

# Improving the Impedance Based Fault Location Method in Distribution Network Considering the Distributed Generation Unit

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**Abstract** – In this paper an improved impedance based fault location method is proposed. In this method, online fault locating is performed using voltage and current information at the beginning of the feeder. Determining precise fault location in a short time increases reliability and efficiency of the system. The proposed method utilizes information about main component of voltage and current at the beginning of the feeder and distributed generation unit (DGU) in order to precisely locate different faults in acceptable time. To evaluate precision and accuracy of the proposed method a 13-node is simulated and tested using MATLAB.

**Keywords** – Distribution Network, Fault Section Determination, Distributed Generation Units, Distribution Protection Equipment.

## I. INTRODUCTION

Electricity distribution networks, which are the last part of electricity generation transmission and distribution chain, have attracted a great attention recently. In addition to this section, nowadays, renewable energies are becoming increasingly popular due to clean and cheap energy they provide. Therefore, the growth of distributed generation units necessitates considering them in all research works [1]. Fault locating is a prominent issue in power system protection. Precise and accurate fault location considerably decreases non-distributed energy, increases system profitability and increases costumers' satisfactory. There are several factors which make fault location complicated and time consuming. These include widespread network, large number of lateral branches, asymmetry between overhead lines or underground cables (intersection and phase arrangement), distribution transformers in different points and installation of only one data register for fault voltage and current data [2]. Power distribution systems are usually a radial system with unbalanced load. In other words, in power distribution systems, current flows in one direction and different loads are located along a horizontal line [3,4]. Nowadays, however, modern technology and increasing demand for electricity has caused the current system to lack sufficient supply for power demand; thus, to compensate for increasing demand various types of distributed generation units have been utilized in power distribution systems [5]. According to performed research, cost of installation and setup of distributed generation units have been much cheaper than the cost of developing transmission lines. There are further advantages for distributed generation units such that it is anticipated that

distributed generation will constitute considerable portion of power plants [6,7]. Distributed generation systems have many permum, but unfortunately, they have inductions when bechance fault, so distributed generation results in multi-fed distribution system which, in turn, leads to protection problems in power distribution system. As a consequence power generation rate of distributed generation units become slower [8]. Distributed generation units usually depend on renewable energies and various commercial strategies in the industry. Presence of distributed generation units and their generated power changes radial characteristic of the system as there is a new source in the system. In this paper, firstly, steady state analysis of a distribution system without distributed generation in presence of fault is performed in presence of fault and fault location is determined. In the second section, the impacts of distributed generation units are studied and analyzed. In third section the proposed fault location method in the distribution network in presence of distributed generation is completely presented. Finally, fourth section includes simulation and test results.

## II. PROPOSED METHOD

### Fault location without distributed generation units

Consider the circuit depicted in figure 1. All loads located further than fault location are represented by an equivalent load,  $Z_r$  and total current sent to these loads is  $I_{La}$ . The voltage measured in local terminal (the terminal where data is measured), is obtained from this equation:

$$V_{S_a} = x \cdot (Z_{L_{aa}} \cdot I_a + Z_{L_{ab}} \cdot I_b + Z_{L_{ac}} \cdot I_c) + I_f \cdot R_f \quad (1)$$

$V_{S_a}$ : phase a voltage

$x$ : fault distance

$Z_{L_{aa}}$ : Impedance matrix [per km]

$Z_{L_{ab}}$ : Impedance between phase a and b

$Z_{L_{ac}}$ : Impedance between phase a and c

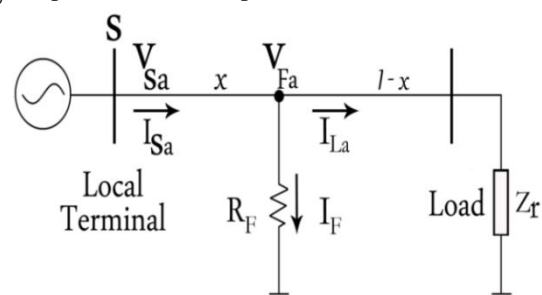


Fig.1. Faulty distribution system

If fault locates in the lateral single phase line, the voltage equation is as follows:

$$V_{S_a} = x \cdot (Z_{L_{aa}} \cdot I_a) + I_f \cdot R_f \quad (2)$$

Note that voltage equation includes three unknown variables: line distance ( $x$ ), fault resistance ( $R_f$ ) and fault current ( $I_f$ ). Considering real and imaginary parts of voltage equation and eliminating fault resistance, the fault distance equation is derived:

$$x = \frac{V_{a_r} \cdot I_{f_i} - V_{a_i} \cdot I_{f_r}}{A \cdot I_{f_i} - B \cdot I_{f_r}} \quad (3)$$

$$A = Z_{L_{aa_r}} \cdot I_{a_r} - Z_{L_{aa_i}} \cdot I_{a_i} + Z_{L_{ab_r}} \cdot I_{b_r} - Z_{L_{ab_i}} \cdot I_{b_i} \\ + Z_{L_{ac_r}} \cdot I_{c_r} - Z_{L_{ac_i}} \cdot I_{c_i}$$

$$B = Z_{L_{aa_r}} \cdot I_{a_i} + Z_{L_{aa_i}} \cdot I_{a_r} + Z_{L_{ab_r}} \cdot I_{b_i} + Z_{L_{ab_i}} \cdot I_{b_r} \\ + Z_{L_{ac_r}} \cdot I_{c_i} + Z_{L_{ac_i}} \cdot I_{c_r}$$

And fault resistance equation is achieved as follows:

$$R_f = \frac{-B \cdot V_{a_r} + A \cdot V_{a_i}}{A \cdot I_{f_a_i} - B \cdot I_{f_a_r}} \quad (4)$$

( $r$ ;  $i$ ) subscript denotes real and imaginary part and ( $I_f$ ) can be calculated using the relation between load current and line current.

$$I_f = I_a + I_{L_a} \quad (5)$$

Equations 3 and 5 are valid for phase to ground fault of decoupled power system. Equations for other fault conditions such as phase to phase, phase to ground and three-phase, might be obtained through the same procedure.

In this paper the following algorithm is employed to estimate fault location:

- $I_{L_a}$  is assumed to be the main load current before fault occurrence.
- Equation 5 is used to estimate fault current.
- Equation 3 estimates fault location.

At this step convergence of  $x$  is checked. If  $x$  converges, it is sent for print; otherwise, the algorithm repeats once more.

- Equation 6 calculates voltage of estimated point.

$$\begin{bmatrix} V_{S_a} \\ V_{S_b} \\ V_{S_c} \end{bmatrix} = \begin{bmatrix} V_{f_a} \\ V_{f_b} \\ V_{f_c} \end{bmatrix} - x \cdot \begin{bmatrix} Z_{L_a} & \cdot & I_{S_a} \\ Z_{L_b} & \cdot & I_{S_b} \\ Z_{L_c} & \cdot & I_{S_c} \end{bmatrix} \quad (6)$$

- Using the fault voltage calculated in the previous step a new load current is calculated
- Using the derived load current, algorithm is repeated again from step B

In the described algorithm in step c, it is necessary to calculate system current which is obtained through circuit analysis. As shown in figure 1, it is easy to derive the current after fault point when voltage in fault point (which is estimated), equivalent load and line impedance are known. Moreover, various line models might be utilized to estimate new load described in equation 5.

If the algorithm converges, fault is estimated wherever it is in the distribution system. In each step of fault location using this algorithm,  $V_{sa}$  and  $I_{sa}$  are updated for the next step. Updating these values decreases faults associated with line loss and topology of power system distribution

components which are resulted from different loads in the line.

Considering figure 2, updated voltage and current are obtained according to equations 7 to 9.

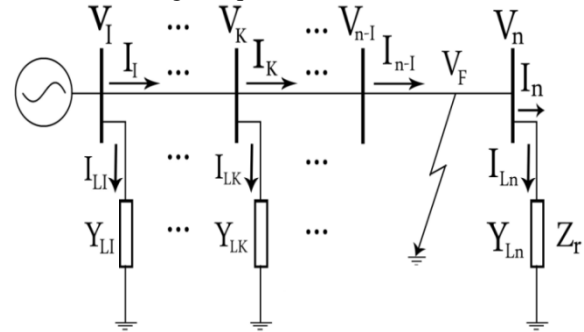


Fig.2. Updated voltage and current in local terminal

$$V_{k+1} = V_k - Z_k \cdot I_k \quad (7)$$

$$I_{L_k} = V_k \cdot Y_{L_k} \quad (8)$$

$$I_k = I_{k-1} - I_{L_k} \quad (9)$$

Updating voltage and current, the algorithm restarts and the new fault point is determined more precisely. This procedure continues till convergence is achieved in the estimation fault location.

### III. EFFECTS OF DISTRIBUTED GENERATION UNITS

Problems associated with connection of power generation equipment in distribution systems arise in different aspects: stability, voltage regulation, system stability and so on. Some of these problems such as voltage sags due to high current protection include several fields of study [9].

The most prominent effect of distributed generation units in power distribution systems is variations in system power flow. Power distribution systems with radial power flow are not radial anymore in presence of distributed generation units. In system protection plan this characteristic must be considered in cases including equipment protection coordination and proper selection. Furthermore, fault current, phase angle and current in different parts of supply line may change. The portion of distributed generation from total power generation can change fault current in many sections of the feeder. Besides, magnitude and direction of fault current depend on power supplied by distributed generation units and their location in the system.

Distributed generation units also affect system protection in distribution systems. Distributed generation units may change direction and amplitude of currents in distribution systems. Therefore, all coordination and adjustments of protection devices must be performed once again. Moreover, as radial property of distribution system is disturbed (when distributed generation unit is connected) new protection equipment must be determined so that effective protection is provided [10].

Determining the effects of distributed generation units on distribution systems described in section 3, a more precise descriptive model of the system could be obtained. For distributed generation units a machine model must be used to precisely specify the status including effects of distributed generation units and facilitates fault location estimation with acceptable precision. Furthermore, distributed generation units must be considered in updated voltage and current states because their injected power depends on the power flows in the system.

#### IV. THE PROPOSED METHOD FOR FAULT LOCATING IN PRESENCE OF DISTRIBUTED GENERATION UNIT

Consider a distribution system in presence of distributed generation unit:

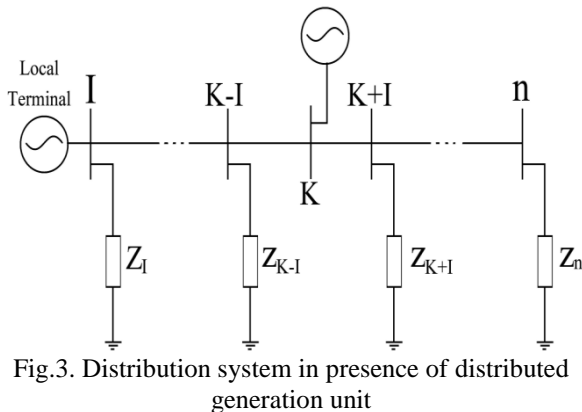


Fig.3. Distribution system in presence of distributed generation unit

As illustrated in the figure, the side before the source is connected to nodes 1 to k-1 and the next section is related to nodes k+1 to n. the proposed fault locating algorithm considering source starts through steps A to F explained in section 2. The algorithm starts while it considers the fault at the beginning of the supply line i.e. before the source.

- $I_{L_a}$  is assumed to be the load current before fault occurrence
- Equation 5 is used for fault current calculation.
- Fault distance is estimated using equation 3. Then convergence is checked and in case of convergence, the calculated value is sent for print; otherwise, the algorithm is repeated.
- fault point voltage is calculated using equation 6, for this purpose the system including distributed generation unit explicated in section 5, is considered. Station voltages and currents for stations before fault location are calculated.

According to figure 2, fault point voltage is derived from undergoing equation.

$$V_f = V_{n-1} - I_{n-1} \cdot Z_{line} \cdot x \quad (10)$$

Where  $Z_{line}$  is line impedance per 1 kilometer of faulty line and  $x$  is the distance from n-1 station to fault point.

e) Using fault point voltage obtained in the previous step, total system Thevenin equivalent circuit is derived in two following states.

e.1. if the fault location estimated in step 3 is after generation unit, equivalent circuit is shunt to loads mixed

by line impedance after fault point. At this time current is updated again (with updated current and voltage values belonging to the first station before fault point). This current is obtained from the following equation.

$$I_{L_a} = \frac{V_f}{V_{th}} \quad (11)$$

e.2. in contrast if fault location is before distributed generation unit, thevenin equivalent circuit includes power supply in the feeder. In this circumstance, new load current is derived from the equation below.

$$I_{L_a} = \frac{V_f - V_{th}}{Z_{th}} \quad (12)$$

d) Algorithm returns to step b. similar to what explained for distribution systems without distributed generation units, the outputs of this algorithm are distance of fault from the beginning of distribution system feeder. To achieve higher precision considering load distribution and loss of distribution lines, it is required to update voltages and currents measured in local terminals to restart algorithm again and another point must be estimated. This update continues till more precise voltages and currents are derived and supply line terminates.

#### V. DESCRIPTIVE MODEL OF DISTRIBUTED GENERATION

The electrical model of distributed generation unit in this study is synchronous generator model demonstrated in figure 4.

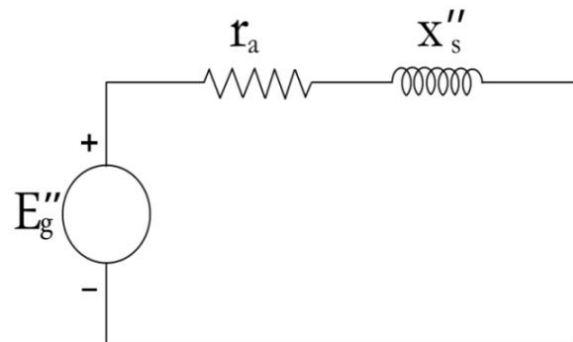


Fig.4. Distributed generator model

This model is a combination of  $X_s''$  (transient reactance),  $r_a$  (armature resistance) and  $E_g''$  (internal voltage) for synchronous generator.

#### VI. SIMULATION AND RESULTS

13-node three-phase system shown in figure 5 is simulated using MATLAB software. Loads are modeled as constant impedances.

The following system is a radial feeder with several distributed loads in the line and these feeders are supplied with a 20kV voltage source. In this system lateral loads, RL loads and sections of each feeder are modeled as series RL circuits between phases. In this system distributed generation unit is connected to node 13 and its voltage is 20 kV.

In table 1 fault percentage in different feeders is calculated with negligible error and table 2 fault percentage in fault starting angles is calculated.

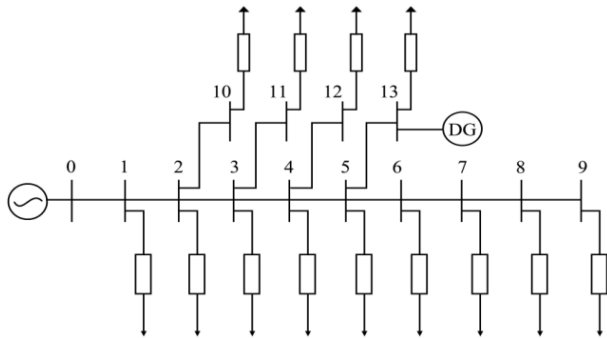


Fig.5. 13 node distribution system with distributed generation unit

**A- Effect of Sections Difference**

By changing the fault section, accuracy is reduced. In other words, the ultimate accuracy is reduced. But, As proposed algorithm has been developed, So changes in difference fault distance in difference sections do not effect on performance of the proposed algorithm. The Results are shown in table [1] confirms this fact.

Table I: Error percentage in different feeders

Error percentage	Obtained Distance	Distance from feeder beginning in terms of Kilometer	First and Final section	No.
0.0003	4.999	5	0-1	0
0.0014	6.9963	27	1-2	1
0.0001	9.4996	49.5	2-3	2
0.0012	9.9967	70	3-4	3
0.0049	11.9821	92	4-5	4
0.0064	13.9832	114	5-6	5
0.0153	14.9601	135	6-7	6
0.0016	9.9956	150	7-8	7
0.0386	2.8996	163	8-9	8
0.0014	9.9962	50	2-12	9
0.0013	8.4964	68.5	3-11	10
0.0025	9.9933	90	4-12	11
0.0089	6.4708	106.5	5-13	12

**B- Effect of Fault Inception Angle**

Because proposed algorithm works based on voltage and current at the beginning of feeder, changes in voltage angle even smallest one, have no considerable effect on algorithm performance. Therefore proposed algorithm has an acceptable performance for voltage angles. Table [2] has summarized results for simulation of fault with different starting angles.

Table II: Error percentage in different fault starting angles

Error Percentage	Fault Starting Angle	Faulty Section	No.
0.00442	0.8525	Fault in distributed generation unit feeder	1
0.01096	0.855		2
0.20142	0.8575		3
0.95288	0.86		4
0.02357	0.8625		5
0.00846	0.865		6
0.93811	0.8675		7
1.322	0.87		8

**VII. CONCLUSION**

In this paper a novel method was presented for fault location in radial distribution systems in presence of distributed generation units. It locates fault based on voltage and current samples of feeder and DGU register. In the impedance based proposed method all sections of distribution systems are investigated to find fault location, first, based on voltage and current information before fault occurrence. Then, all sections are examined based on information registered in the location of main supply after fault occurrence.

Single phase to ground fault was simulated on 13-node distribution system in MATLAB software. The obtained results revealed that the proposed algorithm is precise and its sensitivity to different fault distances is ignorable.

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