A smart algorithm for fault detection and location in electric power distribution system

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ABSTRACT

In an electric power distribution system (EPDS), fault location accuracy is critical for system stability. In the past, several algorithms have shown that they are inefficient. However, the results of these algorithms have been shown to be inefficient, and they should not be used for every sort of the faults. This paper presents a new algorithm capable to determine the location of fault accurately with low error rate. It is based on the voltage and current calculation at the source station for different types of faults by using either one power supply or double power supply. The work includes the formulation analytical development as simulation test results. The test results are produced by numerical simulation using data from a recognized distribution line in the literature.
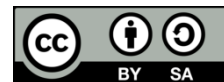
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1. INTRODUCTION

Fault location estimation is an important aspect in power systems restoration. This estimate helps to reduce the time without the injection renewable energy in EPDS to locate the defect therefore improves power quality indexes. The purpose of this work is to ensure this energy while avoiding the faults that may hinder its flow. Based on such concern, several methods have been proposed for the precision of the location [1]-[6] and fault detection by using Beaglebone black card [7] in real-time.

Various fault location methods were developed in the past. For example, Novosel *et al.* [8], use the apparent impedance which is defined as the ratio of the selected voltage to the current over the type of fault and the faulty phases, to locate faults. In Das [9], locates the sections and then the distance to the fault in this calculated section. Yang and Springs [10] propose a defect localization method that corrects the effects of defect resistance. The method proposed by Das *et al.* [11] used fundamental frequency voltages and currents measured at a line terminal before and during failure. In the method proposed by Saha *et al.* [12] estimates the location of the fault by comparing the design impedance of the power supply assuming faults of each section line. Choi *et al.* [13] locate the faults by solving a quadratic equation resulting from the direct circuit analysis. In Senger *et al.* [14] proposed a method based on measurement provided by intelligent electronic devices (IED). In Kim, *et al.* [15] the estimated location of outages on distribution power supplies using power quality monitoring data. A way to optimally place faulty circuit indicators along the feeder is developed by Almeida *et al.* [16]. Methods of reducing and eliminating uncertainty about the location of the fault are elaborated by Krishnathevar and Ngu [17], as well Avendano-Mora *et al.* [17], [18]. In Sadeh *et al.*

[19] suggested a new algorithm for radial distribution systems using modal analysis. Wanjing *et al.* [20] presented a new method based on two types of fault location approaches using the line to neutral or the line to measure from the line to the substation in. Khoudry *et al.* [21] proposed a novel technique based on machine learning algorithms. In Abbas *et al.* [22] proposed a method based on Single line to ground fault detection and location in medium voltage distribution system network based on neural network. In [23] Charalampos *et al.* [23] a voltage-based fault location algorithm for medium voltage active distribution systems.

These proposed methods that we have highlighted above have the weaknesses in precision which make them not effective because they require algorithms adopted for each type of fault. The goal of this work is to develop a new algorithm capable to valid and minimize the error of all types of faults without. The structure of the paper is arranged as follows: The new single line to ground fault location formulation is described in Section 2. The Fault Location methodology is shown in Section 3. The test results and comparison are presented in Section 4 and the conclusions are presented in Section 5.

2. MATHEMATICAL FAULT LOCATION FORMULATION

To properly represent the fault location portion of the electrical network, we begin with a model diagram of a network during a fault, as shown in Figure 1.
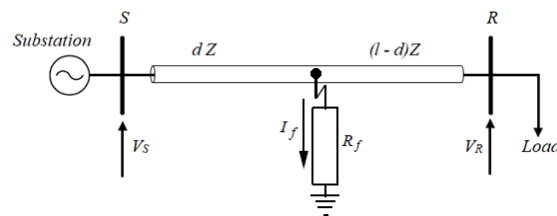

Figure 1. Model of a single-phase distribution line

Z　　:　Characteristic line impedance
V_s　:　Voltage at the source
V_R　:　Voltage at the load
V_F　:　Fault voltage
I_s　:　Current at the source
I_R　:　Current at the load
I_F　:　Fault current
l　　:　The row total length
d　　:　The default distance from the source

From the electrical diagram we presented in Figure 1 we found (1).

$$V_s = dZI_s + V_f \tag{1}$$

The complex notation is:

$$V_s = V_s^r + jV_s^i \tag{2}$$

$$I_s = I_s^r + jI_s^i \tag{3}$$

$$V_f = V_f^r + jV_f^i \tag{4}$$

$$I_f = I_f^r + jI_f^i \tag{5}$$

In the simplest layered parameter model of an overhead line, series resistance (RL) and reaction (XL) are included only Figure 2. Such a model is considered as Figure 2 to represent a short line which is generally less than 80 km long [24].
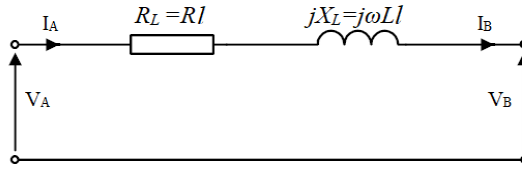
Figure 2. Line model

R, L :   Line resistance and inductance per unit length
  ω :   Angular fundamental frequency
  l :   Line length

So, the line impedance is:

$$Z = R_L + jX_L \tag{7}$$

We replace this impedance in (1).

$$V_s^r + jV_s^i = d(R_L + jX_L)(I_s^r + jI_s^i) + R_f(I_f^r + jI_f^i) \tag{8}$$

We find (7).

$$V_s^r + jV_s^i = \left[d(R_L I_s^r - X_L I_s^i) + R_f I_f^r\right] + j\left[d(R_L I_s^i + X_L I_s^r) + R_f I_f^i\right] \tag{9}$$

Take,

$$A = (R_L I_s^r - X_L I_s^i) \text{ And } B = (R_L I_s^i + X_L I_s^r) \tag{10}$$

So, we find the following system of:

$$\begin{pmatrix} V_s^r \\ V_s^i \end{pmatrix} = \begin{pmatrix} A & I_f^r \\ B & I_f^i \end{pmatrix} \begin{pmatrix} d \\ R_f \end{pmatrix} \tag{11}$$

$$\begin{cases} V_s^r = dA + R_f I_f^r \\ V_s^i = dB + R_f I_f^i \end{cases} \tag{12}$$

Therefore

$$d = \frac{\left(V_s^r I_f^i - V_s^i I_f^r\right)}{\left(A I_f^i - B I_f^r\right)} \tag{13}$$

We have from the diagram in Figure 1.

$$I_s = I_f + I_R \tag{14}$$

At the fault

$$I_R << I_f \tag{15}$$

Therefore

$$I_s = I_f \tag{16}$$

So, (12) becomes:

$$d = \frac{\left(V_s^r I_s^i - V_s^i I_s^r\right)}{\left(A I_s^i - B I_s^r\right)} \tag{17}$$

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Based on this development as well as mathematical evidence, we have found a new, more efficient algorithm for cable fault accuracy.

3. FAULT LOCATION ALGORITHM

The algorithm procedure starts after the fault detection. There are n branches in the system. The following method for detecting the problematic site is begun for each branch:
- Voltage and current measurement at the source
- Comparing the voltage with a voltage referance (Vref)
- While the fault is detected the charging current is low, due to the voltage drops and the dynamics of the systems during the blackout. Hence, the source current during the fault is the same as the current source as show in the (14) and (16).
- The fault distance is calculated by (17).

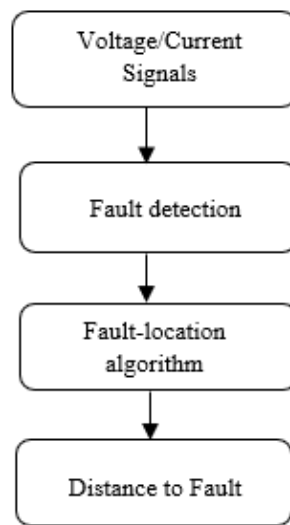The fault location algorithm is displayed in Figure 3.

Figure 3. A new fault location algorithm

4. RESULT AND COMPARISON

The system studied is illustrated in Figure 4 for the two cases, the first with a single power supply in Figure 4 (a) and the second with a double power supply Figure 4 (b). It is part of the distribution network underground. The maximum length between two distribution stations in our city is 6 km and the voltage is 20 KV. It was simulated using a distributed parameter line model as shown in Table 1. Using MATLAB [25] as simulation tool. The proposed technique is extensively tested to verify its efficiency and accuracy. The performance of fault location algorithms is generally measured by the errors over the total line distance:

$$err = \left| \frac{d_{real} - d_{estimer}}{l_{total}} \right| \tag{16}$$

d_{real} : The actual fault distance.

$d_{estimer}$: The distance obtained

l_{total} : The total line length

The simulation and result are made up of two types of connection, the first, one power supply and, and the second power supply and seconde double power supply.
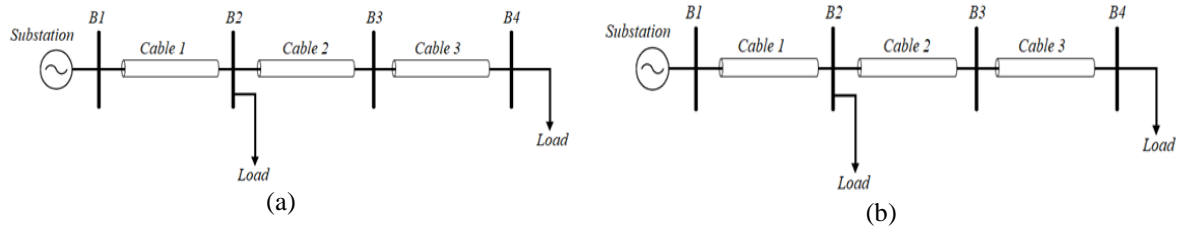
(a)   (b)

Figure 4. Distribution network simulation system, (a) single power supply, (b) Double power supply

4.1. A single power supply

Figure 5 shows a cable modele to be simulation during the fault in the case of power distribution networks connected to a single power supply. The graphs a-e shown in Figure 6 present the errors in the fault distance of five possible faults as shown in Figures 6 (a)-(e) in the case of a single supply. From Figure 6, it can be seen that the average error obtained using the proposed fault location algorithm is 0.07 for double line-fault and the minimum error value is showed in the case of line to ground fault (0.0001). Therefore, errors obtained using the new fault location algorithm is significantly tolerable for one power supply system, this can prove that the proposed algorithm is suitable for fault location in EPDS.
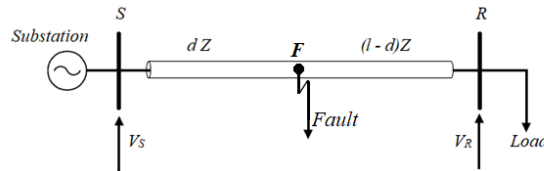

Figure 5. Model of line at a fault in the case of a single power supply

(a)   (b)   (c)

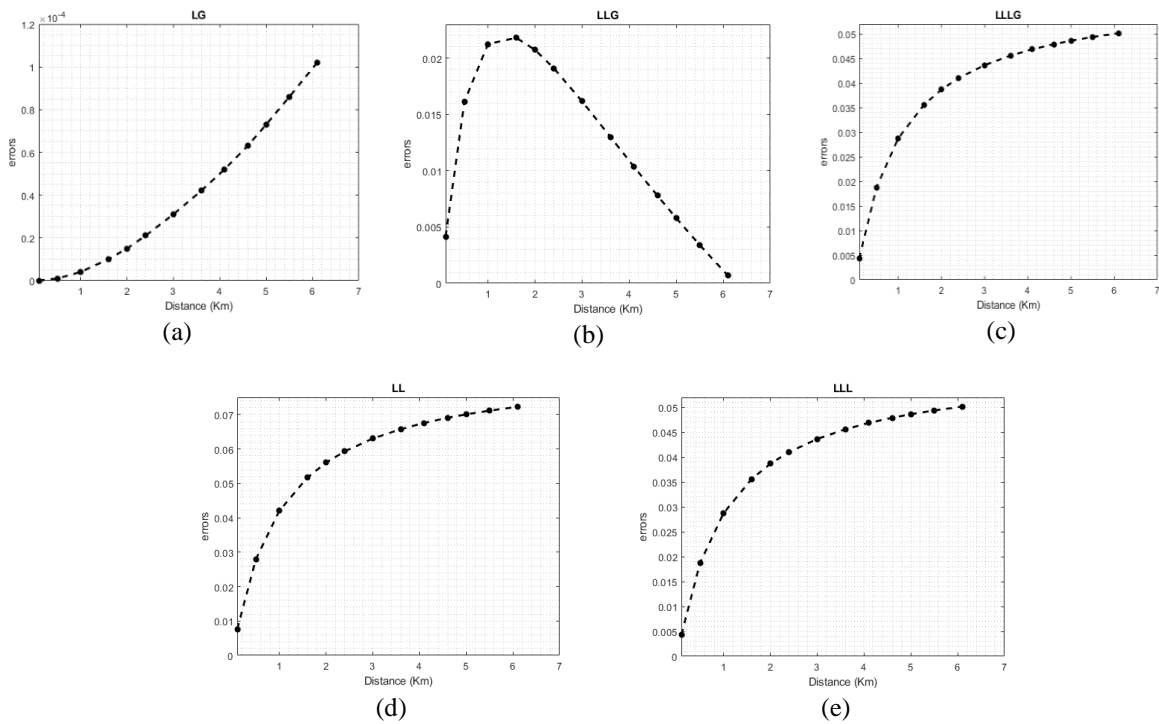(d)   (e)

Figure 6. Result of sumilation for one power supply, (a) line to ground faults (LG), (b) double line to ground faults (LLG), (c) three line to ground faults (LLLG), (d) double-line to fault (LL) and (e) three-line to faults (LLL)

4.2. Double power supply

Figure 7 shows a cable modele to be simulation during the fault in the case of power distribution networks connected to a double power supply. The graphs shown in Figures 8 (a)-(e) present the errors in the fault distance of five possible faults: line-to-ground (LG), double-line-to-ground (LLG), three lines to earth (LLLG), double-line (LL) and three-lines (LLL) in the case of double power supply. From the figure 8, the results of our simulation, we have found a minimum error value (0.02) in the double-phase-to-ground, and the average error is 0.07 for double-line-fault.
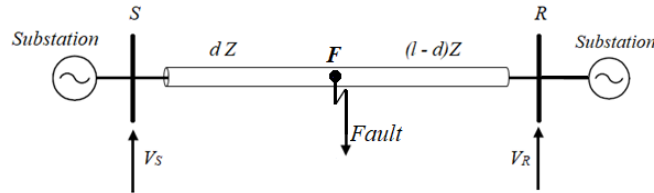

Figure 7. Model of line at a fault in the case of a double power supply
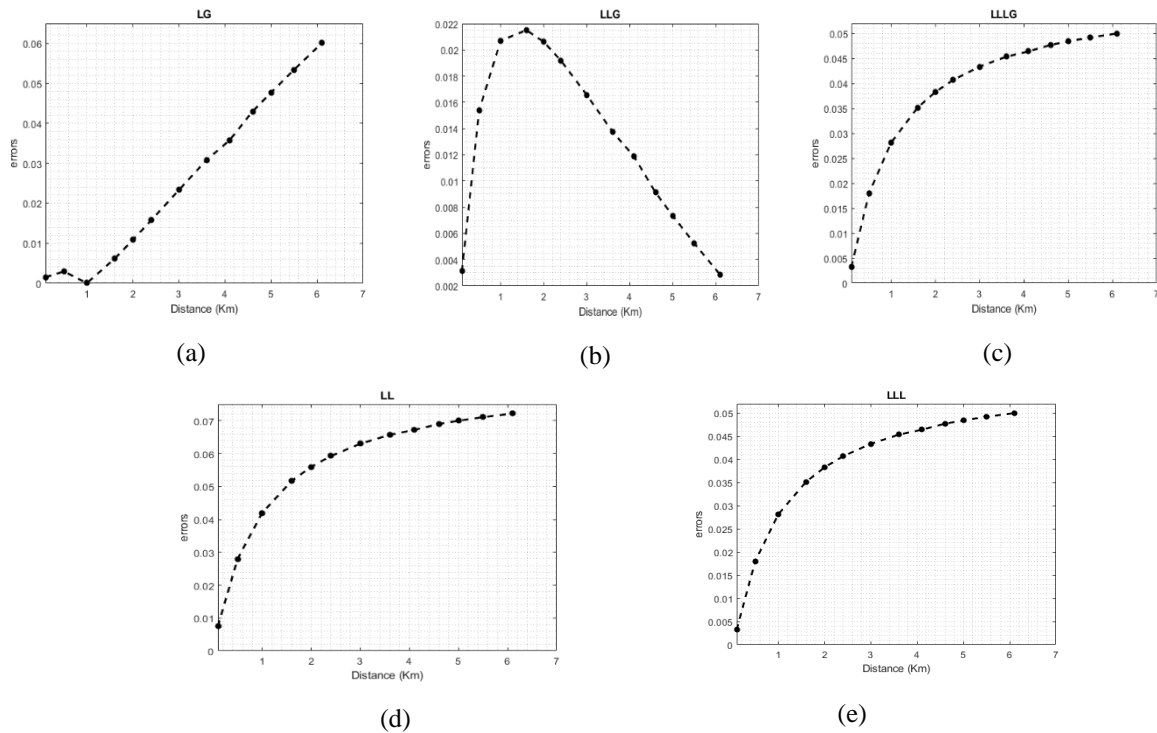

(a)

(b)

(c)

(d)

(e)

Figure 8. Result of sumilation for one power supply, (a) Line-to-ground faults (LG), (b) Double-line-to-ground faults (LLG), (c) Three-line-to-ground faults (LLLG), (d) Double-line fault (LL) and (e) Three-line faults (LLL)

4.3. Comparison

The results of a comparison of a smart algorithm and a proposed algorithm by Hing, *et al.* [26] are shown in Table 1 to examine if a smart algorithm is good for fault location. Table 1 shows that for the three alternative fault cases of single-phase-to-ground, phase-to-ground, and tree-phase-to-ground, the error achieved by a smart algorithm is less than the error obtained by the proposed algorithm. As a consequence, the errors obtained using a smart algorithm show that the suggested approach is capable of locating faults in EPDS.

Table 1. Comparison of results

Fault Type	A smart algorithm		[26]	
	Min Error	Max Error	Min Error	Max Error
LG	0	0.0001	0.03	0.62
LLG	0.0006	0.02	0.02	0.11
LLLG	0.004	0.05	0.01	0.1

5. CONCLUSION

This paper proposes an impedance based on an algorithme for fault location with precision in power distribution networks (PDN) for both options the one power source and double power source with a high accuracy. This algorithme was developed for all types of faults in distribution systems that is not the case in the current state of the art fault location formulation. The implementation of the proposed method can help energy companies reduce the system restoration time improving their power quality indexes.

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