Volume 9, Issue 4, April – 2024 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

Development of Smart Ground Fault Location Model for Radial Distribution System

I. C. Oji[1]; T. O. Ale[2]; C. S. Odeyemi[3]; O. I. Dare-Adeniran[4]; O. A. Aliyu[5]
[1,2,4,5]Department of Electrical and Electronics Engineering,[3] Department of Computer Engineering,
The Federal University of Technology, Akure, Nigeria

Corresponding Author: I. C. Oji[1*]

Abstract:- Fault is a regular incidence on distribution power system because distribution lines are always exposed to the environment with high probability of fault occurrence which when it happens, can cause hazardous conditions, equipment failures, power instability, huge financial loss and other forms of setback. In order to avoid these setbacks, it is necessary to detect and locate the fault on the network as fast as possible so as to prevent power system damages and reduce system downtime. This research study designed a smart fault location system model that detected and located ground faults at the point of occurrence using a developed 33 kV Ubulu-Uku radial distribution system as a test feeder and then formulated fault location equations which resulted into one single equation for all ground fault types on the network. The designed algorithm was evaluated on MATLAB 2023a environment using different line impedances of 0.01 Ω, 0.15 Ω, 0.35 Ω, 0.50 Ω, and 0.65 Ω which produced various ground faults located along path 6 section 17, path 8 section 21, path 8 section 21, path 4 section 12 and path 8 section 21 with distance of fault from the main substation obtained at 3.51 km, 3.93 km, 4.03 km, 4.81 km, and 4.21 km. The results presented show performance of the designed algorithm and can be encouraged for practical implementation with promising result which will achieve some benefits like precise fault location information analysis, reduce the overall response time spent by maintenance crew to locate fault and reduce cost of operational maintenance and supply interruptions.

***Keywords**:- Faults, Distribution Network, Fault Location, Impedance-Based Method.*

I. INTRODUCTION

Faults refer to any abnormal conditions or malfunctions in the distribution system that can disrupt the flow of electricity. It results in the deviation of voltages and current from normal values or state which allows excessively high current to flow and causes damage to equipment and devices [1]. Faults are classified as *series faults* and *shunt faults*, with shunt fault affecting distribution system frequently and severely, occurring as a result of the uneven linking of a lower impedance between two points with different potentials and are characterized by increase in current, and fall in both voltages and frequency [2]. The distribution system, as part of the electrical power system network, connects the bulk sources to the customer's sources using overhead distribution lines allowing the lines to be exposed to environmental disturbances. Faults on distribution system can take various forms and can be caused by factors like equipment failures, weather events, physical damage to power lines such as accidents, vandalism or other issues [3]. It occurs as a result of failure of insulation between overhead conductors or between phase conductors with ground or both and it is evaluated that 80% of customer's disturbances arise due to the impact of faults in distribution system [4] and [5]. In three phase power distribution system, shunt faults are categorized into two (2) groups which are *ground fault* and *phase fault* [4].

When faults occur on distribution line, the nature of the fault must be determined and eliminated and this process can be accelerated if fault location can be either determined quickly or estimated with reasonable accuracy so as to improve system and service reliability. Moreover, as the size and complexity of power system grows, the probability of fault occurrence becomes very high making it necessary to recognize and locate such faults as soon as it occurs using faster and more reliable accurate system [6]. An accurate estimation of fault location in distribution system, at most times, presents a huge and challenging task which are mostly due to the topology and distance covered by the distribution network, inadequate comprehensive real-time monitoring devices, use of obsolete equipment and failure of overhead wire joints and connections [7]. In some local areas in Nigeria today, the fault location techniques associated with distribution networks is still based on receiving trouble calls from the affected customers, visual inspections, and field assessment method [8]. To overcome these challenges, the use of remote monitoring technology and fault location algorithm need to be employed for fault detection and location on distribution networks [9] using various suitable fault location methods.

Various fault location methods, such as travelling wave method, intelligence-based method, and State estimation method exist [6] and a lot of research work have been carried out on related literature on fault location. In [9-11], the use of special properties of travelling wavelet transforms to differentiate between faults occurring along different laterals was presented but was focused on high voltage transmission line with the use of discrete wavelet transform. This method is mostly suitable for high voltage transmission lines and very

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

long distribution networks but characterized by decreased accuracy for network with smaller distances. In [12], the use of high frequency components of currents and voltage was presented using the generated harmonics from the instantaneous values of phase current and voltage from the two node ends of overhead power lines during short circuit to determine and detect the relative value of the distance from the main substation to the short circuit location and locate faults in an automated distribution network. [13] also presented a similar technique were harmonic distortion waveform generated from voltage and current components was used to determine the location and distance of fault. The drawback of this method is that the harmonics generated from the current and voltage were not filtered to reduce the effect of noise and undesirable harmonic components thereby affecting the accuracy of the fault location with considerable error in its desired distance estimation. An algorithm was designed to detect, identify and locate fault in inhomogeneous radial distribution having limited laterals by [14] using one terminal end and also by [15] using two terminal ends through the use of generated signals of voltage and current. The limitation was that the method did not consider a distribution network with many laterals and sub-laterals. Also, the use of voltage sag pattern in locating fault was researched into by [16] with the use of phasor angle of faulted sections. This method was used for large distribution lines of distance not less than 70km (> 70 km) with multiple measurements making it unsuitable for distribution system with smaller distances and real-time limited measurement values thereby reducing its accuracy in locating fault. Intelligence-based methods such as Artificial Neural Network (ANN) by [7], Genetic Algorithm by [17] and Hybrid classifier method by [18] as proposed in their research were used to detect and recognize fault which was simulated on various software program such as MATLAB, and Electromagnetic Transient Program (EMTP). These methods, which were used to analyze, detect and locate faults on active distribution networks, made use of large information and data obtained from past fault records of the network but its major drawback is that it needs to be trained and retrained at any circumstance of the network which increases complexity of the method, and for distribution network with smaller distances and limited real-time measurement, the method may not give accurate result because the more the data obtained and trained, the higher the level of accuracy. [19] proposed algorithm which was developed to determine fault location using deviations from pre-fault and post-fault voltage and current using Electromagnetic Transient Program (EMTP) for simulation and analysis with focus on the secondary (low voltage side) distribution network. [6] also developed an algorithm which was implemented on a Smart Feeder Meter to locate fault using its equivalent load impedance which was simulated on MATLAB. The method is not cost-effective because it requires Smart Feeders Meters (SFM) to be installed at every distribution substation point on the network. However, impedance-based method of estimating fault location and distance was utilized because it does not require high resolution measurement which is a main advantage of the method and it does not require specialized equipment in its analysis but make use of standard voltage, current and line impedance measurements that are readily available, thus making it cost effective and practicable.

II. MATHEMATICAL MODEL DEVELOPMENT

In order to determine the location and distance of fault from the substation, there is need to develop a mathematical equation which will make use of voltage, current and impedance measured from the main substation. A distribution line can be represented by a line model section as seen in Figure (1)

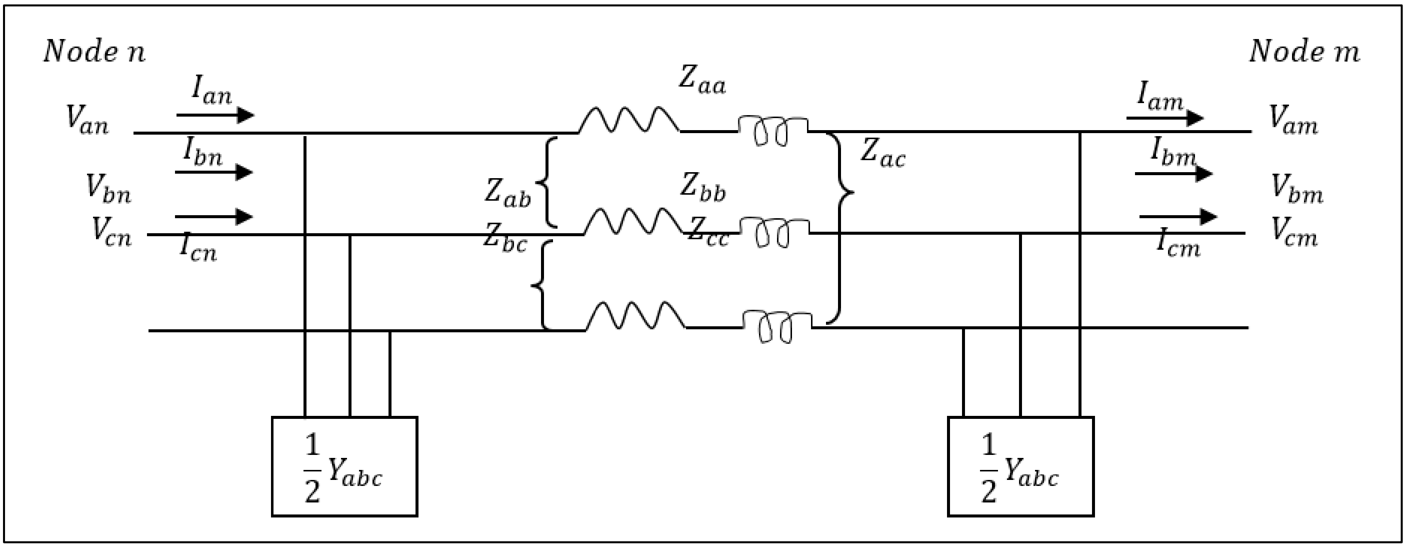


Fig 1: Three-Phase Exact Line Segment Model [20]

Using Kirchoff's voltage and current laws, the general equation defining the output node m and input node n voltage and current are given in Equation (1) expressed in matrix form

$$\begin{bmatrix} V_{abc} \\ I_{abc} \end{bmatrix} \square = \begin{bmatrix} d & -b \\ -c & a \end{bmatrix} \begin{bmatrix} V_{abc} \\ I_{abc} \end{bmatrix} \square \quad (1)$$

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

Where

$$a = d = I + 0.5\, x^2\, Z_{abc}\, Y_{abc} \quad (2)$$
$$b = x\, Z_{abc} \quad (3)$$
$$c = x\, Y_{abc} + 0.25\, x^3\, Y_{abc}\, Z_{abc}\, Y_{abc} \quad (4)$$

Where

I is the third order identity matrix, Z_{abc} is the line series impedance in (Ω/km), Y_{abc} is the shunt admittance in (Ω^{-1}/ km), and *x* is the length of the line section in (m).

For a fault located in *x* kilometer from the beginning of the line, the fault voltage V_f can be written from Equation (1) and expressed as seen in Equations (5).

$$V_f = d_x\, V_n - b_x\, I_n \quad (5)$$

Fault that occurs on distribution line exist in two major forms; *ground fault* and *line fault*. Fault location and distance for ground faults can be determined through the development of a mathematical model.

Ground fault in distribution system occurs when an unintended electrical connection is made between an energized conductor and the earth or ground [1]. This can happen as a result of insulation breakdown, equipment failure or accidental contact with a conductive surface. It is potentially dangerous as it can lead to electrical shock, equipment damage and even fire [21]. It can present itself as *single line – to -ground (SLG), double line – to – ground (DLG)* and *three phase – to – ground* faults.

Considering Figure (2) which presents the most general ground fault.

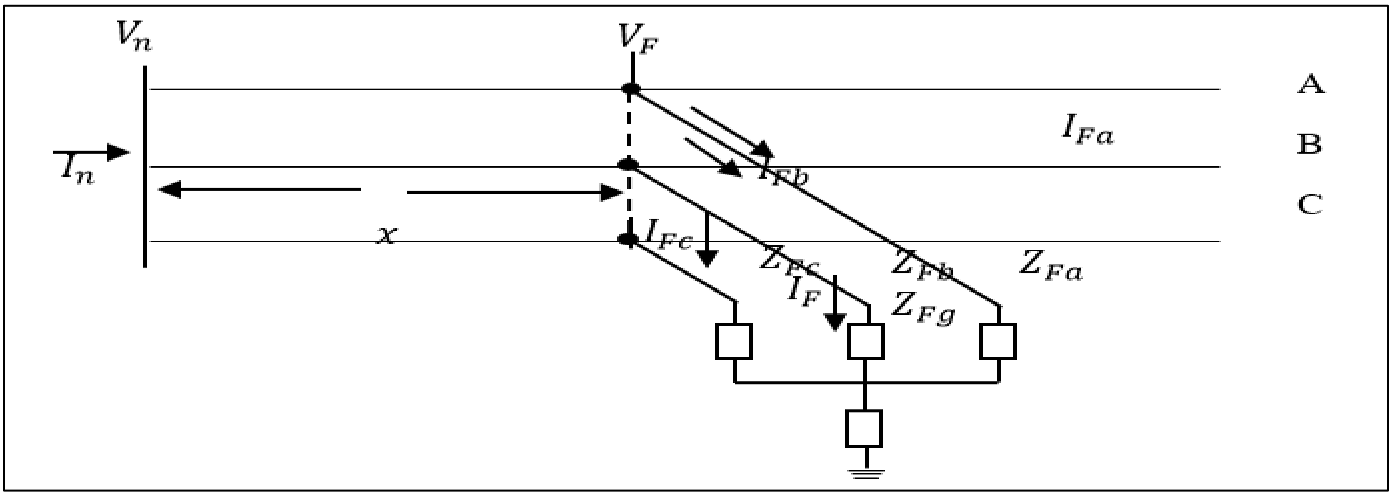


Fig 2: Distribution Line Subjected to Ground Fault [20]

The voltage and current relation at the fault point for this model is given by Equation (6)

$$\begin{bmatrix} V_{fa} \\ V_{fb} \\ V_{fc} \end{bmatrix} = \begin{bmatrix} Z_{fa} + Z_{fg} & Z_{fg} & Z_{fg} \\ Z_{fg} & Z_{fb} + Z_{fg} & Z_{fg} \\ Z_{fg} & Z_{fg} & Z_{fc} + Z_{fg} \end{bmatrix} \begin{bmatrix} I_{fa} \\ I_{fb} \\ I_{fc} \end{bmatrix} \quad (6)$$

Where

$V_{f\,(abc)}$ is the fault point voltage at phase a, b, c (in volt), $I_{f\,(abc)}$ is the fault current on phase a, b, c (in amps), and $Z_{a,b,c\text{-}g}$ is fault impedance at phase a, b, c and ground (in ohms).

From Equation (6), it will be seen that only the faulted phase has fault current that is non-zero ($I_f \neq 0$). Replacing Equation (6) into Equation (5), each faulted phase can be written as seen in Equation (7)

$$Z_{f_k} \cdot I_{f_k} + Z_{f_g} \cdot I_{f_k} = 0.5x^2 \cdot Z_{abc} \cdot Y_{abc} \cdot V_{n_k} - x \cdot Z_{abc} \cdot I_{n_k} + V_{n_k} = 0.5x^2 \cdot M_k - x \cdot N_k + V_{n_k} \quad (7)$$

where

$$M_k = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \cdot \begin{bmatrix} Y_{aa} & Y_{ab} & Y_{ac} \\ Y_{ba} & Y_{bb} & Y_{bc} \\ Y_{ca} & Y_{cb} & Y_{cc} \end{bmatrix} \cdot \begin{bmatrix} V_{n_a} \\ V_{n_b} \\ V_{n_c} \end{bmatrix} \quad (8)$$

$$N_k = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \cdot \begin{bmatrix} I_{n_a} \\ I_{n_b} \\ I_{n_c} \end{bmatrix} \quad (9)$$

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

When expanding Equation (7), it will result in *n* equations existing in their complex form where *n* represents the total number of faulted phases and by conducting algebraic operations involving complex algebra, the fault location equation for ground fault can finally be written as expressed in Equation (11)

$$x^2\left[0.5\sum_{k\in\Omega_k}\{M_k\cdot I^*_{f_k}\}\right] - x\left[\sum_{k\in\Omega_k}\{N_k\cdot I^*_{f_k}\}\right] + \left[\sum_{k\in\Omega_k}\{V_{n_k}\cdot I^*_{f_k}\}\right] = 0 \quad (10)$$

Equation (10) becomes the *Generalized Ground Fault Location Equation* (GFLE) which is used to estimate the possible fault distance equation by using the 3-phase voltages and current measured at the substation, the line parameters and also the fault current. These variables are used to calculate the coefficients M and N in Equation (10) considering its computations obtained from Equations (8) and (9). The fault location equation expressed in Equation (10) is a second-order quadratic equation used in obtaining the equation of fault distance x within a known faulty section. Equation (10) can be further simplified and expressed as seen in Equation (11)

$$\alpha_2 x^2 + \alpha_1 x + \alpha_0 = 0 \quad (11)$$

The fault distance, x, within a known faulty section, whose simplified equation is expressed in Equation (11) is obtained using Equation (12);

$$x = \begin{cases} \frac{-\alpha_1+\sqrt{\alpha_1{}^2-4\alpha_2\alpha_0}}{2\alpha_2} & \alpha_1 > 0 \\ \frac{-\alpha_1-\sqrt{\alpha_1{}^2-4\alpha_2\alpha_0}}{2\alpha_2} & \alpha_1 < 0 \end{cases} \quad (12)$$

Where

$$\alpha_2 = 0.5\, M_k\, I_f;\ \alpha_1 = I\, N_k\, I_f;\ \alpha_0 = V_n\, I_f \quad (13)$$

Where α_0, is a constant while α_1, and α_2, are the coefficients of x and x^2 respectively

The evaluation of the physically correct fault distance requires obtaining the fault distance of the fault point from the main substation. This is possible because all the sections in the radial distribution network are unique with their line parameters and having different distances. Having determined the fault point within a faulty section, the fault distance (F_d) from the main substation can be determined as expressed in Equation (14).

$$F_d = D + x \quad (14)$$

Where

F_d is the fault distance from the main substation, D is the route length to the sending-end node of the faulty section, x is the fault distance within the faulty section.

III. IMPEDANCE-BASED METHOD

The methodology for this research study involved the use of a 22-node, 33 kV Ubulu-Uku radial distribution feeder in Ogwashi-Uku region of Delta State, Nigeria as a test feeder as seen in Figure 3. The entire feeder network in Figure 3, with a total length of 34.12 km with 6 main laterals, and a yet-to-be energized substation point for a possibility of future expansion, was sectionalized into 21 sections and 8 power flow paths. The line length in each section, sections that made up each path and their corresponding route length are presented in Tables 1, 2 and Figure 4.

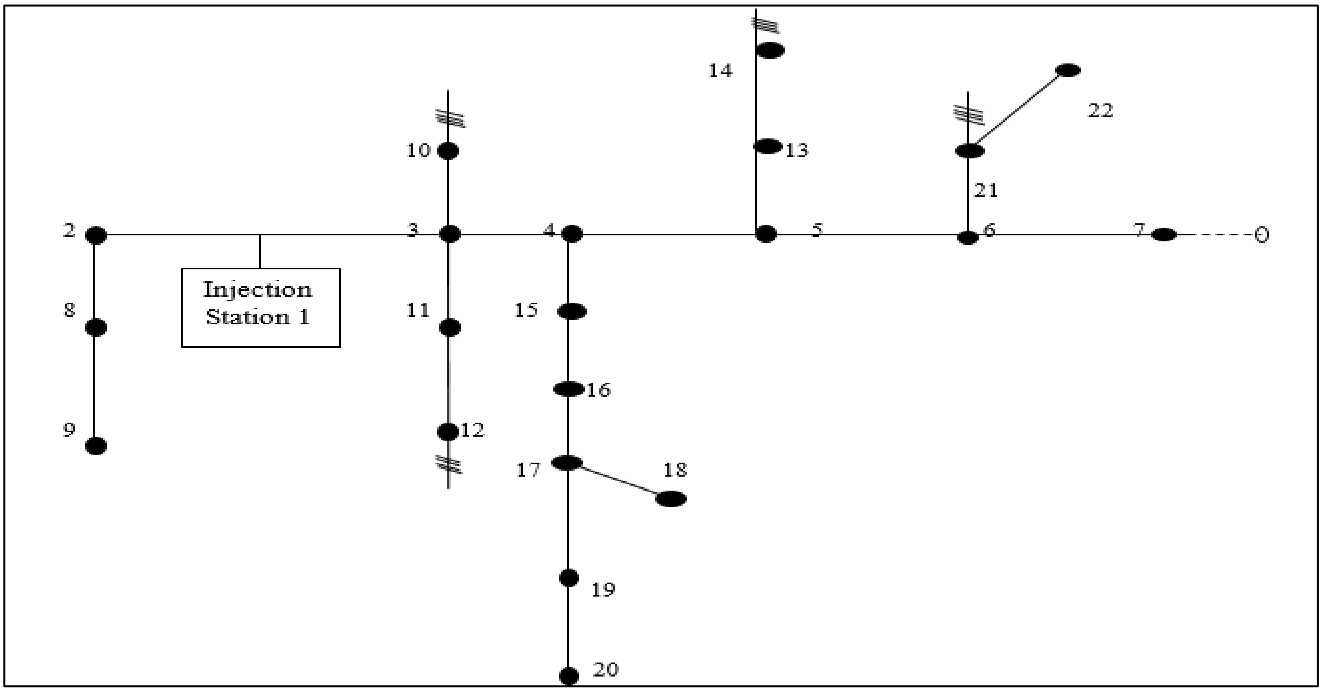


Fig 3: One-Line Diagram of Ubulu – Uku Distribution Feeder Network

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

Table 1: Network's Sectional Span

Sections	Bus		Distance	Sections	Bus		Distance
	From	To	D (km)		From	To	D (km)
1	1	2	0.65	12	17	18	0.85
2	2	8	0.35	13	17	19	2.50
3	8	9	0.75	14	19	20	0.70
4	1	3	1.60	15	4	5	0.85
5	3	10	1.05	16	5	13	0.77
6	3	11	0.65	17	13	14	0.35
7	11	12	0.85	18	5	6	1.10
8	3	4	0.25	19	6	21	0.45
9	4	15	0.50	20	21	22	0.80
10	15	16	0.60	21	6	7	1.20
11	16	17	1.40				

Table 2: Different Sections in Each Power Flow Path

Path	Sections						
P1	Section1	Section2	Section3				
P2	Section4	Section5					
P3	Section4	Section6	Section7				
P4	Section4	Section8	Section9	Section10	Section11	Section12	
P5	Section4	Section8	Section9	Section10	Section11	Section13	Section14
P6	Section4	Section8	Section15	Section16	Section17		
P7	Section4	Section8	Section15	Section18	Section19	Section20	
P8	Section4	Section8	Section15	Section18	Section21		

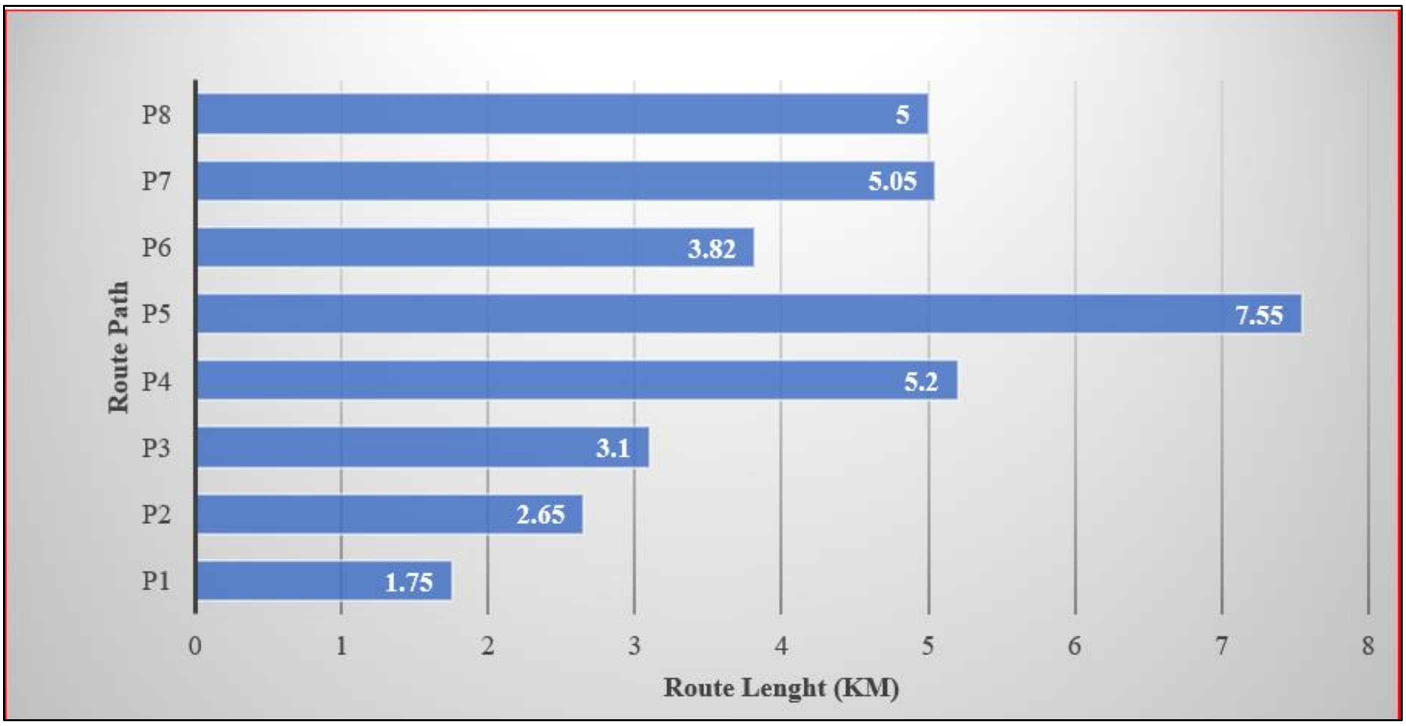


Fig 4: Route Length from the Injection Station

- *Fault Detection and Classification*

Fault detection is an important step in the fault location procedure and the task include the creation of fault classification index, FI, which is used as the indicator and the design of a decision rule to detect and classify the faulty type [14]. The magnitude of the phase impedance a, b, c, the average magnitude of phase impedance Z_A, and the normalized phase impedance Z_{N_k} were obtained as expressed in Equations (17), (18) and (19)

$$Z_a = \frac{V_a}{I_a}; \qquad Z_b = \frac{V_b}{I_b}; \qquad Z_c = \frac{V_c}{I_c} \tag{15}$$

$$Z_A = \frac{Z_a + Z_b + Z_c}{3} \tag{16}$$

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

$$Z_{N_A} = \left|\frac{Z_a}{Z_A}\right|; \quad Z_{N_B} = \left|\frac{Z_b}{Z_A}\right|; \quad Z_{N_C} = \left|\frac{Z_c}{Z_A}\right| \tag{17}$$

Similarly, the normalized phase current was also be obtained by applying Equations 21.

$$I_A = \frac{I_a + I_b + I_c}{3} \tag{18}$$

$$I_{N_A} = \left|\frac{I_a}{I_A}\right|; \quad I_{N_B} = \left|\frac{I_b}{I_A}\right|; \quad I_{N_C} = \left|\frac{I_c}{I_A}\right| \tag{19}$$

Where $V_{a,b.c}$ is Voltage phasor quantities in phase a, b, c, $I_{a,b,c}$, is current phasor quantities in phase a, b, c, $Z_{a,b,c}$, is phase impedances in phase a, b, c, $Z_{Na,b,c}$ is the normalized impedances of phase a, b, c, and $I_{Na,b,c}$ is the normalized currents of phase a, b, c.

As a result of these, fault classification index, FI, was formulated corresponding to the fault type as expressed in Equations (20) to (26)

$$FI_{a-g} = \left(1 - Z_{N_a}\right) + Z_{N_b} + Z_{N_c} \tag{20}$$

$$FI_{b-g} = \left(1 - Z_{N_b}\right) + Z_{N_a} + Z_{N_c} \tag{21}$$

$$FI_{c-g} = \left(1 - Z_{N_c}\right) + Z_{N_a} + Z_{N_b} \tag{22}$$

$$FI_{ab-g} = \left(1 - Z_{N_a}\right) + \left(1 - Z_{N_b}\right) + Z_{N_c} \tag{23}$$

$$FI_{ac-g} = \left(1 - Z_{N_a}\right) + \left(1 - Z_{N_c}\right) + Z_{N_b} \tag{24}$$

$$FI_{bc-g} = \left(1 - Z_{N_b}\right) + \left(1 - Z_{N_c}\right) + Z_{N_a} \tag{25}$$

$$FI_{abc-g} = \left(1 - Z_{N_a}\right) + \left(1 - Z_{N_b}\right) + \left(1 - Z_{N_c}\right) \tag{26}$$

As a result of these, the fault classification index, FI, and decision rule was formulated with the following classifications;

- If FI < 3 and $|I_{a,b,c}| < I_N$, distribution feeder is normal
- If FI > 3, the fault is seen as a single line-to- ground fault or double line-to-ground fault
- If FI < 3 and $|I_{a,b,c}| > I_N$, the fa+ult is seen as a three phase-to- ground fault

➢ *Fault Location Algorithm*

A step-by-step fault location algorithm, which accounts for both laterals and sub-lateral distribution system, was designed to locate faults and fault distance in radial distribution system and is presented as flowchart in Figure 5.

➢ *Fault Distance Error*

The percentage error of the fault distance was obtained as the ratio of the difference between the estimated distance and the simulated distance expressed as percentage of the total length of the feeder as seen in Equation (29).

$$\%\, error = \left|\frac{d_{est} - d_{sim}}{length\ of\ main\ feeder}\right| \times 100 \tag{29}$$

Where

d_{est} is the estimated line distance obtained from the main substation to the mid-point of the faulty line section; and

d_{sim} is the MATLAB simulated line distance from the main substation to the faulty point of the faulty line section.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

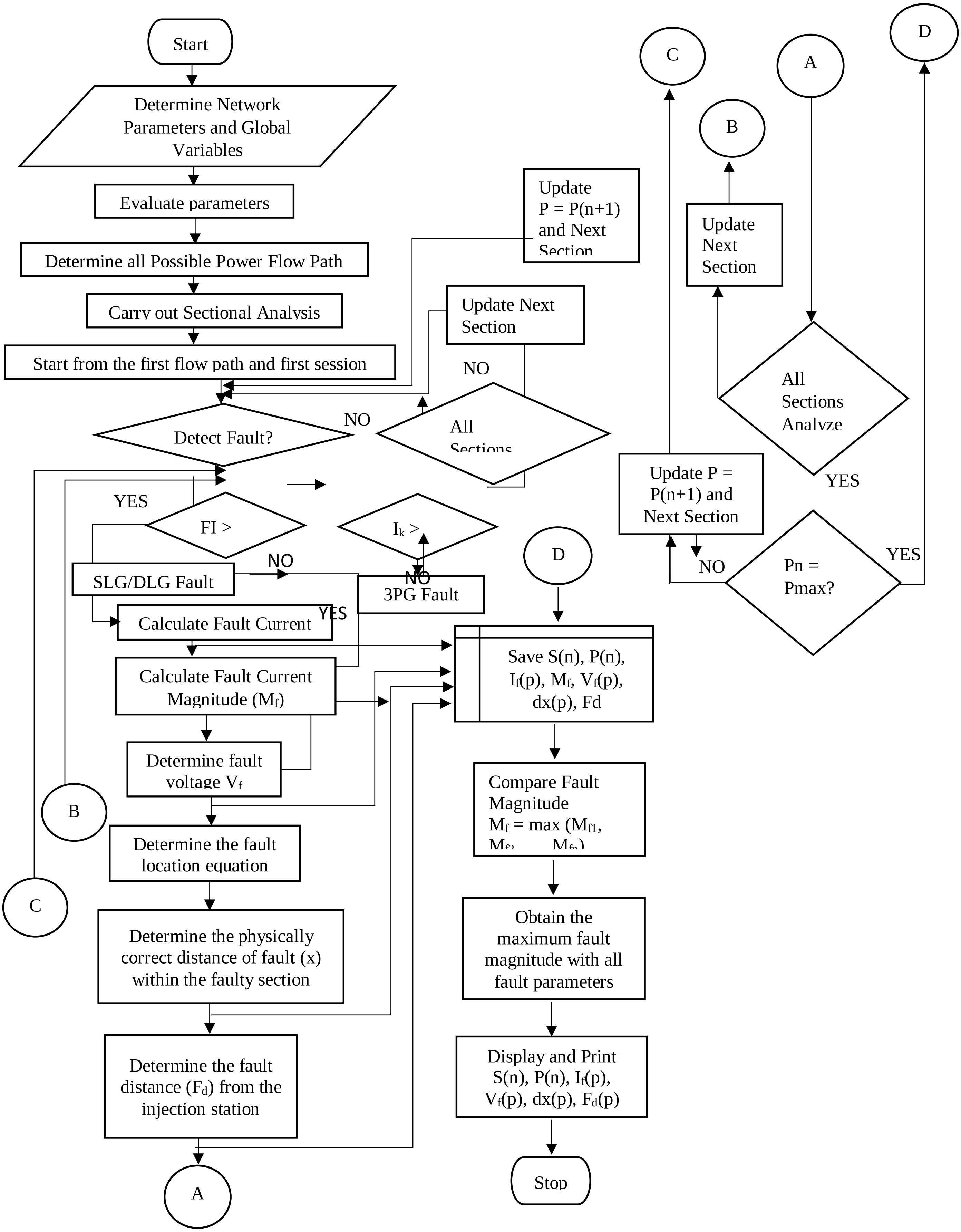


Fig 5: Developed Flowchart of Ground Fault Location

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

IV. RESULTS AND DISCUSSIONS

The results presented in this study were obtained having evaluated the designed algorithm on MATLAB 2023a environment with the real-time line and load parameters of the 22-node 33 kV Ubulu-Uku distribution feeder which was used as the test feeder. These results were obtained by varying the values of the line impedance across each of the 21 sections that made up the distribution feeder. The various values of the line impedance used for the test feeder were 0.01Ω, 0.15Ω, 0.35Ω, 0.50Ω and 0.65Ω, with a total of 315 fault cases and each of them produced different fault magnitude both in ground fault and phase fault. The fault magnitude for each of the 21 sections are presented from Figures 6 to 10.

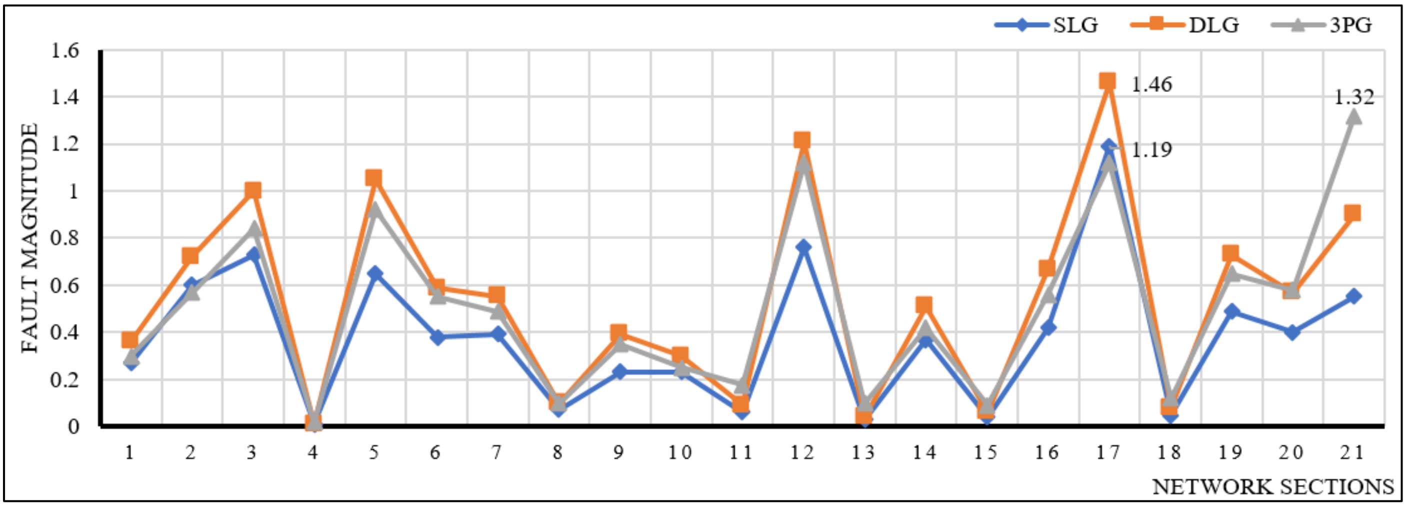


Fig 6: Fault Magnitudes when Z = 0.01 Ω

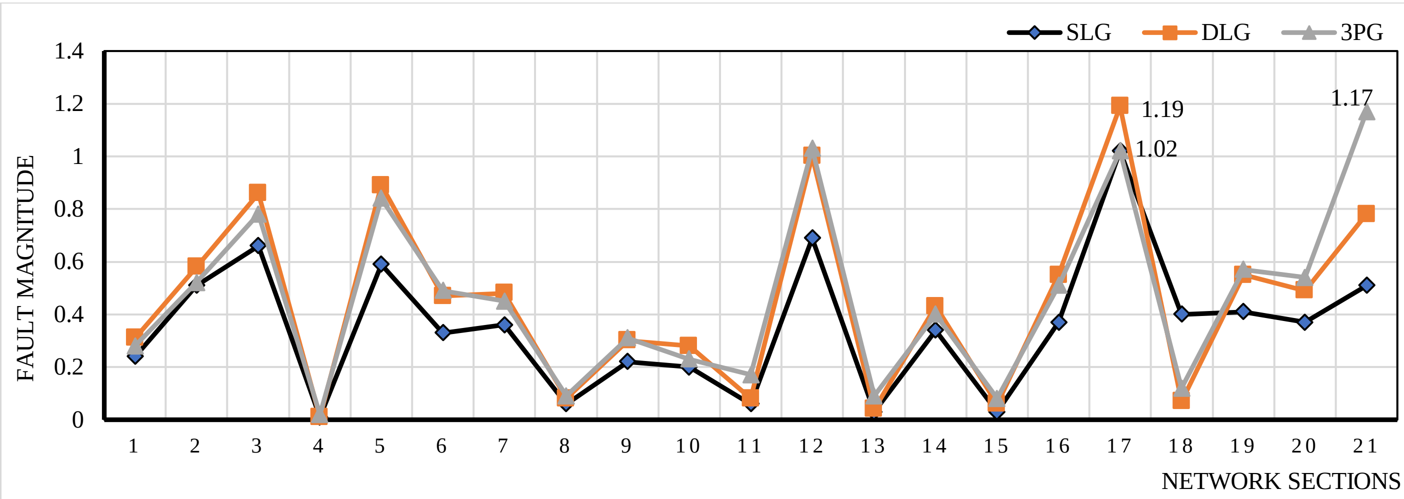


Fig 7: Fault Magnitude when Z = 0.15 Ω

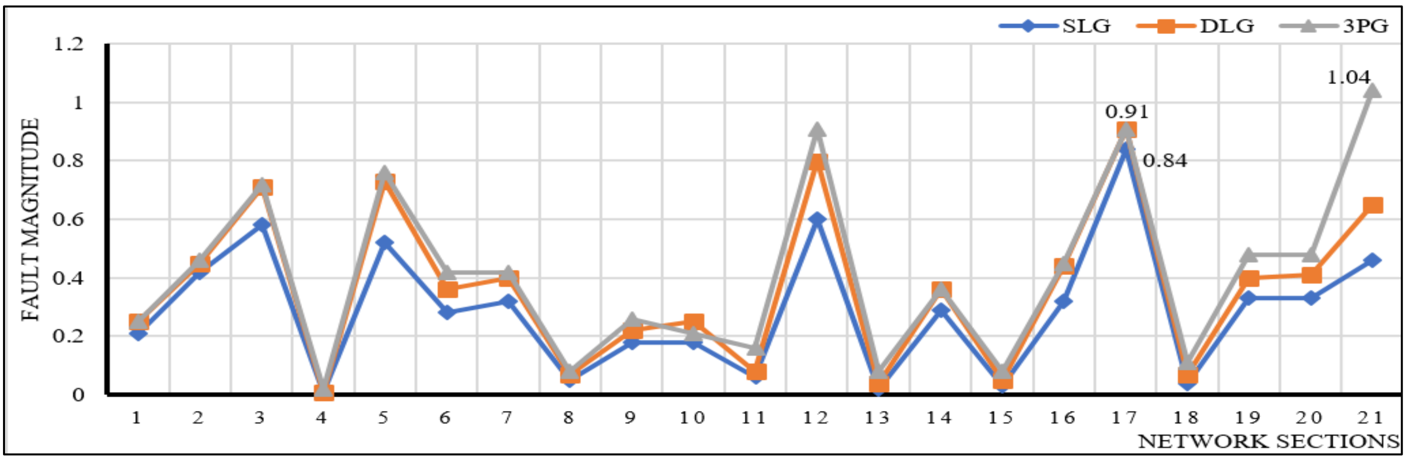


Fig 8: Fault Magnitude when Z = 0.35 Ω

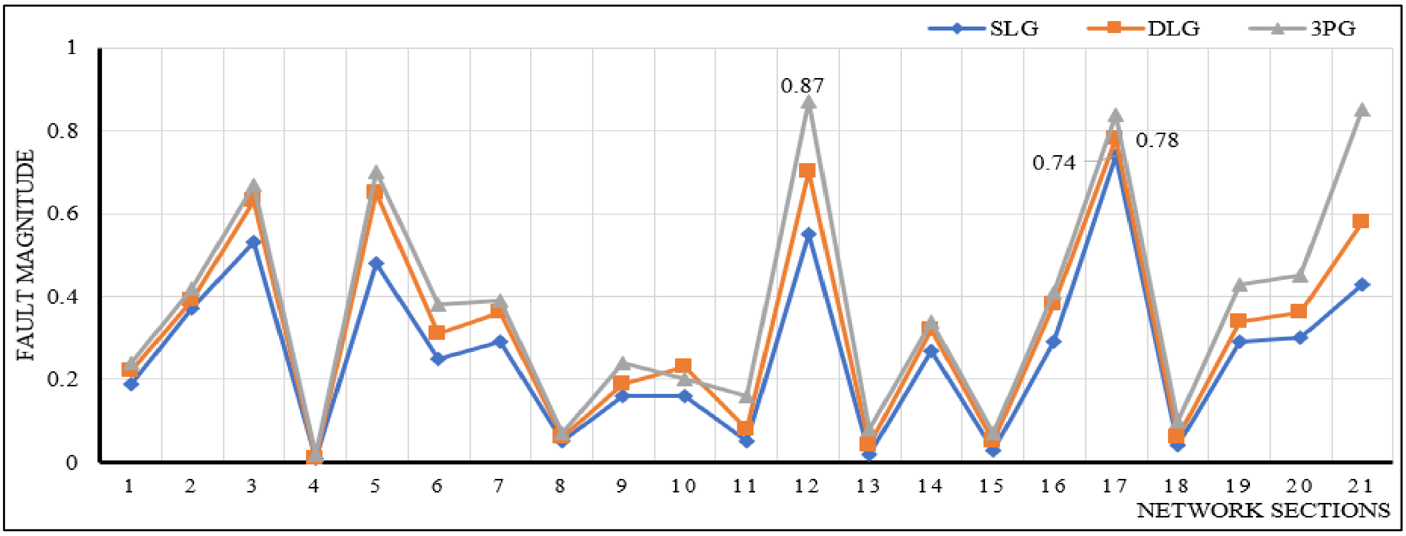


Fig 9: Fault Magnitude when Z = 0.50 Ω

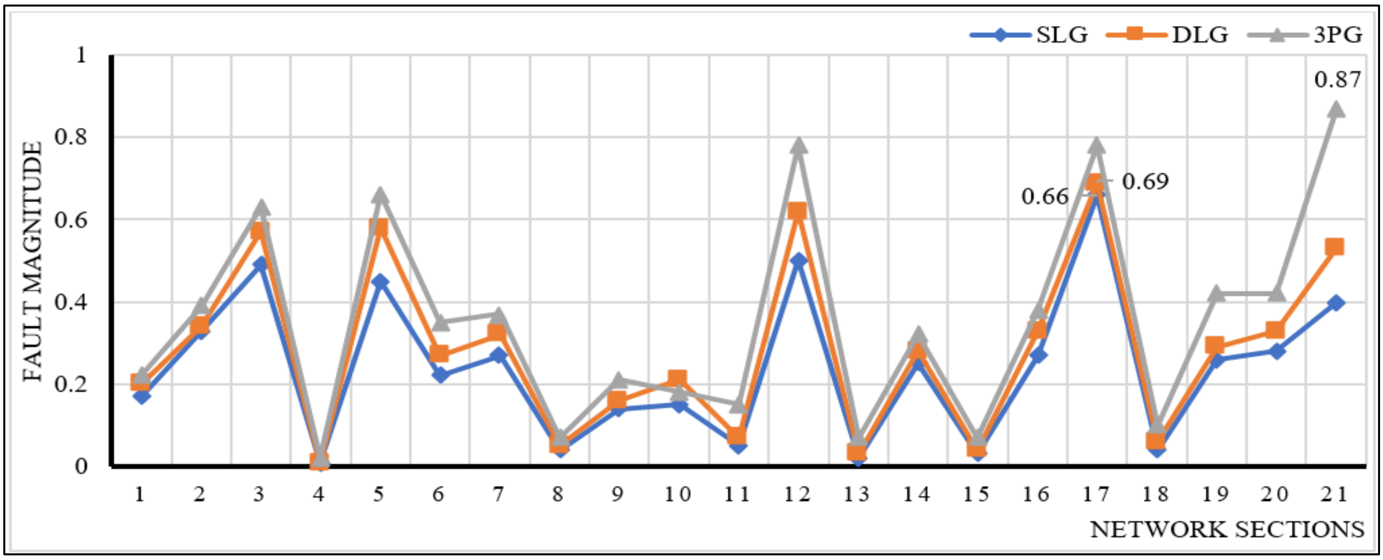


Fig 10: Fault Magnitude when Z = 0.65 Ω

When the line impedance Z_L was reduced to 0.01 Ω, it produced a double line-to-ground fault in Section 17 along Path 6 with a fault magnitude of 1.46. The distance of the fault point from the start of the faulty section was found to be 0.04 km, while the distance of the fault point from the main substation was found to be 3.51 km. This is presented in the graph and fault analysis display in Figures 11 and 12.

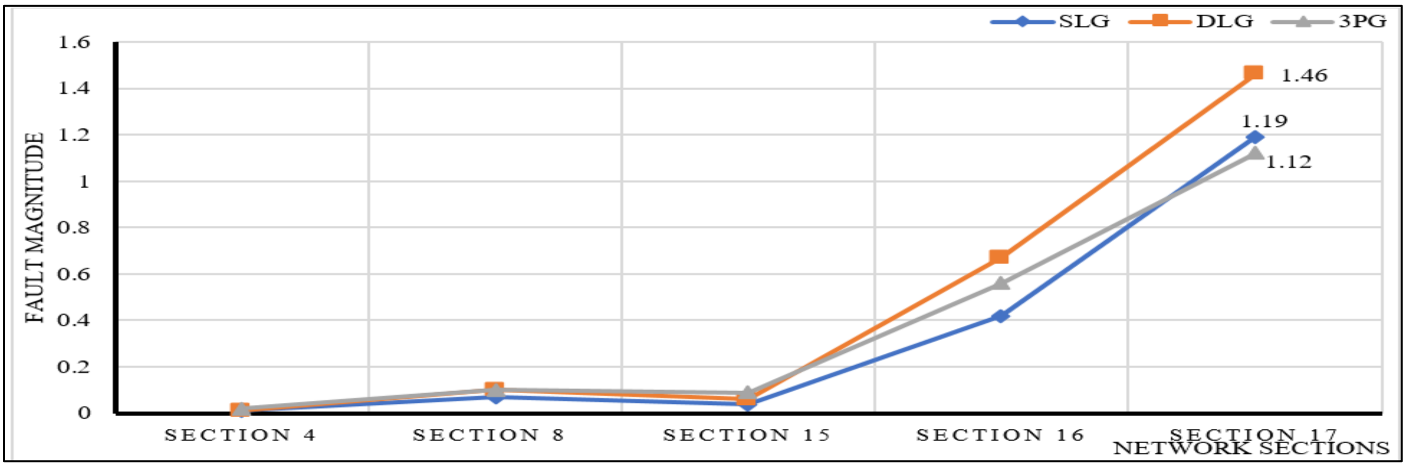


Fig 11: Fault Magnitudes in Faulty Path 6

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

```
Command Window
>> Fault_Analysis_Display
Faulty Section: Section 17: Akwu SS to Ugbah SS
Sectional Span: S = 0.35km
Route Lenght: P6 = 3.82km
Fault current: If = 0.99917A
Fault voltage: Vf = 1.3128V
distance of fault: x = 0.038959km
Fault distance: Fd = 3.509km from the Main SS
Operational Status: Double line-to-ground fault
>>
```

Fig 12: Fault Analysis Display for Faulty Section 17 in path 6

When the line impedance Z_L was increased to 0.15 Ω, it produced a three phase-to-ground fault in Section 21 along Path 8 with a fault magnitude of 1.17. Within the faulty section, the distance of the fault point from the start of the section was found to be 0.13 km while the distance of the fault point from the main substation was found to be 3.93 km. This is presented in the graph and fault analysis display in Figures 13 and 14.

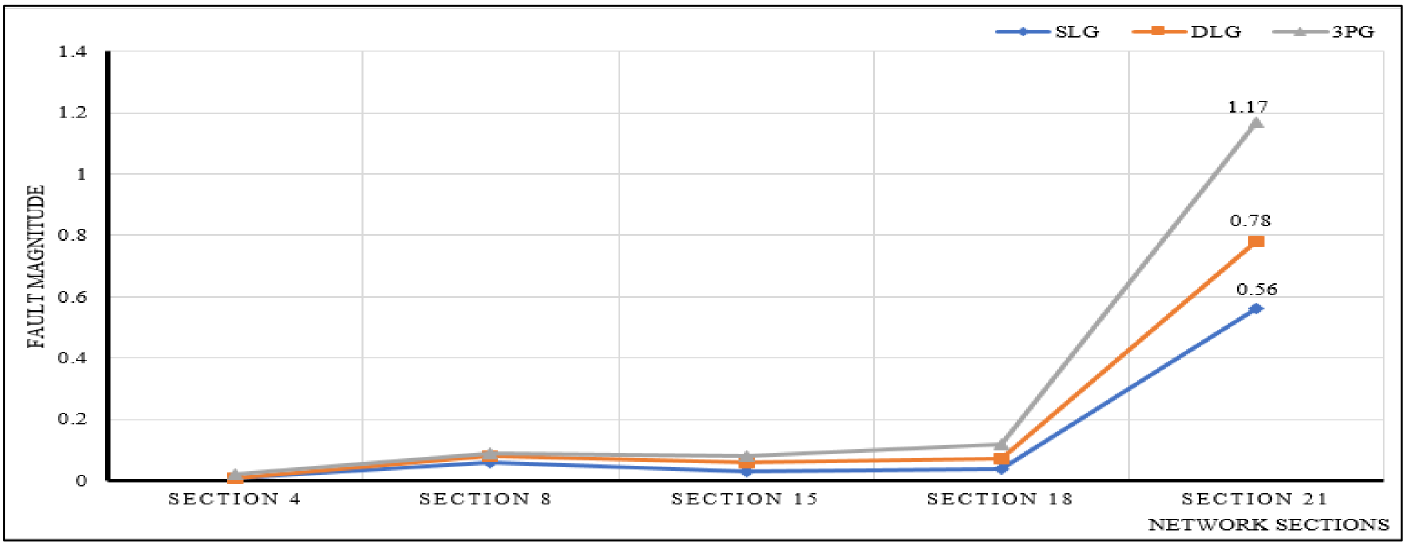


Fig 13: Fault Magnitude in Path 8

```
Command Window
>> Fault_Analysis_Display
Faulty Section: Section 21: Abuedo Phase 1 SS to Abuedo Phase 2 SS
Sectional Span: S = 1.2km
Route Lenght: P8 = 5km
Fault current: If = 0.71963A
Fault voltage: Vf = 1.3639V
distance of fault: x = 0.13226km
Fault distance: Fd = 3.9323km from the Main SS
Operational Status: Three Phase-to-ground fault
>>
```

Fig 14: Fault Analysis Display for Faulty Section 21 in Path 8

A further increase in the line impedance Z_L from 0.15 Ω to 0.35 Ω produced a three phase-to ground fault also in Section 21 along Path 8 with a reduced fault magnitude of 1.04. The distance of the fault point from the start of the faulty section was found to be 0.23 km while the distance from the fault point to the main substation was found to be 4.03 km This is presented in the graph and fault analysis display in Figures 15 and 16.

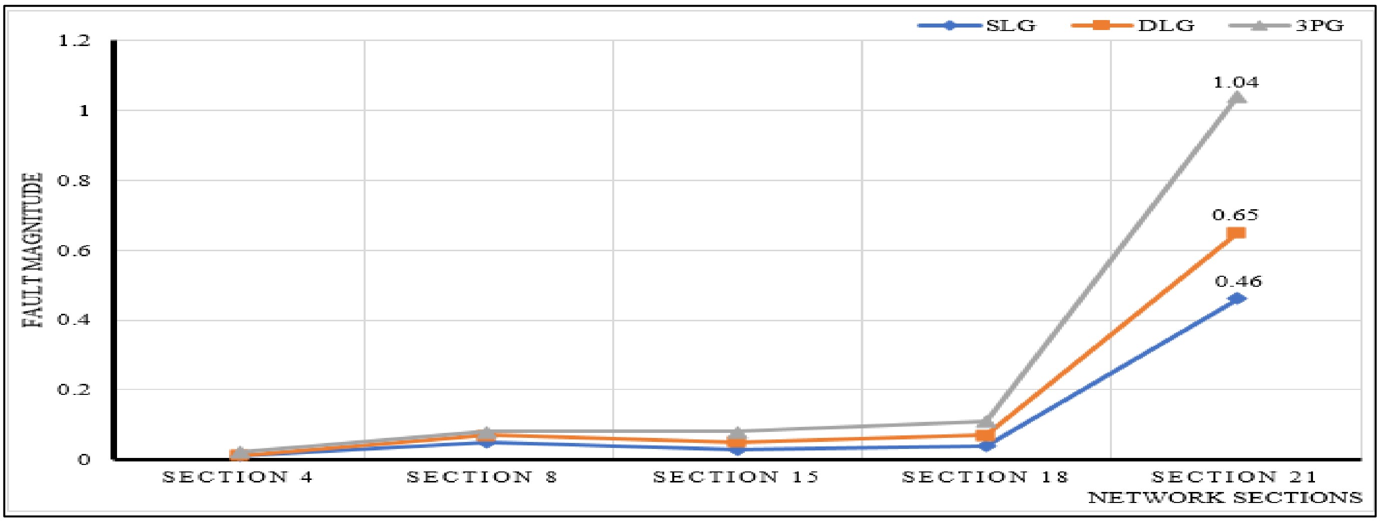
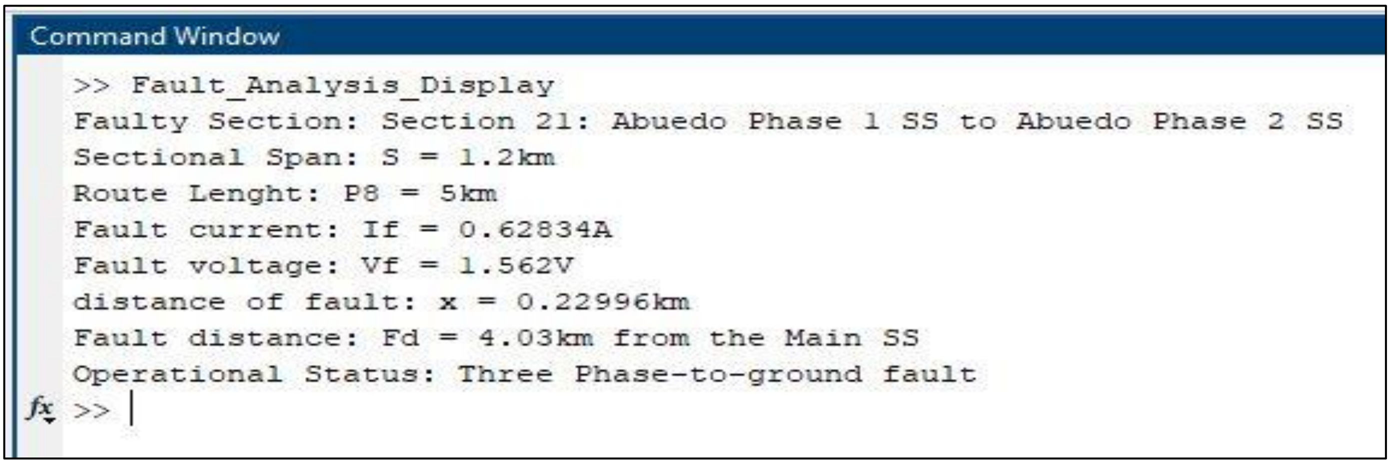


Fig 15: Fault Magnitude in Path 8



```
Command Window
>> Fault_Analysis_Display
Faulty Section: Section 21: Abuedo Phase 1 SS to Abuedo Phase 2 SS
Sectional Span: S = 1.2km
Route Lenght: P8 = 5km
Fault current: If = 0.62834A
Fault voltage: Vf = 1.562V
distance of fault: x = 0.22996km
Fault distance: Fd = 4.03km from the Main SS
Operational Status: Three Phase-to-ground fault
fx >>
```

Fig 16: Fault Analysis Display for Faulty Section 21 in Path 8

When the line impedance Z_L was increased from 0.35 Ω to 0.5 Ω, it produced a three phase-to-ground fault in Section 12 along Path 4 with a reduced fault magnitude of 0.87 with the distance of the fault point to the start of the section being 0.46 km and 4.81 km from the main substation. The graph and fault analysis display are presented in Figures 17 and 18.

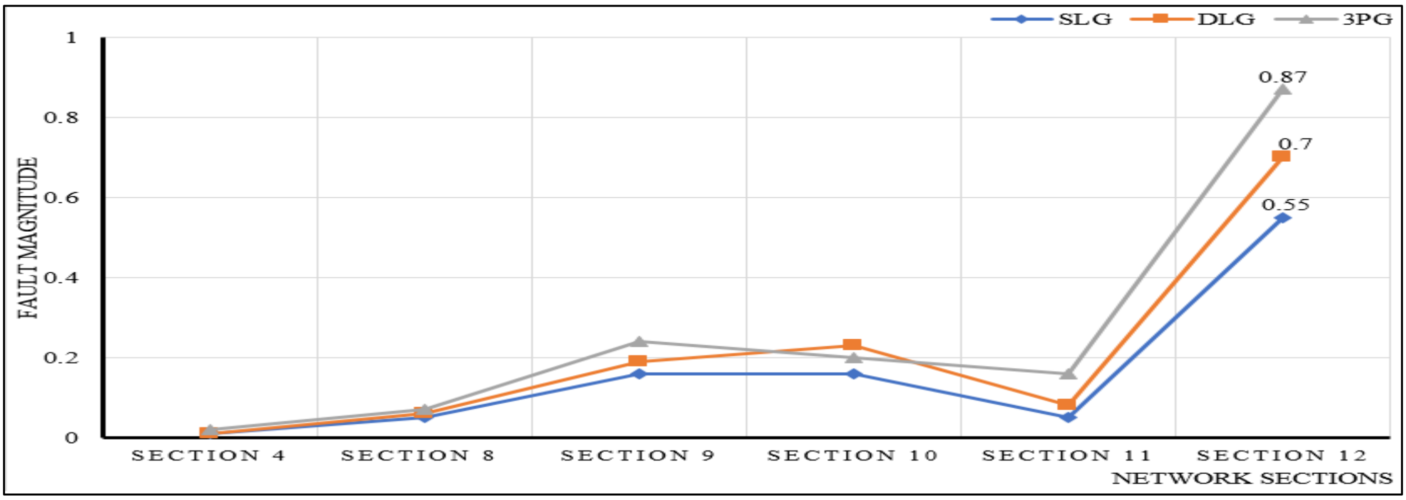


Fig 17: Fault Magnitude in Path 4

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2483

```
Command Window
>> Fault_Analysis_Display
Faulty Section: Section 12: Isho Phase 1 SS to Isho Phase 2 SS
Sectional Span: S = 0.85km
Route Lenght: P4 = 5.2km
Fault current: If = 0.50844A
Fault voltage: Vf = 1.9374V
distance of fault: x = 0.45809km
Fault distance: Fd = 4.8081km from the Main SS
Operational Status: Three Phase-to-ground fault
fx >>
```

Fig 18: Fault Analysis Display for Faulty Section 12 in Path 4

When the line impedance Z_L was increased from 0.50 Ω to 0.65 Ω, it produced a three phase-to-ground fault in Section 21 along Path 8 with a reduced fault magnitude of 0.87. The distance of the fault point from the start of the section was found to be 0.41 km and 4.21 km from the main substation. The graph and fault analysis display are presented in Figures 19 and 20.

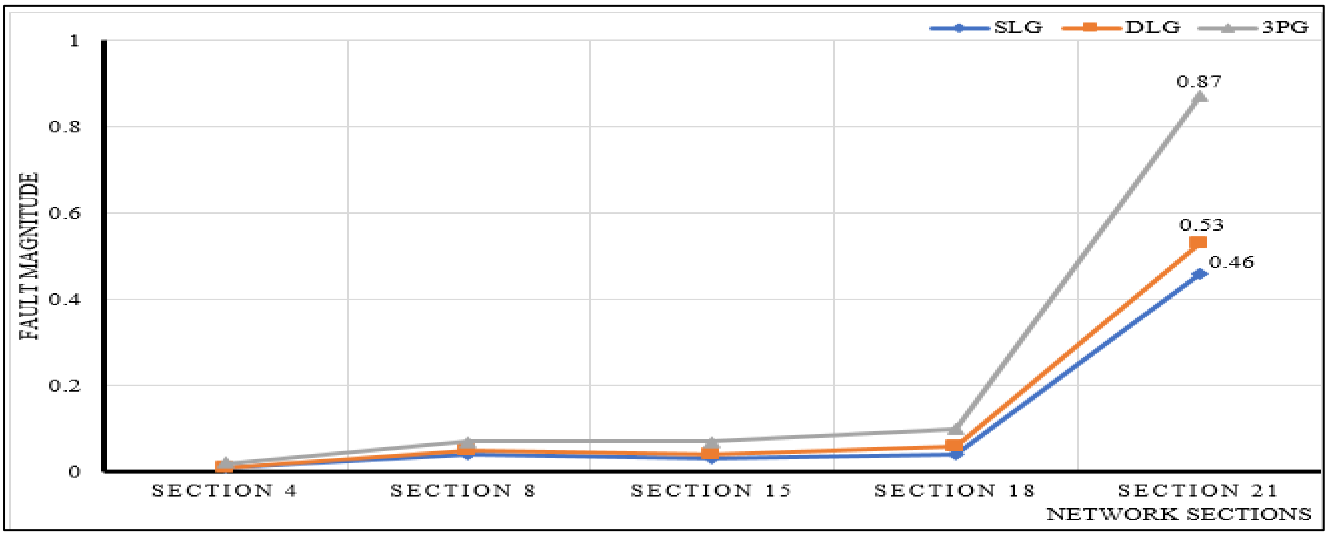


Fig 19: Fault Magnitude in Path 7

```
Command Window
>> Fault_Analysis_Display
Faulty Section: Section 21: Abuedo Phase 1 SS to Abuedo Phase 2 SS
Sectional Span: S = 1.2km
Route Lenght: P8 = 5km
Fault current: If = 0.5279A
Fault voltage: Vf = 1.8592V
distance of fault: x = 0.41106km
Fault distance: Fd = 4.2111km from the Main SS
Operational Status: Three Phase-to-ground fault
fx >>
```

Fig 20: Fault Analysis Display for Faulty Section 19 in Path 7

The percentage error of fault distance for the analyzed fault distance analysis from the main substation to the mid-point of each of the faulty path is presented in Table 3.

Table 3: Percentage Error of Analyzed Fault Distances

Path	Section	Estimated Distance (km)	Simulated Distance (km)	Difference |d| (km)	Percentage Error (%)
6	17	3.645	3.509	0.136	0.40
8	21	4.400	3.932	0.468	1.37
8	21	4.400	4.030	0.370	1.08
4	12	4.770	4.808	0.038	0.11
8	21	4.400	4.211	0.189	0.55

The average percentage error for the simulated fault distances across the 21 sections for types of ground fault is presented in Figure 21.

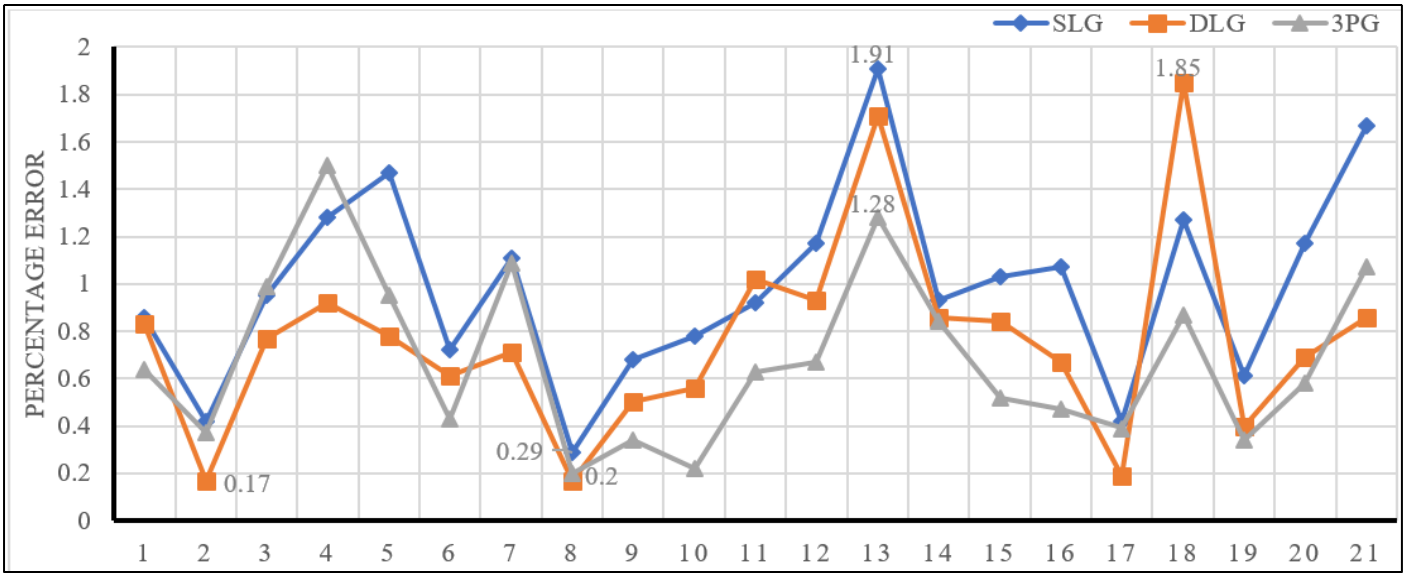


Fig 21: Percentage Error of Fault Distances

V. CONCLUSION

This research project presents a typical radial distribution feeder network which was used as a test feeder to determine and locate faults on it with the generation of load and line parameters which was used as pre-fault values of the feeder and then evaluated on the designed algorithm capable of identifying and locating faults on power distribution feeder. The results presented from the evaluation of the algorithm show that the average minimum percentage error was found to be 0.17 % in path 1 section 2 with a double line-to ground fault type which represents a distance of 0.0014 km while the average maximum percentage error was found to be 1.91 % in path 5 section 13 with a single line-to-ground fault type representing a distance of 0.107 km. The performance of the designed algorithm gives a tolerable error value with encouraging results for practical implementation.

ACKNOWLEDGMENT

The authors which to acknowledge and thank BEDC (Benin Electricity Distribution Company) for assistance rendered in providing real time data used for analysis for the completion of this research work.

REFERENCES

[1]. Prajapat D., "*Faults and Effects in Electrical Power Systems*", Madhav University Publication, India, (2020).

[2]. Zhen Li, Jian Qiao, Yikai Wang, and Xianggen Yin, "*A Comprehensive Method for Fault Location of Active Distribution Network Based on Improved Matrix Algorithm and Optimization Algorithm, International Transactions on Electrical Energy Systems*", Volume 2022, Article ID 4232090, (2022), pp. 1–11, https://doi.org/10.1155/2022/4232090

[3]. Sadeh J., Bakshizadeh E., and Kazemzadeh R., "*A New Fault Location Algorithm for Radial Distribution System using Modal Analysis*", Journal on Electrical Power and Energy System, 45, (2013), pp. 271 – 278.

[4]. Hazarika J., and Roy O.P., "*Distribution System Fault Analysis using MATLAB / SIMULINK*", Intelligent Computing and Technologies Conference, ICTCon2021, (2021) pp: 1 – 8.

[5]. Folarin D. A., Sakala J. D., Matlotse E., and Gesennelwe-Jeffery M. A., "*Modeling and Simulation of fault in Distribution Network System using MATLAB / SIMULINK*", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), e-ISSN: 2278-1676, p-ISSN: 2320-3331, 13(3), Ver. 1, (2018), pp. 43 – 51, www.iosrjournal.org.

[6]. Hamid M., Rahman D., Karsten H., and Hamid R. S., "*Real Fault Location in a Distributed Network using Smart Feeder Meter Data"*, Energies 2021, (2021), 14, 3242, pp. 1 – 16..

[7]. Mbamaluikem P.O., Olabode O.R., and Adedokun A.G., "*Artificial Neural Network Based Smart Shunt Fault Recognition System for the 33kV Nigerian Power lines"*, In Proceedings at the 1st International Conference and Exhibition on Technological Innovation and Global Competitiveness of Federal Polytechnic, Ilaro, 5 – 8 November 2018, pp. 1 – 7.

[8]. Mohammed A. M., and Ali, A.A., "*A Novel Fault Locator System; Algorithm, Principle and Implementation"*, IEEE Transaction on Power Delivery, 25(1), (2010), pp 35 – 46.

[9]. Jelali D., and Moslemi N., "*Fault Location for Radial Distribution System using Fault Generated High Frequency Transient and Wavelet Analysis"*. In Proceedings at the 18th International Conference on Electricity Distribution, CIRED, Turin, 6 – 9 June 2005, 3, pp: 39 - 46

[10]. Ancell, G. B., and Pahalawaththe N. C., (2011), "*Maximum Likelihood Estimation of Fault Location on Transmission Line using Travelling wave"*, IEE Publication, (2011)

[11]. Ale, T. O., and Saliu, R. A., "*Fault Detection on High Voltage Transmission lines using Discrete Wavelet Transform"*, Journal of Emerging Trends in Engineering and Applied Science, 8 (3), (2017), pp. 136 – 142.

[12]. Kulikov A., Ilyushin P., Suslov K., and Filuppov S., (2023), *Estimating the Error of Fault Location on Overhead Power Lines by Emerging State Parameters using an Analytical Technique*, Energies 2023, 16, 1552.

[13]. Gohokar,V. N., and Gohokar, V. V., "*Fault Location in Automated Distributed Network"*, SEL Journal of Reliable Power, 1 (1), (2012), pp. 1 – 9.

[14]. Choowong, W., and Teratum B., "*Algorithm for Detecting, Identifying, Location and Experience to develop the Automated Fault Location in Radial Distribution System"*, Journal of Electrical Engineering and Technology, 5 (1), (2010), pp. 36 – 44.

[15]. Hizan, H., and Crossley, P. A., "*Single-Ended Fault Technique on Radial Network using Fault Generated Current Signal"*, IEE Transaction on Power Delivery, 19 (2), (2012), pp. 153 – 161.

[16]. Awalin, L.J, Mokhlis, H., and Halim A.H.A, "*Improved Fault Location on Distribution Network Based on Multiple Measurement of Voltage Sags Pattern"*. In Proceedings at the IEEE International Conference on Power and Energy (PECon), Kota Kinabalu, Malaysia, 2 – 5 December 2012, pp. 767 – 772.

[17]. Bedekar, P. P., Bhide, Sudhir R, Kale, Vijay S., (2011), "Fault section estimation in power system using Hebb's rule and continuous genetic algorithm," International Journal of Electrical Power & Energy Systems, 33, (2011), pp. 457-465

[18]. Jameli, S., Bahmanya, A., and Ranjbar, S., (2020), "*Hybrid Classifier for Fault Location in Active Distribution System"*, Protection and Control of Modern Power System, https://doi.org/10.1186/s41601-020-00162-y, pp 1 - 9.

[19]. Eminoglu, U., and Hocaoglu, M.H, (2005), *A Robust Power Flow Algorithm for Radial Distribution System*, IEEE Publication, PT05, pp: 8 – 14.

[20]. Salim R.H., Salim K.C.O, and Bretas A.S., "*Further Improvements on Impedance-based Fault Location for Power Distribution System"*, IET Generation, Transmission and Distribution, 5 (4), (2011), pp. 467 – 478.

[21]. Grigsby, L.L., "*Electric Power Generation, Transmission and Distribution"*, 3rd Edition, CRC Press, Boca Raton, London, New York, (2012).