FAULT LOCATION IN DISTRIBUTION SYSTEM BASED ON VOLTAGE SAG ANALYSIS

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ORIGINAL LITERARY WORK DECLARATION

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Field of Study: Power System

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ABSTRACT

Fault in the distribution system is something that cannot be avoided. It is a recurring event that occurs due to various factors such as natural occurrence, mechanism failure, or human error. All this contributes to the phenomenon that will affect the stability of the system and result in the loss of power to the consumers. However, such a fault is something that happens unexpectedly, and it is difficult to be eliminated. Therefore, various research work has been done over the years to overcome the problem. All research is done to find the most effective method of finding the fault location in a short time. In this thesis, a way of identifying a fault location in the distribution system by using the voltage sag measurement is presented. The approach is to match the actual voltage sag magnitude with the stored database from the simulated fault. Any matching data will provide a possible fault section. Simulation result shows that it is possible to identify the fault location based on the analysis of the voltage sags.

ABSTRAK

Kegagalan di dalam sistem pengagihan adalah sesuatu yang tidak dapat dielakkan. Ia adalah kejadian berulang yang berlaku disebabkan oleh pelbagai faktor seperti kejadian semula jadi, kegagalan mekanisme, atau kesalahan manusia. Semua ini menyumbang kepada fenomena yang akan mempengaruhi kestabilan sistem dan mengakibatkan kehilangan kuasa kepada pengguna. Namun begitu, kegagalan tersebut adalah sesuatu yang berlaku tanpa diduga, dan sukar untuk menghapuskannya. Oleh kerana itu, terdapat pelbagai kerja penyelidikan telah dilakukan selama bertahun-tahun untuk mengatasi masalah tersebut. Semua penyelidikan yang dilakukan adalah bertujuan untuk mencari kaedah yang paling berkesan untuk mengenalpasti lokasi kesalahan dalam masa yang singkat. Oleh yang demikian, tesis ini menunjukkan salah satu cara untuk mengenal pasti lokasi kegagalan dalam sistem pengagihan dengan menggunakan pengukuran voltan kendur. Pendekatannya adalah untuk memadankan magnitud voltan sebenar dengan pangkalan data yang tersimpan dari simulasi kegagalan. Sebarang data yang sepadan akan memberikan kemungkinan lokasin kegagalan. Hasil dari simulasi menunjukkan bahawa terdapat kemungkinan untuk mengenal pasti lokasi kegagalan berdasarkan analisis voltan kendur.

ACKNOWLEDGEMENT

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Last but not least, I would like to thank my parents, Ahmad Bin Saad and Rusiah Binti Mohamad Dom for giving their bless and always pray for my success in the world and hereafter.

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LIST OF SYMBOL AND ABBREVIATIONS

ANN	:	Artificial Neural Network
GPS	:	Global Positioning System
IEEE	:	Institute of Electrical and Electronic Engineers
kV	:	Kilo Volt
LLLGF	:	Three-phase to Ground Fault
SLGF	:	Single Line to Ground Fault
p.u	:	Per unit
d_f	:	Fault distance
t_1	:	Reflection time from recorder to fault
t_2	:	Deflection time from fault to recorder
v	:	Velocity of the traveling wave
I	:	Current measured during fault
Z_s	:	Source impedance
Z_l	:	Line impedance
V_s	:	Voltage source
$V_p^{(dbase)}$	:	Measured voltage sag magnitude at node p
$V_q^{(dbase)}$	:	Measured voltage sag magnitude at node q
$V_f^{(meas)}$	:	Measured voltage sag magnitude during fault

CHAPTER 1 : INTRODUCTION

1.1 Overview

Electricity is delivered to every consumer through a complex distribution network either by cables or overhead lines. The main objective of a distribution network is to deliver a reliable and quality power supply. Therefore, whenever a disruption happens, finding the cause is the most crucial thing to do since any fault that occurs within the network will cause enormous losses to utility and consumers. This situation is inevitable and can be caused by many factors, among them are from the environment and human error. The fault can occur due to lightning surges, insulation failure, and mechanical damage by the public.

Disruption to the power system is known to be caused by many factors. However, all these factors may generate different types of faults in the system. Characteristics for each type of fault may vary from one to another. Therefore, it is important to have a deep understanding of the characteristic of a specific fault so that further study can be carried on to detect the fault location.

1.2 Problem Statement

The demands of electrical supply for daily usage increases rapidly especially during the pandemic era which forces peoples to stay put at home. This situation has given no other option for power utility companies to continue providing stable and reliable power supply to the consumers. However, this process can be interrupted when a fault occurred in the distribution system which leads to power disruption on the consumers' side. Any rectification work has to be done within the specified time given or else the fault will create a more catastrophic event and might cause damage to the equipment with a total outage to the consumers.

Even though fault occurrence in the distribution network is unavoidable, the downtime can be greatly improved by locating the affected point quickly. This will help to speed up the process to get the system back online and reduce the outage time which will benefit both the company and consumer. Because of the complexity of the power distribution network, most of the power utility company still practicing the traditional approach in locating the fault. Visual inspection is the most popular method in detecting fault but is very time consuming and restricted to the aboveground application only. Therefore, a method of estimating the fault location shall be considered to eliminate the constraints.

1.3 Objectives

By understanding the importance of fault detection in the power distribution system, the objectives are set as follows:

1) To model an IEEE 33 bus system by using Matlab.
2) To analyze voltage sag pattern that occurs in the bus system due to three phase to ground fault and single line to ground fault.
3) To propose the identification of faulty section in the bus system based on voltage sag pattern.

1.4 Scope of Work

This project will focus on modeling the IEEE 33 bus system and simulate by using Matlab programming development software. The simulation will create a fault on the selected location within the bus system to produce voltage sag.

Two types of the fault will be created in the simulation which is three-phase to ground fault (LLLGF) and a single line to ground fault (SLGF) with various fault resistance of 0.001Ω, 1Ω, 5Ω, 10Ω, and 15Ω.

Results from the simulation will be used to analyze the voltage sag patterns. A set of voltage sag values at the selected buses obtain from the LLLGF and SLGF simulation will be stored as a database to identify the faulty section in the bus system.

1.5 Report Outline

The next chapters in this report are in the following sequences;

Chapter 2 will concentrate on the literature review involving previous studies of fault detection methods for the distribution network.

Chapter 3 describes the undertaking procedure and methodology of the study to meet and comply with the objectives being set forth. A method to identify the faulty section based on a voltage sag pattern will be proposed.

Chapter 4 discusses the voltage sag pattern due to fault. This chapter will compare the results obtain when the fault occurs on the bus and in between the buses.

Chapter 5 provides a conclusion for this research work and proposes for future work.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

Supplying electric power to the consumer requires a systematic distribution system that has a special position in a power system network. However, disruption may occur in the distribution system which is unavoidable and cannot be easily eliminated. This may due to the fault that will lead the currents diverted from the predetermined pathway and create an unusual situation that will then introduce extreme damage to the power system [1]. Therefore, to meet the daily demands of the electric consumptions, an electric provider must have effective planning in its distribution system which includes maintenance and preventive programs.

A good distribution system is the one that able to provide continuous power supply to the consumers. Hence, it is very crucial to locate the faulty line and location in a short period. Identification of the affected point will help the maintenance team to rectify the problem as soon as it occurred and restored the system.

This chapter will discuss various methods that can be used to identify fault locations. A review of methods used in identifying fault locations such as the conventional technique, traveling wave method, impedance-based method, and knowledge-based method is presented in the following sections.

2.2 Conventional Technique

In the early year of the distribution system, the fault is located manually by visual inspection along the line or by turning the relay on or off until the circuit breaker trips. This process will depend on luck since it is considered a try and error method and will consume a lot of time to find the fault location. Initially, the method was based on the outage report provided by the customer. The location of the customer and the connectivity of the distribution network have to be tally for the exact location of the fault to be identified [3]. The visual inspection technique is however limited to above the ground cables only and unable to detect any fault occurs in the underground cables. For above the ground cables, the visual inspection technique can be covered by foot for small and short distance areas. For a larger area, commonly land vehicle or helicopter is used.

A destruction method of sectionalizing that involves “closing-in” on the cable fault was implemented for the detection of a fault in the underground cable. This method consists of two sub-method. The first is known as the “cut and try” method which requires isolation of the faulted section by cutting the actual cable and then individually tested it. The process will be carried on repeatedly until the faulted section is identified and removed. Because of this, the method is said to be crude and costly [2]. The second destruction method is “sectionalizing by refusing”. This is done by isolating a portion of the cable loop before the primary fuse is close. Whenever the fuse opens, the next fuse is closed until the faulted section is identified. The application of this method is however will cause damage to the customer and utility equipment.

2.3 Travelling Wave Method

The traveling wave method is based on the reflection and transmission of the fault generated while the wave moving across the distribution network. The illustration of this concept is shown in figure 2.1.

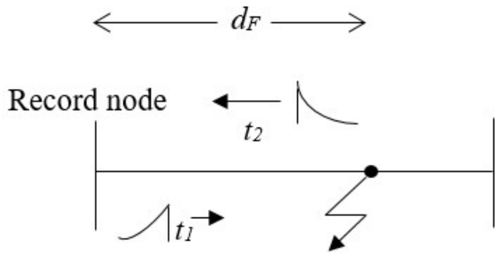

Figure 2.1 : Traveling wave method concept

From the illustration shown, the fault distance from the record node, d_f, can be calculated from the following equation:

$$d_f = \frac{v \times (t_2 - t_1)}{2} \tag{2.1}$$

In this equation, v is the velocity of the traveling wave with the time taken of t_1 for the traveling wave to reach the fault location from the record node. Once the traveling wave reaches the fault, it will reflect the wave to the record node with the time taken of t_2 [4].

Paper [5] explains the use of the traveling waves to detect fault location at a single location in the distribution feeder. The approach used in this paper is by making a comparison on the measured distance of each peak in the high-frequency current signals with known reflection points. A transient power system simulator is used to model the actual network with the possible fault location and the simulation results are then cross-checked against the signal from the real network. The paper, later on, concludes that the suggested method can accurately locate a fault by using a measurement at a single location.

If a fault occurs in a power system with a non-effective grounded neutral, it will produce a very low magnitude of fault current which renders it very difficult to identify the fault location. To overcome this problem, paper [6] suggested a new algorithm based on improved morphological gradient. In this traveling wave method, the algorithm will select the current traveling wave that contains fault signal characteristics before extracting the α-mode by phase module transformation and structuring the morphological filter to filtrate the α-mode. The result from this paper shows that the algorithm is simple with less calculation but has some practical value.

Paper [7] introduced a method to detect the fault location with a wavelet approach. The method is based on a multi-terminal traveling wave with a device that able to identify traveling waves that are installed in every transformer. The method is then simulated by the ATP software with the result that showing the fault could be located quickly and accurately.

The application of a traveling wave-based method to locate a fault in a power system without the use of a global positioning system (GPS) is described in [8]. The transient waves were extracted from the recorded waves at the busbar by using wavelet denoising. The extracted wave carries information about the characteristic of the fault and hence was used in the Artificial Neural Network (ANN) to locate the fault. Even though the proposed method has reduced the cost by not using the GPS, the error in determining the fault location is slightly higher.

A method for locating faults based on wave traveling in real-time is proposed in paper [9]. The approach is based on two terminals which link to the end of a transmission line via a control network. Two potential circumstances of low and high data transmission latency are being suggested for the system. The benefit of the approach is that both terminal data can be utilized in synchronization or non-synchronization.

2.4 Impedance Based Method

The impedance-based method is typically used to determine the location of fault from a voltage or current measurement at the controlled substation using impedance from the monitored node. Based on the Ohms Law, a monitoring node will use the voltage and current to assess failure as seen in figure 2.2.

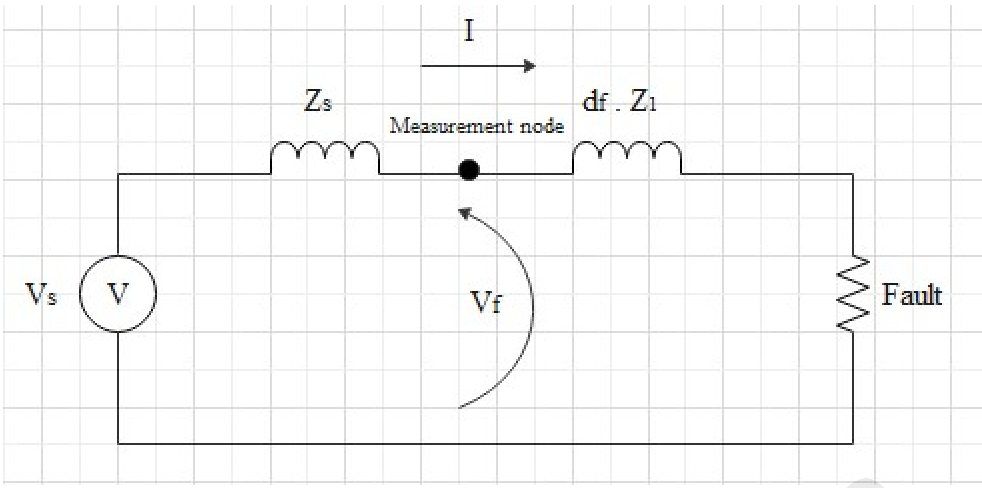

Figure 2.2: Impedance based method

In a faulty condition, the measurement node will record the fundamental components of current and voltage. The fault distance will then be determined from the following expression:

$$d_f = \frac{V_f}{I \times Z_1} \tag{2.2}$$

Where d_f is the fault distance from the measured node, V_f and I are the voltage and current measured during the fault, Z_l is the line impedance per unit length, V_s is the source voltage and Z_s is the source impedance.

Following the expression in (2.2), different methods based on impedance exist. 10 different fault location method based on impedance [11] to [20] were compared in [10] to evaluate its efficiency. All approaches methods were only analyzing voltage and current measurements at the monitored substation. The analysis that was done by this paper also considered the essential aspects of each system. Power system topology, line, and load models and the need for additional information are relevant aspects that distinguish one method from another. When detecting single-phase faults, the general outcomes of all of the proposed approaches demonstrated good performance. This paper focuses on the exactness of the difference between the fault, though, and does not address the multiple fault positions.

Multiple fault locations are a typical issue in most impedance related approaches using a single measurement caused by multiple electrical distances. For a complex distribution network with a lot of branches, the possibility of having multiple fault location increase significantly. Therefore, paper [21] provides a computational approach to solve the problems of multiple fault locations in the impedance-based method by using available current measurements and voltage fundamentals in the power substation. The faulty location is identified in this method based on the performance of the three-phase measurement for each lateral position, provided that the load or line parameters are different. Nevertheless, because the load current is ignored, the method may generate incorrect fault distances.

Paper [22] is using the same approach as in paper [21] to overcome the problem with multiple fault locations by considering the pre-fault current in the faulted feeder. In this method, the various fault location possibilities are resolved by calculating the fault current in the healthy phases. By doing so, it implies that the accuracy of the fault distance is more accurate. However, both approaches in [21] and [22] are more suitable in the unbalanced system.

An improved method for finding faults in the power distribution system that is highly reliable is proposed in paper [23]. The proposed algorithm produces a fifth-order algebraic equation of fault distance using the phase domain of the distributed parameter line model, allowing the accuracy of the determined fault distance for any kind of fault to be improved. The proposed method is evaluated under various fault resistances where the findings indicate a low sensitivity to this parameter. To assess the effectiveness of the proposed method, the modified IEEE 34 Node Test Feeder is used and its efficacy and effectiveness are demonstrated.

2.5 Knowledge Based Method

Due to the complexity of distribution systems and different uncertainty factors, such as cable length and unknown fault resistance which are difficult to address by using impedance and traveling wave techniques, a method based on knowledge has been explored for finding faults. The knowledge based method is based on various approaches, for example, Artificial Neural Network (ANN) and Matching Approach.

2.5.1 Artificial Neural Network

The Artificial Neural Network (ANN) is one of the efficient methods for solving several problems in the classification and optimization of engineering. The ability to detect complex patterns has also made it possible to locate the fault. Such an approach may be of great assistance to operators or engineers. With this approach, the time factor is greatly decreased and human error is avoided.

Figure 2.3 provides an overall concept of ANN in which the training input can be based on measuring data such as voltage, current, circuit breaker status, and feeder with the fault location as the target output.

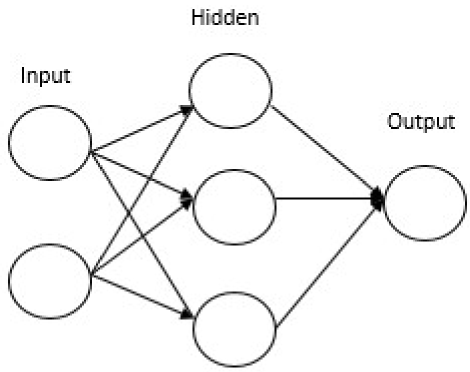

Figure 2.3: Illustration of Artificial Neural Network

To identify and locate faults in the distribution network, a feed-forward ANN approach is used in [24]. To locate fault the system uses fault voltage and current samples obtained from a typical radial distribution system. Different types of fault, location, resistance, and angle of inception of the fault have been tested in the proposed method and up to 3% error was produced in the analyzed test cases. The advantage of using ANN is that data reflecting modifications to the current system could be trained off-line and it can quickly identify the on-line fault location accurately.

The major downside of ANN is that a well-trained ANN algorithm is highly dependent on the quantity and consistency of the trained data. Despite its simplicity in the implementation, however, the performance of the method will be affected by a lack of information. Other issues with this approach are that it has slow convergence in the training phase and that it is important to evaluate correct parameters such as hidden units, layers, learning rate, and momentum values. Furthermore, when there are adjustments to the system, the ANN algorithm needs to be retrained.

2.5.2 Matching Approach

The matching approach is another knowledge-based method that compares the measured to the simulated data. Typically, the fault location is determined from the recorded voltage sag or current data.

Paper [25] and [26] are among the earliest reported work that using voltage sag to locate the fault. The papers use an 11 kV distribution network to estimate the faulty section. For a comparison to be made, a fault was created at various locations via simulation to generate simulated voltage sag and stored in a database. The measured voltage sag is compared to the voltage sag database when a fault occurs in real-time. The fault section is then can be identified when the actual voltage sag match with the database. This approach can be considered as economical for implementation since voltage sag measurement is only required at the primary substation.

The drawback of this technique is that it depends entirely on the simulated database to find a fault. Therefore, the process of creating a voltage sag database is lengthy since it requires simulation at all nodes and the database needs to be updated whenever there are changes in the real network.

In summary, the reviewed papers addressed in this chapter indicate that each method developed to identify the fault location is based on a particular condition and assumption which depends on the complexity of the network. This shows that no single method can solve all the problems that arise. Therefore, in order to make any method more effective, the fundamental working principle must be thoroughly understood.

CHAPTER 3 : METHODOLOGY

3.1 Introduction

Various methods for fault detection has been discussed in Chapter 2. It is understood that the most important thing to be considered in finding the fault is to detect the location quickly and precisely. This will benefit in reducing the outage time significantly and the system will be able to go back online within the specified time given.

The first step in this research is to model a distribution bus system. A single line diagram of the IEEE33 bus distribution system is used as a reference. A completely constructed 33 bus distribution network is needed in this research to generate a set of databases.

The next step is to create a fault at the selected location. The type of fault to be used in the simulation is firstly determined before the simulation takes place. Several simulations are required with different input of fault parameters to generate a strong database. The overall work flow chart used in this research is shown in Figure 3.1.

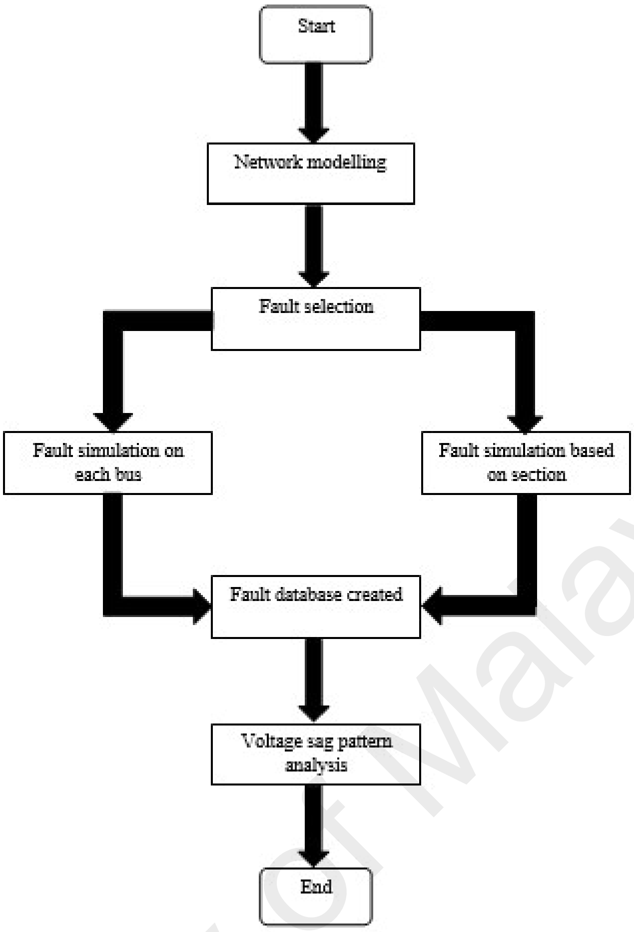

Figure 3.1: Overall work flow chart

3.2 System Modelling

3.2.1 Network Modelling

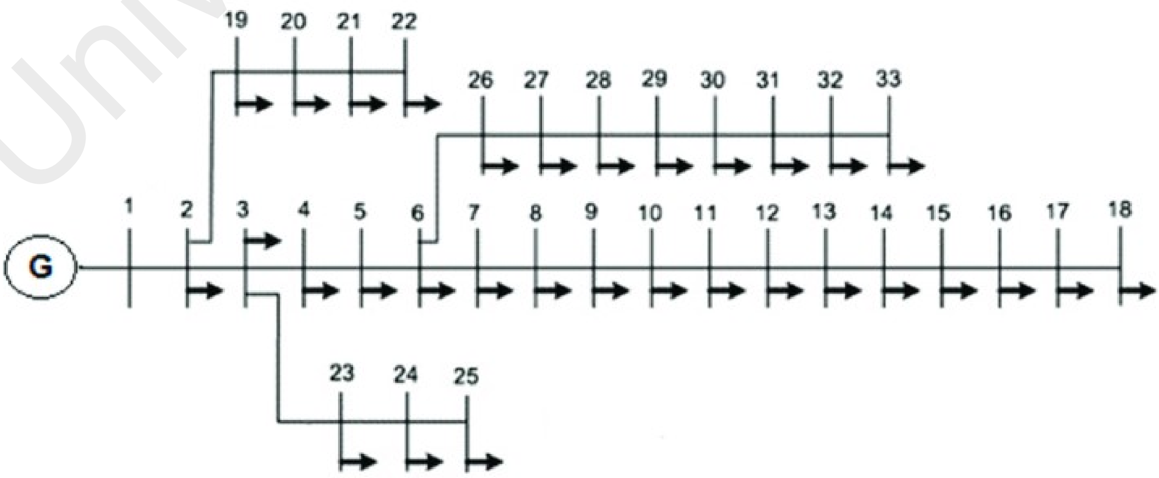

Figure 3.2: Single line diagram of IEEE 33 bus distribution system

IEEE 33 bus distribution network which is used in this research to simulate the fault at the selected location is illustrated in figure 3.2 above. This system consists of 33 buses and 32 lines and has a voltage of 12.66 kV. The bus is indicated from number 1 to 33. This system is made of 4 feeders in total. The arrangement of feeders can be seen in Table 3.1.

Table 3.1: Arrangement of feeders

Number of feeders	Bus
1	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18
2	1,2,19,20,21,22
3	1,2,3,23,24,25
4	1,2,3,4,5,6,26,27,28,29,30,31,32,33

The model begins with the Three Phase Source block to introduce a balanced 3-phase voltage source with an internal R-L impedance. The source block is then connected to the bus number 1 and the Three-Phase Series RLC Branch block. This block incorporates three balanced branches, each of which consists of a resistor, an inductor, or a capacitor, or a series of combinations. The model is later on expanded to 4 feeders based on the single line diagram as in figure 3.3. In this model, the Powergui block is used to provide the discretization of the electrical system for a solution at fixed time steps.

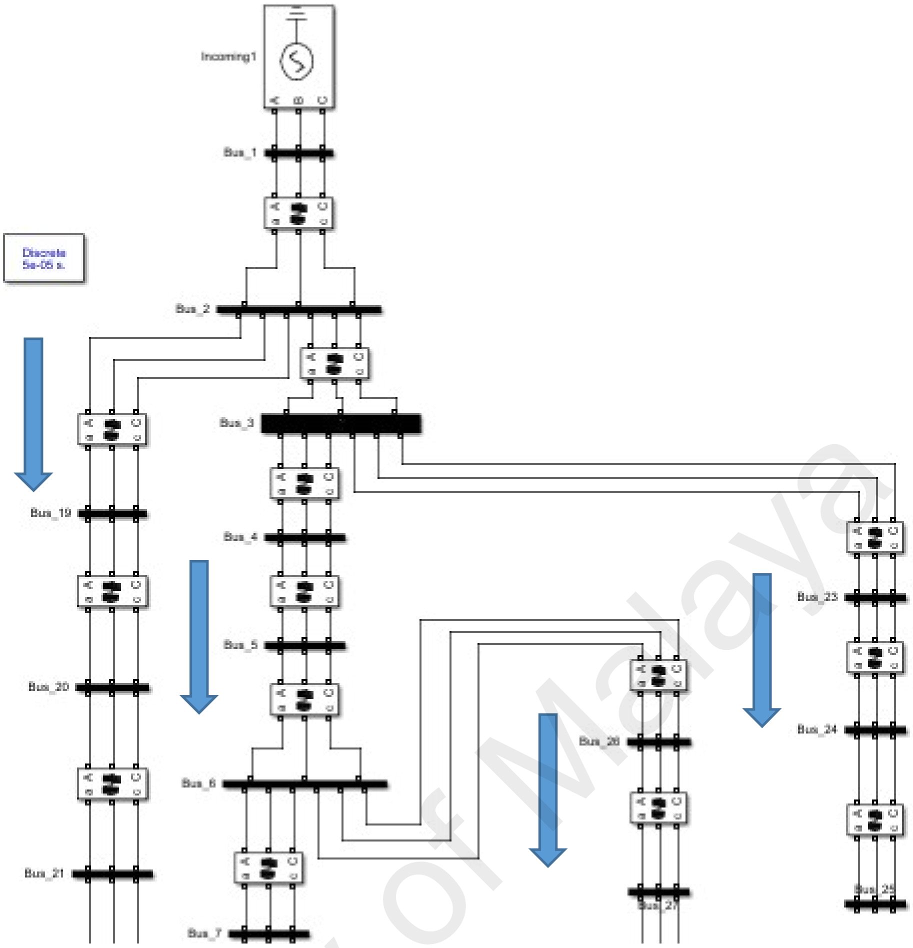

Figure 3.3: Snapshot of 4 feeders in the model

3.2.2 Fault Analysis

This research focuses on two types of faults, which are single line to ground fault (SLGF) and three-phase to ground fault (LLLGF). A single line to ground fault is the most common fault that occurs in the distribution system. It happened when one of the power lines connected to the ground or in contact with the neutral line. This occasion may result from many reasons due to the falling of a tree, lightning surge, high-speed wind, or any other unknown reason.

In order to create fault on the network model, the three-phase fault block is used to implement a three-phase circuit breaker where the opening and closing time can be controlled. The three-phase fault block as shown in figure 3.4 uses three breaker blocks that can be individually switched on and off to program phase to phase faults, phase to ground faults, or a combination of phase to phase and ground faults.

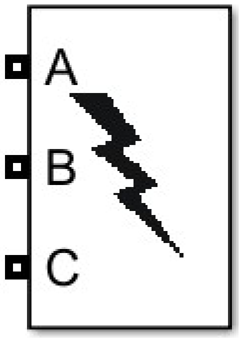

Figure 3.4: Three-Phase fault block

Since two types of fault are required in this analysis, the parameter should be carefully selected before simulation to avoid an incorrect set of data being recorded. As can be seen in figure 3.5, fault between phase A and ground is selected to represent a single line to ground fault. Otherwise, all fault between phases A, B, C, and the ground is selected for the three-phase to ground fault.

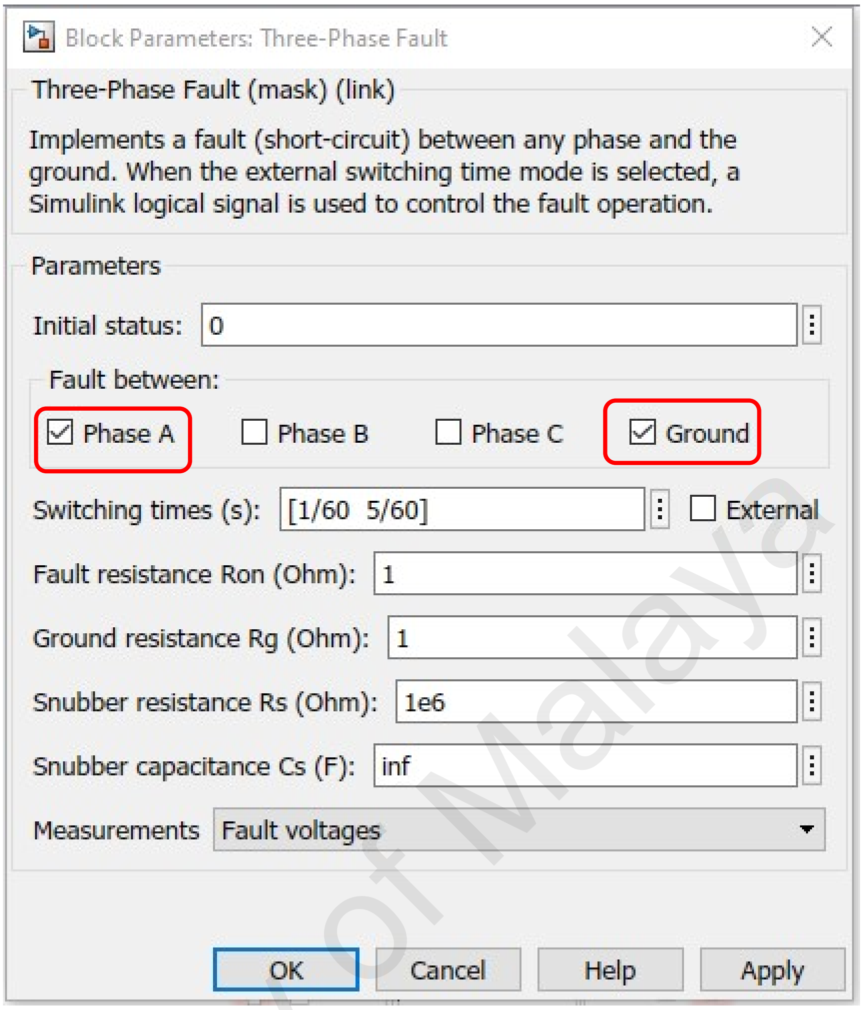

Figure 3.5: Three-Phase block fault parameters

The three-phase fault block will produce measurement in terms of fault voltages. For each type of fault created at the selected point, several fault voltage measurement will be taken at fault resistance of 0.001Ω, 1Ω, 5Ω, 10Ω, and 15Ω.

3.2 Establishment of Voltage Sag Database

Once the distribution network model and the fault are successfully created, the next step is to establish a database from the analytical voltage sags. This can be achieved by recording all the voltage sags value in the database after simulating fault. The procedure to establish the database are as follows:

i) Single line to ground fault is simulated at all buses for fault resistance of 0.001Ω.
ii) Measurement is taken for the lowest magnitude of the fault voltage and stored in the database.
iii) Steps (i) and (ii) are repeated for fault resistance of 1Ω, 5Ω, 10Ω, and 15Ω.
iv) Steps (i) to (iii) are repeated for fault simulated at the section in between the bus.
v) Steps (i) to (iv) are repeated for the three-phase to ground fault.

The process to establish the database is lengthy if it is done manually. Therefore, an automate process can be carried out by using the script as below:

```
clear all
close all
clc
timeTS = (0:0.001:0.15)';
CBStats1 = [zeros(length(timeTS),31)];
resistance=[0.001,1,5,10,15];
y=1;
for j=1:5
    fault_resistance=ones(31,1)*resistance(j);
    for i=1:31
```

```
            CBStats=CBStats1;
            CBStats(:,i)=1;
            siminCB = timeseries(CBStats,timeTS);
            simName = 'filename';
            simIn = Simulink.SimulationInput(simName);
            simIn = simIn.setVariable('siminCB',siminCB);
            simout = sim(simIn);
            x=find(simout.simout(:,1)~=0);
            result(y,:)=[i,resistance(j),min(simout.simout(x,:))];
            y=y+1;
            end
        end
```

3.2 Propose Faulty Section Identification

Based on the voltage sag analysis, the faulty section can be identified by matching the measured voltage sag magnitude at the section in between the bus and the measured voltage sag magnitude took on the bus. Any fault section is identified when the measured voltage sag magnitude lies in between any two adjacent voltage sag magnitude from the database. The relationship is shown in equation 3.1.

$$V_p^{(dbase)} \leq V_f^{(meas)} \leq V_q^{(dbase)} \quad (3.1)$$

In this proposed method, the fault location is determined based on the voltage sag pattern as seen from the monitored bus. The voltage sag magnitude at every adjacent bus is measured and stored in the database. This voltage sag magnitude is represented by $V_p^{(dbase)}$ and $V_q^{(dbase)}$ in equation 3.1. $V_f^{(meas)}$ is the measured voltage sag magnitude when the fault occurred in the system. The location of the fault will then be identified once $V_f^{(meas)}$ match with any voltage sag value in the database. The concept of the matching method is illustrated in the figure 3.6 below.

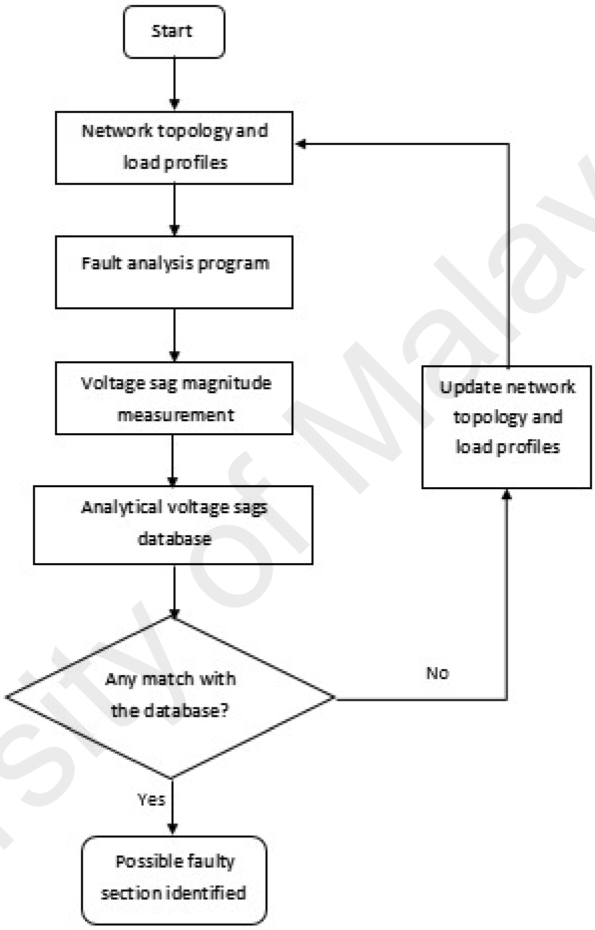

Figure 3.6: Concept of the matching method

CHAPTER 4 : DISCUSSION AND RESULTS

4.1 Introduction

The result and discussion of faulty location in a distribution network based on voltage sag analysis are provided in this chapter. The identification of the faulty section can be beneficial from the pattern analysis of voltage sag variation between two adjacent nodes. The voltage sag values for three-phase to ground fault and a single line to ground fault were obtained from the simulation on each bus and in between sections.

4.2 Voltage Sag Pattern Analysis

Single line to ground fault is known as the most frequent fault that occurs in the distribution network, therefore the simulation started with SLGF. In figure 4.1, it can be seen that the measurement for voltage sag was taken at bus number 2, and the network distribution used in the simulation consists of four feeders. Figure 4.1 shows that the magnitude of voltage sag increases as the fault occurs in a distance away from the measurement point.

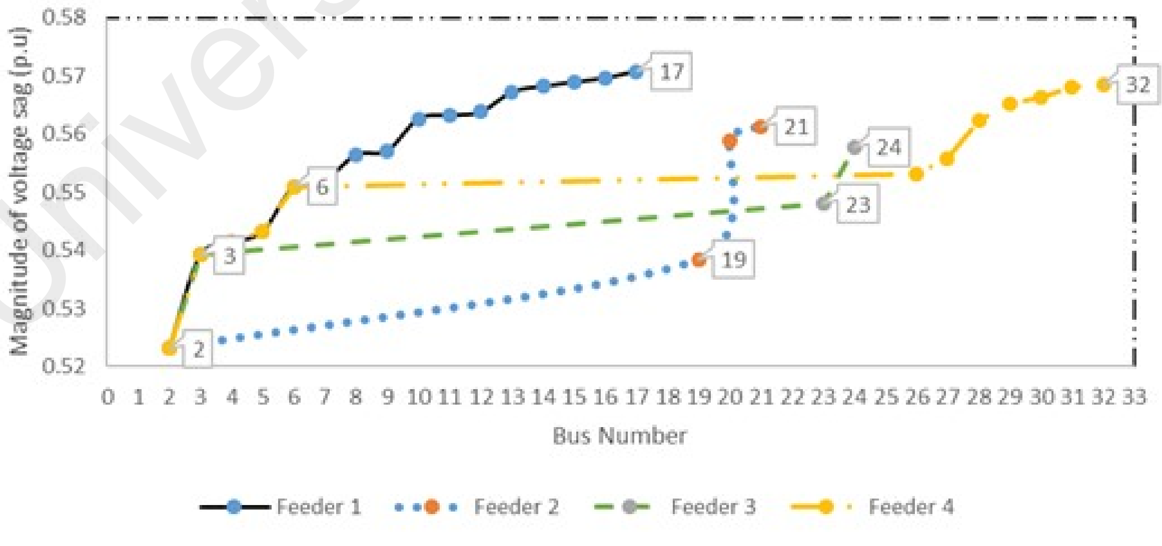

Figure 4.1: SLGF analytical voltage sag magnitude (p.u) for fault resistance 0.001 Ω

Figure 4.1 also shows that the crossover between feeder lines occurs at bus number 2. At bus number 2, crossover happened between feeder 1,3,4 and feeder 4. Another crossover is spotted at bus number 3 between feeder 1,4 and feeder 3. Then, the next crossover between feeder 1 and 4 occurs at bus number 6. This is a situation that will occur at a location where a lateral branch exists.

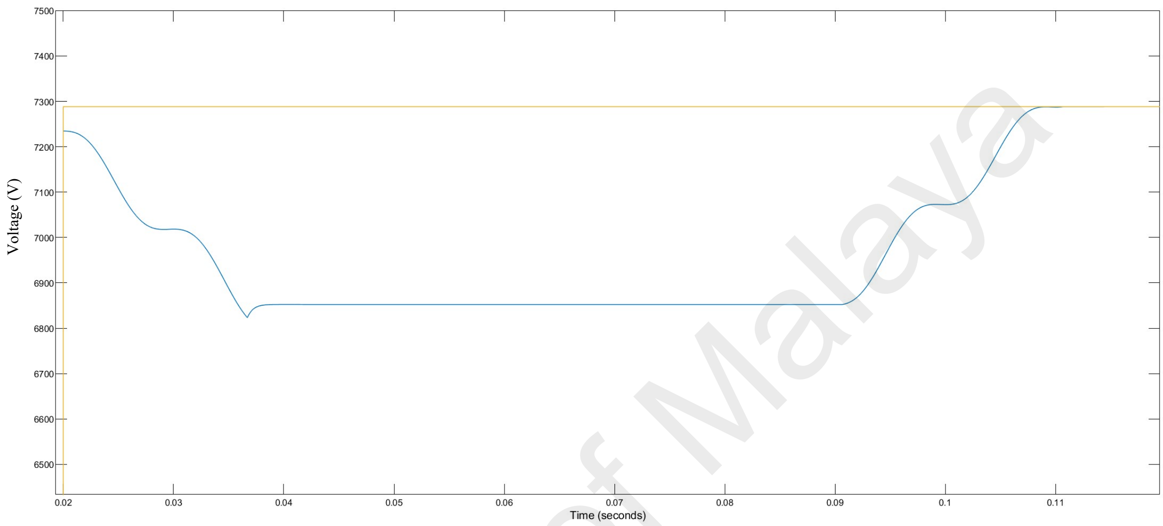

Figure 4.2: SLGF voltage sag pattern for fault resistance 0.001 Ω at bus number 3

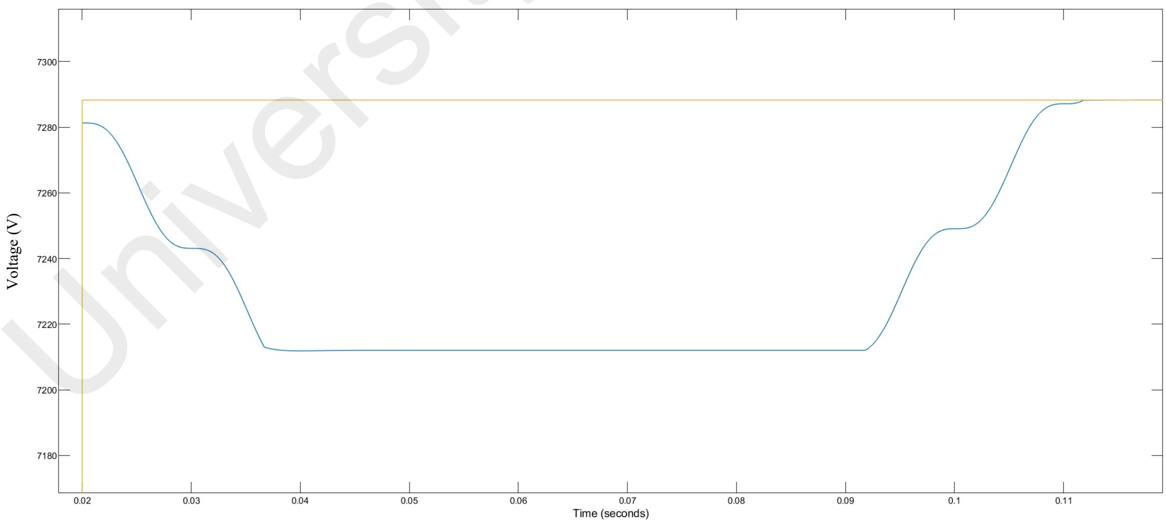

Figure 4.3: SLGF voltage sag pattern for fault resistance 0.001 Ω at bus number 16

Figure 4.2 shows the depth of voltage sag magnitude when SLGF created at bus number 3 which is closer to the measurement point comparing to the depth of voltage sag magnitude when SLGF occurs at bus number 16 as shown in figure 4.3 in the same feeder line but far away from the measurement point. From both figures, it shows that the depth of voltage sag magnitude increases as the fault occurs much closer to the measurement point.

Further analysis of the voltage sag pattern for a single line to ground fault was carried on different fault resistance. The pattern for each different fault resistance is shown in figure 4.4, 4.5, 4.6, and 4.7.

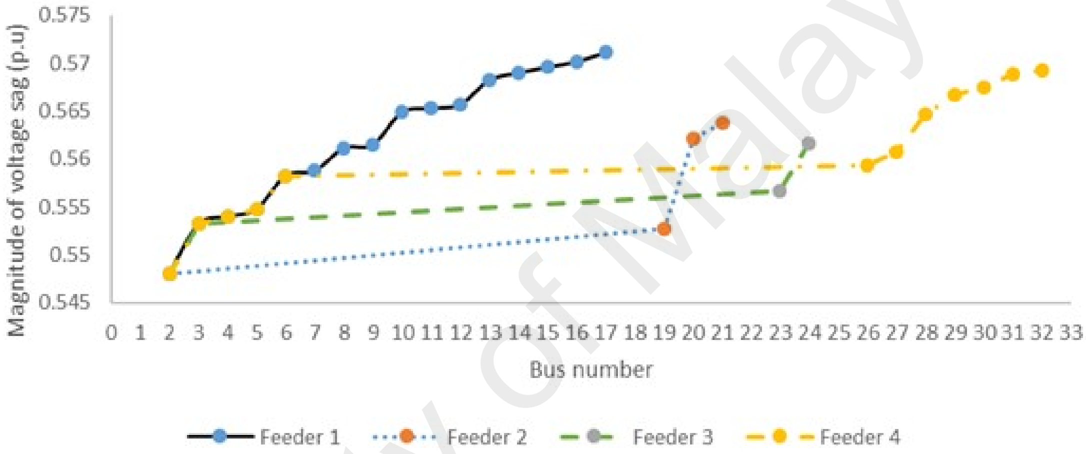

Figure 4.4: SLGF analytical voltage sag magnitude (p.u) for fault resistance 1 Ω

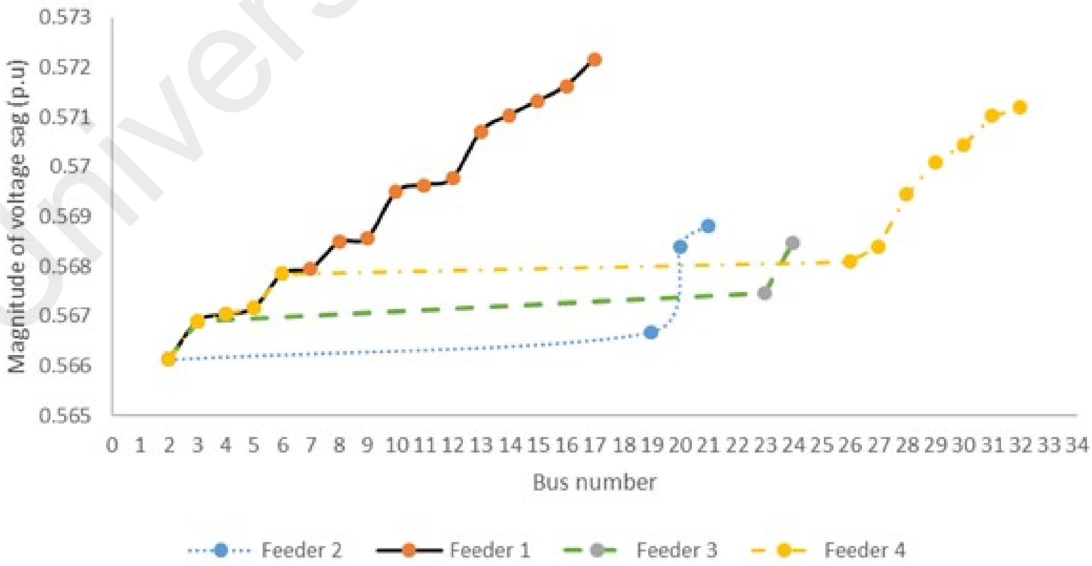

Figure 4.5: SLGF analytical voltage sag magnitude (p.u) for fault resistance 5 Ω

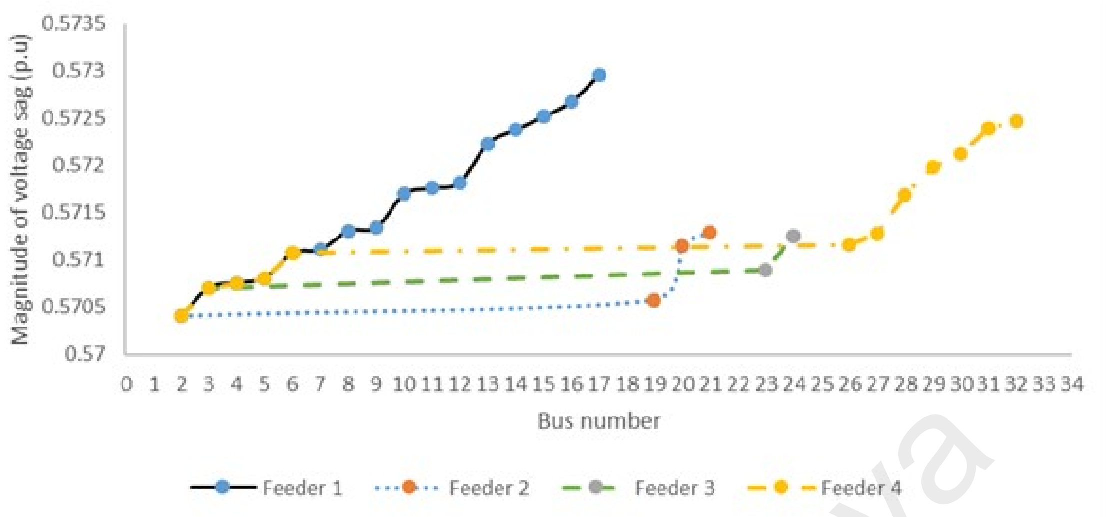

Figure 4.6: SLGF analytical voltage sag magnitude (p.u) for fault resistance 10 Ω

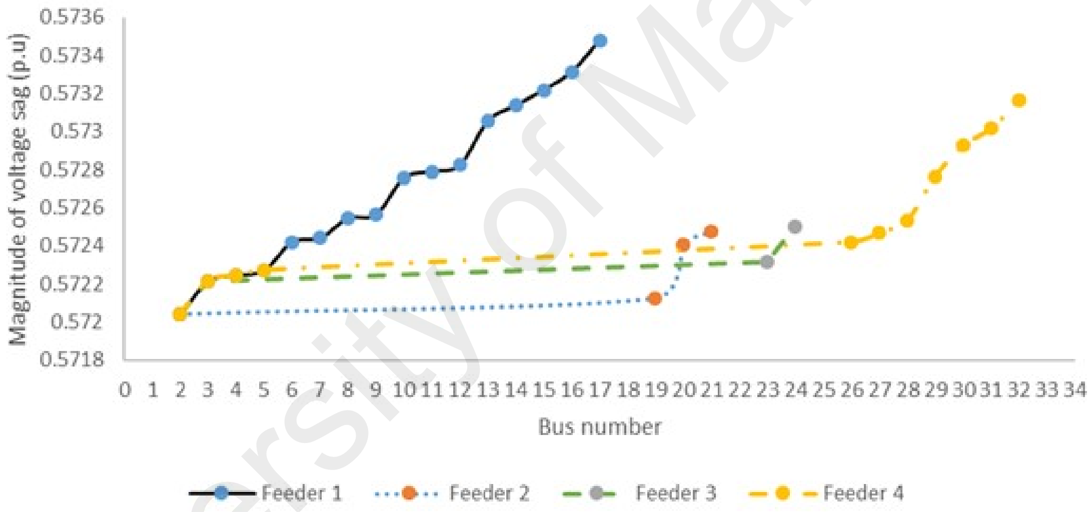

Figure 4.7: SLGF analytical voltage sag magnitude (p.u) for fault resistance 15 Ω

It is clearly shown that any value of fault resistance in a single line to the ground fault will exhibit the same pattern for voltage sag magnitude. Therefore, the analysis of voltage sag pattern will be extended to a different type of fault which is three-phase to ground fault.

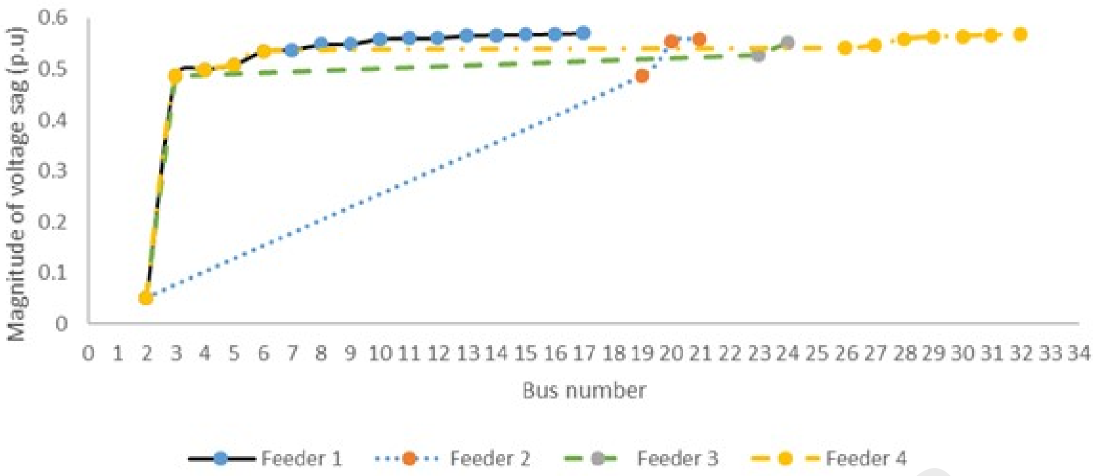

Figure 4.8: LLLGF analytical voltage sag magnitude (p.u) for fault resistance 0.001 Ω

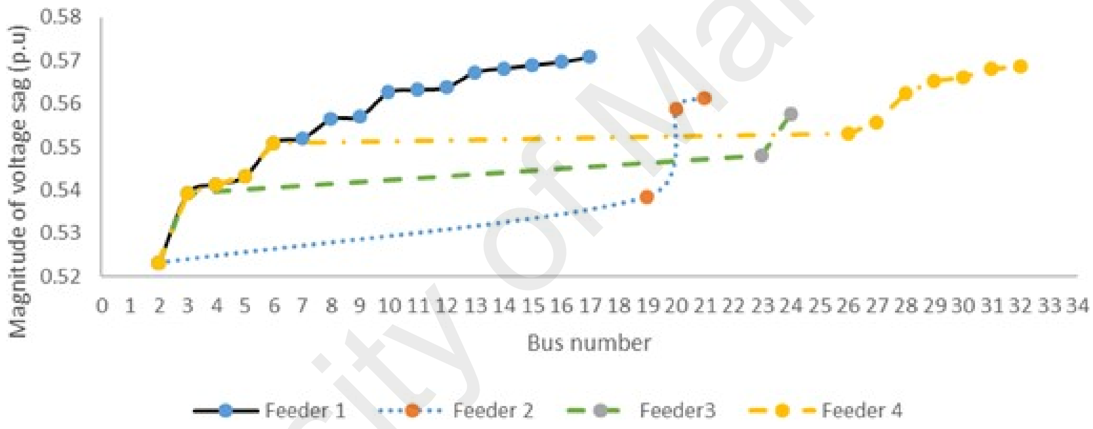

Figure 4.9: LLLGF analytical voltage sag magnitude (p.u) for fault resistance 1 Ω

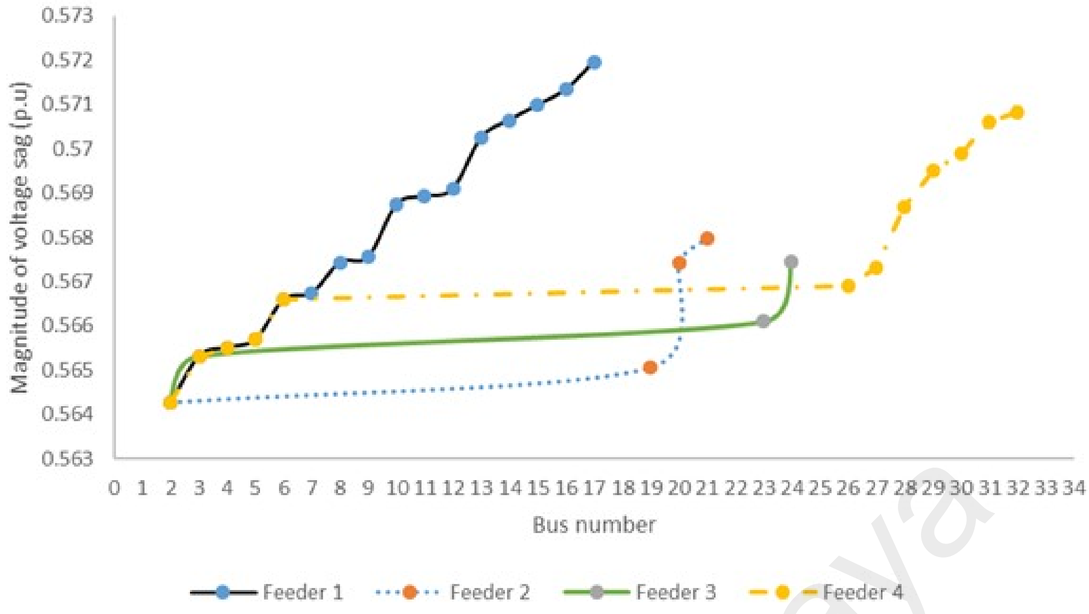

Figure 4.10: LLLGF analytical voltage sag magnitude (p.u) for fault resistance 5 Ω

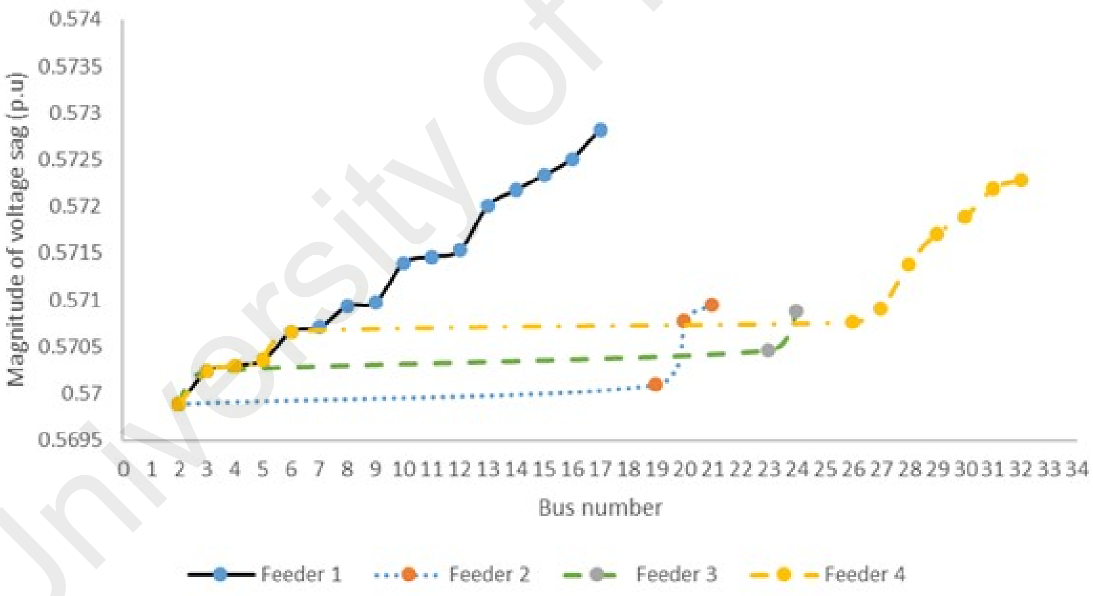

Figure 4.11: LLLGF analytical voltage sag magnitude (p.u) for fault resistance 10 Ω

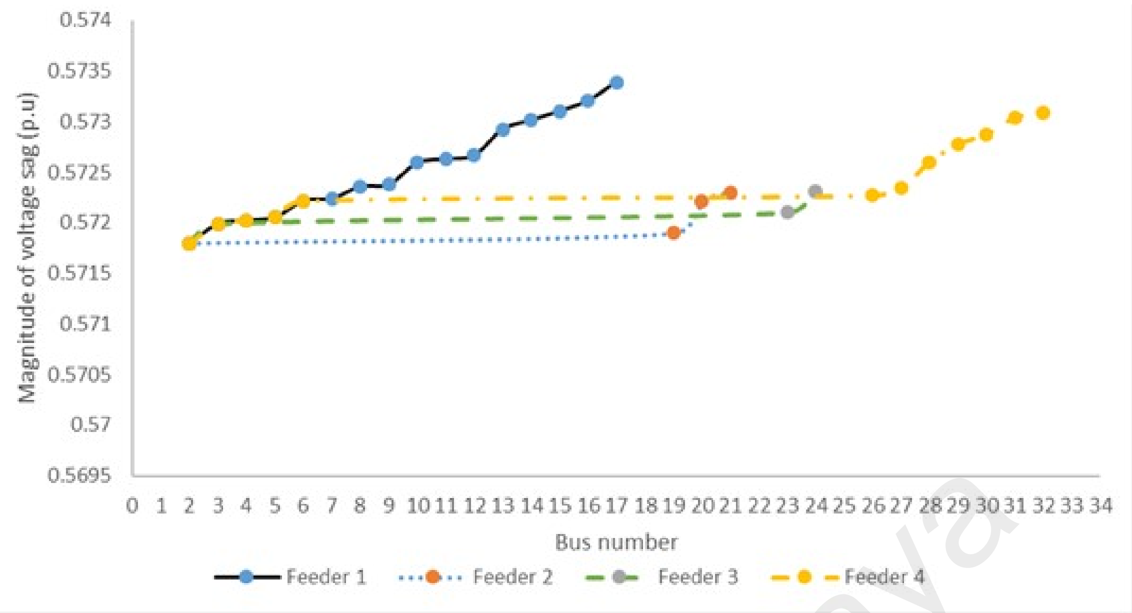

Figure 4.12: LLLGF analytical voltage sag magnitude (p.u) for fault resistance 15 Ω

By comparing the voltage sag pattern between two different types of fault, it can significantly distinguish the sag pattern between them. From the figures shown above, it is indicated that both types of fault are having the same pattern shape.

However, figure 4.13 shows that SLGF produces more severe voltage sag magnitude compare to the LLLGF.

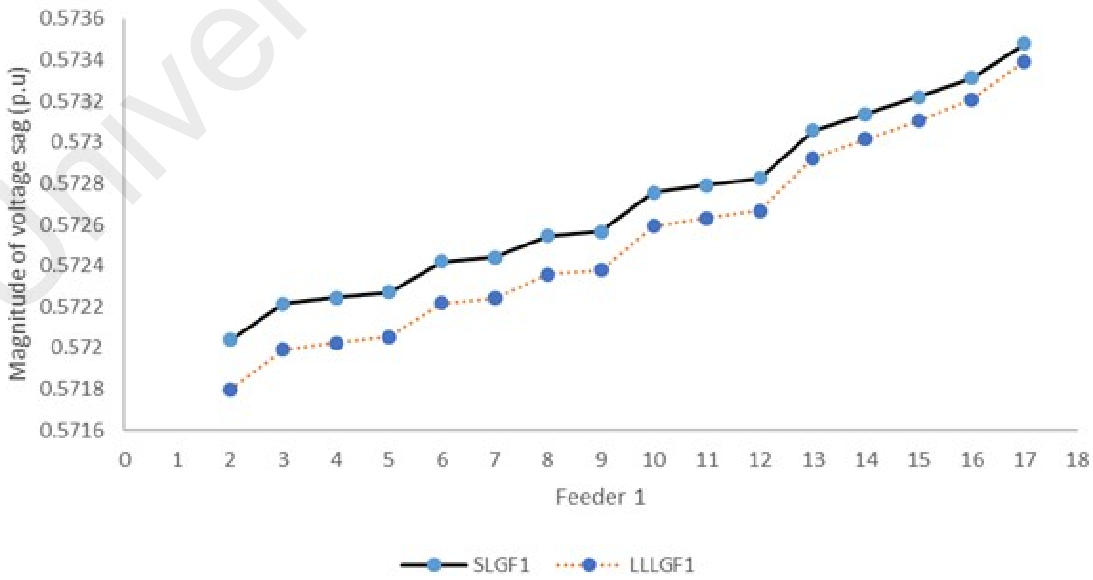

Figure 4.13: Pattern of voltage sags for SLGF and LLLGF on feeder 1

The analysis of the voltage sag effect on the different types of fault suggests that the proposed method can be used to differentiate the fault and hence able to match the voltage sags from the fault databases and leads to the identification of fault location in a network distribution.

4.3 Test Results

Based on the simulation carried out for the single line to ground fault and three-phase to ground fault, the magnitude of voltage sag (p.u) for each bus in the network distribution is stored as a database that will be used to identify the faulty section. When a fault occurs at the middle point between the buses, all possible faulted sections will be looked into. Since the sample of network distribution used in the simulation is complicated, hence there is a possibility to found multiple sections. Table 4.1 shows the number of possible faulty sections for a single line to ground fault occurs at the middle point between 2 buses in feeder 1.

Table 4.1: Possible faulty sections for fault occurs at the middle point in feeder 1

Middle point fault	Possible faulty sections	Number of sections found	Identified feeder
2-3	2-3, 2-19	2	Feeder 1 and 2
3-4	3-4, 19-20, 3-23	3	Feeder 1,2 and 3
4-5	4-5, 19-20, 3-23	3	Feeder 1,2 and 3
5-6	5-6, 19-20, 3-23	3	Feeder 1,2 and 3
6-7	6-7, 19-20, 23-24, 6-26	4	Feeder 1,2,3 and 4

7-8	7-8, 19-20, 23-24, 27-28	4	Feeder 1,2,3 and 4
8-9	8-9, 19-20, 23-24, 27-28	4	Feeder 1,2,3 and 4
9-10	9-10, 20-21, 27-28	3	Feeder 1,2,3 and 4
10-11	10-11, 28-29	2	Feeder 1 and 4
11-12	11-12, 28-29	2	Feeder 1 and 4
12-13	12-13, 29-30	2	Feeder 1 and 4
13-14	13-14, 30-31	2	Feeder 1 and 4
14-15	14-15, 31-32	2	Feeder 1 and 4
15-16	15-16, 32-33	2	Feeder 1 and 4
16-17	16-17, 32-33	2	Feeder 1 and 4

Table 4.1 shows that whenever a fault occurs at the middle point between 2 buses, the possibility of a faulty section can be narrowed down into several sections found and hence eliminate the unnecessary time needed for searching along the line one by one. The feeder line can also be determined and allow the maintenance team to focus only on the identified feeder and section. Table 4.2, 4.3, and 4.4 below show the extracted information for possible faulty sections for fault occurs at the middle point in feeder 2,3 and 4.

Table 4.2: Possible faulty sections for fault occurs at the middle point in feeder 2

Middle point fault	Possible faulty sections	Number of sections found	Identified feeder
2-19	2-19, 2-3	2	Feeder 1 and 2
19-20	19-20, 5-6, 23-24	3	Feeder 1,2 and 3
20-21	20-21, 9-10, 27-28	3	Feeder 1,2 and 3

Table 4.3: Possible faulty sections for fault occurs at the middle point in feeder 3

Middle point fault	Possible faulty sections	Number of sections found	Identified feeder
3-23	3-23, 5-6, 19-20	3	Feeder 1,2 and 3
23-24	23-24, 19-20, 26-27	3	Feeder 2,3 and 4

Table 4.4: Possible faulty sections for fault occurs at the middle point in feeder 4

Middle point fault	Possible faulty sections	Number of sections found	Identified feeder
6-26	6-26, 8-9, 19-20, 23-24	4	Feeder 1,2,3 and 4
26-27	26-27, 7-8, 19-20, 23-24	4	Feeder 1,2,3 and 4
27-28	27-28, 20-21, 9-10	3	Feeder 1,2 and 4

28-29	28-29, 12-13	2	Feeder 1 and 4
29-30	29-30, 12-13	2	Feeder 1 and 4
30-31	30-31, 12-13	2	Feeder 1 and 4
31-32	31-32, 14-15	2	Feeder 1 and 4

CHAPTER 5 : CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research, a method to identify a faulted section in a distribution network is presented. This method used the voltage sag pattern of the simulated distribution network and stored it as a database for matching purposes. In order to produce a constant and reliable database, the voltage sag measurement was taken at a single location only at which in this research it was taken at the bus number 2. Since this method only requires measurement of voltage sags at one point, its implementation can be considered as very economical.

The result obtained in this research which is based on computer simulation has shown that it is possible to identify fault locations based on the voltage sag data. Even though the result has shown multiple possible fault locations detected, however, at the same time it can reduce the locating time by narrowing the possibility. This will benefit the maintenance team to track down the affected section due to the fault and get the system back in time.

While the results are showing good implementation to be considered in the real-time system, there is also a lot of room for improvement.

5.2 Recommendation on future works

The following are some recommendation that can be carried out in conjunction with this research work:

I. Develop a method to detect the fault location precisely or with fewer errors and increase its efficiency.

II. A thorough study of the effect of voltage sags pattern on all types of fault in the distribution network.

III. Comparing the method with other fault locating methods to see the differences in terms of accuracy.

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