Technique Using Low Frequency Current Components-Performance Evaluation Using Recorded Field Data," IEEEIPES.
[4] T. Tagaki, et al., "Development of new type fault locator using the oneterminal voltage and current data," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-101, no. 8, 1982, pp. 2892-2898.
[5] Ankamma Rao J, Bizuayehu Bogale . "Accurate Fault Location Technique on Power Transmission Lines with use of Phasor Measurements ", Vol. 4 - Issue 02 (February - 2015), International Journal of Engineering Research & Technology (IJERT) , ISSN: 2278-0181 , www.ijert.org.
[6] K. Srinvsansan, A. St. Jacques, "A new fault location algorithm for radial transmission lines with loads," *IEEE Transactions on Power Apparatus and Systems*, vol. 4, No. 3, July 1989, pp. 1676-1682.
[7] Anamika Jain, Kale VS, Thoke AS. Application of artificial neural networks to transmission line faulty phase selection and fault distance location. In: IASTED, Chiang Mai, Thailand; 29–31 March 2006. p. 262–7.
[8] M. S. Sachdev and R. Agarwal, "A technique for estimating transmission line fault locations from digital impedance relay measurements," *IEEE Trans. Power Del.*, vol. 3, no. 1, pp. 121–129, Jan. 1988.
[9] L. Eriksson, M. M. Saha, and G. D. Rockefeller, ``An accurate fault locator with compensation for apparent reactance in the fault resistance resulting from remote-end infeed," *IEEE Trans. Power App. Syst.*, vol. PAS-104,no. 2, pp. 423_436, Feb. 1985.
[10] Izykowski J, Rosolowski E, Saha MM (2004) "Locating faults in parallel transmission lines under availability of complete measurements at one end". IEE Proc – Gener Transm Distrib 151(2):268–273.
[11] IEEE Tutorial Course, "Microprocessor relays and protection systems," ZEEE Pub. No. 88EH0269-PWR, Jan. 1988.
[12] E. O. Schweitzer, III, ``Evaluation and development of transmission line fault-locating techniques which use sinusoidal steady-state nformation," *Comput. Elect. Eng.*, vol. 10, no. 4, pp. 269_278, 1983.
[13] *Distribution Fault Location: Field Data and Analysis*, EPRI, Palo Alto,CA, USA, Tech. Rep. 1012438, 2006.
[14] T. Takagi, Y. Yamakoshi, J. Baba, K. Uemura, and T. Sakaguchi, "A new algorithm of an accurate fault location for EHV/UHV transmission lines: Part I—Fourier transform method," *IEEE Trans. Power App.Syst.*, vol. PAS-100, no. 3, pp. 1316–1323, Mar. 1981.
[15] Transmission Line Protection Support Tools: Fault Location Algorithms and the Potential of Using Intelligent Electronic Device Data for Protection Applications, EPRI, Palo Alto, CA, USA, Tech. Rep. 3002002381, 2013.
[16] MATLAB user's guide, The Math Works Inc., Natick, MA.