FAULT LOCATION ESTIMATION FOR DISTRIBUTION SYSTEM USING SIMULATED VOLTAGE SAGS DATA

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ABSTRACT

This paper presents a new method for locating short-circuit fault in electrical distribution system. The method works by matching the actual voltage magnitude and phase angle with the simulated ones from fault analysis that stored in a database. The matching will give the possible faulty section/sections. A matching measurement algorithm is then applied to quantify the matching accuracy and to estimate faulty distance from particular bus on the section. In case more than one possible faulty section available, a ranking procedure is conducted to rank down the sections according to the degree of matching accuracy. A simulation test of the proposed method showed a satisfactory result.

Keywords: Voltage Sags, Database, Fault Location, Distribution Networks.

1 INTRODUCTION

Short-circuit fault in distribution system often causing enormous losses to utility and customer. Such losses can be reduced if the location of fault can be located as quickly as possible. A common technique to locate fault in distribution system (particularly in 11 kV systems) is using trial and error technique. In this technique, the fault location is search by patrolling along the feeder. The location usually is guessed by an experience operator before sending the repairing crews. This technique is time consuming, costly, and exposed the crew to danger. Due to such problems, various automated fault location techniques have been proposed for distribution system.

In general, fault location techniques can be divided into three categories, which are impedance-based method, knowledge-based method and travelling wave method. The impedance-based method estimates the distance of fault from the primary distribution bus to the fault location. This method requires voltage and current values measured at one end or two ends of the line. This method used mathematical equation to estimate the fault location. Most of the method work for radial system only and require other information such as fault current waveforms, circuit breaker status, and fault indicator status for non-radial system [1, 2]. However, a limited status information available on distribution networks, in particular on 11kV networks, makes this approach very difficult, if not impossible, to establish reliable statistical estimates. Some of this method also time consuming due to iterative process and need to know the fault type before specific equation can be applied.

The second category is knowledge-based method for examples Artificial Neural network (ANN), Fuzzy Logic (FL), Expert System (ES) and Genetic Algorithm (GA) [3] – [6]. The accuracy of the result using this method is highly depending to the given set of information such as short-circuit current and information from fault detection devices at the main feeders. Unfortunately, some of the information is not available in many distribution systems since measurement is usually located at the primary distribution bus. This method such as ANN also requires training process that consumes time and need to be repeated whenever there are changes in the system.

Another type of knowledge-based technique is by matching measured data with historical fault data [6]. Whenever fault occurs in the distribution network, the waveform of voltage sags measured at the substation is recorded into the database together with the known fault type and location. This database is updated whenever fault occurs in the system. When actual fault occurs, the measured voltage sags waveforms at the substation are compared to all the voltage sags waveforms in the database. The most matching waveform in the database will give the type of fault and the location. The drawback of this method is that it will not work if the actual fault never happens at particular location, or not recorded in the database.

The last category is using travelling wave method to locate fault location [7]. The principle of this method is based on the reflection and transmission of the fault generated travelling waves on the faulted power network. Although this technique can locate fault with a high accuracy, the implementation is complex and expensive.

Taken into consideration the limitation of available information in distribution system, the proposed method in this paper uses single measurement at the primary distribution bus to estimate fault location. The measured voltage sags will be matched with the voltage sag data and voltage equation stored in the database. These data are obtained from fault analysis. The match will give the location of the fault in term of distance from particular bus in the section. Since the method depends on the simulated database, any changes such as load variation in the system can be addressed by updating the database. The method also not costly for implementation since it requires only single measurement at the main substation

2 BACKGROUND OF THE METHOD

Consider 11 kV distribution system with a measurement point is located at bus 2 as depicted in Figure 1.

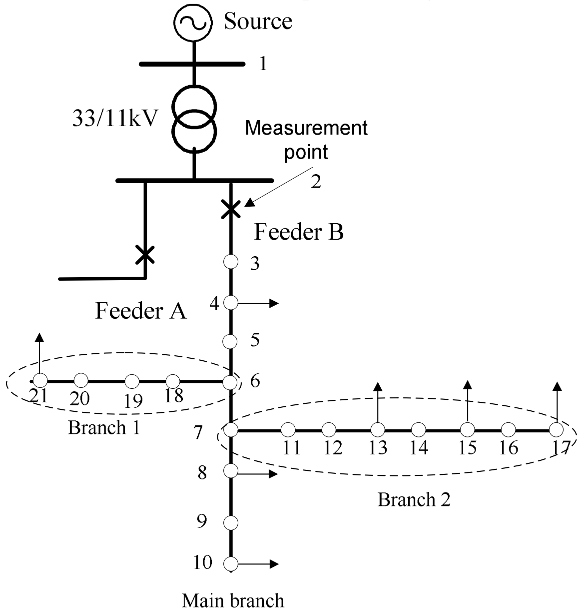

Figure 1 Study case – Typical 11 kV distribution system

If the above system experienced a short-circuit fault at any location in the system, the measured bus will experience a voltage changes. The changes cause voltage magnitude at bus 2 to drop and change the corresponding phase angle, which is referred as voltage sag phenomena. The severity of the sag depends on the distance of fault occurrence from bus 2. The nearest the fault to bus 2 the severe the sag will be experienced at bus 2. Different type of fault also produce different sag characteristic at the monitored bus. Based on this characteristic, fault location can be estimated by comparing the measured voltage at the monitored bus with a voltage sag data and its known location where it occurred. The data can be a collection of practical measurement or from simulation analysis. However, it is almost impossible to obtain a complete set of data from practical experience since short-circuit not always occurs and the location may vary and not necessary cover the whole system. Due to this problem, simulated voltage sags data are used in this study to estimate the faulty location.

The basic idea of the proposed method comes from finger print identification concept. In this technique, an unknown finger print is match with finger prints that have been stored in a database. The match will give the identity of the person. The same concept is applied in the proposed method, but with different approach of matching process

3 DESCRIPTION OF THE METHOD

3.1 Simulated Data

Two types of databases are developed and used for this method. The first type is to store voltage magnitude and phase angle monitored at the measured bus when fault is simulated at all buses. The stored voltage magnitude is the lowest magnitude among the three phases. The second type is to store general equation of voltage magnitude and phase angle as a function of distance. The equations are considering the voltage magnitude and phase angle as measured at the monitored bus. Different type of fault has different databases.

(i) Simulated Voltage Sags at Buses

The data for this type of database is arranged as depicted in Figure 2. The first column is the faulted bus, second column is the voltage magnitude and the third column is the corresponding phase angle.

1	V_1	θ_1
2	V_2	θ_2
3	V_3	θ_3
4	V_4	θ_4
5	V_5	θ_5
⋮	⋮	⋮
x	V_x	θ_x

Figure 2 Data arrangement for fault at buses

(ii) Simulated Sags Equations

From the preliminary study, it was found out that there are three different types of changes for voltage magnitude and phase angle over distance. The types are linear, non-linear and constant. Each section has its own equation and the type of changes may differ depends on the value of the section impedance. The larger the impedance, the more non-linear the changes will be. On the other hand, small impedance will produce a linear and almost constants changes if the impedance is too small. In this study, the equation is assumed to be a polynomial type with the degree of two. The general equations are as follow:

$$V_i = a_0 d^2 + a_1 d + a_2 \tag{1}$$

$$\theta_i = b_0 d^2 + b_1 d + b_2 \tag{2}$$

where,

V	voltage magnitude
θ	phase shift
i	section where the equation can be applied
d	distance
a_0, a_1, a_2	coefficients of the voltage magnitude equation
b_0, b_1, b_2	coefficients of the phase angle equation

The existing of the coefficient will depend on the type of the equation as follows:

a) Non-linear type - all the coefficients have value

b) Linear type - a_0 and b_0 is zero and the rest has value

c) Constant type – only a_2 and b_2 has value, the rest is zero

The following is the arrangement of the data for second type of the database.

$$\begin{array}{ccccc} 2 & 3 & a_0^{2-3} & a_1^{2-3} & a_2^{2-3} \\ 3 & 4 & a_0^{3-4} & a_1^{3-4} & a_2^{3-4} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ i & j & a_0^{i-j} & a_1^{i-j} & a_2^{i-j} \end{array} \qquad \begin{array}{ccccc} 2 & 3 & b_0^{2-3} & b_1^{2-3} & b_2^{2-3} \\ 3 & 4 & b_0^{3-4} & b_1^{3-4} & b_2^{3-4} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ i & j & b_0^{i-j} & b_1^{i-j} & b_2^{i-j} \end{array}$$

Figure 3 Data arrangement for voltage magnitude and phase angle equations

The first column and second column of the database are two adjacent buses. The third, forth and fifth column is the coefficient of the equation as shown in equations (1) and (2)

3.2 Matching Algorithm

The search of the best matching data using the developed databases is based on the following steps:

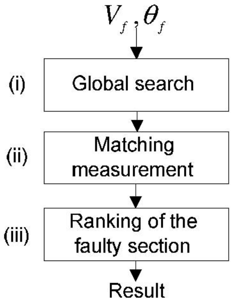

Figure 4 Flow chart showing the general steps of the proposed method

(i) Global Search

The aim of global search is to find all the section that bounds the measured voltage (V_f, θ_f). This section is considered as the possible faulty section. The boundary can be presented in the form of graph as follows:

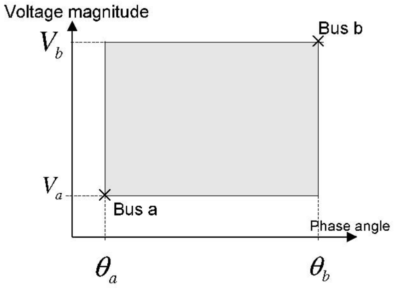

Figure 5 Faulty region for section a-b

The region represents the boundary of voltage magnitude and phase angle values when fault occurs at any location on section a-b. A given voltage magnitude and its corresponding phase angle that fall inside this region will be considered caused by fault at this section. Each section has its own boundary but there is also possibility of overlapping boundary. The overlapping will cause more than one section selected as possible faulty section. The region can be also presented in the form of equations as follows:

$$V_a < V_{fault} < V_b \quad \text{between bus a and bus b} \tag{3}$$

$$\theta_a < \theta_{fault} < \theta_b \quad \text{between bus a and bus b} \tag{4}$$

$$\left|V_{fault} - V_a\right| < \alpha \text{ and } \left|\theta_{fault} - \theta_a\right| < \alpha \text{ at bus a} \tag{5}$$

$$\left|V_{fault} - V_b\right| < \alpha \text{ and } \left|\theta_{fault} - \theta_b\right| < \alpha \text{ at bus b} \tag{6}$$

Where α is the specified threshold to determine the matching between the actual and the simulated one. The threshold is required because it is not possible to obtain exactly the same value of both the simulation and actual measurement.

(ii) Matching measurement

The matching measurement is based on the mismatch between the distance obtained from voltage magnitude equation and distance obtained from phase angle equation. Figure 6 shows how the distance is obtained using both types of equations. In the figure, the function $f_V(V,d)$ represents an equation of voltage magnitude over distance and the function $f_\theta(\theta,d)$ represents phase angle over distance. Both functions are representing a voltage sag profile along the two adjacent buses, which is bus a and bus b. The equation can be any type as discussed in section A and not necessary a nonlinear as presented in Figure 6.

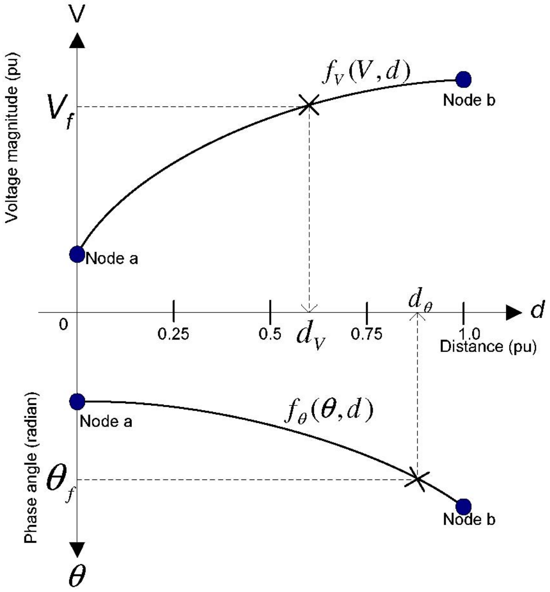

Figure 6 Equations of voltage magnitude and phase angle for section a-b

The matching value is given by the following equation:

$$\sigma = \left|d_V - d_\theta\right| \tag{7}$$

where,

σ matching value or the mismatch of the distance

d_V distance obtained from voltage magnitude equation

d_θ distance obtained from phase angle equation

The matching is considered 100 % math if $\sigma \approx 0.0$. The lower the value of σ, the higher the matching accuracy will be. This measurement also provides an estimation of the faulty distance in the section from bus a in the section a-b, which is given by d_V and d_θ.

(iii) Ranking of the possible faulty section

In the situation if more than one possible faulty section selected from global search, the sections need to be ranked according to its degree of matching. The candidate with the highest degree of similarity will be selected as the most likely faulty section. However, the other candidates are also considered in case the first choice is incorrect upon visual inspection. Due to this reason, a ranking procedure is developed to assign the section according to the priority for inspection. The process can be simplified in the following steps:

a) Find the minimum value from the class group, $\sigma\min = \min\{\sigma_1, \sigma_2 \cdots \sigma_i\}$, $(1 < i < n)$ where n is the number of sections selected from the global search.

b) The section *i* corresponding to lowest value of σ is considered as the most matching pair and assigned as the first possible section.

c) The steps are repeated to find the next most matching pair of data. This step is repeated until all the sections have been ranked.

The final result is the list of possible faulty section/sections than has been ranked according to it degree of matching. At the same time, the algorithm also provides the estimation of fault distance in the section.

4 EVALUATION OF THE METHOD

Due to the absence of a real measurement, the proposed method is tested using simulated ones. A distribution networks in Figure 1 is used to study the ability of the proposed method to locate fault. The network consists of 33kV equivalent network source, a 33/11kV transformer and an 11kV feeder with 21 nodes i.e. 19 sections and 2 branches. In this paper only Single Line to Ground Fault (SLGF) result will be presented. The short-circuit fault in this test is considered a bolted fault**.**

4.1 Database Development

In this study, the database is established from the fault analysis simulation as discussed in section 3. Table 1 shows a sample of a database contains voltage magnitude and phase angle of the lowest voltage magnitude at the monitored bus when SLGF is simulated at all buses in the system.

Table 1: Simulated Voltage Sags at Bus

Faulted Bus	Voltage Magnitude (pu)	Phase Angle (radian)
3	0.0271	0.4354
⋮	⋮	⋮
21	0.3904	-0.0882

Table 2 and Table 3 are the coefficient values of the voltage magnitude versus distance and phase angle versus distance equations respectively.

Table 2: Voltage Magnitude as a Function of distance

Section	Coefficients		
	a_0	a_1	a_2
2 – 3	-0.0004	0.0275	0.0
⋮	⋮	⋮	⋮
20 – 21	-0.0042	0.0586	0.3360

Table 3: Phase Angle as a Function of distance

Section	Coefficients		
	b_0	b_1	b_2
2 – 3	0.0003	-0.0224	0.4575
⋮	⋮	⋮	⋮
20 – 21	0.0099	-0.0705	-0.0275

The graphs in Figure 7 and Figure 8 show two examples of the equation for section 3-4 and section 4-5 of SLGF respectively. The equations represent the value of voltage magnitude and phase angle at monitored bus when fault occur at any location between the two adjacent buses. The location is considered from bus 3 towards bus 4 and bus 4 towards bus 5 respectively. For both section, it can be observed that the changes of voltage magnitude over distance is almost linear. However, the phase angle for both section are non-linear.

In the Figure 7(a) and Figure 8 (a), the severity of voltage sag reduces as fault occur further away from the monitored bus. This can be seen by comparing the voltage magnitude at bus 4 and bus 5 in the graphs of Figure 7(a) and Figure 8(a). At bus 4, the voltage magnitude is around 0.07 pu and at bus 5 it is around 0.17 pu. This characteristic is inline with the characteristic of voltage sag where the nearer the fault to the measured point, the more the drop of voltage magnitude will be.

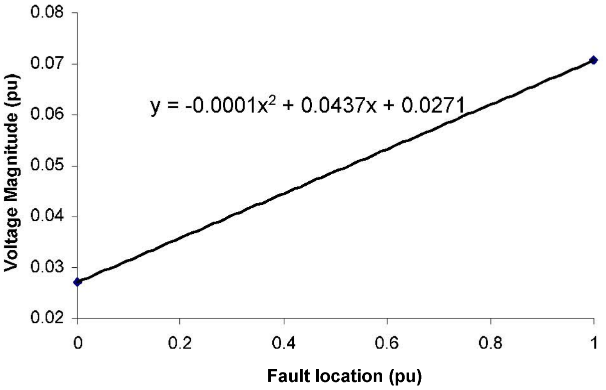

Figure 7(a): Equation of voltage magnitude versus distance for section 3-4

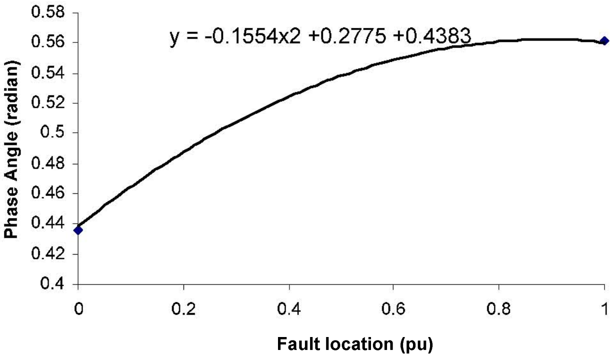

Figure 7(b) Equation of phase angle versus distance for section 3-4

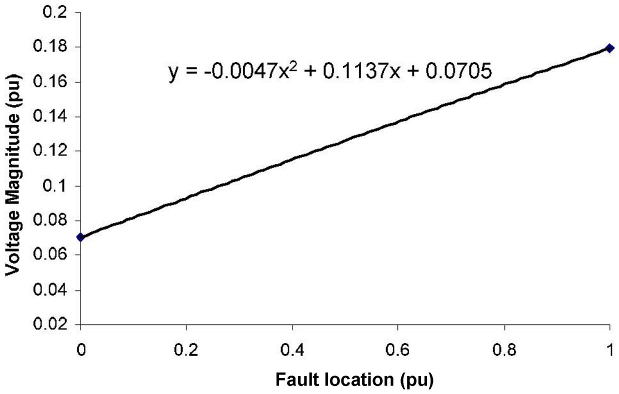

Figure 8(a) Equation of voltage magnitude versus distance for section 4-5

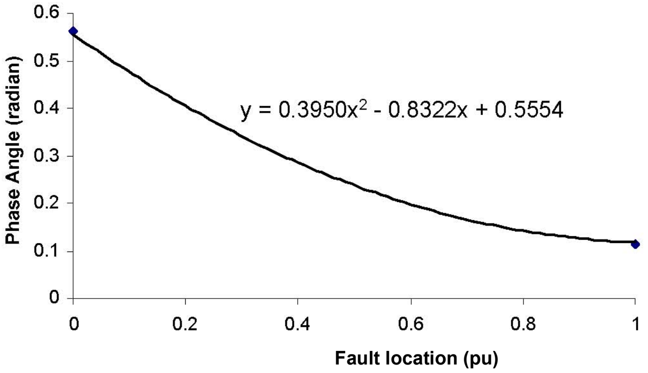

Figure 8(b) Equation of phase angle versus distance for section 4-5

4.2 Simulation Test

Table 4 shows some testing point where Single Line to Ground fault is simulated.

Table 4: Testing Location -SLGF

Test No	Simulated faulty section
1	Section 2-3, 0.50 pu of distance from bus 2
2	Section 3-4, 0.75 pu of distance from bus 3
3	Section 4-5, 0.30 pu of distance from bus 4
4	Section 5-6, 0.75 pu of distance from bus 5
5	Section 6-7, 0.50 pu of distance from bus 6
6	Section 7-8, 0.25 pu of distance from bus 7
7	Section 8-9, 0.75 pu of distance from bus 8
8	Section 9-10, 0.50 pu of distance from bus 9
9	Section 7-11, 0.50 pu of distance from bus 7
10	Section 20-21, 0.75 pu of distance from bus 20

The result is given in Table 5, where the first column of the table is the test no, the second column shows the selected faulty section/section from the algorithm. The third and forth column are the estimated distance from voltage equation and phase angle equation respectively. The fifth column is the degree of matching and finally the last column represents the rank of the selected faulty section.

Table 5: Testing Result

Test No	Selected faulty section	d_V (pu)	d_θ (pu)	σ	Rank
1	2 – 3	0.4982	0.4989	0.0007	1
2	3 – 4	0.7496	0.6676	0.0820	1
3	4 – 5	0.2533	0.2855	0.0322	1
4	5 – 6	0.7521	0.7508	0.0013	1
5	6 – 7	0.5000	0.5010	0.0010	1
	6 – 18	0.4523	0.4704	0.0181	2
6	7 – 8	0.2489	0.2517	0.0028	1
	18 – 19	0.2376	0.3331	0.0955	2
	7 – 11	0.1969	0.4890	0.2921	3
7	8 – 9	0.7482	0.7464	0.0018	1
	20 – 21	0.3681	0.3068	0.0613	2
	13 – 14	0.4322	0.1551	0.2771	3
8	9 – 10	0.5000	0.5000	0.000	1
	20 – 21	0.8427	0.9280	0.0853	2
	15 – 16	0.1310	0.3725	0.2415	3
9	7 – 11	0.4996	0.5007	0.0011	1
	7 – 8	0.6326	0.2580	0.3746	2
	18 – 19	0.8421	0.3423	0.4998	3
10	20 – 21	0.7502	0.7499	0.0003	1
	9 – 10	0.2487	0.2574	0.0087	2

The result in the above table shows some important observations. Firstly is on the possible faulty section. It can be seen that from bus 2 to bus 6, the algorithm only selected one possible faulty section. Whereas, starting from bus 6, more than one section is selected as the possible faulty section. This occurred because of the parallel sections starting from bus 6. Taken test no 5 as an example of this situation, two possible sections are selected i.e. section 6–7 and section 6–18. Both sections are parallel line. The same goes to other parallel sections starting from bus 6. For parallel lines, there is a location at each of the lines where the occurrence of fault will produce the same voltage sag characteristic. This happen because at this location, the electrical distance is the same as seen from the monitored bus. If the system is in a radial form without any branches, the algorithm will get only one possible faulty section.

The second observation is on the ranking of the possible faulty sections. The sections have been ranked according to the value of matching accuracy. The most lower is set as the first choice for visual inspection and followed by the other sections. In the table, the most likely faulty section is in the grey box. For example, for test no 9, three possible sections have been selected. The sections have been ranked in sequence, where section 7-11 is the first possible faulty section, followed by section 7-8 and finally section 18-19. The first section will be checked first and if this choice is incorrect, the second section will be inspected and if still incorrect the third one can be checked. The possibility of having more than one section cannot be avoided using this method, unless the branch where the fault occurrence can be identified. This can be done by placing a fault indicator at the end of each branch.

The third observation is on the estimation of the fault distance. For example, for test no 1, the faulty location is estimated occur at section 2-3 with estimation of location at 0.4982 pu or 0.4989 pu from bus 2. These faulty distance estimation would help the repairing crew to have a reasonable estimation where to look first instead of guessing the location based on previous experienced that might be wrong

5 FUTURE WORKS

In the future, the proposed method will be improved to consider the effect of fault resistance. A thorough study will also be conducted to study the performance of the method due to measurement error and how to overcome such problem. The method also will be tested using other distribution networks.

6 CONCLUSIONS

In this paper, a new method to estimate fault location for distribution system has been presented. The test of the method shows a promising result and hence the method can be further improved to address fault resistance effect and measurement error. The method is simple and inexpensive for implementation since its only requires single measurement at the monitored bus. Any changes such as load variations or network reconfiguration can be adapted by this method by updating the database.

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