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Evaluation of earth fault location algorithm in medium voltage distribution network with correction technique

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ABSTRACT

This paper focused on studying an algorithm of earth fault location in the medium voltage distribution network. In power system network, most of the earth fault occurs is a single line to ground fault. A medium voltage distribution network with resistance earthing at the main substation and an earth fault attached along the distribution network is modeled in ATP Draw. The generated earth fault is simulated, and the voltage and current signal produced is recorded. The earth fault location algorithm is simulated and tested in MATLAB. The accuracy of the earth fault location algorithm is tested at several locations and fault resistances. A possible correction technique is explained to minimize the error. The results show an improvement fault location distance estimation with minimum error.

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1. INTRODUCTION

The medium voltage distribution network is the most sensitive part of the distribution network. It is because most of the blackout experienced by customers is caused by disturbances in the medium voltage network. Mostly, weather changes cases are the main reason for the electrical power supply disturbance, especially for the overhead lines that located in the forests. Thus a reliable network is required due to the increased use of electricity [1].

The fault may happen at any point in a power system. The fault that occurs on power system was classified as a symmetrical fault and unsymmetrical faults. The symmetrical fault is where all three phases of the transmission line are shorted together. While unsymmetrical faults can be divided into three categories; single line-to-ground, line-to-line and double line-to-ground fault. Earth fault accounts for about 80% of the distribution network faults, which makes the detecting and locating of single-phase earth fault important [2].

Based on [3], the researcher studied the instantaneous single-phase-to-earth fault that occurs, and the fault arc that disappears automatically because of the rapid compensation of arc suppression coil current. To solve that problem, they used TSC (Thyristor Switched Capacitors) automatic tuning arc suppression coil with a parallel resistor. While in [4] studies explained about the unreliability of the localization criterions in Polish medium voltage power distribution networks. A new adaptive algorithm based on the wavelet analysis enabling detection of specific dynamics of the measuring signal during intermittent earth faults is produced. In [5] studies about an earth fault distance estimation by using transient signal but more focused on isolated and compensated neutral in medium voltage network. Work in [6] proposed a scheme to locate an earth fault in unearthed or a compensated neutral medium voltage (MV) network using transient signal recorded from MV/LV substations. The algorithm applies continuous wavelet Transform (CWT) to locate the dominant charge transient frequency and then fast Fourier transform (FFT) to extract coefficients to be used in the fault location scheme.

Another researcher [7], studies about high-impedance faults (HIFs) which produce a small fault current, thus not detectable by some overcurrent protection devices. To solve that problem, the researcher analyzed the data by converting the harmonic analysis of current waveforms in the MATLAB by using Fourier transform. Also, researcher in [8] studies about detection and identification of high impedance faults in power networks, but the researcher used the wavelet output to construct a detection criterion and used an algorithm to determine the faulted phase and feeder.

According to [7], fault location techniques for distribution networks have been classified into three different groups: fundamental frequency measurements, high-frequency measurements and the use of artificial intelligence (AI). Referring to [9], the short-circuit fault, reliable earth fault indicators are lacking, and the fault distance computation is still an open issue for utilities. Based on researcher work in [9] the researcher uses voltage and a current signal; prefault, fault, and post-fault to find the fault location. Figure 1 shows the network model used for fault distance calculation.

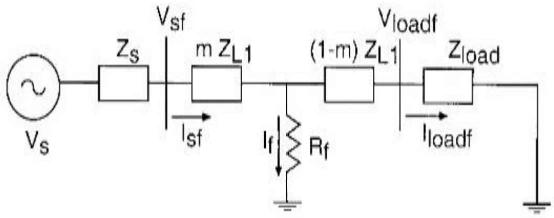

Figure 1. Simple schema of the network model used for fault distance calculation [10]

Based on [11] studies, the researcher modeled the network in PSDAC/EMTDC which has studied on the simulation, varying ground resistivity, fault resistance, fault type and the location of the fault. The researcher uses prefault and fault signal to find the location of the fault. Figure 2 shows the simulated voltage and currents signal in prefault and fault conditions during a single line-to-ground fault with a fault resistance of 5Ω.

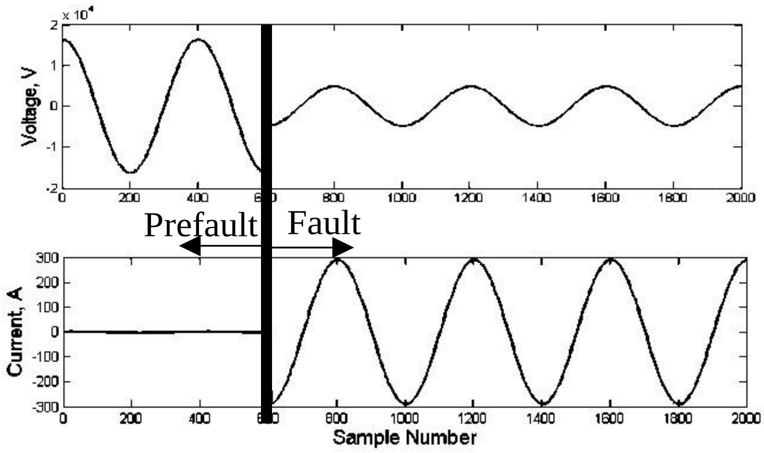

Figure 2. Simulated voltage and current signal during single line to ground fault

2. RESEARCH METHOD

Figure 3 shows the schematic diagram of modelled simple power network modeled in ATP draw. It consists of three phase source alternating current (AC), step down transformer, three-phase distribution line, and load.

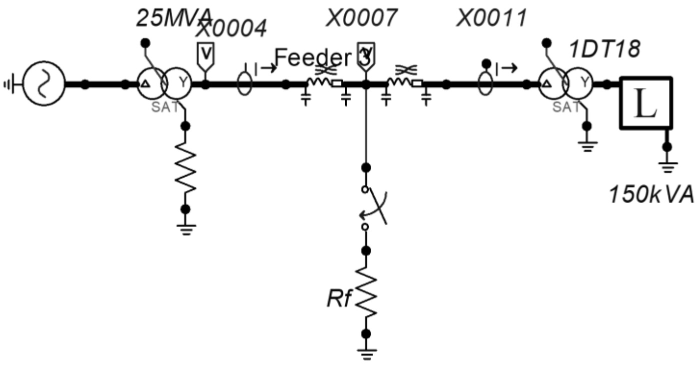

Figure 3. Schematic diagram of simple power network modeled in ATPDraw

2.1. Fault location algorithm

According to [12], based on the equivalent circuit shown in Figure 4, fault location estimation (1) is developed.

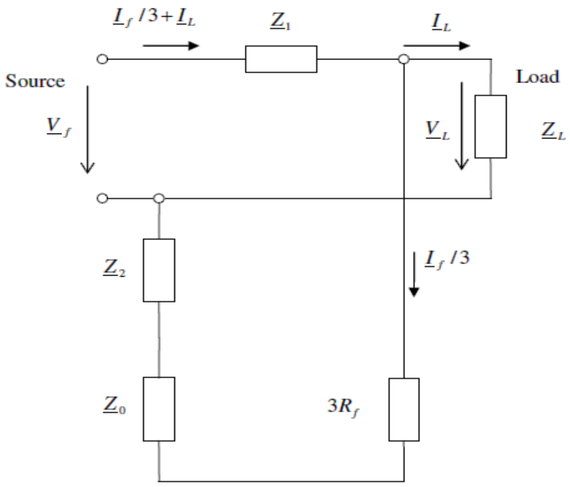

Figure 4. The symmetrical component model of a radially operated network for the conventional fault location method

$$Fault\_Location = \frac{\frac{V_f}{I_f} - R_f}{\frac{1}{3}\left(Z_0 + Z_1 + Z_2\right) + \frac{I_L}{I_f} Z_1} \quad (1)$$

V_f is the fault phase voltage, I_f is the fault current, I_L is the load current, Z_0, Z_1, and Z_2 are the zero-, positive- and negative- sequence impedances of the line per km, and R_f is the fault resistance. In [13], a fault resistance value can be determined by using (2). R_f is the fault resistance, V_s is the fault phase voltage and I_s is the fault current.

$$R_f = \frac{V_s}{I_s} \quad (2)$$

2.2. Correction factor

To minimize the error of fault location and fault resistance, a linear and parabolic regression is used to generate equations. From curve fitting application tool in MATLAB, under 'APPS' section, a statistical solution can be developed. By using method of least squares, the coefficients *m* (slope) and *b* (y-intercept) of the straight line equation can be formed.

$$y = mx + b \tag{3}$$

Figure 5 shows the line fit plot based on Table 1 data. The straight line is plot by using the actual value versus the calculated value. The straight line equation formed is used as correction factor in this work. It is used to minimize the earth fault location error. Table 1 shows an example data used to develop equation to minimize the fault resistance error. While Table 2 shows the summary of the fitted line plot in Figure 5.

Table 1. Sample Data of Fault Resistance

Actual Value (Ω)	Calculated Value (Ω)
20	22.552
40	44.399
60	63.082
80	83.049

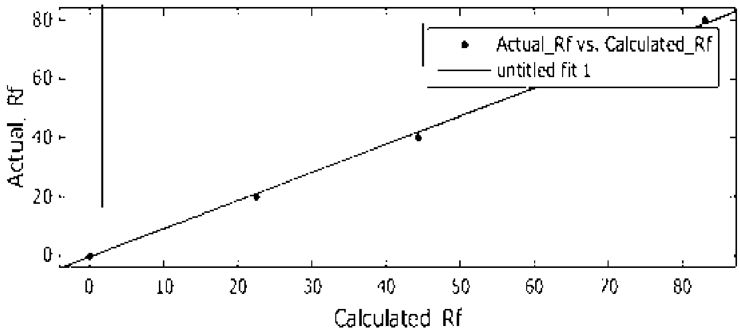

Figure 5. Line fit plot

Table 2. Summary for the Plotted Line Fit

Linear model Poly1:	= p1*x + p2
p1	= 0.9542 (0.9237, 0.9846)
p2	= -0.4144 (-1.658, 0.8292)
Goodness of fit:	
SSE	=7.13
R-square	=0.999
Adjusted R-square	=0.9988
RMSE	=1.09

By referring to Table 2, from [14] error sum of squares (SSE) can be calculated by performing (4). Where *SST* is the total sum of squares, *SSTR* is the treatments sum of squares, while *SSBL* is the block sum of the squares.

$$SSE = SST - SSTR - SSBL \tag{4}$$

R-squared is a statistical measure of how close the data are to the fitted regression line. The definition of *R-squared* is fairly straight-forward; it is the percentage of the response variable variation that is explained by a linear model. Or [15]:

$$R\text{-}squared = SSTR / SST \tag{5}$$

R-squared is always between 0 and 100%. 0% indicates that the model explains none of the variability of the response data around its mean. While 100% indicates that the model explains all the variability of the response data around its mean.

As the number of regressors increases, the R^2 value also increases, so R^2 cannot be a useful measure for the goodness of model fit. Therefore, R^2 is adjusted for the number of explanatory variables in the model. The adjusted R^2 is defined as in equation [16]:

$$R^2{}_{adj} = 1 - \left(1 - R^2\right)\frac{n-1}{n-p-1} = \frac{(n-1)R^2 - p}{n-p+1} \tag{6}$$

The RMSE a way of estimating the difference between the values predicted by a statistical model and the measured values from the actual system [14].

$$RMSE = \frac{SSE}{(k-1)(n-1)} \tag{7}$$

The statistical solution for fault resistance less than 100Ω is given as:

$$New\_R_f = (R_f * 0.9542) - 0.4144 \tag{8}$$

2.3. Accurate region

A cycle of a faulted *Vs*, *Is* and *IL* signal consists of 400 samples is used in (1) and the result of fault location estimation is presented in a signal form as shown in Figure 6. Figure 6 shows the estimated fault location at 2km from the substation. Fault location is determined by observing the accurate region.

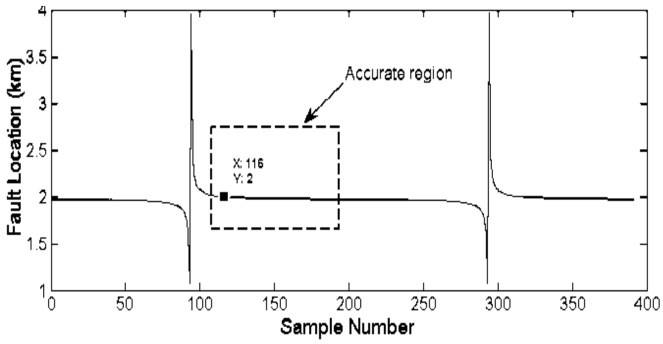

Figure 6. Fault distance estimation for fault at 2km from the measuring point

3. RESULTS AND ANALYSIS

Several tests have been conducted to test the accuracy and suitability of the algorithm to the circuit.

3.1. Sampling frequency

This test was done to find the most suitable method and sampling frequency to locate the fault location. The algorithm has been tested with a sampling frequency of 10kHz up to 50kHz with 5kHz increment. For example, based on accurate region as shown in Figure 6 the median, mean and fix fault distance of that region is 1.982km, 1.984km and 2.000km respectively. For fix fault distance, the position for data collected is different depends on the number of the samples for tested sampling frequencies, then after a sampling frequency was chosen, the fixed sample number is used for every test. For example, based on Figure 6, 116 is the used sample number. The sampling frequency were tested on four different distances (2km, 4km, 6km, and 8km). The fault resistance used in this simulation is 1Ω, and load of 83kVA. Table 3 shows the result of the simulation and Figure 7 shows the difference in percentage between actual distance and estimated distance with three different methods.

Table 3. Results of Fault location Estimation tested with Different Sampling Frequencies and Distances

Fault location / Sampling freq	2km			4km			6km			8km		
	Mean	Median	Fix	Mean	Median	Fix	Mean	Median	Fix	Mean	Median	Fix
10k	1.975	1.974	1.999	3.959	3.957	3.999	5.942	5.940	5.999	7.925	7.921	7.999
15k	1.999	1.982	2.000	3.998	3.971	4.001	5.997	5.959	6.002	7.996	7.946	8.003
20k	1.984	1.982	2.000	3.974	3.970	4.001	5.964	5.957	6.002	7.953	7.944	8.003
25k	1.989	1.985	2.000	3.982	3.976	4.002	5.975	5.966	6.003	7.968	7.956	8.004
30k	1.988	1.986	2.000	3.981	3.977	4.001	5.974	5.968	6.001	7.966	7.958	8.002
40k	1.993	1.990	2.000	3.988	3.984	4.002	5.984	5.978	6.003	7.979	7.971	8.004
50k	1.993	1.991	2.000	3.989	3.985	4.001	5.985	5.980	6.002	7.980	7.974	8.003

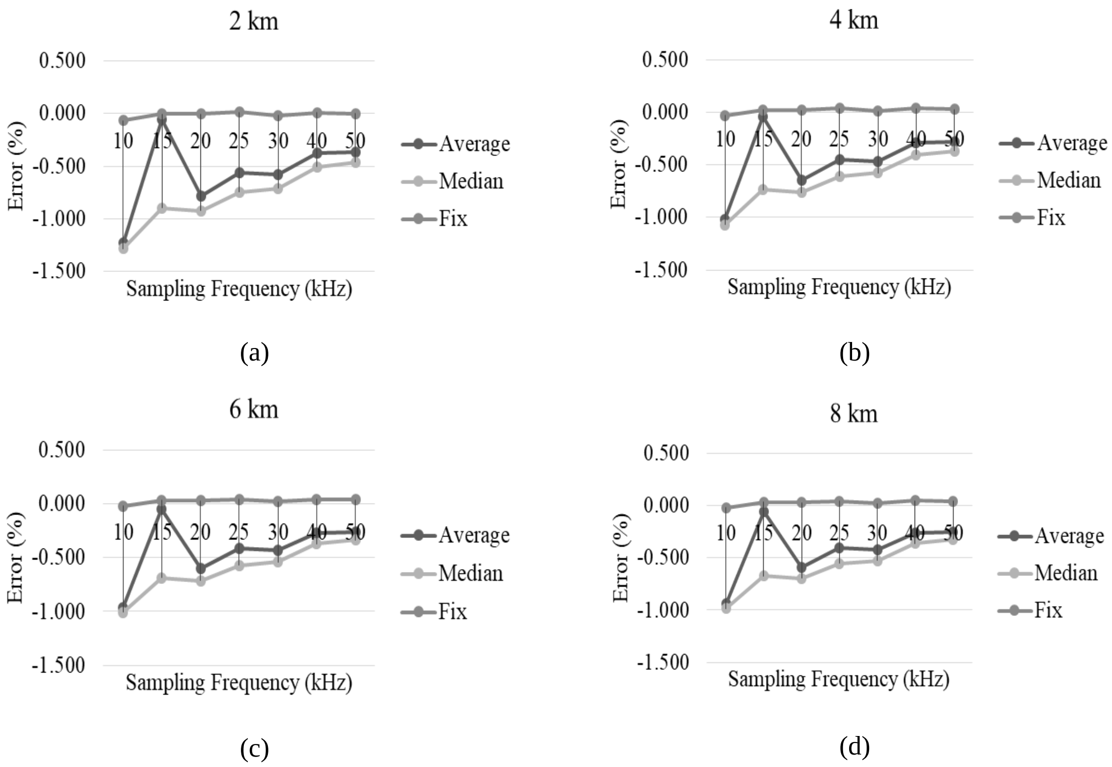

Figure 7. Graph of percentage of error versus sampling frequency (a) fault at 2km (b) fault at 4km (c) fault at 6km, and (d) fault at 8km

Based on the result obtained as shown in Figure 7, the sampling frequency of 20 kHz and method of fix number were chosen. The selection is based on the most stable, and has the lowest distance error compared to other methods when estimating the earth fault location.

3.2. Performance evaluation with varies load

The fault location algorithm was tested with two different loads, 50kVA and 150kVA. The sampling frequency used is 20 kHz and 50 kHz. The distance was tested to 2km, 4km, 6km, and 8km. Table 4 shows the result obtained from the test. Based on the result shown in Table 4, the algorithm have shown a low error of fault distance.

Table 4. Result of Fault distance Estimation with difference load condition

Fs	Load	Fault Distance (km)	Estimated (km)	Errror (km)
20kHz	50kVA	2	2.005	0.005
		4	4.010	0.010
		6	6.015	0.015
		8	8.020	0.020
	150kVA	2	2.009	0.009
		4	4.016	0.016
		6	6.023	0.023
		8	8.030	0.030
50kHz	50kVA	2	2.004	0.004
		4	4.008	0.008
		6	6.012	0.012
		8	8.016	0.016
	150kVA	2	2.006	0.006
		4	4.011	0.011
		6	6.016	0.016
		8	8.021	0.021

3.3. Fault resistance

Another factor that affect the accuracy of the algorithm is the fault resistance, R_f. In this simulation, the actual value of fault resistance is used to find the fault location. Table 5 shows the result of fault location when test with a different value of fault resistance. Based on results in Table 5, the accuracy of the algorithm is accepted.

Table 5. Fault Location Algorithm tested with different value of R_f at 90^0 Inception angle and load of 50kVA

Distance (km)	Rf (Ohm)	Estimated (km)	Error (km)
4	0	4.010	0.010
	25	4.017	0.017
	50	4.020	0.020
	100	4.018	0.018
10	0	10.028	0.028
	25	10.030	0.030
	50	10.033	0.033
	100	10.029	0.029
16	0	16.030	0.030
	25	16.043	0.043
	50	16.046	0.046
	100	16.042	0.041

3.4. Estimated Fault Resistance

As mention in [13], the fault resistance can be estimated by using equation (2). Table 6 shows the estimated fault resistance. In Table 6, it shows that estimated fault resistance has small differences compared to the actual value, however it give a huge impact on estimated fault location. It seems that if fault resistance value larger than 100Ω the error will be huge. This will give huge impact on the fault estimation algorithm. By referring to 2.2, a statistical solution is developed to get the most accurate estimation value.

Table 6. Result of fault resistence estimated

Actual Ω	Estimated Ω	Error (Ω)
20	22.552	2.552
40	44.399	4.399
60	63.082	3.082
80	83.049	3.049
200	185.866	-14.135
400	358.038	-41.962
600	551.612	-48.388
800	811.636	11.636

Based on the data collected in Table 6, from the estimated value of fault resistance, if the value of the estimated fault resistance is less than 100Ω, (8) will be used to estimate the fault location. However, if the value of the estimated fault resistance is equal or larger then 100Ω, (9) will be used. Table 7 shows the result of the estimated fault resistance with correction factor. *New_Rf* in (8) and (9) were indicated the new estimated Ω in Table 7.

$$New\_Rf = (Rf*0.9567) + 43.85 \quad (9)$$

Based on results in Table 7, the difference of fault resistance decreases. The smallest error is -0.222Ω and the largest is -28.423Ω.

Table 7. Result of Fault Resistance Estimated with Correction Factor

Actual (Ω)	Estimated (Ω)	Error (Ω)
20	21.105	1.105
40	41.951	1.951
60	59.778	-0.222
80	78.831	-1.169
200	221.668	21.668
400	386.385	-13.615
600	571.577	-28.423
800	820.342	20.342

3.5. Without fault resistance

The algorithm is also tested if the fault resistance in (1) is negligible. During this test, the load was fixed to 50kVA, and the fault resistance is set to 0Ω. Table 8 shows the estimated fault distance with negligible of fault resistance. The estimated earth fault distance shows a close to the actual fault distance.

Table 8. Results of Estimated earth Fault Distance Without Fault Resistance

Actual (km)	Estimated (km)	Error (km)
2	2.005	0.005
3.7	3.709	0.009
4	4.010	0.010
5	5.013	0.013
6	6.015	0.015
7.2	7.218	0.018
8	8.020	0.020
9.6	9.624	0.024
10	10.025	0.024
12	12.029	0.029
12.5	12.531	0.031
14	14.035	0.034
15	15.036	0.036
16	16.038	0.038
17.2	17.241	0.041
18	18.044	0.044
19.4	19.447	0.047
20	20.049	0.049

4. CONCLUSION

Fault localization can be determined by analyzing voltage and current faulted signal. Sampling frequency (f_s), fault resistance, unexpectedly can give the minor error effect to the algorithm. Sampling frequency can be determined by running several simulations to choose which f_s is the most stable when test with various distances. Several tests have been conducted to test if the error of estimated distance is increases or decreases. It is proven that the value of estimated fault resistance does affecting the accuracy of the distance algorithm. This means that a correction technique is needed to minimize the estimated earth fault distance error. Overall, the presented results shows that the distance algorithm and correction technique can be used as a solution to locate the earth fault location.

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