

Research Article

Application of Composite Method for Determining Fault Location on Electrical Power Distribution Lines

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Distribution line is one of the most important components of the distribution system. Troubleshooting faults on these lines are often a tedious task requiring service vehicles and personnel moving from one place to another in order to locate the fault and fix the problem. The study, therefore, is on how a composite fault location technique can be applied to predict the location of faults on the distribution lines. The calculations for the estimation of the fault location are performed using one terminal voltage and current data of the distribution line. A composite method that combines the impedance-based method and the fuzzy inference system method is used in the fault location algorithm. The presented algorithm has been extensively tested using the MATLAB-Simulink model of a 33 KV 40-kilometer distribution line. The simulation result demonstrates good accuracy and robustness of the algorithm.

1. Introduction

In developing countries, inadequate provision of social amenities abound which undoubtedly include poor electricity supply. Distribution of electricity in these areas has been haunted by continuous malfunctions of electrical equipment especially distribution lines. So far, corrective maintenance is often done by the usual method; that is, personnel patrol around in a service van from place to place in an effort to locate the fault [1]. Responding to this situation in this manner is unarguably inefficient as the patrol team spends time locating the fault and, in some cases, may mistake the place where the fault occurred for another place. This has led to lengthened downtime and hence has made power delivery unreliable. Therefore, there is a need for a timely, effective, and efficient method of locating faults. This paper discusses a technique in the maintenance of electricity distribution infrastructure by bringing about on-time location of faults.

Maintenance is defined in [2] as the combination of all technical and administrative actions with the intention of

retaining an equipment in (or restore it to) an operating state in order for it to perform its required functions. It is also defined as any work undertaken in order to keep or restore a facility to any acceptable standard. As stated in [2], there are two broad types of maintenance, namely, preventive maintenance and corrective maintenance. While preventive maintenance includes condition monitoring and servicing, as well as planned outages, corrective maintenance involves modifying faulted equipment so as to restore normal operation. This paper addresses the problem of corrective maintenance on distribution lines.

According to [3], faults can be caused by short-circuits, faulty equipment, disoperation, overload, growing vegetation, aging, etc. Based on statistics, line faults happen to be the commonest faults in power systems [3]. Line faults that occur in power systems include single line-to-ground, line-to-line, double line-to-ground, and balanced three-phase faults [4]. Faults may be temporary (if the fault is cleared after the circuit breaker closes back) or permanent (if the fault is not cleared after opening and closing of the circuit breaker) [5]. Permanent faults can lead to loss of service lines

and as such must be traced so as to restore operation [5]. Fast response times are also important to ensure continuity of service because the availability of power supply increases for shorter mean times to repair (MTTR) [6].

2. Literature Review

In all the methods studied in the course of this work, there is similarity in their overall design. They all include a fault locating system and a means of communicating the location to the repairs people. Several works have been done in a bid to design an accurate fault locator. The various methods designed include impedance-based method, travelling wave method, noncontact magnetic field measurement method, fuzzy inference system method, and artificial neural networks method [3, 6]. These methods are by default used for transmission lines but can also be used for distribution lines [3–9]. If Global Positioning System (GPS) capability is added to the setup, the method is said to be synchronized, but if not, it is said to be unsynchronized [6]. The impedance method is the commonest one. It can be one-ended, two-ended, or multiended [3]. It leverages on the assumption that the line is uniform; that is, the line parameters are distributed evenly throughout the line and therefore they can be obtained by ordinary methods for analyzing transmission line [3]. The prefault and postfault voltages and currents and their symmetrical components are obtained and, together with the line parameters, are used to estimate the fault location. It is for a fact that uneven spacing between the phase conductors causes line inductance to vary; temperature of the day affects line resistance and the amount of sag of conductors (due to thermal expansion) which in turn affects line capacitance [4]. This method has been revised in the “modified” impedance method [7]. By way of illustration, for simplicity, suppose that the algorithm gives a fault point, Y , for an input current, X , and the algorithm can be tested using example cases of known fault points. A pattern in the error may be discovered after which the algorithm is improved [7]. In the travelling wave method, either the disturbance created by the fault on the line is detected and analyzed or impulse voltages are injected into the line and the reflected wave is observed using time-domain reflectometry (TDR) in order to determine the impedance characteristics of the line [3, 8]. Like the impedance method, it can be one-ended, double-ended, or multiended [3]. The wave captured usually contains noise that must be filtered out. A signal processing method using wavelet transform is employed to do this [9]. The noncontact magnetic field measurement method involves the use of a magnetometer (which contains a magnetic sensor) to sense the magnetic field produced by a fault current and relay the data so gotten to a central unit for processing [3]. The fuzzy inference system formulates mappings between fault currents and voltages (inputs) and the location of the fault (output). It does this using a series of fuzzy if-then rules. A merit of this method is that it follows human intuition and takes advantage of the fact that results are not always exact. A limitation of the fuzzy inference system is that it is only useful when its parameters are well tuned. The artificial

neural network (ANN) method uses a network of nodes or objects whose output depends on the input(s) and an internal mechanism that can be modified on training. This gives the network the property of being able to learn. An artificial neural network, which is one of the soft computing techniques, requires a model to be trained with actual fault data. The data need to be up-to-date to take into account changes happening on the line with time and have to be unbiased so that the model will be accurate [9]. A demerit of the ANN method is that the accuracy of the model increases with increase in its complexity (i.e., depth of the network) and with the amount of data it is trained with [9]. Sometimes, more than one of these methods is employed in parallel, in which case they are called composite methods, in an effort to minimize the error that ensues [10, 11].

A new and state-of-the-art method is the smart fault location method. This is a feature of major electric power systems of the world today [3]. This makes use of intelligent electronic devices (IEDs) installed throughout the power system to monitor it around-the-clock [5]. The IEDs act as sensors and relay sensor data, for example, temperature of component and line current, to a control station [12]. This has been made possible with advances in Big Data and radio silicon and wireless sensor network technologies [12]. There is incentive to adopt this method because of the flexibility and scalability it affords, especially for smart power systems. An advantage of a smart power system is the economy in power supply it provides through efficient energy management systems and support for distributed generation to augment the conventional power generation [10]. It also makes static var control and “self-healing” in power system networks possible through coordinated transmission and distribution of electric power [10]. But the infrastructure to put this in place is expensive, although there has been progressive decrease in costs as a result of advancements in integrated circuit (IC) technologies, information and communications technologies (ICT), and battery production technologies [11]. As stated in [5], a smart fault location system will use knowledge of the network parameters, current topology, and type of data to determine the fault location method that best suits the situation.

There are different software tools and associated hardware in use today with the fault location methods to monitor transmission and distribution systems and hence faults in them. Traditionally, remote terminal units collect measurements (bus voltages, currents flowing in the lines, frequency, breaker status, transformer tap position, etc.) called supervisory control and data acquisition (SCADA) from monitored equipment using field devices like sensors and measuring instruments [13]. Control action is carried out using on-site programmable logic controllers or remote terminal units [13]. This arrangement incorporates a software application that provides a graphical user interface for monitoring of the system [13].

In the work of [14], the identification methodology of main distribution line faults in OV MV BPL networks was presented and assessed. Result of the work shows that the identification of main distribution line faults is based on the coupling reflection coefficients derived from the original and

the extended TM2 methods as well as their differences. Federico and Tonello in their paper [15] used two monitoring techniques, namely, the symbol level sensing and mains level sensing, which allow monitoring different types of anomalies. The results show that correctly identifying and locating an anomaly does not depend much on the size of the network or on the noise but rather on the topology of the network and how it is taken into account by the detection and localization algorithms.

In the methods described so far, impedance method is the cheapest and simplest method to implement. A combination of the impedance method with any of the artificial intelligent methods of fault location will give good precision of the fault location. In this paper, the impedance-based method and the fuzzy inference system are used.

3. Methodology

A composite method combining the impedance method and the fuzzy inference system method is used as the fault location algorithm.

3.1. Impedance-Based Method. A single-ended impedance-based method is employed as measurements will be obtained at the substation. In the impedance-based method, first the symmetrical components of the fault currents are obtained by evaluating the analysis equation as follows:

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}. \quad (1)$$

On the basis of the result, the fault type can be ascertained as different fault types have different effects on the line. In order to draw the equivalent sequence network, the sequence impedances of the sequence networks must be determined. To do this, the line impedances have to be transposed so that self-impedances of the line become equal and mutual impedances of the line become equal. Then the sequence impedances are found by the following:

$$[V_{abc}] = [Z_{abc}][I_{abc}]. \quad (2)$$

For a transposed line,

$$[Z_{abc}] = \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix}. \quad (3)$$

Z_s and Z_m are the self-impedances and mutual impedances of the line, respectively.

By using the technique of symmetrical components, the phase-impedance matrix is transformed into the sequence-impedance matrix using the following equation:

$$[A]^{-1}[Z_{abc}][A] = [Z_{012}], \quad (4)$$

where $[A]$ is the symmetrical components transformation matrix:

$$[Z_{012}] = \begin{bmatrix} (Z_s + 2Z_m) & 0 & 0 \\ 0 & (Z_s - Z_m) & 0 \\ 0 & 0 & (Z_s - Z_m) \end{bmatrix}. \quad (5)$$

Or

$$[Z_{012}] = \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix}. \quad (6)$$

Z_0 , Z_1 , and Z_2 are the zero, positive, and negative sequence impedances, respectively. Z_0 , Z_1 , and Z_2 are calculated as follows:

$$Z_1 = Z_2 = Z_s + Z_T + Z_L, \quad (7)$$

$$Z_0 = Z_T + Z_{L0}, \quad (8)$$

$$Z_{L0} = K_0 Z_L. \quad (9)$$

Z_T is the transformer impedance.

Z_L is a function of distance along the feeder to the fault point:

$$Z_L = s \left[r_L + jw l_n \frac{D_{eq}}{D_s} \right], \quad (10)$$

where s = length of line, r_L = line resistance, D_{eq} = equivalent spacing = $(D_{12}D_{23}D_{31})^{1/3}$, D_s = self GMD of conductor, and K_0 = Earth and ground wire condition.

Use

$$Z_B = \frac{V_{B-LL}^2}{S_{B-3\phi}} = \frac{V_{B-LN}^2}{S_{B-1\phi}}. \quad (11)$$

So we get Z_L in pu as

$$Z_{L\text{ pu}} = \frac{Z_L}{Z_B}. \quad (12)$$

The fault impedance Z_f is

$$Z_f = \frac{R_{FLT}}{Z_B}, \quad (13)$$

where R_{FLT} is the arcing fault resistance in ohms.

Thus, the fault currents are as follows:

$$I_{f-3\phi} = \frac{V_f}{Z_s + Z_T + Z_L + Z_f}, \quad (14)$$

$$I_{f-LL} = \frac{\sqrt{3}V_f}{2(Z_s + Z_T + Z_L) + Z_f}, \quad (15)$$

$$I_{f-SLG} = \frac{3V_f}{2Z_s + 3Z_T + (2 + K_0)Z_L + 3Z_f}. \quad (16)$$

As can be observed, the sequence impedances are functions of the distance s from the substation to the fault point. Since the parameter of interest is "s" and all other

parameters are known or can be calculated, "s" can be easily computed.

For 3- \emptyset fault,

$$s = \frac{[(V_f/I_f) - Z_s - Z_T - Z_f]}{[r_L + jw\ln(D_{eq}/D_s)]} \quad (17)$$

For line-to-line fault,

$$s = \frac{[(\sqrt{3} V_f/2I_f) - (Z_f/2) - Z_s - Z_T]}{[r_L + jw\ln(D_{eq}/D_s)]} \quad (18)$$

For single-line-to-ground fault,

$$s = \frac{[(3V_f/(2 + K_0)I_f) - (2Z_s + 3Z_T + 3Z_f/(2 + K_0))]}{[r_L + jw\ln(D_{eq}/D_s)]} \quad (19)$$

The flow chart for the impedance method is shown in Figure 1.

The Simulink model of the distribution system used for the impedance-based method is as follows.

The algorithm for the impedance-based method is done in the embedded MATLAB function of Figure 2. In Figure 3, the faults are placed at an interval of 10 km on the line. At any time, only one of the three-phase fault blocks is switched on.

3.2. Fuzzy Inference System. The structure of the fuzzy inference system is as shown in Figure 4.

The output of the system is the weighted average of the inputs based on the fuzzy logic if-then rules. The "if" statements are the antecedent blocks, while the "then" statements are the consequent blocks. The type of fuzzy inference system is the Mamdani fuzzy inference system because it gives fuzzy outputs, an indication that the result is an approximation. MATLAB's fuzzy logic toolbox is used to model the fuzzy inference system (FIS) and Simulink is used to test the system using SimPowerSystems library and fuzzy logic controller block. Two fuzzy inference systems were created. The first fuzzy inference system determines whether the fault is single-line-to-ground, line-to-line, double-line-to-ground, or line-to-line-to-line, while the second fuzzy inference system determines the location of the fault.

3.2.1. Fault Classifier FIS. The fault classifier identifies a fault as either single-line-to-ground fault, line-to-line fault, double-line-to-ground fault, three-phase-clear-of-ground fault, or three-phase-to-ground fault. Postfault currents of the phases after the transient period are used since at that time the fault currents would have attained their highest values. The ratios R_1 , R_2 , and R_3 are calculated first and normalized to get R_{1n} , R_{2n} , and R_{3n} of R_1 , R_2 , and R_3 , respectively, followed by the differences Δ_1 , Δ_2 , and Δ_3 . This is as follows:

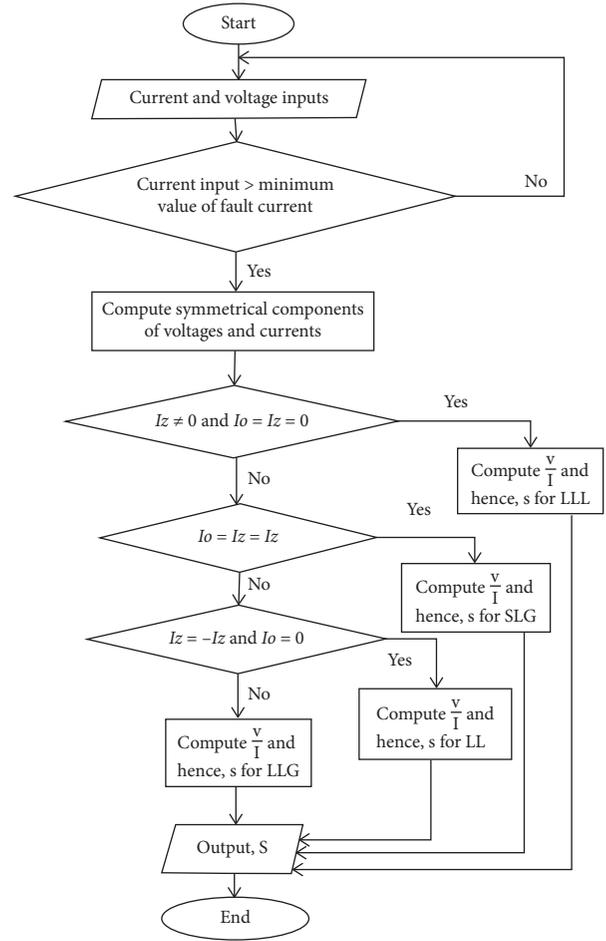


FIGURE 1: Flow chart for the impedance method.

$$R_1 = \frac{|I_a|}{|I_b|}, \quad (20)$$

$$R_2 = \frac{|I_b|}{|I_c|}, \quad (21)$$

$$R_3 = \frac{|I_c|}{|I_a|}, \quad (22)$$

$$R_{1n} = \frac{R_1}{\text{maximum}(R_1, R_2, R_3)}, \quad (23)$$

$$R_{2n} = \frac{R_2}{\text{maximum}(R_1, R_2, R_3)}, \quad (24)$$

$$R_{3n} = \frac{R_3}{\text{maximum}(R_1, R_2, R_3)}, \quad (25)$$

$$\Delta_1 = R_{1n} - R_{2n}, \quad (26)$$

$$\Delta_2 = R_{2n} - R_{3n}, \quad (27)$$

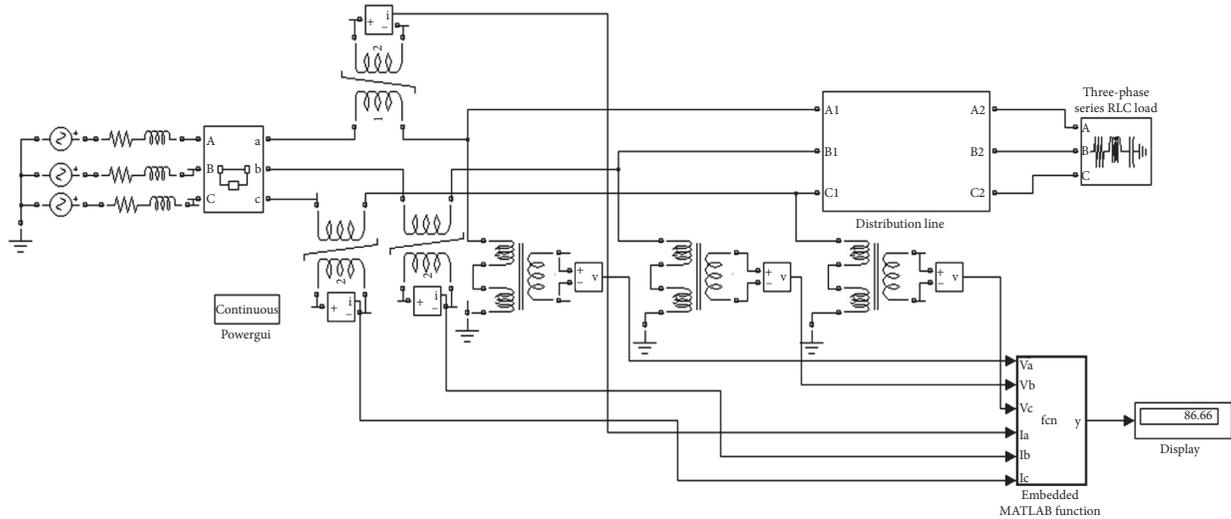


FIGURE 2: Simulink model for the impedance-based method.

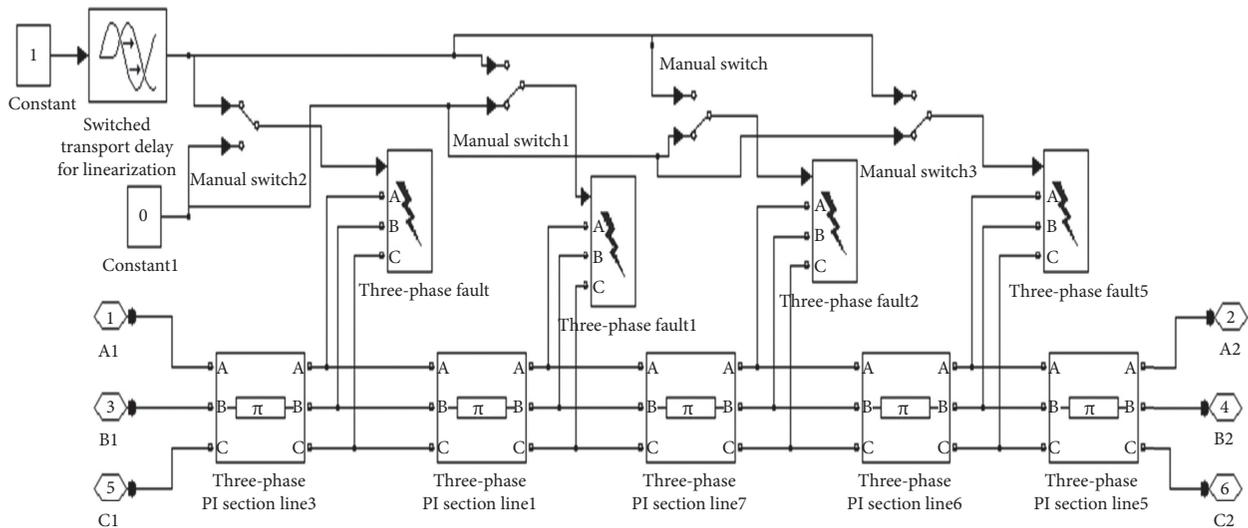


FIGURE 3: Simulink model for the distribution subsystem of Figure 2 with the faults switched on manually.

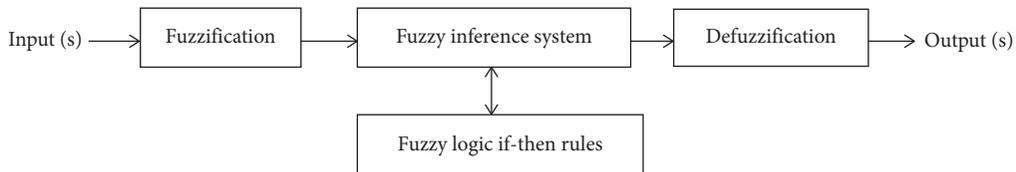


FIGURE 4: Structure of a fuzzy inference system.

$$\Delta_3 = R_{3n} - R_{1n}. \tag{28}$$

The ratios R_1 , R_2 , and R_3 determine the relative magnitude of the current in each phase with respect to another phase; it is expected that the phase (or phases) where the fault has occurred is the phase (or phases) with the largest current(s). Dividing the ratios by their maximum normalizes the ratios so that they have values

between one and zero. Δ_s determine the phases that are connected in a line-to-line fault; a small value for delta implies that the phases are connected in a line-to-line fault. If all three Δ_s are small, a three-phase fault exists between the three phases. In the event that a fault to ground occurs, the neutral current is no more zero, which implies that the zero-sequence current is not zero. The zero-sequence current is given as

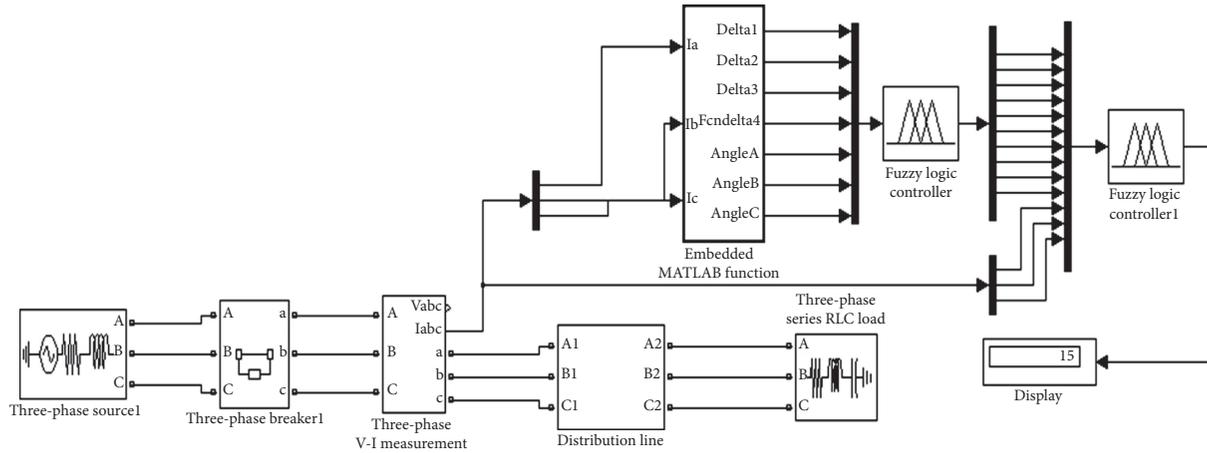


FIGURE 5: Simulink model for the fuzzy inference system method.

$$I_0 = \frac{I_N}{3} = \frac{1}{3} (I_a + I_b + I_c), \quad (29)$$

where I_a , I_b , and I_c represent phase 'a,' phase 'b,' and phase 'c' currents, respectively, and I_0 and I_N are zero-sequence and neutral currents, respectively. To take into account the zero-sequence current, Δ_4 is computed using the following equation:

$$\Delta_4 = |I_0| \quad (30)$$

A large value for Δ_4 shows the presence of a ground fault. The values of Δ_1 , Δ_2 , Δ_3 , and Δ_4 show what type of fault occurred. Δ_s calculated are not sufficient for fault classification; the phase differences between positive and negative sequence currents of each of the unbalanced current phasors have to be found. These are represented by angle A for phase "a," angle B for phase "b," and angle C for phase "c." The angles can be determined bearing in mind that the negative sequence is the positive sequence reversed. For a single-line-to-ground fault, phase "a" currents of the sequence networks are in phase; therefore,

$$\text{angle A} = |\arg(I_{a1}) - \arg(I_{a2})| = 0^\circ, \quad (31)$$

$$\text{angle B} = |\arg(I_{b1}) - \arg(I_{b2})| = 120^\circ, \quad (32)$$

$$\text{angle C} = |\arg(I_{c1}) - \arg(I_{c2})| = 120^\circ, \quad (33)$$

where $\arg(I_{a1})$ and $\arg(I_{a2})$ are the arguments of the positive and negative sequence components of current in phase 'a'; $\arg(I_{b1})$ and $\arg(I_{b2})$ are the arguments of the positive and negative sequence components of current in phase 'b'; and $\arg(I_{c1})$ and $\arg(I_{c2})$ are the arguments of the positive and negative sequence components of current in phase 'c.' The absolute value sign clears any negative that may arise from taking the difference. For three-phase faults, $\arg(I_{a2})$, $\arg(I_{b2})$, and $\arg(I_{c2})$ have no significance, since the fault is a balanced fault.

(a) *Fuzzification.* The inputs Δ_1 , Δ_2 , Δ_3 , Δ_4 , angle A, angle B, and angle C have to be converted to fuzzy variables. The process of doing so is called fuzzification. Membership functions are used to generate grades for the variables depending on their actual values. The triangular membership function is used. There is no rule for assigning membership functions to the inputs; rather membership functions are selected by trial and error with the aim of improving the result.

(b) *Fuzzy if-then rules.* The fuzzy if-then rules for the FIS are as shown in Appendix A.

(c) *Defuzzification.* To defuzzify the output, the centroid method is used. The outputs are the fault types: single-line-to-ground, double-line-to-ground, line-to-line, and three-phase faults.

3.2.2. *Fault Location FIS.* This takes as inputs the fault type from the first FIS and the fault currents detected by the CTs. Given the fault type and values of fault current, it outputs a distance s that corresponds to the pair. In the simulation, the faults are placed at intervals of 10 km in a 40 km line. With the knowledge of the maximum fault current that can flow on the line (when the fault occurs very close to the substation) for a given fault type, the fault location FIS is able to predict the location of the fault by associating different fault positions to different faults types. The if-then rules are listed in Appendix B.

The Simulink model for the entire setup is shown in Figure 5.

The Simulink model for the distribution subsystem of Figure 5 is shown in Figure 6.

4. Simulation and Results

In the MATLAB simulation, three-phase faults were placed at intervals of 10 km on a 40 km distribution line and the

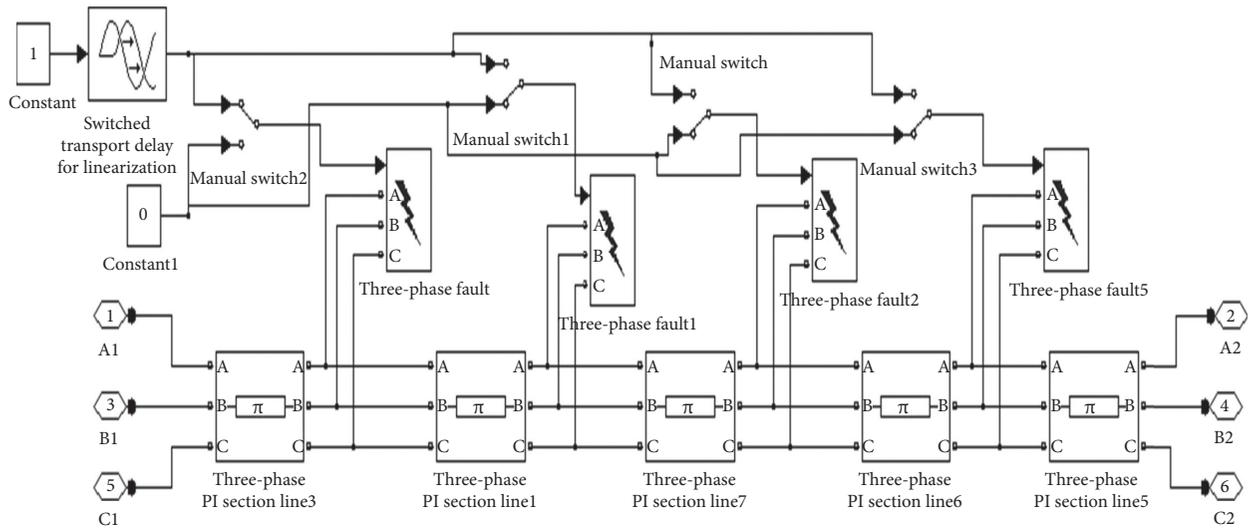


FIGURE 6: Simulink model for the distribution subsystem of Figure 5 with the faults switched on manually.

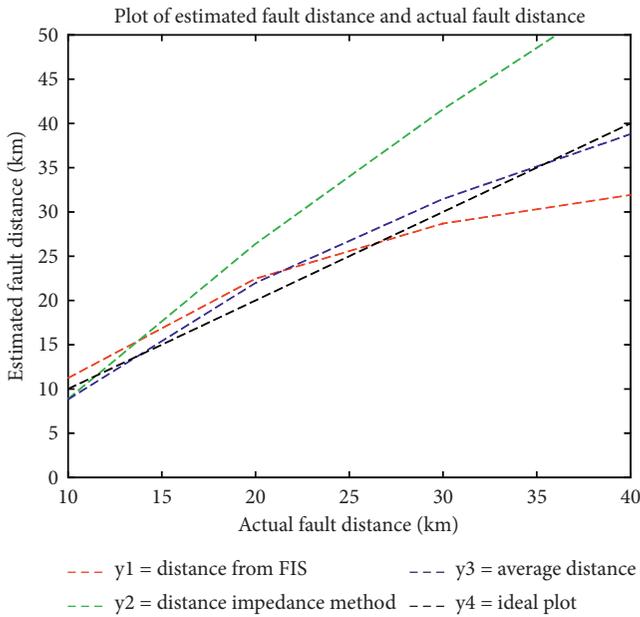


FIGURE 7: Plot of estimated fault distance versus actual fault distance for overhead distribution system.

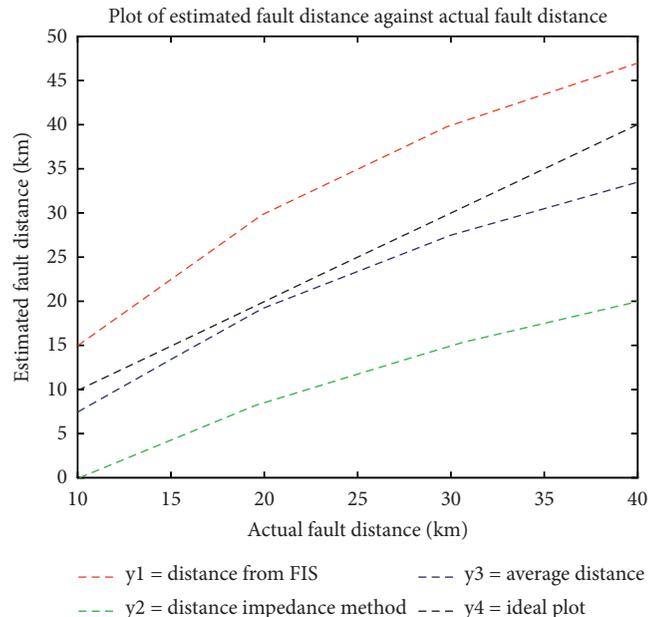


FIGURE 8: Plot of estimated fault distance versus actual fault distance for underground distribution system.

impedance-based method and fuzzy inference system method were used to estimate the location. The results of the simulation are shown in Figure 7.

As seen from the graph, taking the average is more accurate than using the result obtained from any of the two methods alone. If the error is estimated and added to the average fault distance, a better result will be obtained.

4.1. Application of the Proposed Method in the Underground Distribution System. The proposed methods were applied to a 40 km underground distribution system. The simulation results are shown in Figure 8.

5. Conclusion

In this work, an algorithm for calculating distance to the fault location on the distribution lines using impedance-based method and fuzzy inference system method was developed and applied on three-phase overhead and underground distribution systems. The algorithm can be implemented using information from a microprocessor-based relay, a microcontroller, and a simple spreadsheet, making both methods accessible tools for the small utility. The fuzzy inference system method should provide improvement over the impedance-based method for faults when the parameters are well tuned. Although the

simulation result shows that the composite technique is of good quality, the error in fault location estimation can be limited by calculating the error factor and multiplying the average fault distance by the error factor. This will give an improved average fault distance, thereby forming a good basis for small utilities to develop their own fault location method.

Appendix

A. The Fuzzy If-Then Rules for Fuzzification

- (1) If $\Delta 1$ is high and $\Delta 2$ is moderate and $\Delta 3$ is low and $\Delta 4$ is high and angle A is approx. 30° and angle B is approx. 150° and angle C is approx. 90° then fault type is phase "a" to ground.
- (2) If $\Delta 1$ is low and $\Delta 2$ is high and $\Delta 3$ is moderate and $\Delta 4$ is high and angle A is approx. 90° and angle B is approx. 30° and angle C is approx. 150° then fault type is phase "b" to ground.
- (3) If $\Delta 1$ is moderate and $\Delta 2$ is low and $\Delta 3$ is high and $\Delta 4$ is high and angle A is approx. 150° and angle B is approx. 90° and angle C is approx. 30° then fault type is phase "c" to ground.
- (4) If $\Delta 1$ is low and $\Delta 2$ is high and $\Delta 3$ is low and $\Delta 4$ is high and angle A is approx. 30° and angle B is approx. 90° and angle C is approx. 150° then fault type is phase "a" to phase "b" to ground.
- (5) If $\Delta 1$ is low and $\Delta 2$ is low and $\Delta 3$ is high and $\Delta 4$ is high and angle A is approx. 150° and angle B is approx. 30° and angle C is approx. 90° then fault type is phase "b" to phase "c" to ground.
- (6) If $\Delta 1$ is high and $\Delta 2$ is low and $\Delta 3$ is low and $\Delta 4$ is high and angle A is approx. 90° and angle B is approx. 150° and angle C is approx. 30° then fault type is phase "c" to phase "a" to ground.
- (7) If $\Delta 1$ is low and $\Delta 2$ is high and $\Delta 3$ is low and $\Delta 4$ is low and angle A is approx. 30° and angle B is approx. 90° and angle C is approx. 150° then fault type is phase "a" to phase "b."
- (8) If $\Delta 1$ is low and $\Delta 2$ is low and $\Delta 3$ is high and $\Delta 4$ is low and angle A is approx. 150° and angle B is approx. 30° and angle C is approx. 90° then fault type is phase "b" to phase "c."
- (9) If $\Delta 1$ is high and $\Delta 2$ is low and $\Delta 3$ is low and $\Delta 4$ is low and angle A is approx. 90° and angle B is approx. 150° and angle C is approx. 30° then fault type is phase "c" to phase "a."
- (10) If $\Delta 1$ is moderate and $\Delta 2$ is moderate and $\Delta 3$ is low and $\Delta 4$ is low and angle A is none and angle B is none and angle C is none then fault type is phase "a" to phase "b" to phase "c."
- (11) If $\Delta 1$ is moderate and $\Delta 2$ is low and $\Delta 3$ is moderate and $\Delta 4$ is low and angle A is none and angle B is none and angle C is none then fault type is phase "a" to phase "b" to phase "c."
- (12) If $\Delta 1$ is low and $\Delta 2$ is moderate and $\Delta 3$ is moderate and $\Delta 4$ is low and angle A is none and angle B is none and angle C is none then fault type is phase "a" to phase "b" to phase "c."
- (13) If $\Delta 1$ is moderate and $\Delta 2$ is low & $\Delta 3$ is low and $\Delta 4$ is low and angle A is none & angle B is none and angle C is none then fault type is phase "a" to phase "b" to phase "c."
- (14) If $\Delta 1$ is low and $\Delta 2$ is moderate and $\Delta 3$ is low and $\Delta 4$ is low and angle A is none and angle B is none and angle C is none then fault type is phase "a" to phase "b" to phase "c."
- (15) If $\Delta 1$ is low and $\Delta 2$ is low and $\Delta 3$ is moderate and $\Delta 4$ is low and angle A is none and angle B is none and angle C is none then fault type is phase "a" to phase "b" to phase "c."

B. The Fuzzy If-Then Rules for Defuzzification

- (i) If fault type is *a-g* and I_a is low then location is far
- (ii) If fault type is *a-g* and I_a is medium then location is middle
- (iii) If fault type is *a-g* and I_a is high then location is near
- (iv) If fault type is *b-g* and I_b is low then location is far
- (v) If fault type is *b-g* and I_b is medium then location is middle
- (vi) If fault type is *b-g* and I_b is high then location is near
- (vii) If fault type is *c-g* and I_c is low then location is far
- (viii) If fault type is *c-g* and I_c is medium then location is middle
- (ix) If fault type is *c-g* and I_c is high then location is near
- (x) If fault type is *a-b* and I_a is low and I_b is low then location is far
- (xi) If fault type is *a-b* and I_a is medium and I_b is medium then location is middle
- (xii) If fault type is *a-b* and I_a is high and I_b is high then location is near
- (xiii) If fault type is *b-c* and I_b is low and I_c is low then location is far
- (xiv) If fault type is *b-c* and I_b is medium and I_c is medium then location is middle
- (xv) If fault type is *b-c* and I_b is high and I_c is high then location is near
- (xvi) If fault type is *c-a* and I_c is low and I_a is low then location is far
- (xvii) If fault type is *c-a* and I_c is medium and I_a is medium then location is middle

- (xviii) If fault type is $c-a$ and I_c is high and I_a is high then location is near
- (xix) If fault type is $a-b-g$ and I_a is low and I_b is low then location is far
- (xx) If fault type is $a-b-g$ and I_a is medium and I_b is medium then location is middle
- (xxi) If fault type is $a-b-g$ and I_a is high and I_b is high then location is near
- (xxii) If fault type is $b-c-g$ and I_b is low and I_c is low then location is far
- (xxiii) If fault type is $b-c-g$ and I_b is medium and I_c is medium then location is middle
- (xxiv) If fault type is $b-c-g$ and I_b is high and I_c is high then location is near
- (xxv) If fault type is $c-a-g$ and I_c is low and I_a is low then location is far
- (xxvi) If fault type is $c-a-g$ and I_c is medium and I_a is medium then location is middle
- (xxvii) If fault type is $c-a-g$ and I_c is high and I_a is high then location is near
- (xxviii) If fault type is $a-b-c$ and I_a is medium and I_b is medium and I_c is low then location is far
- (xxix) If fault type is $a-b-c$ and I_a is high and I_b is high and I_c is high then location is middle
- (xxx) If fault type is $a-b-c$ and I_a is very high and I_b is very high and I_c is very high then location is near

Data Availability

The data used for this research are available and can be provided upon request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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