The Caspian Sea Journal
ISSN: 1578-7899

Volume 10, Issue 1, Supplement 4 (2016) 568-575

Determination Phase-Ground Fault by Distance Relay in Short Transmission Line Using Linear Differential Equation

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ABSTRACT– Distance relay is the best relay to protect energy transfer networks because only enjoying such machine disconnects any connection in any place of the network in the shortest time about 0.1 second; therefore distance relay is used to protect high tension and medium pressure networks. Common distance relay in phase to ground fault does wrongly by apparent impedance measurement. Wrong function of them leads to wide shortcomings. Distance relay function against phase to ground faults should be improved. Supposing total resistance after error point is zero, algorithm to determine phase to ground fault was suggested by distance relay in short line model in the present research that the error distance from measurement point to error occurrence point was calculated by linear differential equation. The proposed method will be compared with another method and its results will be presented.

Keywords: error distance calculating, linear differential equation, short transfer line model, distance protection, phase to ground fault

Introduction

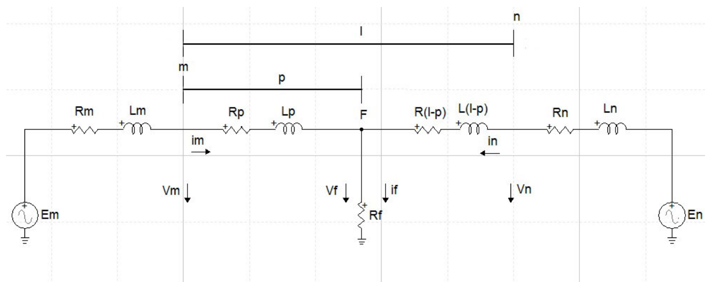
To have error in transfer line causes to disturb the function of the network; therefore it is necessary to identify the place of error and should be removed as soon as possible. Microprocessor distance relay is enjoyed vastly to protect the main high voltage transfer lines and high voltage. Distance relay are designed to disconnect the error between measurement point and selected point. The distance relay protecting the lines is overcurrent relay. It is happened because the time of distance relay function on the line is very short and the time of overcurrent relay function is rather long. Mentioned relay has internal impedance calling set impedance relay. The impedance (Z_0) is a part of the line that relay should protect the part. An Proportional current with short transfer current is passed through Winding acting and when error current gets to threshold the winding will be induced and connect related contacts; therefore relay is happened and the circuit will be disconnected. According to impedance adjustment, the distance relays are worked. The impedance is mixed; therefore it has domain and phase. A distance relay with any type of curve has three protection areas. The impedance equals 80% first line Impedance is set in the first area and its function time is about 0.1 second and it is enjoyed as main line protection. The second area of setting impedance of relay is main line of total impedance plus fifty percent of impedance of next line and its function time is about 0.4 second. The third area of distance relay have adjustment impedance equals all the lines plus all the second line plus twenty – five percent of the third line. It is clear that the time function of the area is about 0.8 seconds. A linear equation was proposed to determine the phase to ground fault through distance relay from the measurement point to error point in the reference (Suonam, Wang and Meng, 2011) and (Xu, Jiang and Yang, 2010) and both methods boost the carrying capacity of distance relay. When the error is happened in the terminal, it calculates the error more than its normality. Non - linear equation was transferred to linear equation and distance error was estimated by a terminal in the reference (Xu, Li, Yu and Yang, 2010). Transfer system of the three phase was considered in the condition of phase to ground fault to the shape of a single transmission line system (the phase that the error happened in it). We will have a differential equation through transfer line relations finally that phase to ground fault is calculated by deriving the linear equation through distance relay in the proposed algorithm.

Studying the proposed method

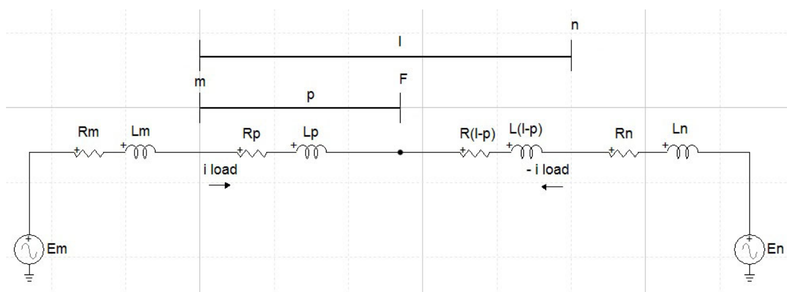
Protecting the equipment and power system machines against faults and connections are done by power outlets, windings should be fed before opening power outlet. The feeding is done by protective relays. relay is a machine induced by changing in electrical quantity such as voltage and current or physical quantity such as degree and oil (Buchholz relay) and causes to handle other machines and finally cutting the circulation is done by power outlet (in production and transfer and distribution system; therefore the location of fault is separated from the network by relay and causes healthy parts of the network continue their activity and keep the stability and network stability as the same state. We study the distance protection in the proposed frame and analyzing the error theoretically in this part according to single line system. Consider the explanations and the relations under figure (1) to understand better. Figure (1) is a circuit as single line and fluent model of part of short transfer system that is a transfer line between bus m and n. In figure (1-a) phase to ground fault that the amount of error resistance is R_f, in point F by distance P is happened from bus m and the real distance p is defined. Suppose that the current flow from terminal m to terminal n

and circuit is located in terminal m.V_m is phasor voltage in terminal m, V_n is phasor voltage in terminal n and V_f is phasor voltage of point F.I_m ، I_n و I_{load} represents Phasor current in terminal m and phasor current in terminal n (in error condition) and load current respectively. I_f ، ΔI_m و ΔI_n show error phasor current, phasor current changes of terminal m and phasor current changes of terminal n respectively. R_m ، L_m و Z_m are resistance, inductance and impedance in terminal n respectively. R, L and Z are resistance, inductance and impedance pryunyt of transfer line respectively. L was defined as transfer line (the distance between terminal m and n) and p was defined as real distance of error.
For common relay distance the ratio of voltage to current is defined as follow:

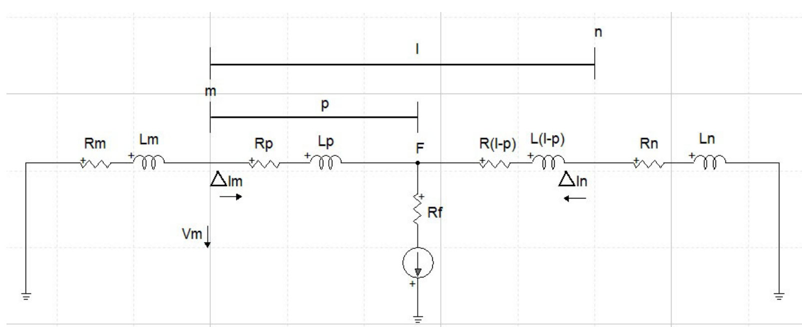
$$Z_{ap} = \frac{V_m}{I_m} \tag{1}$$



(1-a)



(1-b)



(1-a)

Figure 1: Linear circuit of transfer system transient model. (1-a): the circuit in error condition. (1-b): the circuit in loading condition. (1-c): the circuit of network error component

Figure (1) shows that linear circuit and transient model of a system are short transfer. figure (1-a) shows equivalency circuit in error condition and figure (1-b) shows equivalency circuit in loading condition and also figure (1-c) shows linear circuit and transient model. of short transfer system. figure (1- a) shows in error condition and figure (1- b) shows equivalency circuit in loading condition and figure (1-c) also shows equivalency circuit of network error. Consider figure (1-a) to achieve the apparent impedance (Z_{ap}). According to figure (1-a):

$$V_m = I_m Zp + I_f R_f \quad (2)$$
$$I_f = I_m + I_n = \Delta I_m + \Delta I_n \quad (3)$$

By putting equation (2) instead of V_m in equation (1), it will be:

$$Z_{ap} = Zp + \frac{I_f}{I_m} R_f \quad (4)$$

Therefore; the apparent impedance can be calculated by equation (4) that Z is line impedance, I_m is phasor current in terminal m, I_n is phasor current in terminal n, R_f is error resistance and I_f is error current (fault current). Consider figure (1 – b) to achieve the error current.

$$\Delta I_m (Z_m + Zp) = V_f \quad (5)$$
$$\Delta I_n [Z_n + Z(l - p)] = V_f \quad (6)$$

And by putting the equations (5) and (6) to each other and replacing (3) instead of ΔI_n in (6), it will be:

$$\Delta I_m [Z_m + Zp + Z_n + Z(l - p)] = I_f [Z_n + Z(l - p)] \quad (7)$$

And according to $Zl = Zp + Z(l - p)$ and replacing it in equation (7), it will be:

$$I_f = \Delta I_m \frac{Z_m + Zl + Z_n}{Z_n + Z(l-p)} \quad (8)$$

Thus; error current (I_f) can be calculated by equation (8) that Z_m is impedance in terminal m, Z_n is impedance in terminal n, l is transfer line length, p is error distance and ΔI_m is phasor current changes of terminal m. current distribution factor is ΔI_m to I_f $\left(\frac{\Delta I_m}{I_f}\right)$ and is defined (Zhang and Kang, 2013) as follows:

$$C = \frac{Z_n + Z(l-p)}{Z_m + Zl + Z_n} = |C| < \theta \quad (9)$$

$|C|$ و θ are the size and current distribution factor phase respectively. According to it, equation (8) can be rewritten as fallow:

$$I_f = \frac{\Delta I_m}{C} \quad (10)$$

Error current as an unknown phenomenon has incompatible effect on the function of distance relay; but it is, generally, one of the most important uncertainties. If the error current be zero, the measured impedance at the relay point is only dependent on the some part of line length existing between relay and error place; but if the error current not be zero ($R_f \neq 0$), measured impedance existing with some part of line between relay and error point is not equal; therefore uncertainty error current is concluded in distance relay (Horowitz and Phadkeh, 2008). Transformer in posts are connected to the field directly in high voltage transfer systems most of the time. It causes that system is considered as reactance. In another hand, transfer line current than transfer line reactance is smaller (Zhang and Kang, 2013); therefore passing up current after error point($R_f \neq 0$), a method will be to calculate the distance error according to equation (9):

$$C" = \frac{j\omega \sum L_n}{\sum Z_m + j\omega \sum L_n} = |C"| < \theta \quad (11)$$

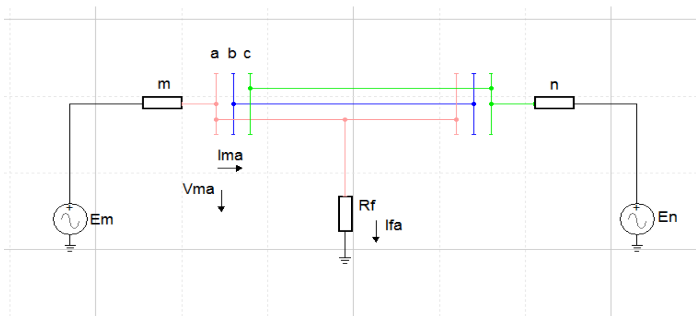
Achieved current from transient resistance is defined by putting $\frac{1}{C"} = \frac{\sum Z_m + j\omega \sum L_n}{j\omega \sum L_n}$ in $I_f = \frac{\Delta I_m}{C"}$ as follow:

$$I_f = \Delta I_m \frac{\sum R_m + j\omega \sum L}{j\omega \sum L_n} \tag{12}$$

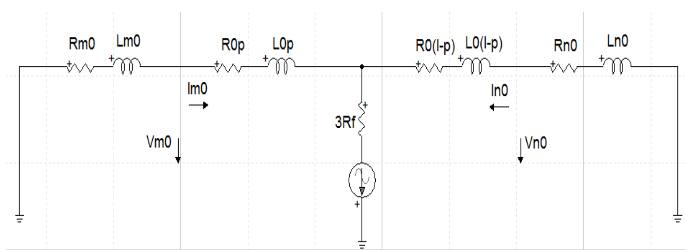
Symmetrical components analytical method is a strong tool to analyze unbalanced systems. A unbalanced system n phases can be changed to n balanced systems; therefore any unbalanced three phase system can be analyzed to three systems with the positive sequence component, negative sequence and zero sequence; therefore consider figure (2). figure (2) shows phase to ground fault in a three phase. Phase a is considered for phase to ground fault. Following equations are done at the time of phase to ground fault:

$$Z_+ = Z_- \ , \quad Z_0 \neq Z_+$$
$$V = I_+Z_+ + I_-Z_- + I_0Z_0 = (I_+ + I_- + I_0)Z_+ + I_0(Z_0 - Z_+)$$
$$\Rightarrow V = I + I_0 Z_+ \frac{(Z_0 - Z_+)}{Z_+} \tag{13}$$

Z_- ، Z_+ و Z_0 are negative, positive impedance and zero respectively. I_- ، I_+ and I_0 are positive current, negative sequence ،and zero respectively. V is voltage and I is phase flow



(2-a)



(2-b)

Figure 2: The circuit of three phase transfer system in the condition of phase to ground fault (2 – a): the circuit in error condition. (2 – b): linear circuit in zero sequence

Differential linear differential equation will be achieved through transfer line equation that phase to ground fault is calculated by derivation of the linear circuit in the proposed algorithm. Consider table (2) to have above – mentioned inear differential equation According to table (2) the exact error detection formula based on the reference (Suonam and Qi, 2005) is as follow:

$$V_{m_a} = \left(I_{m_a} + K_z I_{m_0}\right) Z_1 p + 3R_f I_{f_0} \ , \quad I_{f_0} = I_{m_0} k_0 \tag{14}$$

And equation (14) is rewritten based on the proposed method as follow:

$$V_{m_a} = \left(I_{m_a} + K_z I_{m_0}\right) Z_1 p_c + 3R_f I_{f_0} \ , \quad I_{f_0} = I_{m_0} k''_0 \tag{15}$$

That is defined as $K_z = \frac{Z_0 - Z_1}{Z_1}$, $\sum Z_{n_0} = Z_0(l-p) + Z_{n_0}$, $K"_0 = \frac{1}{C"} = \frac{\sum Z_{m_0} + j\omega \sum L_{n_0}}{j\omega \sum L_{n_0}}$ and $K_0 = \frac{1}{C} = \frac{\sum Z_{m_0} + \sum Z_{n_0}}{\sum Z_{n_0}}$. $K"_0$ and K_0 is reverse flow distribution coefficient, K_z is flow coefficient of zero sequence, $\sum Z_{n_0}$ is total impedance after error point in zero sequence, Z_1 is line impedance transfer the positive sequence, p is error real distance and p_c is the calculated distance by relay. Equation (14) will be defined as continued $F(p, \sum R_{n_0})$ and will have:

$$F(p, \sum R_{n_0}) = V_{m_a} - (I_{m_a} + K_z I_{m_0}) Z_1 p - 3R_f I_{m_0} k_0 = 0 \tag{16}$$

and also will have for (15):

$$F(p_c, 0) = V_{m_a} - (I_{m_a} + K_z I_{m_0}) Z_1 p_c - 3R_f I_{m_0} k"_0 = 0 \tag{17}$$

Equation (16) and (17) are linear functions as it is seen. We know that linear functions are always differentiable. According to the premise, we have $\sum R_{n_0} = 0$ and $p = p_c$; therefore Tylor case can be followed; therefore we will have:

$$p_c = p + \frac{F\prime(0)}{F\prime(p_c)} \sum R_{n_0} \tag{18}$$

By putting in the following equations:

$$\begin{cases} \sum Z_{m_0} = Z_0 p + Z_{m_0} \\ \sum Z_{n_0} = Z_0(l-p) + Z_{n_0} \\ Z_0(l-p) = R_0(l-p) + j\omega L_{n_0}(l-p) \end{cases}$$

$$\begin{cases} Z_{n_0} = R_{n_0} + j\omega L_{n_0} \\ \sum R_{n_0} = R_0(l-p) + R_{n_0} \\ j\omega \sum L_{n_0} = j\omega L_{n_0} + j\omega L_0(l-p) \end{cases}$$

and $K_0 = \frac{\sum Z_{m_0} + \sum Z_{n_0}}{\sum Z_{n_0}}$ in equation (33-3), we will have:

$$F(p, \sum R_{n_0}) = V_{m_a} - (I_{m_a} + K_z I_{m_0}) Z_1 p - 3R_f I_{m_0} \left[\frac{Z_0 p + Z_{m_0} + R_{n_{0\sum}} + j\omega \sum L_{n_0}}{\sum R_{n_0} + j\omega \sum L_{n_0}} \right] \tag{19}$$

Now, we solve equation (18). It should be differentiated According to p_c once and another time it should be differentiated according to $\sum R_{n_0}$ from equation (19) and then data values $\sum R_{n_0} = 0$ and $p = p_c$ should be replaced; therefore we will calculate $\frac{\partial F}{\partial \sum R_{n_0}}$:

$$F'(0) = 3R_f I_{m_0} \left[\frac{\sum Z_{m_0}}{(j\omega \sum L_{n_0})^2} \right] \tag{20}$$

It is necessary to mention that first $\sum R_{n_0} = R_0(l-p) + R_{n_0}$ and $j\omega \sum L_{n_0} = j\omega L_{n_0} + j\omega L_0(l-p)$ should be replaced in equation (37-3) before differentiated to calculate $\frac{\partial F}{\partial p}$ and then differentiate. Now we calculate $\frac{\partial F}{\partial p}$:

$$\frac{\partial F}{\partial p} = -(I_{m_a} + K_z I_{m_0}) Z_1 - 3R_f I_{m_0} \frac{Z_0(\sum Z_{m_0}) + Z_0(\sum Z_{n_0})}{(\sum Z_{n_0})^2} \tag{21}$$

Finally, proposed algorithm will be achieved as follow:

$$p_c = p - \frac{3R_f I_{m_0} (\sum Z_{m_0}) (\sum Z_{n_0})^2 (\sum R_{n_0})}{(\sum X_{n_0})^2 \left[(I_{m_a} + K_z I_{m_0}) Z_1 (\sum Z_{n_0})^2 + 3R_f I_{m_0} \left(Z_0 (\sum Z_{m_0} + \sum Z_{n_0}) \right) \right]} \tag{22}$$

That p_c is calculated error distance by proposed algorithm, p is error real distance, I_{m_0} is the current toward terminal m in zero sequence, I_{m_a} is phase current a toward terminal m and $Z_0$is transfer line impedance the zero-sequence. Protection criteria (measure of protection) is defined as $p< p_{set}$. p_{set} is a distance defining as the scope of protection for distance relay and include 90 percent of transfer line and includes ninety percent of transfer line. A flowchart was presented to perform the distance relay in figure (3). The flowchart has three sections:

1. It is examined in the first part whether phase to ground fault was happened or not. This is done by phase error selector in distance relay.
2. As phase to ground fault was identified in the second section, error distance is calculated according to (22).
3. Relay is separated the section from the network after analyzing the error distance in the third part.

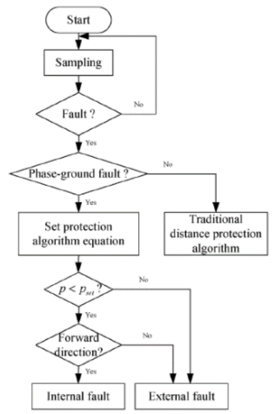


Figure 3: Flowchart

Proposed algorithm results

figure (4) is a RL three phase line that phase to ground fault was happened in phase a and was simulated in simulink through MATLAB software. 110 KV system with 50 Hz frequency and 50 kilometers length was considered to analyze and study the proposed method.

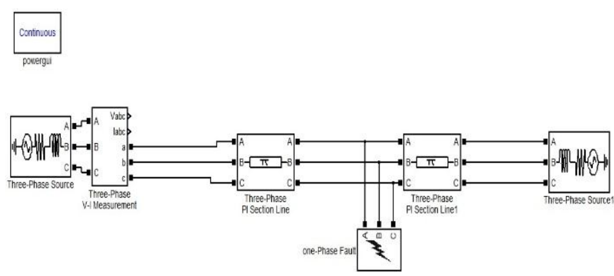


Figure 4: Simulated RL three phase transfer line by MATLAB in error condition

Table 1: The parameters of 110 KV system

Quantity	Amount	Quantity	Amount
$R_0(\Omega/km)$	0/315	$Z_0(\Omega/km)$	3/787
$X_0(\Omega/km)$	3/774	$Z_1(\Omega/km)$	1/262
$R_1(\Omega/km)$	0/105	$Z(\Omega/km)$	6/311
$X_1(\Omega/km)$	1/257	$Z_{n_0}(\Omega)$	7/257
$R_{n_0}(\Omega)$	0/173	$Z_{m_0}(\Omega)$	3/644
$X_{n_0}(\Omega)$	7/254	$V_{m_a}(KV)$	73/33
$R_{m_0}(\Omega)$	0/471	$I_{m_a}(KA)$	0/051
$X_{m_0}(\Omega)$	3/61	K_z	2

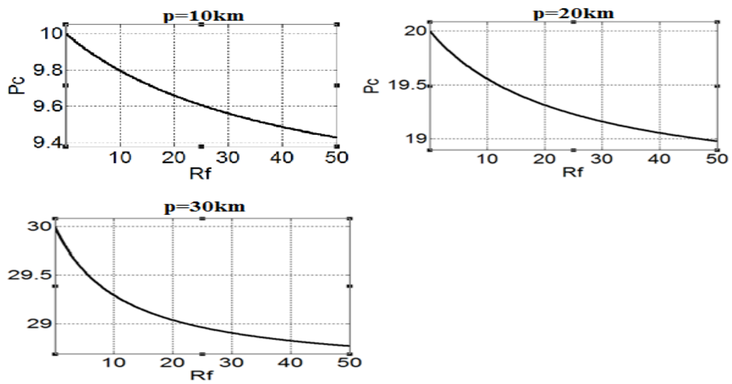


Figure 5: Calculated error by proposed algorithm

Table 2: The results of error estimation of the impedance method and proposed method

Real distance (km)	Error resistance (Ω)	Calculated error distance 1 (km)	Calculated error distance 2 (km)
10	10	9/798	10/10
	20	9/659	10/19
	50	9/425	10/39
20	10	19/56	19/93
	20	19/31	19/86
	50	19/01	19/73
30	10	29/3	29/48
	20	29/07	29/07
	50	28/77	28/23
40	10	39/24	38/06
	20	39/12	36/64
	50	39/04	33/97

The amount done according to calculations in the first method were gathered in the above table. When the error distance is 30 and 40 kilometers as it is seen in table (2), the presented errors is closer to real distance than the metdod of error estimate impedance (Xu, Jiang and Yang, 2010); therefore the error of proposed method will be less than the error of error estimate impedance method. For example; when error resistance is 50 Ohm about 30 km, the error distance was calculated 28/77 kilometers by presented method, but the error distance was 28/33 kilometers in error estimate impedance method and error percentage is 3/54 percent in this method. When an error happens about 40 km transfer line, error distance was 39/04 kilometers for a fault resistance of 50 ohms by proposed method and the error percentage of presented method is 1/92 percent while the error distance was 33/97 in errorestimate impedance method and the rate of error percentage is 12/06 percent for this method; therefore the error of proposed method is less than the error of estimate impedance method; thus the proposed method can calculate the distance more accurate than estimate impedance method in more distances. When the error distance is 10 kilometers, the calculated distance in estimate impedance method per different mount of resistance are 10/10, 10/19 and 10/39 respectively meaning that distance error is getting more than 10 kilometers in error estimate impedance method while the error is 9/798, 9/659 and 9/425 in the proposed method respectively. It can be concluded that presented algorithm can prevent calculating the distance more than real amount.

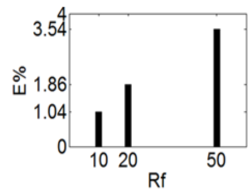


Figure 6: Bar graph of error percentage of estimate impedance metod in p = 30 km

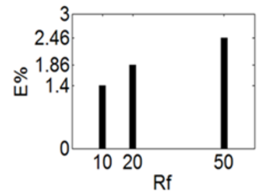


Figure 7: Bar graph of error percentage of proposed method in p = 30 km

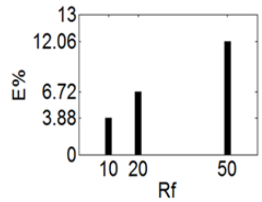


Figure 8: Bar graph of error percentage of estimate impedance method in p = 40 km

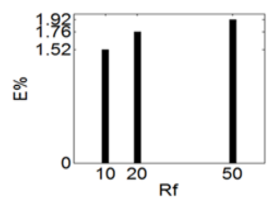


Figure 9: Bar graph of error percentage of proposed method in p = 40 km

Conclusion

Achived results from the comparison between presented method and error estimate impedance method were peresented in three different states for different values.The difference between calculated distances with real distance was alittle more by increasing the resistance error and/or incresing the error distance in both methods. The effect of resistance error on the function of distance relay was less in the proposed method. The proposed algorithm could prevent calculating more than distance measure than real measurement of error distance when phase to ground fault. happens by the opposite terminal or across it as it was expected and calculate the error distance comparing to error estimation of the impedance method with less differerence in more distances. In other words the error of the presented method was less in the above distances. Further work such as minimizing the error percentage and keeping distance desirable relay function are propsed against the effects of error arc resistance and power swing in this study.

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