RADIAL DISTRIBUTION NETWORK MODELING AND ANALYSIS CONSIDERING POWER FLOW AND RECONFIGURATION

(A CASE STUDY OF AZARE DISTRIBUTION NETWORK)

BY

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AHMADU BELLO UNIVERSITY, ZARIA

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES,AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER DEGREE IN POWER SYSTEMS ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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NIGERIA

JUNE, 2015

DECLARATION

I KABIR Abdulrashid Muhammad hereby declared that this Dissertationentitled "Radial Distribution Network Modeling and Analysis Considering Power Flow and Reconfiguration (A Case Study of Azare Distribution Network)" has been carried out by me in the department of Electrical Engineering under the supervision of Prof. U. O.Aliyu and Dr. Abdullahi A. Mati as part of the requirements for the Award of Degree of Master of Science in Power Systems Engineering. This research work to the best of my knowledge has never been submitted anywhere for the award of any degree. All literatures used and cited are duly acknowledged in the reference pages.

AbdulrashidMuhammadKABIR:________________ _____________

(Signature) **Date**

CERTIFICATION

This Dissertation "Radial Distribution Network Modeling and Analysis Considering Power Flow and Reconfiguration (A Case Study of Azare Distribution Network)" meets the Requirements for the Award of Degree of Master of Science (M.Sc) in Electrical Engineering by Ahmadu Bello University, Zaria and it is approved for its contribution to knowledge and literature.

Chairman Supervisory Committee ____________ __________

(Prof. U. O.Aliyu) **(Signature)** **Date**

Member Supervisory Committee _____________ __________

(Dr. Abdullahi A. Mati) **(Signature)** **Date**

Head of Department _____________ __________

(Prof. M. B. Mu'azu) **(Signature)** **Date**

Dean, School of Postgraduate Studies _____________ __________

(Prof. A. Z. Hassan) **(Signature)** **Date**

DEDICATION

This research work is dedicated to GOD and to the promoters of peace and those who in one way or the other make a significant difference in an ordinary person’s life and impact the world.

ACKNOWLEDGEMENT

In the name of GOD: the most beneficent and the most merciful. All praises are due to GOD the creator of the heaven and earth, and the Lord of universe. May the peace and blessings of GOD be upon Prophet Muhammad (S.W.A), his companions and all those who follow the right part until the day of judgments.

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KABIR Abdulrashid Muhammad

June, 2015.

ABSTRACT

The complexity and large number of computations involved in power flow and reconfiguration analysis of large distribution networks necessitates the need for the improvement of power flow and reconfiguration techniques. In this research work, a GPS based method is used in modeling Azare distribution network and in selecting the most appropriate positions of Tie branches (required for network reconfiguration). Radial distribution network power flow and reconfiguration algorithms are developed based on improved Backward-Forward Sweep (BFS) and All Spanning Trees of Undirected Network Graph (ASTUNG) techniques respectively.MATLAB GUI based simulators are also developed for power flow and reconfiguration analysis. The developed simulators are used in simulating power flow and reconfiguration on the Azare distribution network. A voltage profile improvement of 64.11% and a total real power loss reduction of 54.4% are achieved in the optimum configuration compared to the original configuration. Finally, the effectiveness of the developed power flow simulator is also demonstrated by testing it using the Standard IEEE 30 and 33 bus networks and comparing the results with those obtained in other similar literatures; while the effectiveness of the reconfiguration simulator isdemonstrated using the standard IEEE 33 bus network. The developed reconfiguration simulator was able to improve the voltage profile of the standard 33 buses IEEE radial network by 65.7% and reduce its total real power loss by 56.17%; and when compared with other similar literatures, an improvement of 14.23% is made in voltage profile while a reduction of 0.31% is achieved in power loss. All computations and simulations were performed using MATLAB V.7.0 Software.

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LIST OF ABBREVIATION

GPS	Global Positioning System
BFS	Backward – Forward Sweep
ASTUNG	All Spanning Tress of Undirected Network Graph
GUI	Graphic User Interface
VSI	Voltage Stability Index
SLBI	System Load Balancing Index
BLBI	Branch Load Balancing Index
VP	Voltage Profile
pu	Per-Unit
IEEE	Institute of Electrical Electronics Engineering
MATLAB	Matrix Laboratory (software)
L.G.A	Local Government Area
TCN	Transmission Company of Nigeria
JEDPLC	Jos Electricity Distribution Public Limited Liability Company
kV	Kilo-Volt
MVA	Mega-Voltage-Ampere
BTSs	Base Transceiver Stations
GRA	Government Residential Area
GIS	Geographical Information System
(‘)	Minutes (angular)
(“)	Seconds (angular)
(^{O})	Degrees (angular)
SW	Switch
kA	Kilo-Amps
Frm_Bus	Sending-end (node/bus) of a network branch

To_Bus	Receiving-end (node/bus) of a network branch
S_L	Load Active Power
S_{inj}	Bus Injected Power
IM	Information Matrix
BIM	Bus Incidence Matrix
S_{loss}	Branch Active Power Losses
VD	Voltage Deviation
m. File	MATLAB Function File
CSG	Candidate Solution Generator
TM	Tie Matrix
RNGIM	Reduced Network Graph Information Matrix
CS	Candidate Solution
VI	Voltage Profile Improvement
TVD	Total Voltage Deviation
Lng	GPS longitude coordinates
Lat	GPS latitude coordinates
Pf	Power factor
LBI_j	Branch Load Balancing Index
LBI_{sys}	System Load Balancing Index

CHAPTER ONE

GENERAL INTRODUCTION

1.3 General Background

Distribution system is the largest portion of the electrical power system. It can be defined as the part of a power system that distributes power to various customers in ready-to-use form at their place of consumption .(Ramesh *et al*, 2009). Optimal planning and design of the distribution systems involves network reconfiguration for distribution loss minimization, load balancing under normal operating conditions and fast service restoration to minimize the zones without power under failure conditions (Muhtazaruddin *et al*., 2014). Most of the distribution networks are configured radially which simplifies over-current protection of the feeders (Muhtazaruddin *et al.*, 2014). The manual or automatic switching operations are performed to vary the configurations. As the operating conditions change, the purposes of network reconfiguration are (Muhtazaruddin *et al*., 2014):

(i) To minimize the system power loss;

(ii) To balance the loads in the network.

(iii) To improve the voltage profile.

Power flow analysis is the determination of steady state conditions of a power system for a set of specified power generations and load demand. It involves the solution of a set of non-linear power flow equations (Ashokumar *et al*., 2009). Applications, especially in the fields of power system optimization and distribution automation, require repeated fast power flow solutions (Ashokumar *et* *al*., 2009). Due to the large number of interconnections and continuously increasing demand, the size and complexity of the present day power systems, have grown tremendously (Cossi *et al*, 2012). In the last few decades efficient and reliable power flow techniques such as Gauss Seidel (GS), Newton-Raphson (NR) and fast decoupled power flow (FDPF) have been developed and widely used for powers system operation, control and planning. However, it has repeatedly been shown that these methods may become inefficient in the analysis of distribution systems due to the following facts (Kashem *et al*,2010).

1. Distribution networks can be numerically ill-conditioned (network with high conductor losses) due to wide range of *X/R* ratios and the inherent radial structure.
2. Distribution power flow equations are different in nature from transmission power flow equations

The Global Positioning System (GPS) is a technology, which provides accuracy and flexibility in the determination of stationary or moving spatial objects (Beyers *et al*., 1996). In electrical power distribution system, it is used for finding the location of any object e.g. poles, substations, transformers, tracking of routes etc. It gives the position in form of latitude and longitude, which can directly be imported on computer screen.GPS are becoming very effective tools for GIS data capture (Boulaxis & Papadopoulos, 2002). The GPS can easily be linked to a laptop, computer in the field, and, with appropriate software. Users can also have all their data on a common base with very little distortion. Thus GPS can help in several aspects of construction of accurate and timely GIS databases.

Researchers have developed various techniques such as: modified-NR {Zhang *et al*, *2011*); modified-FDNR (Aravindhababu *et al*, *2010*); and Layer-By-Layer Backward-Forward Sweep (BFS) (Yan *et al*., 2003), for radial distribution network power flow analysis. Furthermore, techniques such as: Evolutionary Algorithm (Amasifen *et al, 2014*); Artificial Intelligence Algorithm (AIA) (Qlu *et al*, *2014*); improved binary particle swarm optimization (IBPSO) (Sedighizadeh *et al*, *2014*); All Spanning Trees of Undirected Network Grapgh (ASTUNG) (Zhang *et al*, *2014*); and refined genetic algorithm (RGA) (Zhu, 2010), have also been developed for radial distribution network reconfiguration analysis. BFS and ASTUNG techniques are relatively flexible, less complex, and easier to implement as compared to all other power flow and reconfiguration techniques respectively.

The major setback in most of the power flow and reconfiguration techniques is that, they eventually become too complex to apply as the network size increases and cannot be easily implemented in computer as tool for power flow and reconfiguration analysis. The flexibility and robustness of some of these techniques can be improved using numerical analysis techniques rather than complex differential equations.

In this research work, a radial distribution network is mapped using GPS, and a number of suitable position for tie-switches needed for network reconfiguration is determined. Then, the unique structure of the radial distribution system is exploited in order to come up with fast and flexible radial distribution system power flow and reconfiguration techniques based on Backward-Forward-Sweep (BFS) and All Spanning Trees of Undirected Network Graph (ASTUNG) respectively.

1.2 Azare Distribution Network

Azare as the major and most populated town in Katagum L.G.A. of Bauchi State has the highest number of consumers of electricity in Katagum zone of Bauchi State (www.google.com/population/azare/katagum/bauchi/niguria). Plate 1.1 shows the complete geographical map of Bauchi state showing the various local governments and the major road map.

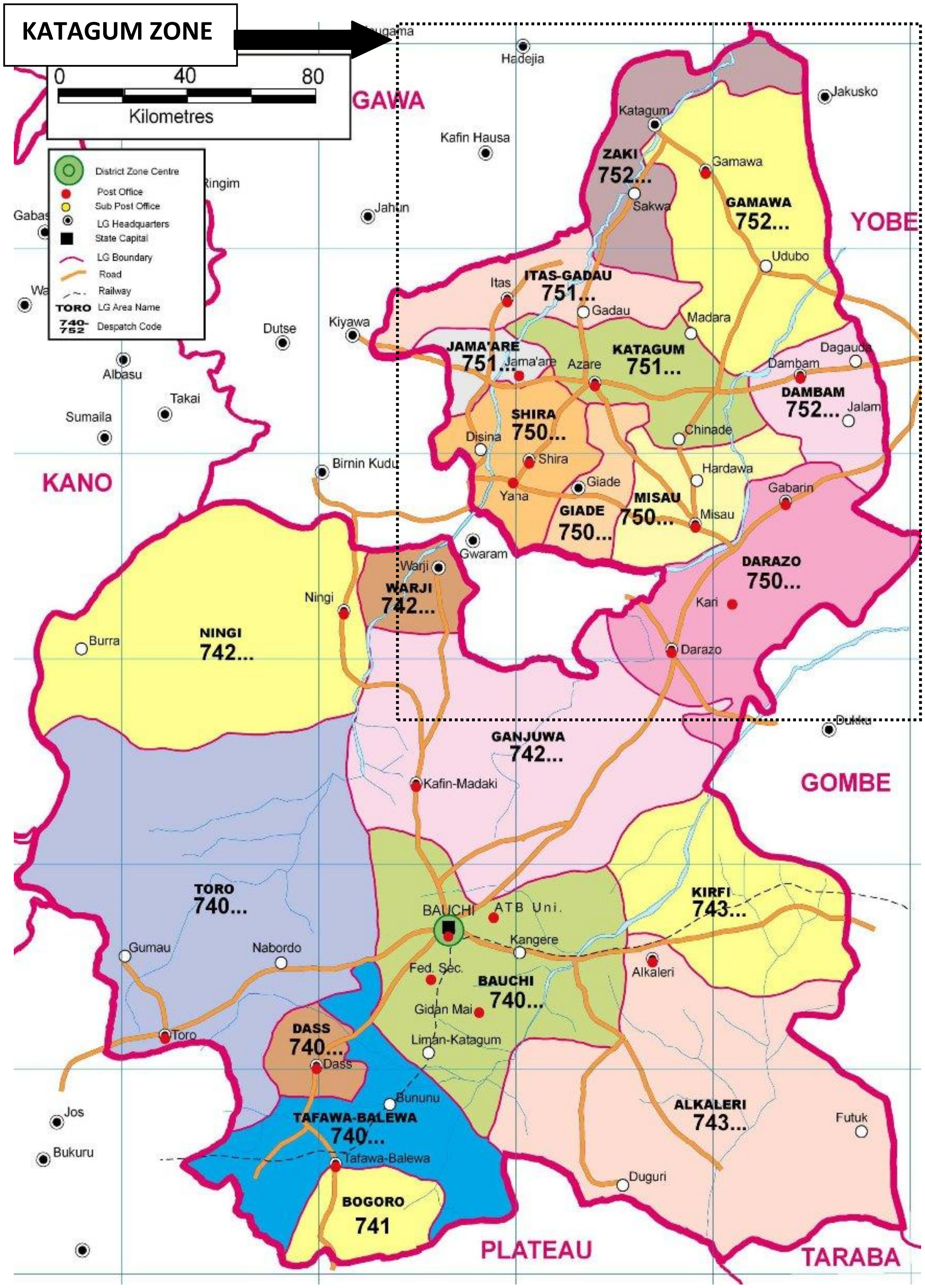

Plate 1.**1:** Map of Bauchi State, Showing the Major Roads Network and Various Local Governments (www.google.com/zip-codes/bauchi-state/nigeria)

Azare has a single 33/11kV injection substation which is being fed from a 132/33kV injection substation located within its vicinity. The schematic diagram of Azare 33kV network is shown in Figure 1.1. All, except the Azare injection substation power transformer in Figure 1.1, are 33/0.415kV distribution transformers which are dedicated to special consumers (Factories, BTSs, Institutions, Hospitals, etc.).

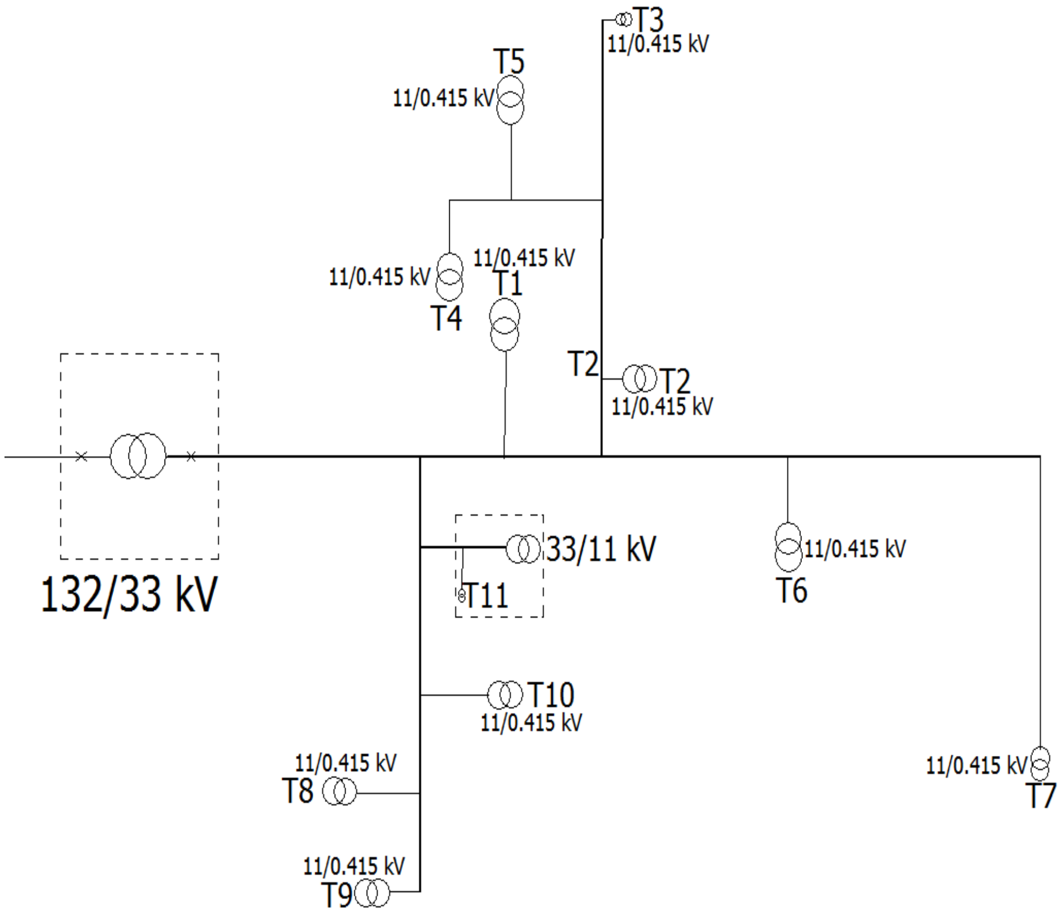

Figure 1.1: Schematic Diagram of the 33kV Distribution Network of JEDPLC, Azare, Dec. 2013

The Azare Injection Substation has a 7.5MVA, 33/11kV power transformer. 2x11kV main feeders radiate outward from the substation to serve two categories of customers on the 11kV network. The two categories of customers are:

1. The GRA Feeder Consumers.
2. The Town Feeder Consumers.

The complete network diagram of the two main feeders and their laterals are shown in Figures 1.2 and 1.3 respectively.

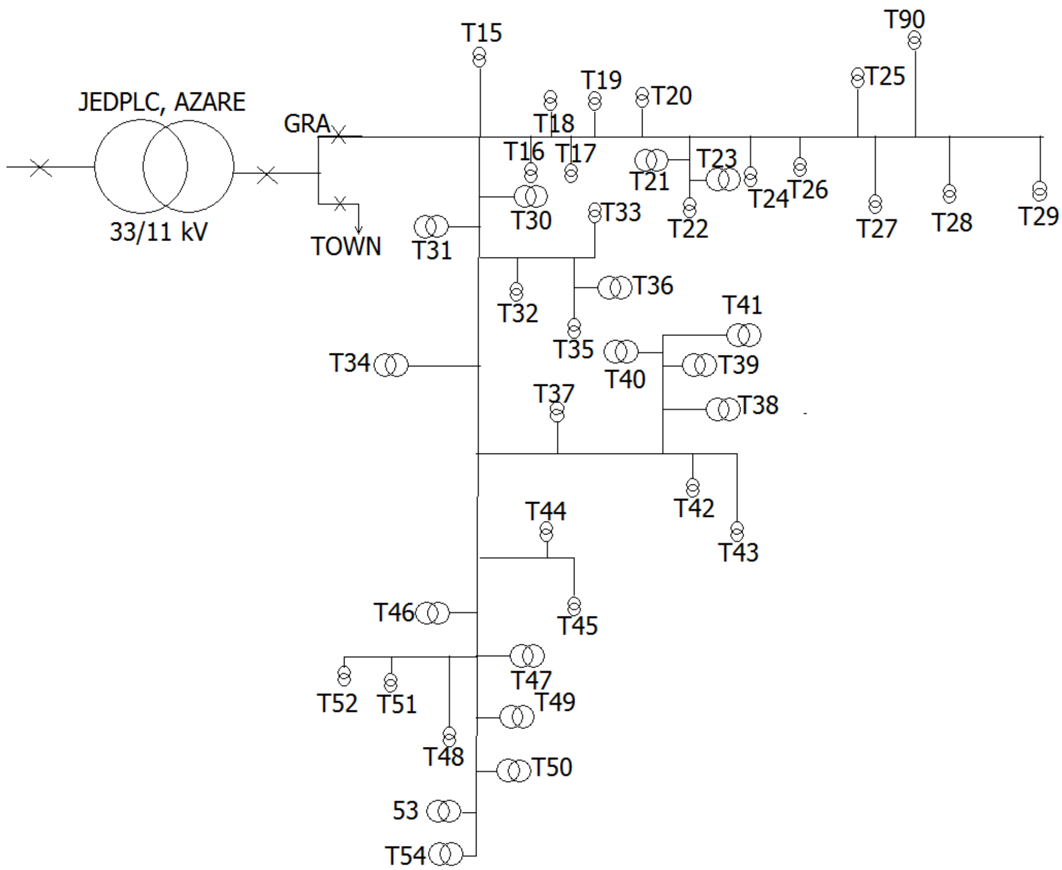

Figure 1.2: Schematic Diagram of the 11kV GRA Main Feeder and its Laterals of JEDPLC, Azare, 2013

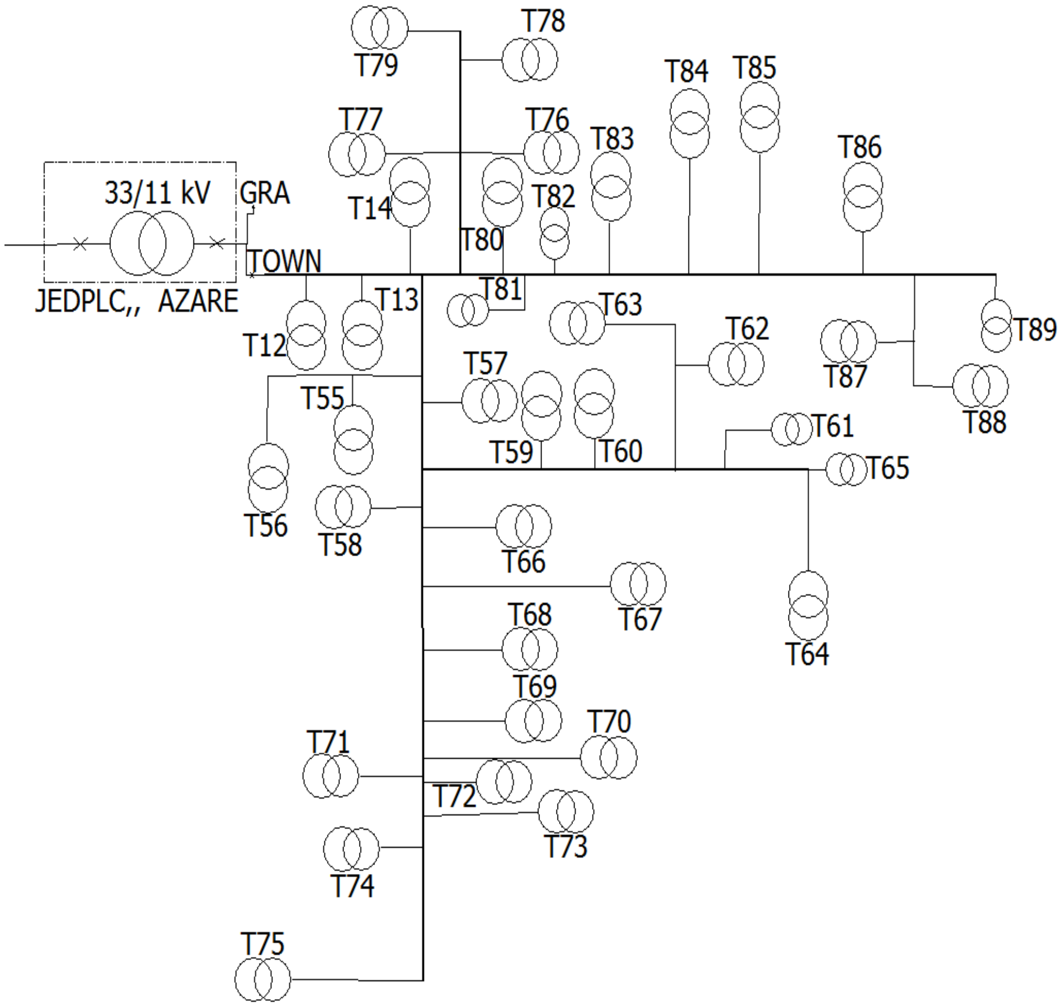

Figure 1.3: Schematic Diagram of 11kV Town Main Feeder and its Laterals
of JEDPLC, Azare, 2013

1.3 Azare Electricity Supply Systems

The route of power supply to JEDPLC, Azare can easily be described by Figure 1.4. The power supply originates from Mando Regional Transmission Station at Kaduna and runs through a Sub-regional Transmission Station at Kano (TCN. Kumbotso), a Sub-transmission Station at Jigawa (TCN. Dutse) and finally terminate at TCN, Azare. The Schematic diagram of TCN, Azare substation is shown in Figure. 1.5.

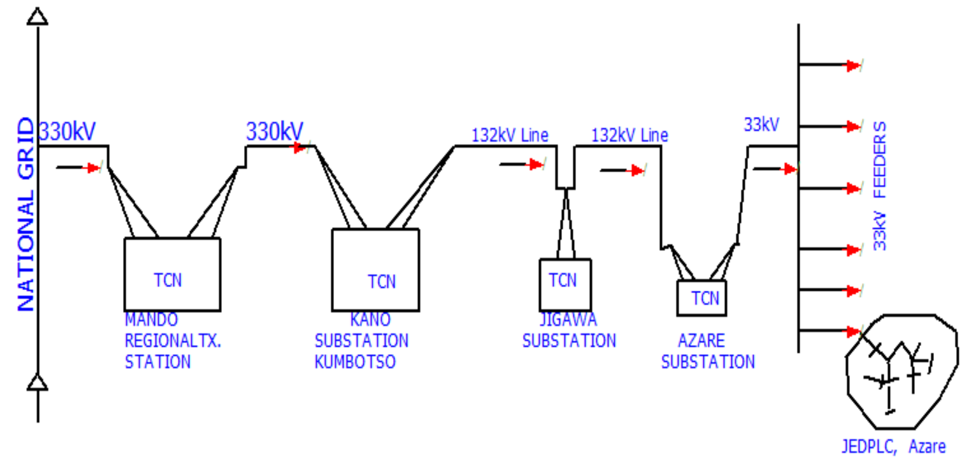

Figure 1.4: The Schematic Diagram of the Electricity Supply-Chain to JEDPLC, Azare

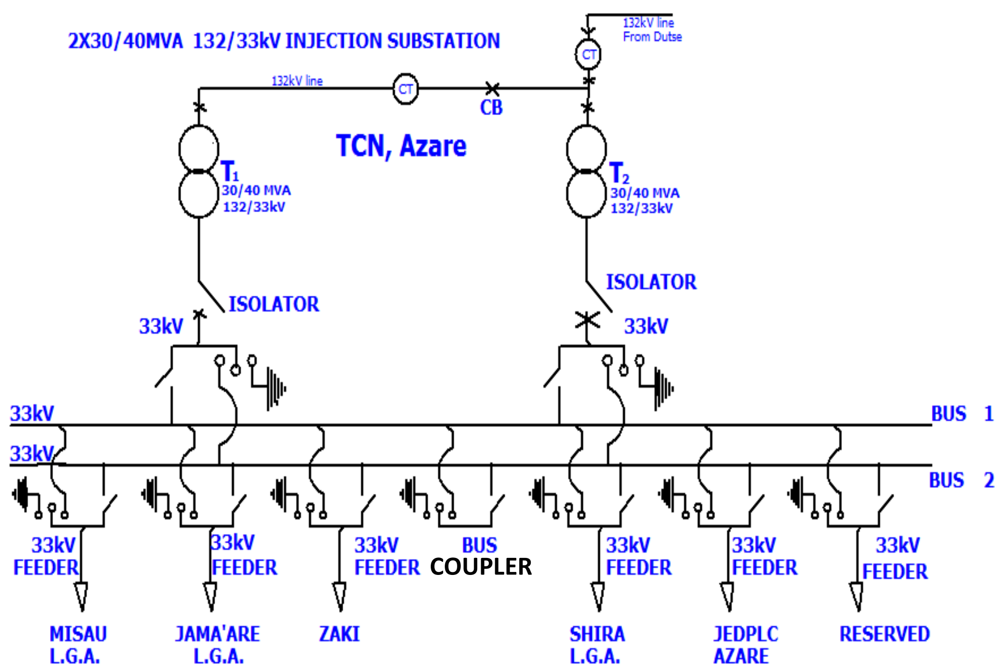

Figure 1.5: The Schematic Diagram of TCN, Azare

1.4 Azare Electricity Consumers

Even though, Azare has a 2MVA, 11/0.415kV Transformer which has not been in service for the past 5 years (the company that owns it has not been operational), its electricity is majorly consumed by house-hold appliances due to the fact that only a few number of small and medium scale industries exist. Currently, the largest installed and operating distribution transformer (33/0.415kV) has a capacity of 830kVA. It provides service to GILMO Water Board and a few numbers of other customers within its vicinity. This distribution transformer supplies not more than 50% of its rated capacity. The boundaries of Azare are rapidly expanding due to continuous construction of houses. This results in continuous increase in its average number of electricity consumers. The Percentage-load contributed by each of the categories is shown in Figure 1.6.

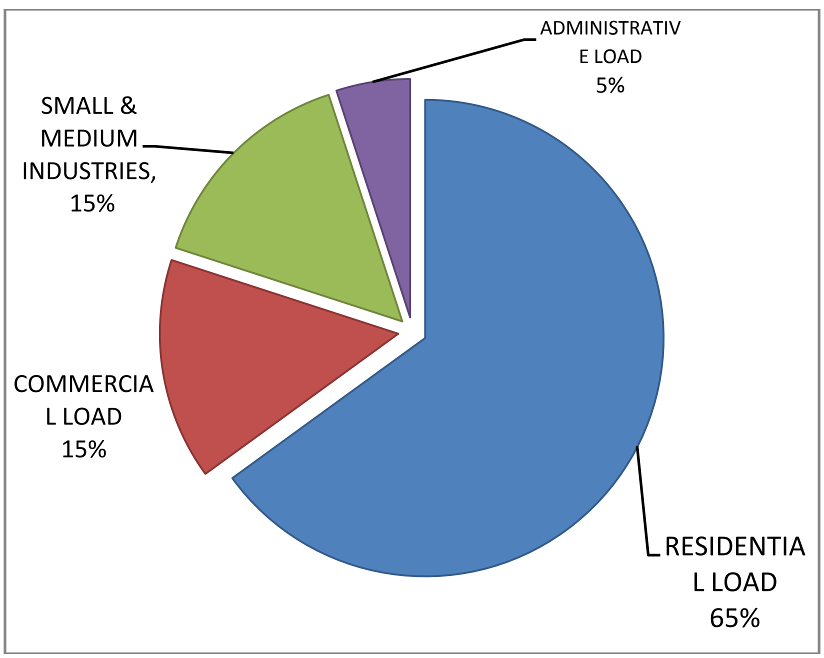

Figure 1.6 Percentage Load contributions of the Main Load Categories in Azare, 2013

1.5. Aim and Objectives

The aim of the proposed research work is to model a radial distribution network, and develop robust computer aided power flow and reconfiguration techniques based on improved Backward-Forward Sweep (BFS) and All Spanning Trees of Undirected Network Graph (ASTUNG) techniques respectively. In achieving this, the following objectives are met.

1. To collect relevant data from Azare distribution network and organizing them;
2. To develop improved power flow and reconfiguration models and algorithms.
3. To design and program MATLAB GUIs based on the developed power flow and reconfiguration algorithms;
4. To simulate power flow and reconfiguration on Azare distribution network;
5. To validate the developed models and algorithms using standard IEEE 30 and 33 bus radial distribution networks.

1.6 Problem Statement

The continuous growth in electrical energy demand and pressing need for better quality of service has necessitated the need for continuous radial distribution network analysis. Power flow and reconfiguration analysis form the bases of network reconditioning for safety loss reduction and reliability. The major challenge is that, power flow and reconfiguration analysis involves iterative computations that are time consuming and gets more complex as the network size (number of nodes) increases. Various techniques have been developed by researchers to address the stated problems. The flexibility and robustness of some of these techniques can be improved by developing a robust computer aided techniques for radial distribution network power flow and optimal reconfiguration based on improved BFS and ASTUNG techniques respectively. Azare distribution network was selected as a case study in order to carry out power flow and reconfiguration analysis. A GPS based technique is used to model the distribution network and to determine the most appropriate position of the tie switches required for network reconfiguration.

1.7 Methodology

The following steps would be adopted in order to achieve the aim and objectives of this research work:

1. Obtaining the network topology of the Azare distribution network and propose optimum location of tie switches/branches (required for network reconfiguration) using GPS coordinate system;
2. Development of power flow and reconfiguration models and algorithms base on improved BFS and ASTUNG techniques for radial distribution network power flow and reconfiguration analysis respectively;
3. Design and programming of Graphic User Interfaces (GUIs) in MATLAB based on the developed power flow and reconfiguration algorithms to

serve as tools for power flow and optimal reconfiguration analysis (simulators);

4. Performing power flow and optimal reconfiguration simulations on Azare distribution network using the developed GUIs and comparing the optimum and original configurations in terms of Real Power Loss, Voltage Profile, System Load Balancing Index (SLBI), Voltage Stability Index (VSI);
5. Validating the developed techniques using standard IEEE 30 and 33 bus radial distribution networks.

1.8 Significant Contributions

This research work offers the following significant contributions to the existing body of knowledge:

1. Development of radial distribution network power flow and reconfiguration algorithms based on improved Backward-Forward Sweep (BFS) and All Spanning Trees of Undirected Network Graph (ASTUNG) techniques respectively. The developed algorithms introduce flexibility and decrease the complexity arising from large network simulation by breaking the solution strategy into a number of subsections (MATLAB function blocks) that works together to achieve the set objectives. .
2. MATLAB GUI based software packages (simulators) have been developed based on the developed power flow and reconfiguration algorithms. The developed simulators can easily be used to accurately

perform power flow and reconfiguration analysis on either small or large distribution network.

3. The developed optimal reconfiguration simulator was able to improve the voltage profile of the simulated Azare distribution network by 64.11% and reduce its total real power loss by 54.4%. The simulator was also able to improve the voltage profile of the standard 33 buses IEEE radial network by 14.23% and reduce its total real power loss by 0.31% compared to the corresponding optimum values obtained in the work of Rao *et al*., 2011.

1.9 Thesis Organization

In chapter one, general background on distribution system is presented; followed by an overview of Azare distribution system. In chapter two, a concise review of the fundamental concepts and literatures regarding radial distribution network power flow and reconfiguration are presented. In chapter three, the proposed improved BFS and ASTUNG techniques and algorithms as applied to radial distribution network power flow and reconfiguration are presented respectively; Power flow and reconfiguration simulators (MATLAB GUIs) are also developed and presented in the chapter. In chapter four, Azare distribution network power flow and reconfiguration are simulated using the developed simulators (presented in chapter three); the results are presented and briefly discussed; and the developed simulators were further tested using IEEE standard 30 and 33 bus radial networks as a means of validation. Chapter five presents the conclusion, recommendations, and limitations of the entire research work

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In carrying out the research work, some literatures were reviewed, which served as a guide towards achieving the set goals. The review of these relevant literatures is categorized into two parts namely: Review of fundamental concepts, and Review of similar works, which are further discussed as follows.

2.2 Review of Fundamental Concepts

Some of the fundamental concepts regarding the proposed research work are discussed as follows.

2.3 Electric Power Systems

Electric power system can be defined as a combination of electrical components/device (technically combined together) aimed at transforming/ converting other forms of energy into electrical energy (generation of electricity); transmitting it from the location where it is converted (produced); and distributing it to various kinds of consumers (load centers). The production, transmission, and distribution of electricity is relatively efficient and inexpensive, although unlike other forms of energy, electricity is not easily stored and must generally be used as it is being produced (Grigsby, 2001). A modern electric power system consists of six main components (Grigsby, 2001) namely:

1. The power stations (generating stations);

2. Transformers (step-up) to raise the generated power to the high voltages used on the transmission line;
3. The transmission lines (inter-connections between generation stations and distribution substations);
4. The substations at which the power is stepped down to the voltage on the distribution lines;
5. The distribution lines (inter-connections between distribution substations and the consumer (load centers)); and
6. The transformers (step-down) that lower the distribution voltage to the level used by the consumer equipments.

2.4 Distribution System

The distribution networks are typically located at every part of every town and village, to provide electricity to all the individual customers. Obviously the distribution system must be suitable to meet the individual consumer requirements such as the electricity demand, reliability, power quality etc. As an example, certain load centers need high level of reliability and different load centers have different demand growth etc. Therefore the process of optimal planning has to begin from distribution system (Aghaei *et al*, 2014). Nowadays, advanced computer aided analysis tools such as NEPLAN, ETAP, PSCARD, etc. are available to carry out the optimal planning process (Chuang *et al*., 2014).

2.4.1 Types of Distribution System

Distribution networks are typically of two types, radial network and interconnected network as shown in Figures 2.1 and 2.2 respectively. A radial network leaves the station and passes through the network area with no normal connection to any other supply. This is typical of long rural lines with isolated load areas {Short, 2014}. An interconnected network has multiple connections to other points of supply. These points of connection are normally open but allow various configurations to be formed by the operating utility by closing and opening switches. Operation of these switches may be by remote control from a control centre or manually operated by linesmen (Short, 2014). The benefit of the interconnected model is that in the event of a fault or required maintenance, a small area of network can be isolated and the remainder kept on supply. Distribution systems are also classified based on their operating voltage, as discussed below (Short, 2014):

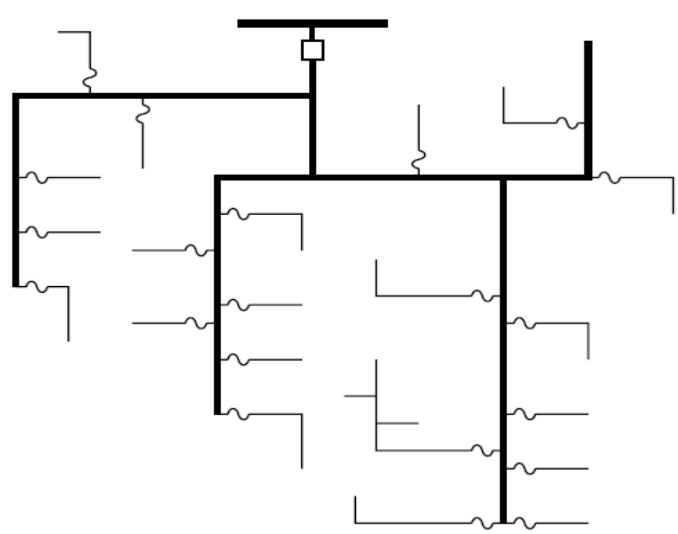

Figure 2.1: A Typical Radial Distribution Network {Short, 2014}.

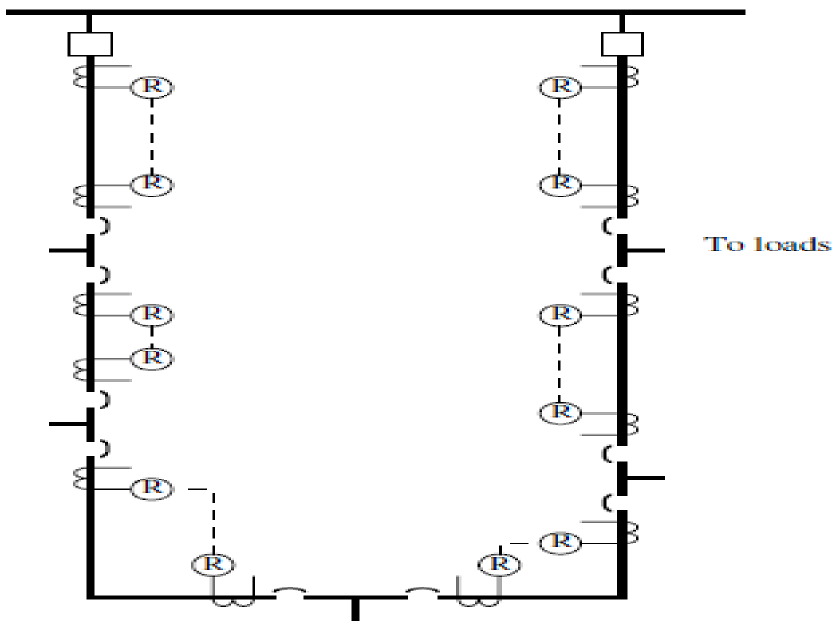

Figure 2.2: A Typical Interconnected Distribution Network with Auto-Re-closers (R) (Short, 2014)

2.4.1.1 *Primary Distribution System*

These consist of high voltage (11 and 33kV) networks from primary and sub-primary substations. These substations are interconnected with high voltage transmission lines. In most cases, large industrial consumers like cement factories, refineries, breweries, flour mills, and steel rolling mills and so on take supply at primary distribution system with associated transformers, switchgears and breakers (Short, 2014).

2.4.1.2 *Secondary Distribution System*

These consist of low voltage (415V) feeder networks from the secondary transformers that are constructed *along* main roads and streets. Service connections are made to individual consumers by service cables from these networks feeder lines. The various system of alternating current distribution for domestic consumers include: Single-phase 2-wire system, Single-phase 3-wire system, Three-phase 3-wire system, Three-phase 4-wire system. Of these, the single phase, 2-wires and the three phase 4-wire system are predominant **(**Short, 2014).

2.5 Network Reconfiguration

Reconfiguration problem of distribution systems is essentially a combinatorial optimization problem since various operational constraints are to be considered. Therefore it is difficult to obtain a true and fast solution for a real system (Muhtazaruddin *et al*., 2014).

Two types of switches, normally open switches (tie switches) and normally closed switches (sectionalizing switches), are used in primary distribution systems for protection and configuration management (Muhtazaruddin *et al*., 2014). The distribution network reconfiguration is obtained by closing tie (normally open) switches and opening sectionalizing (normally closed) switches in the network. The structure of the distribution network is maintained radially and all loads are energized while switching operations are performed. Obviously, the possibilities of network reconfiguration are greater when large number of switches is present. The network reconfiguration is illustrated through a simple system as shown in

Figure 2.3. Consider two switches, SW1 (sectionalized) and SW2 (tie) and two substations, S1 and S2 as shown in Figure 2.3 (a) (Muhtazaruddin *et al*., 2014).

A reconfiguration to reduce the system losses can be obtained by altering the system topology as shown in Figure 2.3 (b). It is recommended to open SW1 and close SW2 for the reconfiguration of the system. The effect of constraints on reconfiguration must be thoroughly studied before changing the basic configuration. One of the major constraints to be considered is that the network must have radial structure. Some of the general optimization algorithms fail in satisfying this radial constraint directly (Muhtazaruddin *et al*., 2014). Particularly a meshed network containing all switches closed will have fewer losses, but the radial constraint is violated (Muhtazaruddin *et al.*, 2014)..

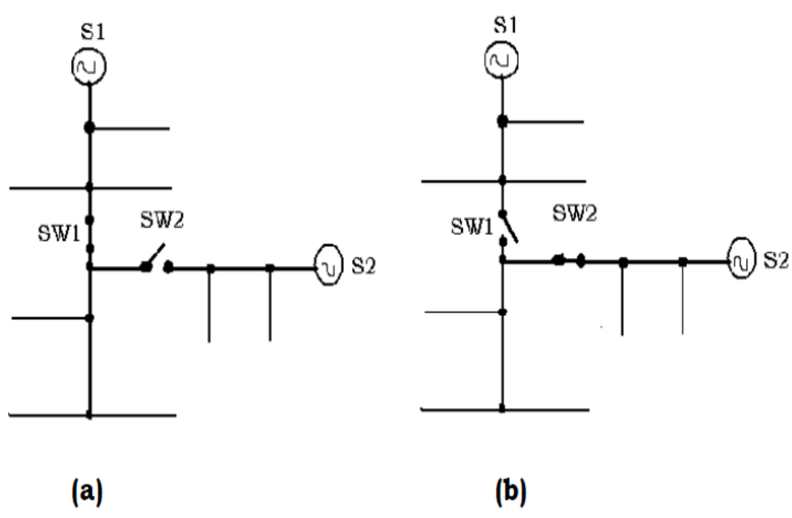

Figure 2.3: Illustration of reconfiguration. (a) Initial configuration. (b) Recommended Configuration (Muhtazaruddin *et al*., 2014)

2.6 Single Phase Representation of a Balanced Three Phase System

The power system has three phases. These three phases can be either balanced or unbalanced. A balanced three phase network can easily be represented by a single phase equivalent circuit. This equivalent single phase circuit can be used to analyze the three phase system. The parameters (current, voltage, impedance, etc.) of the three phase network can be estimated using the single phase equivalent circuit (*Das*, *2006*). Figure 2.4 shows a simple balanced three phase network. As the network is balanced, the neutral impedance Z_n does not affect the behavior of the network. Figure 2.5 gives the single phase equivalent of a balanced three phase network of Figure 2.4. As the system is balanced, the voltage and currents in the other phases have the same magnitude but are shifted in phase by 120^o (*Das, 2006*) .

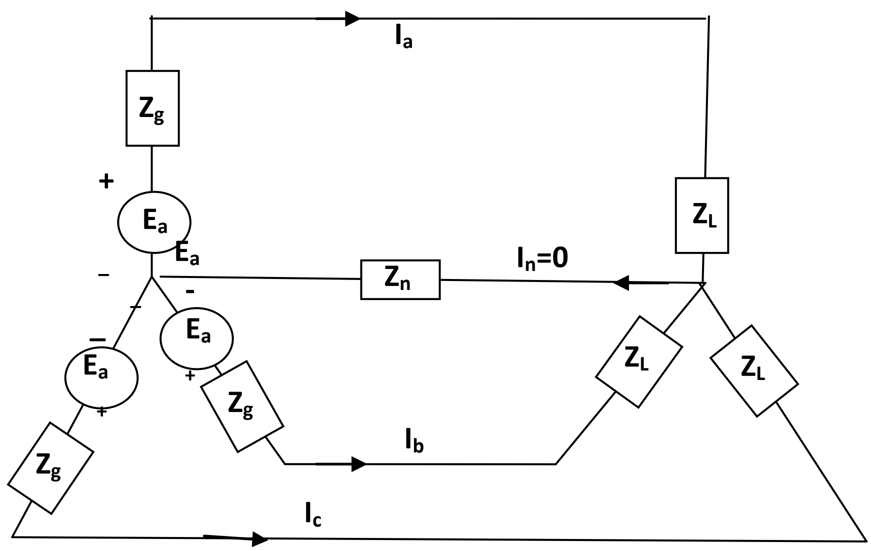

Figure 2.4: A Balanced Three Phase Network (*Das*, *2006*).

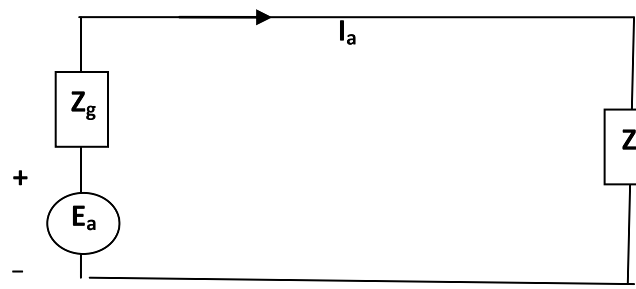

Figure 2.5: Single Phase Representation of Balanced Three Phase Network (*Das, 2006*).

For the reference phase a;

$$E_a = (Z_g + Z_L).I_a \tag{2.1}$$

Where: Z_g, Z_L, and Z_n are the impedances per-phase of the generator, load, and neutral respectively. I_a, I_b, I_c, and I_n are the currents flowing in phase a, b, c, and neutral (n) respectively. E_a, E_b, and E_c are the generator emf per-phase respectively.

2.7 Per-Unit (pu) System

The per-unit system of analysis is based on the application of Ohm's law to a single impedance or admittance as illustrated in Figure 2.6(a). Using actual physical units of kilovolts (kV), kilo-amps {kA), ohms (Ω) and Siemens (S) the voltage drop across the impedance and injected current into the admittance are given by equations (2.2) and (2.3) respectively (Tleis, 2008):

$$V_{Actual.kV} = Z_{Actual.\Omega} x I_{Actual.kA} \tag{2.2}$$

$$I_{Actual.kA} = Y_{Actual.S} x V_{Actual.kV} \tag{2.3}$$

Where V, I, Z and Y are complex phasors representing actual physical quantities of voltage, current, impedance and admittance, respectively. To calculate a per-unit value for each of these quantities, a corresponding base quantity must be defined.

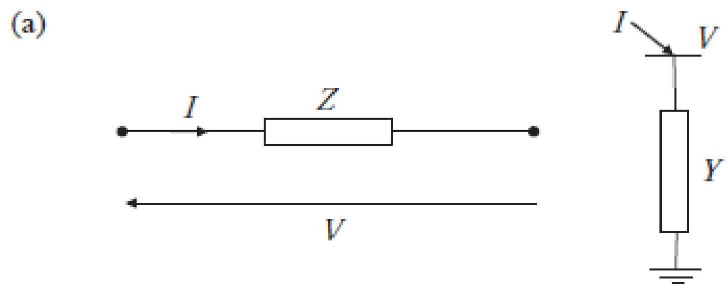

Figure 2.6 Per-Unit Analysis of (a) Single-Phase Impedance and Admittance Connections (Tleis, 2008).

Firstly, Let $V_{Base,kV}$ and $I_{Base,kA}$ be the base voltage and base current, respectively. Therefore, equations (2.2) and (2.3) can be written as equations (2.4) and (2.5) or (2.6) and (2.7) respectively (Tleis, 2008):

$$\frac{V_{Actual.kV}}{V_{Base.kV}} = \frac{Z_{Actual.\Omega}}{\frac{V_{Base.kV}}{I_{Base.kA}}} x \frac{I_{Actual.kA}}{I_{Base.kA}} \tag{2.4}$$

$$\frac{I_{Actual.kA}}{I_{Base.kA}} = \frac{Y_{Actual.S}}{\frac{I_{Base.kA}}{V_{Base.kV}}} x \frac{V_{Actual.kV}}{V_{Base.kV}} \tag{2.5}$$

$$V_{pu} = Z_{pu} x I_{pu} \tag{2.6}$$

$$I_{pu} = Y_{pu} x V_{pu} \tag{2.7}$$

where:

$$V_{pu} = \frac{V_{Actual.kV}}{V_{Base.kV}} \tag{2.8}$$

$$I_{pu} = \frac{I_{Actual.kA}}{I_{Base.kA}} \tag{2.9}$$

$$Z_{pu} = \frac{Z_{Actual.\Omega}}{Z_{Base.\Omega}} \tag{2.10}$$

$$Z_{Base.\Omega} = \frac{V_{Base.kV}}{I_{Base.kA}} \tag{2.11}$$

$$Y_{pu} = \frac{Y_{Actual.S}}{Y_{Base.S}} \tag{2.12}$$

$$Y_{Base.S} = \frac{I_{Base.kA}}{V_{Base.kV}} = \frac{1}{Z_{Base.\Omega}} \tag{2.13}$$

$Z_{Base\Omega}$, and $Y_{Base,S}$ are also defined as shown in equations (2.11) and (2.13) respectively, likewise the per-unit expression for the product of the actual voltage and current is defined in equation (2.14). It should be noted that the base quantities $V_{Base,kV}$ and $I_{Base,kA}$ are defined as real numbers so that the phase angles of V_{pu} and I_{pu} remain unchanged from $V_{Actual,kV}$ and $I_{Actual,kA}$, respectively. Using equation (2.15), we have (Tleis, 2008):

$$V_{Actual.kV} x I_{Actual.kA} = V_{Base.kV} V_{pu} x I_{Base.kA} I_{pu} \tag{2.14}$$

$$V_{pu} x I_{pu} = \frac{V_{Actual.kV} x I_{Actual.ka}}{V_{Base.kV} x I_{Base.kA}} \tag{2.15}$$

$$MVA_{pu} = \frac{MVA_{Actual}}{MVA_{Base}} \tag{2.16}$$

$$MVA_{Actual} = V_{Actual.kV} x I_{Actual.kA} \tag{2.17}$$

$$MVA_{Basel} = V_{Base.kV} x I_{Base.kA} \tag{2.18}$$

$$MVA_{pu} = V_{pu} x I_{pu} \quad (2.19)$$

It is noted that by defining $V_{Base,kV}$ and $I_{Base,kA}$, MVA_{Based} is also defined according to equation (2.18). In practical power system analysis, it is more convenient to define or choose MVA_{Base} and $V_{Base,kV}$ and calculate $I_{Base,kV}$ if required (Tleis, 2008). Therefore, using equations (2.8), (2.9) and (2.18), equations (2.20) and (2.21) can be obtained (Tleis, 2008):

$$I_{pu} = \frac{I_{Actual.kA}}{\frac{MVA_{Actual}}{V_{Base.kV}}} \quad (2.20)$$

$$V_{pu} = \frac{V_{Actual.kV}}{\frac{MVA_{Actual}}{I_{Base.kA}}} \quad (2.21)$$

Also, using equations (2.11) and (2.18), equations (2.22) and (2.23) can be written (Tleis, 2008):

$$Z_{Base.\Omega} = \frac{V_{Base.kV}}{I_{Base.kA}} X \frac{V_{Base.kV}}{V_{Base.kA}} = \frac{(V_{Base.kV})^2}{MVA_{Base.}} \quad (2.22)$$

$$Y_{Base..S} = \frac{1}{Z_{Base.\Omega}} = \frac{MVA_{Base.}}{(V_{Base.kV})^2} \quad (2.23)$$

Substituting equation (2.22) into equations (2.10) and equation (2.23) into equation (2.11), equation (2.24) can be obtained (Tleis, 2008):

$$Z_{pu} = \frac{Z_{Actual.\Omega}}{(\frac{(V_{Base.kV})^2}{MVA_{Base.}})} \quad (2.24)$$

$$Y_{pu} = \frac{Y_{Actual.S}}{(\frac{MVA_{Base.}}{(V_{Base.kV})^2})} \quad (2.25)$$

To convert per-unit values to per cent, the per-unit values are multiplied by 100 (Tleis, 2008).

2.8 **Bus Classification**

In electrical power system analysis, four quantities are associated with each bus. These are voltage magnitude |V|, phase angle □, real power P and reactive power Q. In a power flow study, two out of four quantities are usually specified and the remaining two quantities are to be obtained through the solutions of equations. The system buses are generally classified into three categories (*Das, 2006*), namely:

1. **Slack Bus**: Also known as swing bus and taken as reference where the magnitude and phase angle of the voltage are specified. This bus provides the additional real and reactive power to supply the transmission losses, since these are unknown until the final solution is obtained (*Das, 2006*). In distribution system analysis, the injection substation buses are usually considered as the slack buses (reference buses) (*Das, 2006*),
2. **Load Bus:** Also Known as PQ bus. At these buses, the real and reactive powers are usually specified. The magnitude and phase angle of the bus voltage are unknown until the final solution is obtained (*Das, 2006*). In

distribution system analysis, all except the source (reference) bus are usually considered as load buses (*Das, 2006*),

3. **Voltage Controlled bus:** Also known as the generator bus or regulated bus or P-|V| bus. At this bus, the real power and voltage magnitude are specified. The phase angle of the voltage and the reactive power are unknown until the final solution is obtained. The limits on the value of reactive power are also specified. With the advent of distributed generation, this kind of bus may also be present on a distribution network (*Das, 2006*).

Table 2.1 shows the summary of the above discussion.

Table 2.1: Bus Classification (*Das, 2006*)

Bus Type	**Specified Quantity**	**Unknown Quantity**
Slack Bus	|V|, □	P, Q
Load Bus	P, Q	|V|, □
Generator Bus	P, |V|	Q, □

2.9. Conventional Power Flow Techniques

The most common conventional power flow techniques are the Gauss-Seidel iterative method and the Newton Raphson method. These techniques serve as powerful tools for power flow analysis and simulation. The Newton Raphson method offers an advantage of reduced number of computations and fast rate of convergence than the Gauss-Seidel method (*Das, 2006*). These methods can readily be applied to strongly and weakly meshed networks. The limitation of these techniques is that, they may fail to converge when directly applied to radial networks (*Das, 2006*). The mathematical formulation of the Gauss-Seidel and Newton Raphson power flow techniques can simply be modeled using equation (2.26) to (2.46) as follows:

Conventionally:

$$S = VI^* = P + jQ \tag{2.26}$$

$$S = V^* I = P - jQ \tag{2.27}$$

$$\mathrm{P_i} = \sum_{k=1}^{n} |\mathrm{V_i}|\,|\mathrm{V_k}||\mathrm{Y_{ik}}|\cos\left(\theta_{\mathrm{ik}} - \delta_{\mathrm{i}} + \delta_{\mathrm{k}}\right) \tag{2.28}$$

$$\mathrm{Q_i} = \sum_{k=1}^{n} |\mathrm{V_i}|\,|\mathrm{V_k}||\mathrm{Y_{ik}}|\sin\left(\theta_{\mathrm{ik}} - \delta_{\mathrm{i}} + \delta_{\mathrm{k}}\right) \tag{2.29}$$

$$\mathrm{P_{ik}} = |\mathrm{V_i}||\mathrm{V_k}||\mathrm{Y_{ik}}|\cos(\theta_{\mathrm{ik}} - \delta_{\mathrm{i}} + \delta_{\mathrm{k}}) - |\mathrm{V_i}|^2|\mathrm{Y_{ik}}|\cos\theta_{\mathrm{ik}} \tag{2.30}$$

$$\mathrm{Q_{ik}} = -|\mathrm{V_i}||\mathrm{V_k}||\mathrm{Y_{ik}}|\cos(\theta_{\mathrm{ik}} - \delta_{\mathrm{i}} + \delta_{\mathrm{k}}) + |\mathrm{V_i}|^2|\mathrm{Y_{ik}}|\sin\theta_{\mathrm{ik}} - |\mathrm{V_i}|^2|\mathrm{Y_{ik}^{o}}| \tag{2.31}$$

$$\mathrm{P_{Loss.ik}} = \mathrm{P_{ik}} + \mathrm{P_{ki}} \tag{2.32}$$

$$\mathrm{Q_{Loss.ik}} = \mathrm{Q_{ik}} + \mathrm{Q_{ki}} \tag{2.33}$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.34}$$

where:

S is the complex active power;

V is the complex voltage;

I is the complex current;

P is the real power;

Q is the reactive power;

δ is the voltage angle;

θ is the admittance angle;

P_{Loss} is the real power loss;

Q_{Loss} is the reactive power loss;

Y^o is the shunt admittance/ grounding admittance;

a) Gauss-Seidel (GS) Iterative Method:

$$V_i^{(a+1)} = \frac{1}{Y_{ii}}\left(\frac{P_i - jQ_i}{V_i^{(a)}} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right) \tag{2.35}$$

b) Newton Raphson (NR) Method:

$$\delta_i^{(a+1)} = \delta_i^{(a)} + \Delta\delta_i^{(a)} \tag{2.36}$$

$$|V_i|^{(a+1)} = |V_i|^{(a)} + \Delta|V_i|^{(a)} \tag{2.37}$$

$$\Delta P_i^{(a)} = P_i^{Scheduled} - P_i^{(a)} \tag{2.38}$$

$$\Delta Q_i^{(a)} = Q_i^{Scheduled} - Q_i^{(a)} \tag{2.39}$$

The NR method is further classified into three (3) categories as follows:

I. Coupled NR:

$$\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2 \\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta \\ \Delta|V|\end{bmatrix} \tag{2.40}$$

II. Decoupled NR:

$$\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & 0 \\ 0 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta \\ \Delta|V|\end{bmatrix} \tag{2.41}$$

III. Fast Decoupled NR:

$$\frac{\Delta P_i}{|V_i|} = -B'\Delta\delta \tag{2.42}$$

$$\frac{\Delta Q_i}{|V_i|} = -B''\Delta\delta \tag{2.43}$$

Condition for terminating the iterative process:

$$max|V_i^{(a+1)} - V_i^{(a)}| \leq \varepsilon \tag{2.44}$$

$$\max\ |\Delta P| \leq \varepsilon \tag{2.45}$$

$$\max\ |\Delta Q| \leq \varepsilon \tag{2.46}$$

The decoupled and fast decoupled NR methods require more iteration than the coupled NR method but require less computation time per iteration (*Das, 2006*).

where:

J_1 and J_4 are the decoupled Jacobain square matrices of size (n-1) and (n-1-m) respectively;

J_2 and J_3 are the coupled jacobain square matrices of size (n x m) and (m x n) respectively;

Δ represents a change;

$q^{(a)}$ is the value of parameter q at the ath iteration;

|q| is the absolute value of parameter q;

ik represents 'from i to k';

B' and B" are the imaginary part of the bus admittance matrices;

ε is the Maximum absolute error

2.10. Backward-Forward Sweep (BFS) Technique for Power Flow Analysis

In the BFS technique, the network is assumed to be balanced, as such; it is represented by an equivalent single line diagram. The analysis proceeds from one branch to another in a systematic way until all the branches in the feeders have been traced (Yan *et al.*, 2003). Firstly, the voltages at all the buses, except the slack/swing bus, are assumed to be one (1) pu at angle zero (0). Based on these voltages and specified active and reactive power, simultaneously, the branch currents, starting from the end buses to the source, are calculated and saved (Backward Sweep). This, of course, requires a logical procedure to ensure that the branches of the system are correctly traced; therefore, the branch incidence table is usually used. Then, branch currents, are computed in order to find the active and reactive power losses in the system. The current at the source end is now calculated using equation (2.47). The computation then proceeds from source to the end of the feeders to find the voltage drop using equation (2.48), current (I_{ij}), real and reactive power losses using equations (2.49) and (2.50) respectively (Forward Sweep). The branch incidence table is again used to facilitate proper retracting of the network branches. Once this process is completed, the total losses are calculated and compared to the values initially obtained. If the difference is outside the specified tolerance limits, the source current is re-computed using equation (2.47), in terms of the newly obtained values for losses, and the path retracting operation is repeated. The process is repeated until the difference in losses between 2 successive values of the source current is within the specified tolerance limits (Yan *et al.*, 2003).

$$I = \left(\sum_{\substack{i=1 \\ i\neq s}}^{n} P_i + \sum_{\substack{j=1 \\ i=1 \\ i\neq j}}^{n} P_{Loss.ij} + j\left(\sum_{\substack{i=1 \\ i\neq s}}^{n} Q_i + \sum_{\substack{j=1 \\ i=1 \\ i\neq j}}^{n} Q_{Loss.ij}\right)\right)/V_s^* \tag{2.47}$$

$$Z_{ij} = R_{ij} + jX_{ij} \tag{2.47}$$

$$V_{Drop.ij} = V_j - V_i = I_{ij}Z_{ij} \tag{2.48}$$

$$P_{Loss.ij} = I_{ij}^2 R_{ij} \tag{2.49}$$

$$Q_{Loss.ij} = I_{ij}^2 X_{ij} \quad (2.50)$$

where:

$\sum_{\substack{i=1 \\ i \neq s}}^{n} P_i$ is the sum of the load real power connected to the entire receiving end buses;

$\sum_{\substack{i=1 \\ i \neq s}}^{n} Q_i$ is the sum of the load reactive power connected to the entire receiving end buses;

$\sum_{\substack{j=1 \\ i=1 \\ i \neq j}}^{n} P_{Loss.ij}$ is the sum of the branch (ij) real power loss across the entire network branches;

$\sum_{\substack{j=1 \\ i=1 \\ i \neq j}}^{n} Q_{Loss.ij}$ is the sum of the branch (ij) reactive power loss across the entire network branches;

V_s^* is the the conjugate of the source voltage;

I is the current at the source end;

Z_{ij} is the impedance of branch ij;

R_{ij} is the resistance of branch ij;

X_{ij} is the reactance of branch ij;

$V_{Drop.ij}$ is the voltage drop across branch ij

V_j and V_i are the voltage at bus j and i respectively;

I_{ij} is the current flowing from bus i to j.

2.11 All Spanning Trees of Undirected Network Graph (ASTUNG) Technique

Distribution network reconfiguration is a complex combinatorial optimization problem (Zhang *et al*., 2014). In order to decrease the number of spanning trees and reduce calculation complexity of a distribution network graph, adjacent branches located on a loop whose crossing point have a degree of 2 are incorporated into one edge, and branches not located on any loop can be removed from the graph of the distribution network. Thus, the graph of distribution network can be simplified to a graph G. Spanning tree of G is a sub-graph of G, in which, any two nodes have one and only one simple path. Spanning tree of G has all nodes of G, but do not have all edges of G. Different spanning trees are composed of different edges. Tie branches are supplementary set of spanning tree. That is, tie branches equal to spanning tree subtracted from G. The number of edges in tie branches equals to the number of independent mesh in G.

Figure 2.4 is an IEEE typical three feeder test system, in which, dotted lines are the branches on which tie switches are located. In order to facilitate finding all the spanning tree, bus 1, 2 and 3 are connected together. With adjacent branches located on a loop whose crossing point have a degree of 2 incorporated into one edge, with branches not located on any loop removed; Figure 2.4 is simplified to Figure 2.5. It can be seen from Figure 2.5, that, edges 1, 3, 4, and 5 constitute a spanning tree while, edges 2, 6, and 7 are the corresponding tie branches. Edges 1, 2, 4, 5 constitute another spanning tree while edges 3, 6, 7 are the corresponding tie branches. All spanning trees and the corresponding tie branches of Figure 2.5 are listed in the 2^{nd} and 3^{rd} column of Table 2.2 (Zhang *et al.*, 2014).

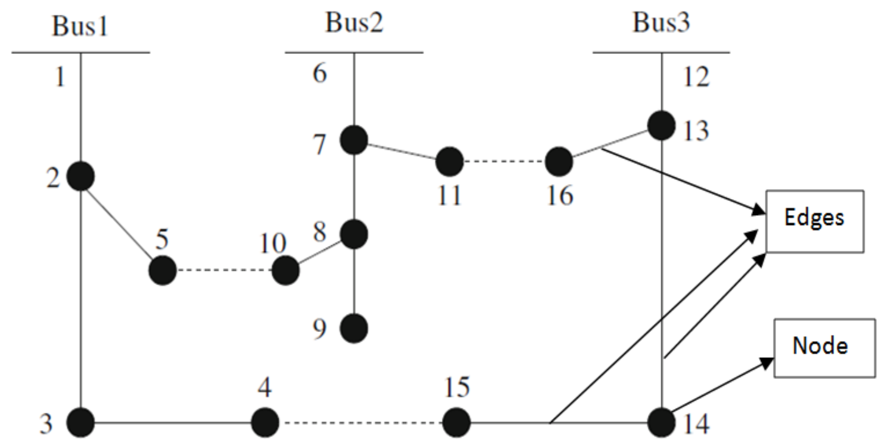

Figure 2.4: IEEE typical three feeder test system (Zhang *et al.*, 2014)

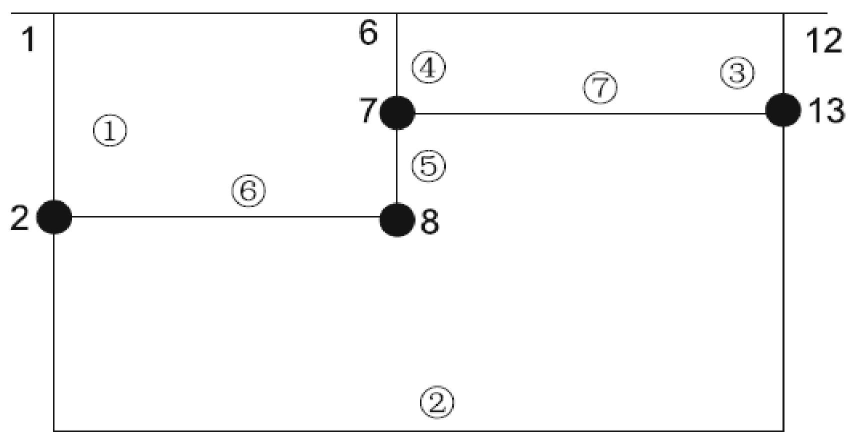

Figure 2.5: Simplified system (Zhang *et al.*, 2014)

2.11.1 Candidate solutions

Any combination of open switches that meet the radial and connected constraints for distribution network operation is defined as a candidate solution for network reconfiguration (Zhang *et al.*, 2014). The optimal solution can only be one of the candidate solutions. One candidate solution can be created if only one switch is located on each tie branch. As to each spanning tree, the number of candidate solutions equals to the product of each component of the corresponding base vector (number of edges that were combined to form a single edge) (Zhang *et al*., 2014). Table 2.2 shows the spanning trees; tie branches; and number of Candidate solutions of Figure 2.4

Table 2.2: Spanning Trees, Tie Branches and No. of Candidate Solution (Zhang et al., 2014)

No	Spanning tree	Tie Branch	No. of Candidate solution
1	3 5 6 7	1 2 4	5
2	2 3 5 7	1 4 6	3
3	1 3 5 7	2 4 6	15
4	2 3 6 7	1 4 5	1
5	1 3 6 7	2 4 5	5
6	2 3 5 6	1 4 7	3
7	2 3 4 6	1 5 7	3
8	2 3 4 5	1 6 7	9
9	3 4 5 6	1 2 7	15
10	1 3 4 5	2 6 7	45
11	1 3 4 6	2 5 7	15
12	1 3 5 6	2 4 7	15
13	2 4 6 7	1 3 5	1
14	2 4 5 7	1 3 6	3
15	4 5 6 7	1 2 3	5
16	1 4 5 7	2 3 6	15
17	1 4 6 7	2 3 5	5
18	2 4 5 6	1 3 7	3
19	1 2 4 5	3 6 7	9
20	1 2 4 6	3 5 7	9
21	1 5 6 7	2 3 4	5
22	1 2 5 6	3 4 7	9
23	1 2 6 7	3 4 5	1
24	1 2 5 7	3 4 6	3
Total			190

2.11.2. Infeasible Solution

It is required that a candidate solution is capable of transforming the looped network into a completely radial network (Zhang *et al*., 2014). An infeasible solution is defined as a set of branches (sectionalizing switches) that will not meet the radial and connected constraints for distribution network operation (Zhang *et al*., 2014). Example of such set of branches includes; [1 4 3], [1 6 4], [4 7 3], etc. The presence of infeasible solutions makes the problem of random switch selection a complicated one. Therefore the formation of candidate solutions has to be logically carried out in order to eliminate infeasible solutions from the solution sets (Zhang *et al*., 2014).

2.12. Model of network reconfiguration

The objective of network reconfiguration is that the total power loss is minimal after network reconfiguration under necessary constraints for distribution network operation. The objective function is formulated as in equation (2.51) (Zhang *et al*., 2014).

$$\text{Minimize } F = \sum_{i=1}^{n} \frac{P_i^2 + Q_i^2}{U_i^2} r_i k_i \tag{2.51}$$

where: P_i and Q_i are active and reactive power flowing through the terminal of branch i, respectively; U_i is the terminal node voltage of branch i; n is the total number of branches; r_i is the resistance of branch i; k_i is the switch state of branch i, which is a 0 or 1 discrete variable, with 0 indicating switch open, and 1 indicating switch closed; F is the active power loss of network, which can be obtained by power flow calculation. Node voltage and branch power must meet the following constraints (Zhang *et al*., 2014):

i. Node voltage constraint

$$U_{i,\min} \le U_i \le U_{i,\max} \tag{2.52}$$

where: U_{imin} and U_{imax} are the upper and lower voltage constraints for node i, respectively.

ii. Branch power constraint

$$S_i \le S_{i,\max} \tag{2.53}$$

where: S_i and S_{imax} are the calculated and allowed maximal power value flowing through branch i respectively (Zhang *et al.*, 2014).

2.13. Load Model

In constant power type of load model it is assumed that the power demand of the load remains same irrespective of the change in terminal voltage. But it is not true for most of the loads (Kersting, 2012). Power demand changes with the change in terminal voltage of the loads. Due to this change in power demand of the loads with the change in terminal voltage, there is an effect on the convergence of the load-flow solution (Kersting, 2012). The characteristics of exponential load models can be expressed as in equations (2.54) and (2.55) (Kersting, 2012):

$$P = P_{i0}(V/V_0)^{n_p} \tag{2.54}$$

$$Q = Q_{i0}(V/V_0)^{nq} \tag{2.55}$$

where: P_0 and Q_0 stand for active and reactive power respectively at nominal voltage, V and V_0 stand for node voltage and nominal load voltage respectively and n_p and n_q are the respective load exponents (Kersting, 2012).

2.14 Ampacity

The ampacity of an electrical conductor (line) is the maximum designed current carrying capacity of that conductor (Short, 2014). This current carrying capacity is normally given in amperes. A given conductor has several ampacities, depending on its application and the assumptions used (Short, 2014). Some simplifying equations help in evaluating some of the significant impacts of temperature on ampacity. The effect of change in ambient and allowable temperature on ampacity can be estimated using equation (2.56), (Short, 2014).

$$I_{new} = I_{old}\sqrt{\frac{T_{c,new} - T_{a,new}}{T_{c,old} - T_{a,old}}} \tag{2.56}$$

where: I_{new} is the new ampacity based on a new conductor limit $T_{c,new}$ and a new ambient temperature $T_{a,new}$. Likewise, I_{old} is the original ampacity based on a conductor limit $T_{c,old}$ and an old ambient temperature $T_{a,old}$.. This approach neglects solar heating and the change in conductor resistance with temperature (both have small impacts). Doing this simplifies the ampacity calculation to a constant (dependent on weather and conductor characteristics) times the difference between the conductor temperature and the ambient temperature. The simplified ampacity equation can also be used to estimate the conductor temperature at a current higher or lower than the rated Ampacity (Short, 2014). This is given by equation (2.57)

$$T_{c,new} = T_{ac,new} + \frac{I_{new}^2}{I_{old}^2} T_{c,old} - T_{a,old} \qquad (2.57)$$

When examining a line's ampacity, always recall that the overhead wire may not be the weakest link; substation exit cables, terminations, re-closers, or other gear may limit a circuit's current before the conductors do. Also, with currents near a conductor's rating, voltage drop is high (Short, 2014).

2.15. Load Balancing

Usually a mixture of residential, commercial and industrial type loads, varying from time to time, appears on distribution lines or line sections. Each of these has different characteristics and requirements. This leads to the fact that some parts of the distribution system become heavily loaded at certain times and less loaded at other times of the day. In order to reschedule the load currents more efficiently for loss minimization, it is required to transfer the loads between the feeders or substations and modify the radial structure of the distribution feeders (Kersting, 2012).

2.15.1. Model of load balancing

An objective function for load balancing is presented which consists of two components. One is the branch load balancing index and the other is the system load balancing index. Branch load balancing index (LBI_j) is defined as a measure of how much a branch can be loaded without exceeding the rated capacity of that branch (Kersting, 2012). The objective is to optimize the branch load balancing indices so that the system load balancing index is minimized. In order words, all the branch load balancing indices are set to be more or less the same value and are also nearly equal to the system load balancing index (Kersting, 2012). The load balancing problem is formulated in the form of branch load balancing and system load balancing indices as in equations (2.58) and (2.59) respectively (Kersting, 2012):

i. The load balancing index (LBI_j) of the jth branch:

$$LBI_j = S_j / S_{j,\max} \tag{2.58}$$

ii. The System load balancing index (LBI_{sys}):

$$LBI_{sya} = \frac{1}{nb}\sum_{j=1}^{nb} LBI_j \tag{2.59}$$

where: nb is the total number of branches in the system, S_j is the apparent power of branch j, and $S_{j,\max}$ is the maximum capacity of branch j.

iii. Objective function:

$$\text{Minimize} \quad F = LBI_{sys} \tag{2.60}$$

The system load balancing index will be minimized when the branch load balancing indices are optimized by rescheduling the loads. In effect, all the branch load balancing indices (LBI_j), are made approximately equal to each other and also closely approximate to the system load balancing index (LBI_{sys}). The conditions taken into consideration are (Kersting, 2012).

1. The system loss must be minimized.

2. The voltage magnitude of each node must be within permissible limits, i.e.:

$$V_{i,\min} \leq V_i \leq V_{i,\max} \qquad (2.61)$$

3. Current capacity of each branch:

$$I_i \leq I_{i,\max} \qquad (2.62)$$

where: V_{min} and V_{max} are the lower and upper limits of the node voltage respectively. $I_{j.max}$ is the maximum allowable current that could flow through branch j.

When the load balancing index (LBI_j), of a branch is equal to 1 then the condition of that branch will become critical and the branch rated capacity will be exceeded if it is greater than 1. The system load balancing index (LBI_{sys}), will be low if the system is lightly loaded and its value will be closer to zero. The individual branch load balancing indices will also be low. If the loads are unbalanced, the load balancing indices of individual branches will differ widely, whereas, the balanced load will make the load balancing indices of all the branches nearly equal. It is not practically possible to make all the branch load balancing indices (LBI_j), exactly equal. However, it is possible that by reconfiguration the load balancing indices of the branches will be adjusted, and hence the load balancing in the overall system improved. The proposed method uses a set of simplified feeder-line flow formulations for power flow analysis to prevent complicated computation (Kersting, 2012).

2.16 Voltage Stability index (VSI)

Voltage Stability Index is the measure of the deviation of the various node voltages from their rated value (Chakravorty & Das, 2001). It is also defined as the square-root of the sum of the difference between the rated, and the calculated value of the node voltage. It is expressed mathematically as in equation (2.63) (Chakravorty & Das, 2001).

$$VSI = \sqrt{\frac{\sum_{k=1}^{n}(V_{rated} - V_k)^2}{n}} \tag{2.63}$$

where:

n is the total number of nodes

V_{rated} is the rated voltage (source voltage)

V_k is the voltage at the kth node

2.17. Voltage Drop

The voltage drop is a quantity which defines the voltage relationship between any two points on a given network. Let the voltage of two points on a give network be $V_{A.}$ and V_B. The voltage drop between these two points can be expressed using equation (2.64) (Chakravorty & Das, 2001):

$$V_{AB} = V_B - V_A \tag{2.64}$$

$$V_{AB} = -V_{BA} \tag{2.65}$$

In distribution network analysis, the source node voltage is usually considered as the reference/rated voltage, from which other node voltages are estimated. This estimation is carried out using iterative techniques. Therefore the voltage drop

(VD_k) along the path linking the source and kth node can be expressed using equation (2.66) (Chakravorty & Das, 2001).:

$$VD_k = V_{rated} - V_k \tag{2.66}$$

Thus: it is possible to express the VSI as a function of voltage drop as in equation (2.67) (Chakravorty & Das, 2001).

$$VSI = \sqrt{\frac{\sum_{k=1}^{n} {VD_k}^2}{n}} \tag{2.67}$$

If V_{rated} and V_k are in pu, VD_k is less than Unity. As VD_k gets smaller, VSI tends to zero. Since a good network has low VD_k. The lower the VSI of a network, the better the network is, in terms of voltage profile (node voltages). Therefore, the voltage profile of a distribution network can be improved by decreasing the VSI of that network (Chakravorty & Das, 2001).

2.18 Review of Similar Work

In literature, a large number of publications have been made on the various aspects of power distribution network system. Quite a number of such publications have been consulted which serve as a guide towards achieving the aim and objectives of the research work. Some of these publications are summarized below.

Majtaba *et al.*, (2014) presented a method for radial distribution network expansion. In the work, genetic algorithm was proposed for network expansion while the BFS technique was used in carrying out network power flow analysis.

The work was categorized into two stages. At the first, power flow was simulated using a standard 30 buses IEEE radial network. Secondly, the network was expanded and power flow analysis was performed on it again. The limitation of the work is in that, it considers upgrading the entire network branches which might not be cost efficient and can result in large capital investment.

Rao & Sivanagaraju, (2012) presented a method for loss reduction through distribution network reconfiguration and load balancing using plant growth simulation algorithm. In the work, Plant Growth Simulation algorithm was proposed with a view to enhance speed and robustness. Load balancing problem was formulated. A method that does not require external parameters such as barrier factors, crossover rate etc was introduced. The method was then tested on a 16 node radial distribution system for loss minimization and load balancing. The results showed that the proposed method was able to perform reconfiguration effectively. The limitation of the work is that; the approach used cannot be easily applied to large distribution networks.

Ramos et al, (2012) presented a reconfiguration method by modeling a network based on the available distribution paths. In the work, a 33-bus network was considered. The available distribution paths were obtained and tabulated (path table). A mixed integer linear model was then developed and used in reshaping the non linear power flow equations. The resulting linear power flow equations were then used to solve power flow on the 33-bus test network. The power flow results were then presented and discussed. Though a linear technique was developed, this may be simple and easy to handle. A linear technique might fail in simulating a real distribution network and might not optimize it either.

Baran & Wu, (2012) presented an improved Newton Raphson method for power flow computations. The traditional Newton Raphson equations were modified to solve radial distribution network power flow. The work compared the developed method with other existing methods using the power flow results for 9, 13 and 63 bus network. The proposed method converged faster than the existing methods. The developed method required sequential node numbering and will not be suitable for implementation on computer as tool for radial distribution network power flow analysis.

Wu & Tsai, (2012) presented a method of feeder reconfiguration using binary coding particle swamp optimization technique. In the work, a set of possible configurations were represented using binary codes. A network reconfiguration algorithm was developed based on binary coding particle swamp optimization. The developed algorithm was used to perform reconfiguration on the coded possible configurations of a 35-bus network. The best configuration was found. The network total loss was reduced by 7%. One of the limitations of the work is that, it only considered a small set of possible solutions. Particle swamp optimization involves a random search and therefore might be trapped in a local minimum.

Ghosh & Sherpa, (2012) introduced a new method of power flow using fuzzy logic. In the work, the conventional power flow equations were transformed into their fuzzy equivalent (a set of decisions). The equations were then used to perform a constrainted power flow computation on a 15 bus distribution network. The node voltages of the distribution system were estimated and presented. The nature of fuzzy logic made the work very difficult and unfavorable for a network with large number of nodes. Detailed information about the simulation was not also presented.

Subrahmanyam, (2012) presented an algorithm for the calculation of unbalanced radial distribution power flow. In the work, a three-phase distribution network power flow model was developed based on simple algebraic recursive expression of voltage magnitude and mutual coupling between the phases. The work proceeded by developing an algorithm for unbalanced radial distribution network power flow. The developed algorithm was tested on 4 different unbalanced distribution test networks and the results look promising. An extension was made to find the optimum location of reactive power compensators. The proposed algorithm is computationally expensive due to its complexity. A large number of parameters are required to carry out power flow.

Kaur, (2012) developed an algorithm for computing the power flow of a radial distribution network and harmonic content detection. At first, mathematical model for harmonic content detection was developed. The developed model was then incorporated into the traditional power flow model. The resulting model was then tested on a 33-bus network and the results looks promising. The developed models will be too complex to apply to large distribution networks. The algorithm in the research work mainly focused on harmonic content detection and therefore will not be suitable for balanced radial power flow analysis.

Papadopoulos et al., (2011) presented a new method for distribution feeder reconfiguration. The method involves tabulating the network nodes based on their position and section in the network. The network line flows and line losses were computed. The feasibility of each of the candidate solutions was then logically tested. The developed method was tested on a 16-bus network. The best configuration was found to reduce the total network losses by 12%. In the work, only a few numbers of possible solutions were tested. Therefore the results obtained may not be the global best. The technique used will not be suitable for implementation on computer as tool for network analysis.

Rao *et al.*, (2011) presented a method for radial distribution network feeder reconfiguration. In the work, genetic algorithm was used in solving a reconfiguration problem by optimally selecting an optimal position for tie branch placement. A 33 buses standard IEEE radial network was reconfigured using genetic algorithm and the results were compared to those presented in order literatures. The limitation of the work/method is that it failed to provide detail information of the simulation process, and that genetic algorithm is built based on a random probabilistic search and therefore has no guarantee in its rate of convergence.

Kashem et al, (2010) presented a novel method for loss minimization through distribution feeder reconfiguration. In the work, an algorithm to reconfigure distribution networks for loss minimization was developed. An improved technique was then used to determine the switching combinations, select the status of the switches, and find the best combination of switches for minimum loss. The proposed method was tested on a 33-bus system. The test results indicated that the proposed method was able to determine the appropriate switching-options for the best or (near best) configuration with less computation. The test results were also compared with those of other similar works. The proposed method will not be suitable for application in large distribution networks.

Most of the similar literatures reviewed so far, employed power flow and reconfiguration techniques that gets more and more complex as the number of network nodes increases. Only a few numbers of the similar literatures made use of techniques that looks promising in minimizing solution complexity but failed to present details of how the techniques can be achieved. Finally, the power flow and reconfiguration algorithms developed in the similar literatures cannot be easily implemented on a computer as tools for network power flow and reconfiguration analysis.

The robustness and flexibility of some of the power flow and reconfiguration techniques can be improved through iterative procedures using numerical analysis rather than complex differential equations. This will decrease the rate at which the iterative procedure (involved in power flow and reconfiguration computations) gets complex as the network size increases. In this research work, improved BFS and ASTUNG techniques are developed for power flow and optimal reconfiguration analysis respectively. The proposed power flow technique does not require sequential node numbering and the use of branch incidence table. The proposed optimal reconfiguration technique employs the use of a number of matrices to logically overcome the challenge in satisfying the radial and connected constraint of distribution networks. MATLAB GUI based programs are also developed based on the proposed power flow and reconfiguration techniques to serve as tools for power flow and reconfiguration simulation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this chapter, the data collected are described; the assumptions made are presented; the most appropriate tie switches position are proposed using GPS mapping; Improved power flow and reconfiguration models and algorithms are developed; finally, power flow and reconfiguration simulators (GUIs) are developed.

3.2 Data Collection

In order to carry out network modeling and analysis, detailed information about the network topology and parameters are needed. Relevant sample data were collected from the distribution sub-station; by regularly visiting the load points (taking readings with a clamp meter); and using GPS. These data were organized using MATLAB V.7.0 software. The detail description of these data is as follows:

1. **Distribution Station (JEDPLC, Azare/TCN, Azare) Network Data**

   At the substation the following data were obtained

   a. A schematic Network Diagram of the 11kV and 33kV network: The schematic diagram was used for tracing the network feeders to their destinations, in order to obtain the GPS coordinates needed for network mapping.

b. Load Dispatch: Hourly loads: Daily Energy supplied; Outages; and Load Shedding, provides information about the demand allocated to the various sections of the network.

2. Load Point (11/0.415kV and 33/0.415kV Substations (0.415kV)) Data

i. Load current (per-phase): The load Current of various transformers was measured at their secondary side using a clamp meter. This was used in determining the average demand on each of the transformers.

ii. Load Voltage (per-phase): The phase voltages of the various transformers are measured from the feeder pillar.

3. GPS Data (longitude and latitude)

i. Transformer Location: The Azare major road Google Map (as printed from Google Earth software) and the network schematic diagram (as obtained from JEDPLC, Azare) were used to locate the distribution transformers in order to obtain their GPS coordinates.

ii. Bus/Node Location: The GPS coordinates of other network junctions (nodes without transformer) were also determined.

The transformer rated data (capacity, date of manufacture, etc) are shown in Table 3.1 (Appendix A1). This data was obtained from the sub-station.

3.3 Assumptions

Most radial distribution network have three phases. The loads connected to these phase are usually not equal, as such the network is unbalanced. The complexity arising from unbalanced three phase network analysis can be greatly reduced by the assumption that the network is balanced such that it can be represented by an equivalent single phase circuit. Therefore the following assumptions where made while achieving the aim and objective this research work.

1. The three phases of the radial distribution network are balanced and as such can be represented by an equivalent single phase;
2. The network is fed from a constant voltage source
3. The loads connected to the network buses consumes constant active power regardless of bus voltage variation;
4. The Source node has a voltage magnitude of one (1pu) at an angle of zero (0rad);
5. The mutual coupling effect between the line conductors is negligible;

3.4 Azare Distribution Network Map

The GPS coordinate data of the various nodes/buses were collected using a 'Location Software' installed on an Android mobile phone. The GPS data were then organized and are shown in column 2 and 3 of Table 3.7 (Appendix A4). These data were transferred into a Google Earth Software in order to obtain a plot of the GPS coordinate points on Azare Google Map in relation to one another. The resulting plot was then saved and imported into an EPLAN Software. The

Azare major road networks were traced, followed by a trace of the Azare primary distribution network. Figure 3.1 is the resulting plot which was obtained from the EPLAN Software.

In Figure 3.1, the brown lines represent the Azare major roads while blue and green lines represent the 11kV GRA and Town feeders respectively. The red lines represent the 33kV feeder which originates from the TCN, Azare substation and served as the main source of power to Azare 33/11kV injection sub-station (JEDPLC, Azare). In this research work, only the 11kV network feeders are considered for simulation.

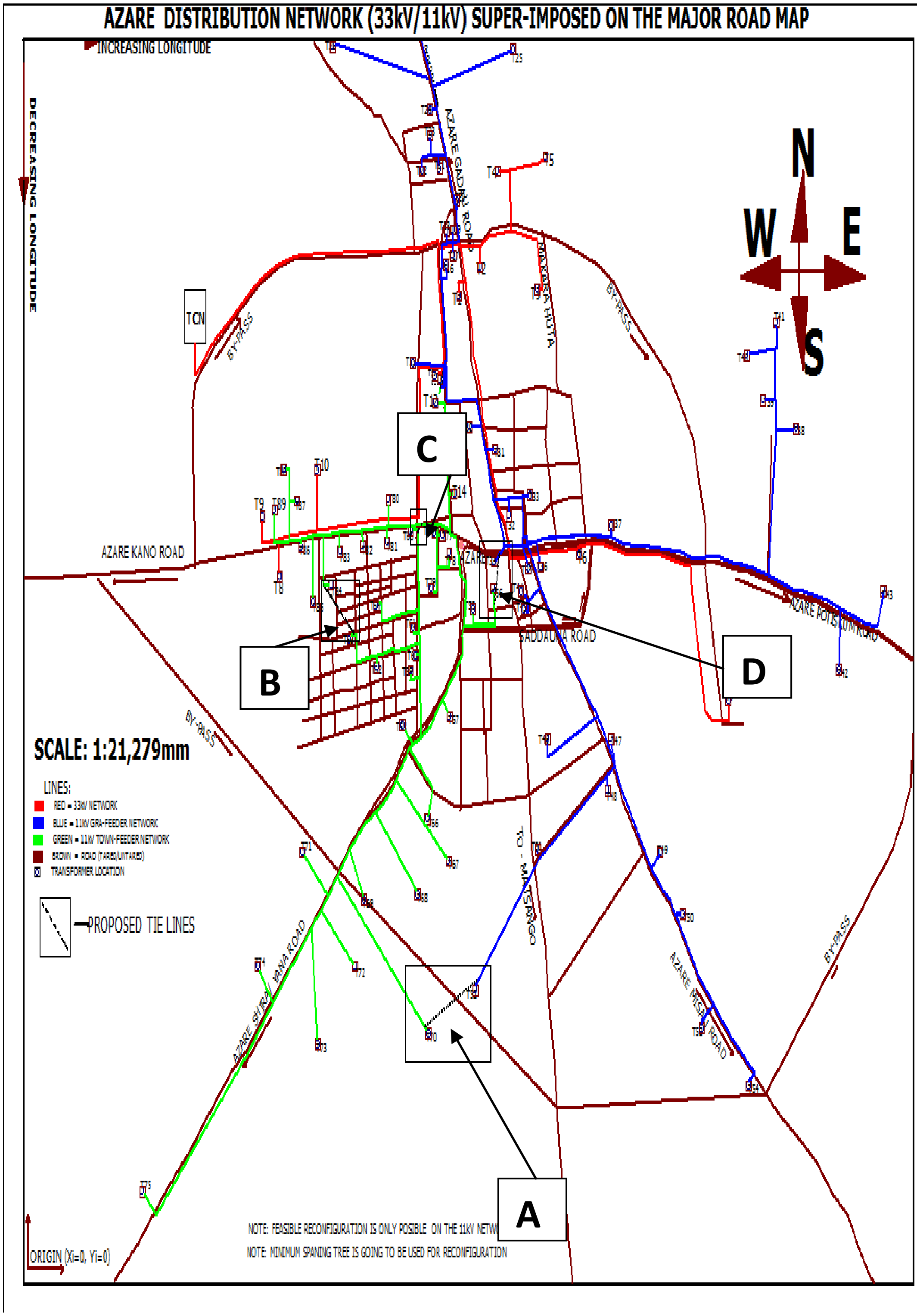

Figure 3.1: Azare Primary Distribution Network Superimposed on Azare Major Road Map Using GPS.

3.4.1 Tie Switch Placement

A Tie Switch is a normally opened switch. Tie switches are used to link two buses (tie buses) in order to transfer loads from one bus to the other. Tie switches are sometime called tie lines; this is due to the fact that, they are usually made up of short conductors/lines. It is therefore necessary to minimize the displacement between any two tie buses. In order to determine the most appropriate position of a tie switch, a detailed network topology is required. In this research work, the network topology of Azare distribution network is obtained using GPS. The GPS coordinate system is derived based on the assertion that the earth is spherical in shape. Therefore it is possible to estimate the approximate shortest displacement between any two nodes using equation (3.1).

$$D_{ij} \approx \frac{2\pi R D'_{ij}}{360\ x\ 60\ x60} \approx \frac{2\pi R D'_{ij}}{1296000} \tag{3.1}$$

$$D'_{ij} \approx \sqrt{\left(\left(Lng(x_{i,}y_i, z_i) - Lng(x_{j,}y_j, z_j)\right)^2 + \left(Lat(x'_i y'_i z'_i) - Lat\left(x'_j y'_j z'_j\right)\right)^2\right)} \tag{3.2}$$

$$Lng(x_{i,}y_i, z_i) = 3600x_i + 60y_i + z_i \tag{3.3}$$

$$Lat(x'_i y'_i z'_i) = 3600x'_i + 60y'_i + z'_i \tag{3.4}$$

where:

D_{ij} is the displacement between bus i and j in km;

D'_{ij} is the displacement between bus i and j in seconds (‘);

R is the radius of the earth in km;

$Lng(x_{i,}y_i, z_i)$ is the longitudinal location of bus i;

$Lng(x_{j,}y_j, z_j)$ is the longitudinal location of bus j;

$Lat(x'_i y'_i z'_i)$ is the latitudinal location of bus i.

$Lat(x_j' y_j' z_j')$ is the latitudinal location of bus j;

$x_i and\ x_i'$ are in degrees (^{o});

$y_i and\ y_i'$ are in minutes (‘);

$z_i and\ z_i'$ are in seconds (“);

$Lng(x_{i,} y_i, z_i)$ and $Lat(x_i' y_i' z_i')$ are in seconds (“).

Although quite a number of tie branches could be place on the Azare distribution network, in the proposed research work, the following criteria were used in determining the number of tie branches to be placed.

i. The displacement between the tie buses must not be greater than 500m

ii. The closed loop that can be formed by closing the tie branches must contain as many buses as possible

In Figure 3.1, positions A, B, C and D were found as the most appropriate positions to place the tie switches (tie lines) for reconfiguration. The tie buses are shown in Table 3.1 as follows:

Table 3.1: Displacement between Tie Buss

Tie line	Node (i)	Node (j)	Lng (i) Second (‘)	Lat (i) Second (‘)	Lng (j) Second (‘)	Lat (j) Second (‘)	D_{ij}' (‘)	D_{ij} km
B	34	56	36675	42030	36685	42026	10.8	0.333
A	52	70	36679	41961	36664	41956	15.8	0.488
C	63	85	36631	42019	36628	42024	5.8	0.18
D	66	132	36664	41990	36660	42038	4.82	0.149

The Schematic diagram of Azare distribution network is extracted from Figure 3.1. The tie lines are also added to the resulting schematic diagram and shown in Figure 3.2.

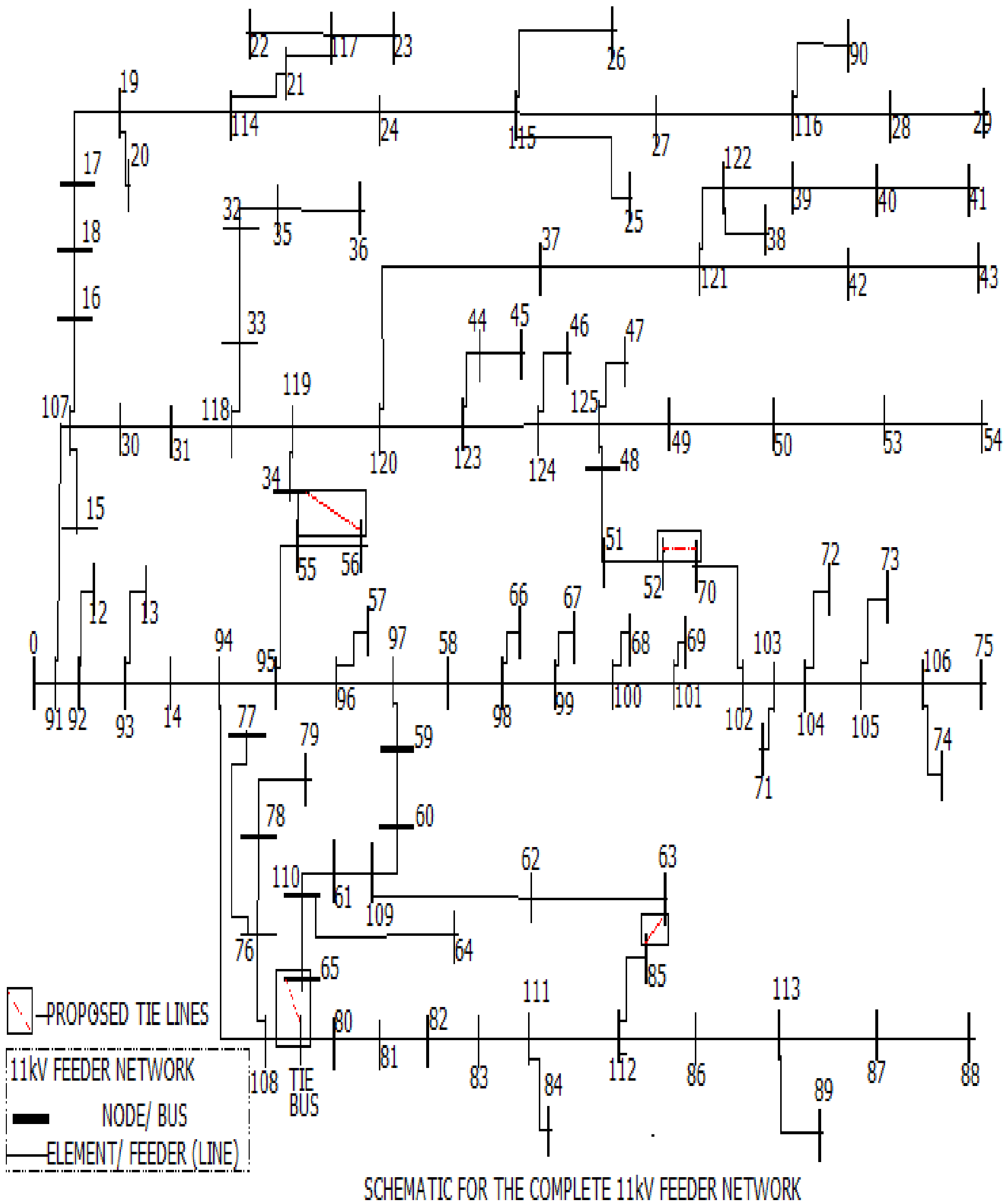

Figure 3.2: Complete Schematic Diagram for the 11kV Azare Distribution Feeders and their Laterals (Original Configuration)

3.5 Proposed Power Flow Model

In the proposed power flow model, the network parameters are stored in two matrices namely the line data and bus data matrices. The line data matrix is a matrix of size (b x 5), where b is the number of branches in the network. The five columns in the line data matrix are defined as follows:

a. Column 1: Branch serial number;
b. Column 2: Sending end bus number (Frm_Bus);
c. Column 3: Receiving end bus number (To_Bus);
d. Column 4: Branch resistance;
e. Column 5: Branch reactance.

While, the bus data matrix is a matrix of size (a x 5), where a is the number of buses (excluding the source bus) in the network. The five columns in the bus data matrix are defined as follows:

a. Column 1: Bus serial number;
b. Column 2: Magnitude of the load active power connected to a bus;
c. Column 3: Power factor of the load connected to a bus;
d. Column 4: Magnitude of the initial bus voltage;
e. Column 5: initial bus voltage angle.

The line and bus data of Azare 11kV distribution network are shown in Tables 3.5 and 3.6 of Appendixes A2 and A3 respectively. Consider the 10 nodes network (excluding the source node) shown in Figure 3.3. Node ‘0’ is the source node. In this research work, the source node is always represented by the index ‘0’ so as to be able to differentiate it from any other node, especially during computer data processing.

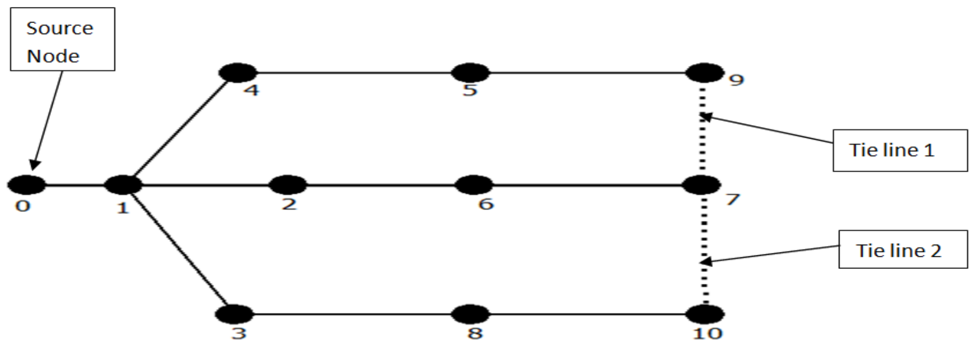

Figure 3.3: A Simple 10 Bus Radial Network with Two Tie-Switches (Lines/Branches)

The characteristic of a network topology can be described using the first three columns of the line data. The first three columns of the line data of Figure 3.3 are shown in Table 3.2.

Table 3.2: Line data of Figure 3.3

Line_No.	Frm_Bus.	To_Bus.
1	0	1
2	1	2
3	1	3
4	1	4
5	4	5
6	2	6
7	6	7
8	3	8
9	5	9
10	8	10

Let: S_{inj} be a matrix of power injected into every bus, such that S_{inj} has a size of n x1; let V be a matrix of voltage at every bus, such that V has a size of n x1; let SL be a matrix of load power at every bus, such that SL has a size of n x1; and let Z be a matrix of line impedance, such that Z has a size of n x1, where n is the number of buses in the network, then Z, SL, and the initial value of V, can be derived from the line and bus data matrices using the following MATLAB scrip:

```
1    Z=line_data(:,4)+1i*linedata(:,5);
%    Z=R+iX
2    SL=bus_data(:,2).*bus_data(:,3)-…
               1i*bus_data(:,2).*sin(acos(bus_data(:,3)));
%    |SL|.Pf-i|SL|.sin(cos^-1(Pf))
3    V=bus_data(:,4).*(cos(bus_data(:,5))+…
               1i*sin(bus_data(:,5)));
%    |V|.cos(□)+i.|V|.sin(□)
```

3.5.1 Information Matrix (IM)

The information matrix (IM) is a matrix of size (b x Ls), where b is the number of branches in the network, and Ls is the number of branches on the longest section of the network (as traced from the source node (0)). Each row of the IM represents a possible path (backward trace). The IM is used during the backward sweep to trace each node back to the source node (0) and during the forward sweep to trace the source node (0) to each other node.. The following MATLAB Function (Script) can be used to build the information matrix using the line data matrix as input.

```
line_data(:,[2 3])=fliplr(line_data(:,[2 3]));
% reverse the second and third column of the line data
[v,w]=size(line_data);
%
bus=v;
x=zeros(bus);
x(:,[1 2])=line_data(:,[2 3]);
    for i=1:bus
    for j=2:bus
    for k=1:bus
        if  line_data(k,2)==x(i,j)
            x(i,[j j+1])=line_data(k,[2 3]);
        end
    end
    end
    end
del=zeros(bus,1);
X=x;
    for l=1:bus
        if X(:,l)==del
            [a,b]=size(x);
            x(:,b)=[];
        end
    end
IM=sortc(x,1);
```

The information matrix of Figure 3.3 is shown in equation 3.5.

$$IM = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 2 & 1 & 0 & 0 \\ 3 & 1 & 0 & 0 \\ 4 & 1 & 0 & 0 \\ 5 & 4 & 1 & 0 \\ 6 & 2 & 1 & 0 \\ 7 & 6 & 2 & 1 \\ 8 & 3 & 1 & 0 \\ 9 & 5 & 4 & 1 \\ 10 & 8 & 3 & 1 \end{bmatrix} \tag{3.5}$$

3.5.2 Bus Incident Matrix

The bus incident matrix (BIM) is a square matrix of size (b), where b is the number of branches in the network. The BIM contains only ones and zeros. The

BIM is used during the forward sweep process to estimate the branch voltage drop and power loss, and in the backward sweep process to estimate the power injected at every bus. IM is also used in building a BIM. BIM can be built using following MATLAB script:

```
[k,l]=size(IM);
bb=zeros(k);
for i=1:k
    for j=1:l
      if bbb(i,j)~=0
         for amk=1:k
               if bbb(amk,1)==bbb(i,j)
                     gotit=amk;
               end
         end
               bb(i,gotit)=bbb(i,j);
      end
    end
end
BIM=bb;
[k,t]=size(BIM);
for q=1:k*t
    if BIM(q)~=0
        BIM(q)=1;
    end
end
```

The BIM of Figure 3.3 is shown in equation 3.6.

$$BIM = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \end{bmatrix} \tag{3.6}$$

3.5.3 Bus Injected Power (S_{inj})

In the proposed power flow model, the power injected into every bus is calculated during the backward sweep process. The load connected to each bus and the BIM are used in computing the power injected into every bus. The following MATLAB script can be used to estimate the power injected into every bus in the network (at the first backward sweep).

```
[k,t]=size(BIM);
II=[];
for e=1:t
    II=[II,SL];
end
II=II.*BIM;
II=sum(II);
II=II';
Sinj=II;
```

3.5.4 Power Loss (S_{loss})

In the proposed power flow model, the fist backward sweep is characterized by the assumption that the power loss on every line is equal to zero (0). At the subsequent backward sweep, the power loss (S_{loss}) on the lines is not equal to zero (0). Once the bus injected power (S_{inj}) is calculated, the power loss (S_{loss}) on the branches can be estimated using the following MATLAB script:

```
Sloss=(abs(Sinj-SL)./conj(V))^2).*Z;
```

Once the power loss (S_{loss}) is estimated, the bus injected power (S_{inj}) can be estimated during the subsequent backward sweep using the following MATLAB script:,

```
[k,j]=size(IM);
kj=k*j;
for jk=1:kj
    for jj=1:k
        if line_data(jj,3)==IM(jk);
            total_loss(jk)=Sloss(jj);
        end
    end
end
Total_Loss=sum(total_loss,2);
Sinj=Sinj+Total_Loss;
```

3.5.5 Voltage Deviation (VD)

Once the branch power loss are estimated, the BIM and IM can then be used during the forward sweep (FS) to estimate the voltage deviation of the network buses. The following MATLAB script can be used to estimate the voltage drop at every bus.

```
vdrop=sqrt(Sloss./Z)*Z;
      [k,j]=size(BIM);
kj=k*j;
for jk=1:kj
    for jj=1:k
    if line_data(jj,3)==IM(jk);
        total_vdrop(jk)=vdrop(jj);
     end
    end
end
VD=sum(total_drop,2);
```

Power flow simulation is performed using a number of MATLAB functions (Scripts) that work together to achieve power flow. These scripts are briefly described as follows:

1 RADFLOW: The main function that control the power flow execution. It requires the line data, bus data, and the source voltage as input. It has a MATLAB syntax of 'RADFLOW(line_data,bus_data,Vs)';

2 Sortbus: A sub-function that performs the backward and forward sweep. It uses of the line data to sweep (add-up) a desired parameter D across the entire network. It has a MATLAB syntax of 'sortbus(line_data,D)';

3 Sortc: A sub-function that Sorts a matrix M in reference to a column C. It has a MATLAB syntax of 'sortc(M,C)';

4 VDROP: A sub-function that computes the bus voltage deviation of a network using the line data. It has a MATLAB syntax of 'VDROP(line_data,drop', where drop is the voltage drop across the network branches.

5 Wizbus: A sub-function that constructs the information matrix (IM) using the line data. It has a MATLAB syntax of 'wizbus(line_data)';

The functions (Scripts) 1 to 5 are shown in Appendix B to F. Figure 3.4 shows a MATLAB block diagram of the proposed power flow model. In Figure 3.4, the arrows indicate the directions of the data flow during the power flow simulation/computations. In Figure 3.4, power flow computation is performed by a set of MATLAB functions that work together. The functions form a robust power flow analysis tool and make the proposed power flow model flexible. The proposed power flow model does not require sequential node numbering.

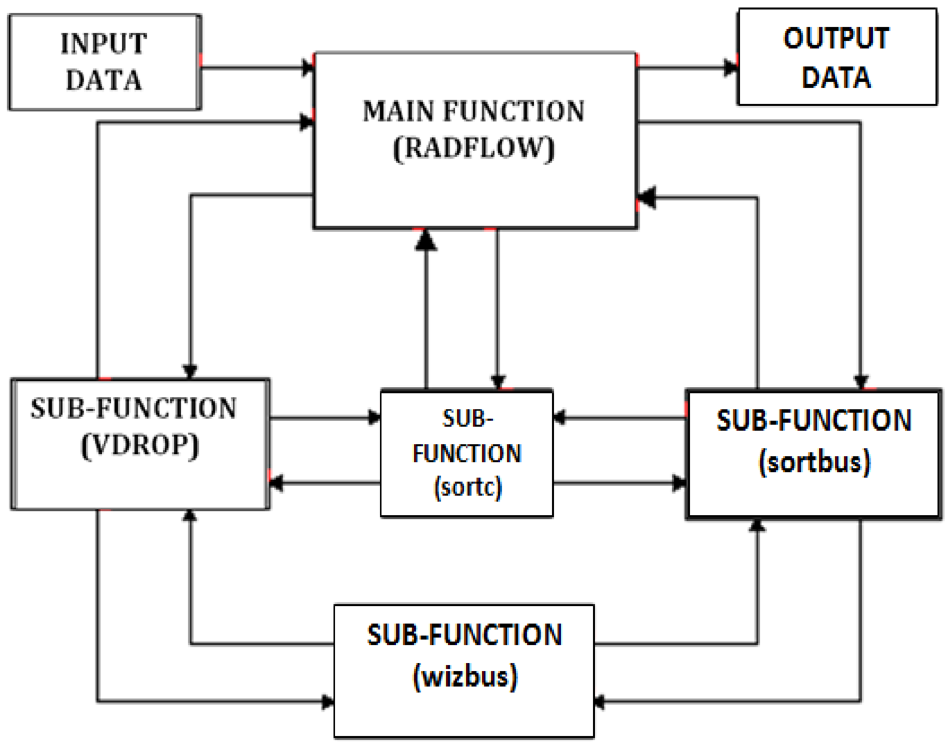

Figure 3.4: MATLAB Function Block Diagram of the Proposed Power Flow Model.

3.5.6 Significant Features of the Proposed Power flow Approach

The proposed power flow approach (improved BFS) offers the following advantages over the conventional BFS technique. In the proposed power flow approach;

1. The number of computations are reduced by executing the various steps involved based on power, thereby avoiding intermediate current estimations/conversion;
2. The entire network buses are considered at a time, rather than jumping from one bus to another. This make the proposed approach robust and reduce the complexity introduced by growth in network size;

3. The iterative process is broken into smaller sub-processes; each sub-process is carried out separately; the result obtained from one sub-process serves as the input to another. This makes the proposed approach flexible and quite efficient;
4. Iterative manipulation of matrices is involved rather than complex mathematical formulations. This helps in addressing the complexity introduced by the rugged nature of large radial distribution network;
5. The use of the IM and the BIM makes backward and forward tracing of network nodes much easier and thus decrease the computation time.

3.5.7 Proposed Power Flow Algorithm

In the proposed power flow algorithm, radial distribution power flow is achieved by logically executing the following set of instructions. A flow chart for the proposed algorithm is also illustrated in Figure 3.5. The proposed power flow algorithm is as follows:

1. Construct the network's line data matrix, bus data matrix, and define the source voltage and the voltage error limit (e);
2. Execute the backward sweep, by logically tracing each and every node back to the source while computing the power flowing on the network branches and their respective branch power losses. This can be achieved using the MATLAB function 'sortbus';
3. Execute the forward sweep, by logically tracing the source to every other node while computing the voltage drop along the branches and then the

voltage deviation VD of the network buses (based on the results obtained from the second instruction (2) above). This can be achieved using the MATLAB Function ‘VDROP’;

4. Update the node voltages using the results obtained from the third instruction (3) above, and store the updated node voltages as V_{F1};
5. Re-execute instructions two (2) and three (3) above; re-update the updated node voltages (as in four (4) above); and store the re-updated node voltages as V_{F2};
6. Compute the change in node voltage between two successive forward sweeps (which represents the absolute voltage error ($|V_{F1}-V_{F2}|$);
7. Repeat instructions two (2) to six (6), as long as the maximum absolute voltage error is greater than the error limit (e).
8. Print the results, if the condition in instruction seven (7) is violated.

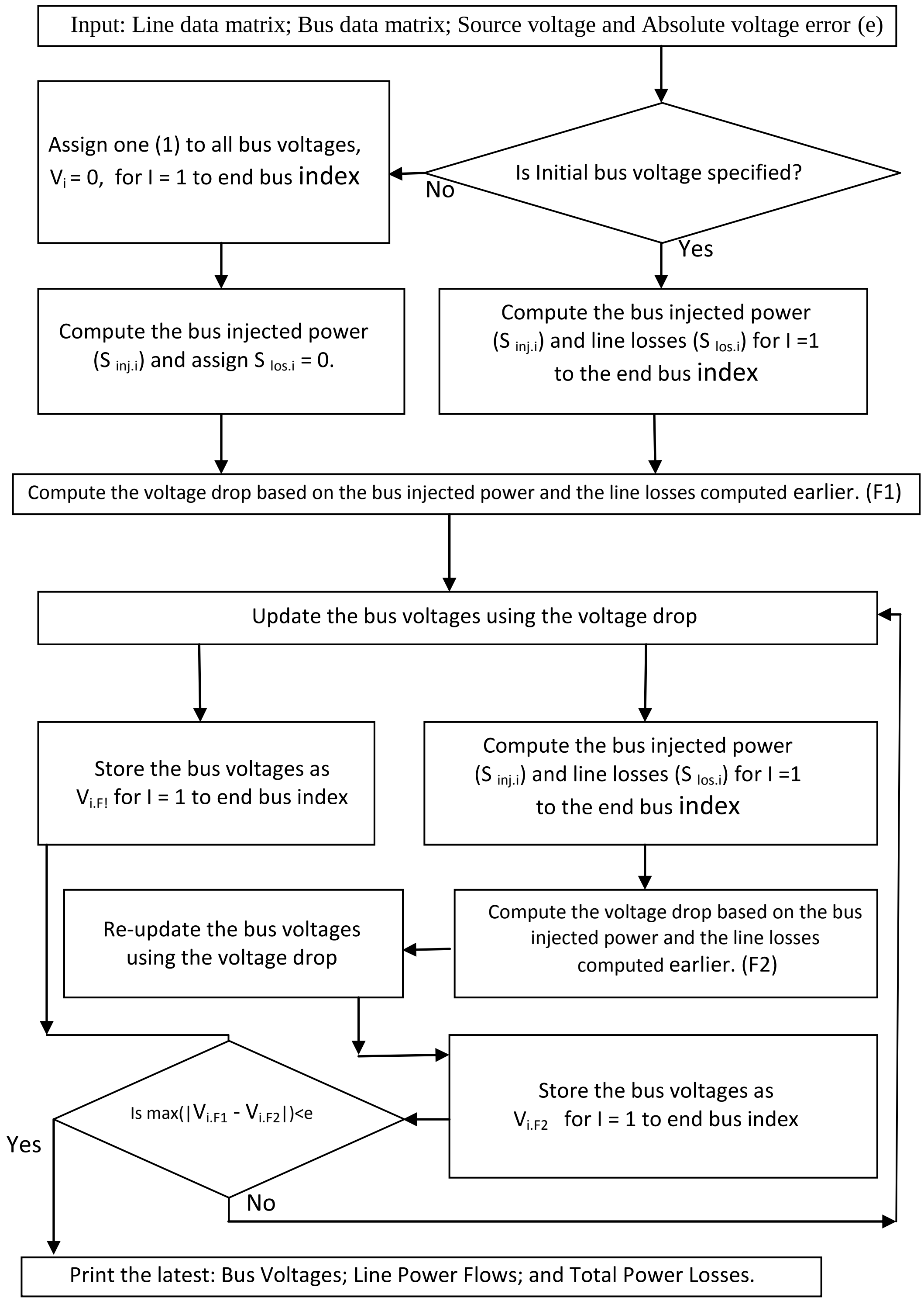

Figure 3.5: Flow Chart of the Proposed Power Flow Algorithm.

3.6 Proposed Reconfiguration Model

Electrical loads are usually connected to the network nodes/buses. These loads cause power to flow through the network branches. As the loads increases, some of these branches eventually become over loaded. Necessary actions have to be taken in order to reduce the loads on these branches in order to ensure safety and reliability. Network reconfiguration can be carried out in order to transfer loads from the heavily loaded feeders to the lightly loaded feeders in order to uniformly distribute the loads across the network. These uniform load distribution results in the following:

i. Voltage profile improvement;

ii. Real power loss reduction.

The process of feeder reconfiguration is achieved by randomly operating pair of switches (tie and sectionalizing switches) to transfer loads from one feeder to another. It is therefore very critical that the branches do not get overloaded in order to minimize equipment failure and to ensure safety. To achieve this, the following constraints have to be imposed on the various branches and nodes while performing reconfiguration:

1. The node voltage constraint;
2. The branch active power constraint;
3. The radial constraint.

Consider the ten (10) buses network shown In Figure 3.3. Reconfiguration can be performed by closing the tie switches (tie lines 1 and 2). Branches are numbered based on the receiving end nodes. In the proposed reconfiguration method, the network is reduced by eliminating all the branches that do not form part of the closed loops (meshes). In Figure 3.3, branch 1 can be eliminated. The reduced network therefore has 11 branches including the tie branches. Reconfiguration is performed by opening L (L = number of meshes) switches in order to convert the meshed network (obtained by closing the tie switches) into a completely radial network.

The set of L branches that satisfies the radial constraint is termed as a candidate solution (CS). In the proposed reconfiguration method, the entire possible CSs are first generated; then the power flow of the resulting network (obtained by opening the branches contained in a candidate solution) is simulated while imposing the voltage and active power constraints.

3.6.1Candidate Solution Generator (CSG)

The candidate solution generator (CSG) is a MATLAB function ('configs') that generates the entire possible set of tie branches that satisfy the radial and connected constraint of a given meshed network. CSG makes use of the reduced network graph information matrix (RNGIM) as input. Figure 3.6 shows the reduce network graph of Figure 3.3.

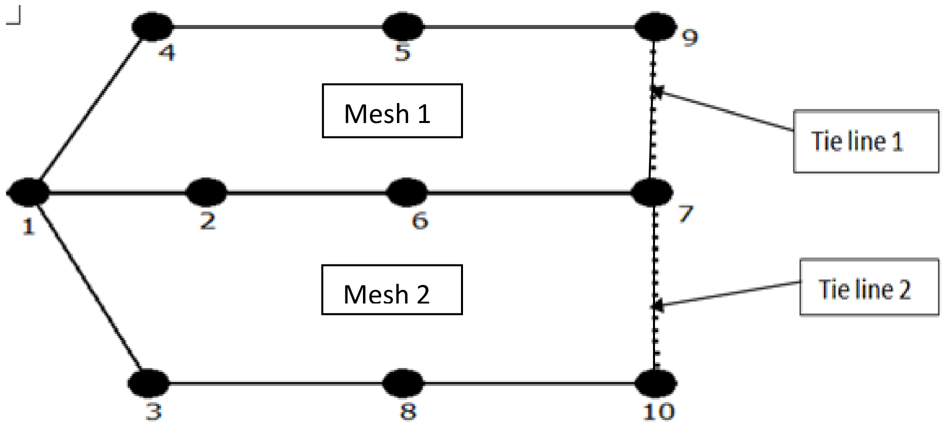

Figure 3.6: Reduced Network Graph of Figure 3.3.

3.6.2 Reduced Network Graph Information Matrix (RNGIM)

The RNGIM is a matrix of m rows by m * s columns, where m is the number of meshes in the reduced network graph and s is the number of branches in the longest section (a section with the highest number of branches). RNGIM is derived from the reduced network graph by grouping the network branches into sections. Note that; each of the branches in a section will result into a candidate solution. Therefore, the number of candidate solutions can be reduced by considering a group of sectional branches as a single branch. Figure 3.6 has two meshes, three sections and three branches per section (the tie lines are not considered as part of the sectional branches). In constructing the RNGIM, the length of the sections must be equal. To achieve this, the missing branches are replaced with zeros (0). The RNGIM of Figure 3.6 can be expressed using equation (3.7) and (3.8).

$$RNGIM = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \tag{3.7}$$

where:

S_{11} is the set of branches in the section belonging to mesh 1 only;

S_{21}, and S_{12} are equal and are the set of branches in the section belonging to meshes 1 and 2;

S_{22} is the set of branches in the section belonging to mesh 2 only;

S is matrix of size 1 x s.

Thus:

$$RNGIM = \begin{bmatrix} 4 & 5 & 9 & 2 & 6 & 7 \\ 2 & 6 & 7 & 3 & 8 & 10 \end{bmatrix} \quad (3.8)$$

The Candidates solutions of Figure 3.6 are shown in Table 3.3.

Table 3.3: Candidate Solutions of Figure 3.6

S/N	Candidate Solutions		SN	Candidate Solutions		SN	Candidate Solutions	
1	4	2	10	4	3	19	2	3
2	5	2	11	5	3	20	6	3
3	4	6	12	4	8	21	2	8
4	9	2	13	9	3	22	7	3
5	4	7	14	4	10	23	2	10
6	5	6	15	5	8	24	6	8
7	9	6	16	9	8	25	7	8
8	5	7	17	5	10	26	6	10
9	9	7	18	9	10	27	7	10

In Table 3.3, there are 27 candidate solutions (3 x 9) which results from the three (3) sections of the nine branches of the network graph in Figure 3.6. Each of the candidate solutions can be used to reconfigure the network by eliminating the branches contained in the solution set from the original network. The remaining branches constitute the spanning tree.

Consider candidate solution number 15, the resulting configuration after eliminating branches 5 and 8 is shown in Figure 3.7.

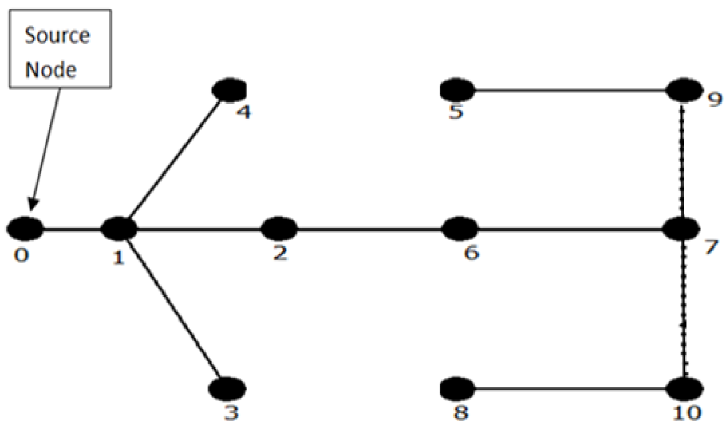

Figure 3.7: Fifteenth (15) Possible Configuration of Figure 3.3

In Figure 3.3, the direction of power flow on branches 9 and 10 is from bus 5 to bus 9 and from bus 8 to bus 10 respectively. The opposite occur in Figure 3.7 i.e. from 9 to 5 and from 10 to 8 respectively. Therefore Table 3.2 no longer represents the first three (3) columns of the line data of Figure 3.7. The first three (3) columns of the line data matrix of figure 3.7 can be built using the IM, the candidate solution (CS_i) and the tie matrix (TM). TM for Figure 3.7 can be represented by any of the matrices i to iv, while the CS_i is given by equation (3.9). The IM of Figure 3.7 is the same as that of Figure 3.3.

$$CS_{15} = [5 \quad 8] \tag{3.9}$$

TM can be any of the matrices i to iv:

i. $\begin{bmatrix} 7 & 10 \\ 7 & 9 \end{bmatrix}$;

ii. $\begin{bmatrix} 7 & 10 \\ 9 & 7 \end{bmatrix}$;

iii. $\begin{bmatrix} 10 & 7 \\ 7 & 9 \end{bmatrix}$ or

iv. $\begin{bmatrix} 10 & 7 \\ 9 & 7 \end{bmatrix}$.

The MATLAB Script in Appendix G can be used to generate the line data of Figure 3.7 using the line data of the original network (line_data_original), TM and CS_{15}. The first three columns of the line data of Figure 3.7 is shown in Table 3.4

Table 3.4: The line data of Figure 3.7 (the 15th possible configuration)

Line_No.	Frm_Bus.	To_Bus.
1	0	1
2	1	2
3	1	3
4	1	4
9	7	9
6	2	6
7	6	7
10	7	10
5	9	5
8	10	8

In the proposed method, each candidate solution results into a new configuration which results in a new line data. The bus data remain the same throughout the reconfiguration process. Reconfiguration can be performed using the following MATLAB functions and those of power flow computation earlier described on page 75 (working together as a single function).

i. Optconfig: The main function that control the execution of reconfiguration. It requires the following data as inputs:

1. Line data matrix;
2. Bus data matrix;
3. Upper voltage limit;
4. Lower voltage limit;
5. Source voltage;
6. Tie matrix (TM); and
7. The reduce network graph information matrix (RNGIM);

It's MATLAB syntax 'optconfigs(line_data,bus_data,Vs,Vmin,Vmax,… TM,RNGIM)';

ii. Configs: A sub-function (CSG) that generates the entire candidate solutions (CS) that represents the possible feasible configurations. It's MATLAB syntax is 'configs(RNGIM))'.

Functions (Scripts) i and ii are shown in Appendix G and H. Figure 3.8 shows a block diagram of the reconfiguration program in MATLAB. In Figure 3.8, the arrows indicate the directions of the data flow during the optimal reconfiguration simulation.

In Figure 3.4, the developed power flow MATLAB function is extended to perform reconfiguration using two addition MATLAB functions (Optconfig and Configs). This indicates that the developed power flow model can be extended to perform other tasks. The functions form a robust optimal reconfiguration analysis tool and make the proposed reconfiguration model flexible. In the proposed reconfiguration model, the CSG eliminates the challenge of satisfying the radial and connected constraint

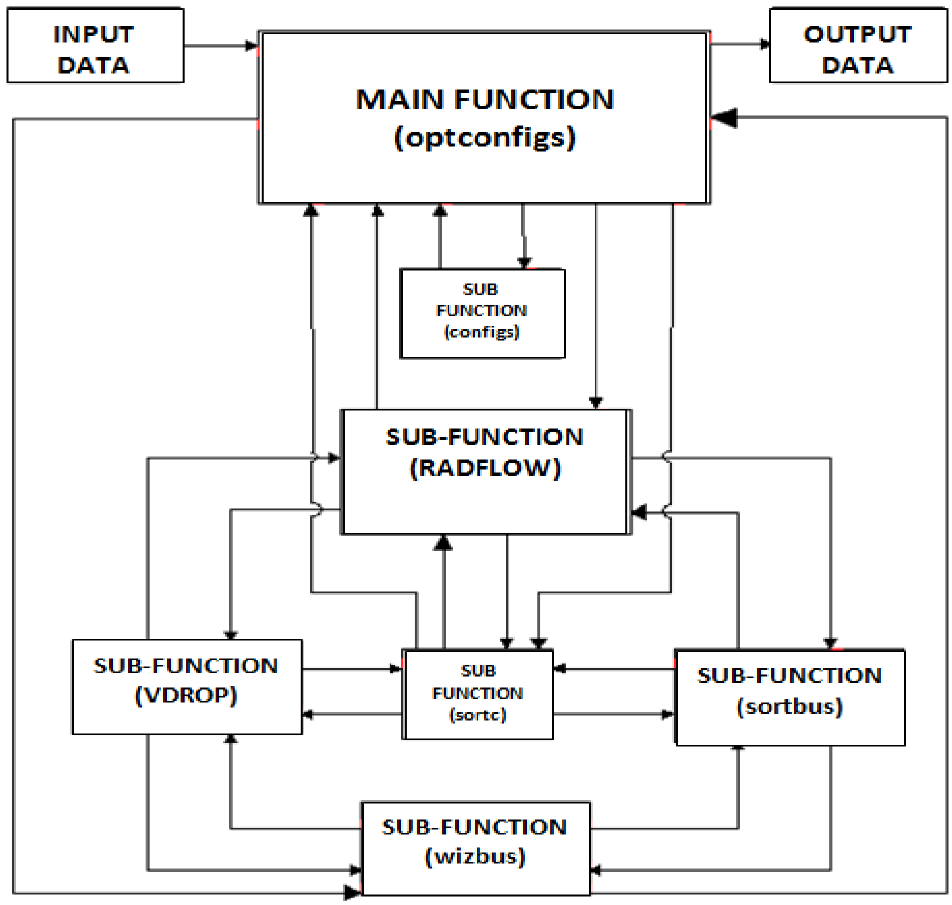

Figure 3.8: The MATLAB Function Block Diagram of the Proposed Reconfiguration Model

3.6.3 Significant Features of the Proposed Reconfiguration Approach

The proposed reconfiguration approach (improved ASTUNG) offers the following advantages over the conventional ASTUNG technique. In The proposed reconfiguration approach;

1. The entire possible feasible candidate solutions are usually generated (by CSG) at the beginning of the reconfiguration process; this eliminates the need to check if a particular configuration satisfies the radial and connected constraint (which is the most difficult of all the constraints) and thus, robustness is enhanced;
2. The use of the RNGIM makes it possible to eliminate some branches (which may be critical) from the solution search and thereby narrowing the search space (decreasing the computational time);
3. A set of possible configurations can be selected from the universal set of possible configurations (generated by the CSG) and tested for optimality (This makes the proposed approach flexible).

3.6.4. Proposed Reconfiguration Algorithm

The radial distribution network reconfiguration can be successfully carried out by logically executing the following set of instructions. These set of instructions forms the proposed reconfiguration algorithm. A flow chart of the proposed reconfiguration algorithm is also illustrated in Figure 3.8. The proposed reconfiguration algorithm is as follows:

1. Construct matrices for the line data, bus data, RNGIM, TM and define the voltage limits (upper and lower limit);

2. Generate the entire possible candidate solutions for the reconfiguration problem, using RNGIM. This can be achieved using the MATLAB command ‘configs’;
3. Execute the BFS algorithm for each candidate solution while imposing the voltage and active power constraints on the network nodes and branches respectively;
4. Store the power flow results of the candidate solutions that satisfy the voltage and active power constraint (the local optimum solutions);
5. Compare the stored results to determine the best solution (the global optimum solution) in terms of voltage profile, real power loss, and load balancing;
6. Plot the relevant graphs;
7. Print the best solution as the power flow results of the optimum configuration.

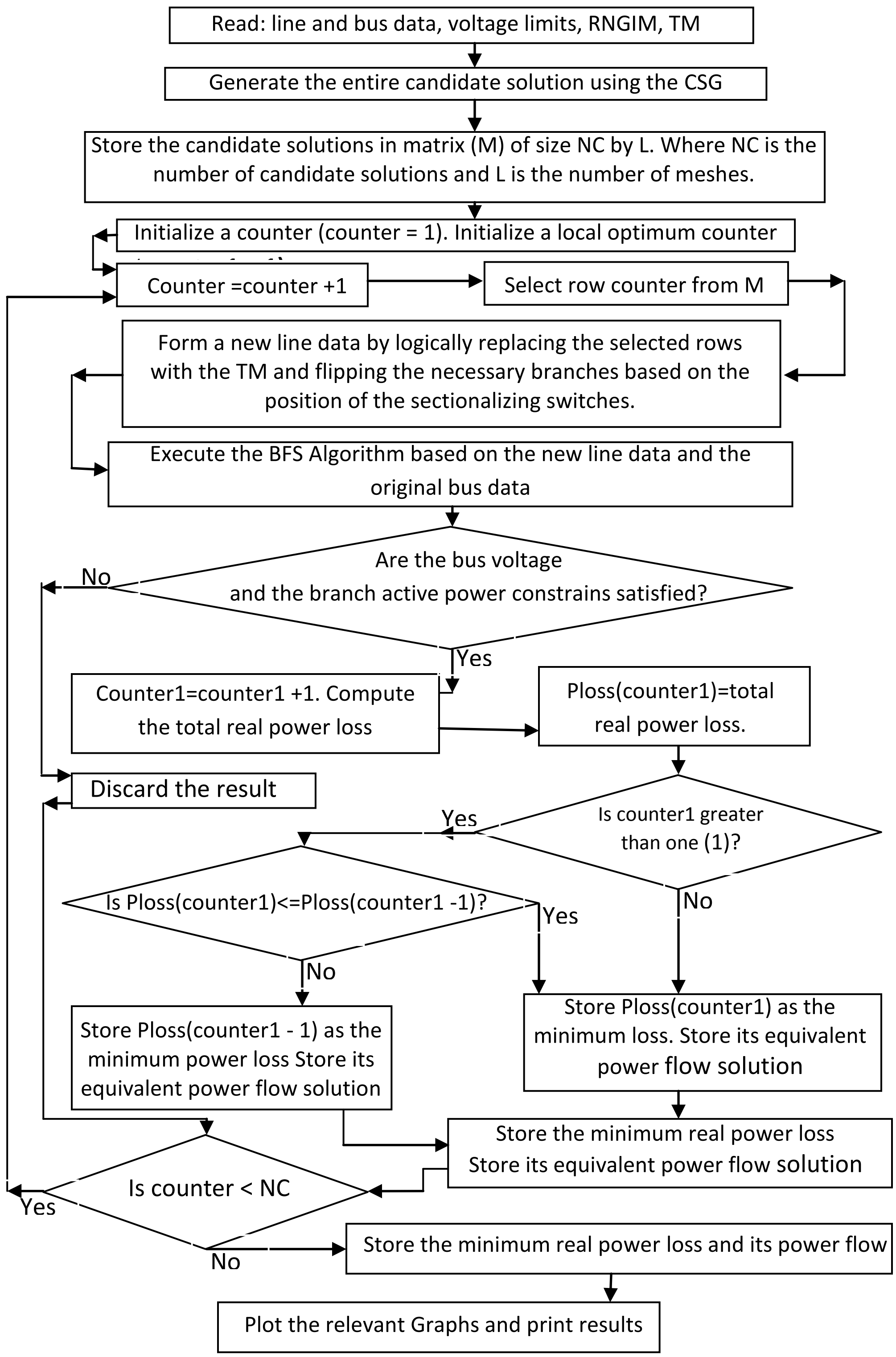

Figure 3.8: Flow Chart of the Proposed Reconfiguration Algorithm.

3.7 Matlab GUI for Power Flow and Reconfiguration Simulators

MATLAB graphic user interface (GUI) is a MATLAB tool that helps users (especially those that are less familiar with MATLAB) to carry out simulations/computations using MATLAB, through a pre-designed interface/window. MATLAB command window can be avoided via a GUI. Therefore it is possible to execute a MATLAB command without actually knowing its syntax. To access a specific GUI, a user simply needs to double-click on its icon (which is created in the design phase of the GUI). GUI icons are created and saved in the MATLAB folder in the Document directory (at default), but can be copied to the Desktop to aid easy access. A typical MATLAB GUI is made up of three programs, which includes:

1. The main program;
2. The user interface; and
3. The sub-program (program that execute the computations/intended function).

3.7.1 Power Flow and Reconfiguration GUI Design and Programming

Radial distribution power flow and reconfiguration can be easily simulated using a MATLAB GUI. This allows a user to input the required parameter using key board in the 0space provided on the GUI window, and to press the desired button in order to carry out simulation. When a button is pressed, the GUI main program feeds the input parameters to the sub-programs; which then performs computation and display the results in the desired format and at the desired location (the GUI panel or the command window). Figure 3.9 and 3.10 shows the designed radial distribution network power flow and reconfiguration GUI respectively.

In the Figure 3.9, a GUI is designed to simulate an n buses network power flow, it allows a user to enter the line data matrix (as an n rows by 5 columns matrix); the bus data matrix (of the same size as the line data); and the value of the source voltage. The simulation is initialized by clicking the ‘RUN POWER FLOW’ button. The GUI then processes the data and displays the results (branch active power flow, bus/node voltages, total network power loss, simulation time, the number of iterations and a number of graphs). The GUI can support line and bus data in different format depending on the choice of a user (selection of one of the three data types). If the size of the results (branch active power and bus voltage magnitude) exceeds the dimension of the space provided, the program automatically displays the result in the command window.

Figure 3.10 also accepts the power flow data as described earlier and other data such as the TM, the RNGIM, the lower voltage limit (Vmin), and the upper voltage limit (Vmax). In this case, an additional column is required in the line data matrix. The column represents the maximum branch currents or active power depending on user choice (data type). The reconfiguration GUI can be used for finding the optimum network configuration or simulating reconfiguration for a given set of candidate solutions. The output includes a number of graphs and a detailed result displayed on the MATLAB command window. The developed power flow and reconfiguration programs can handle large distribution networks depending on the computer speed and memory (RAM).

The GUIs shown in Figures 3.9 and 3.10 are controlled by the MATLAB functions (scripts) shown in Appendixes M and N respectively.

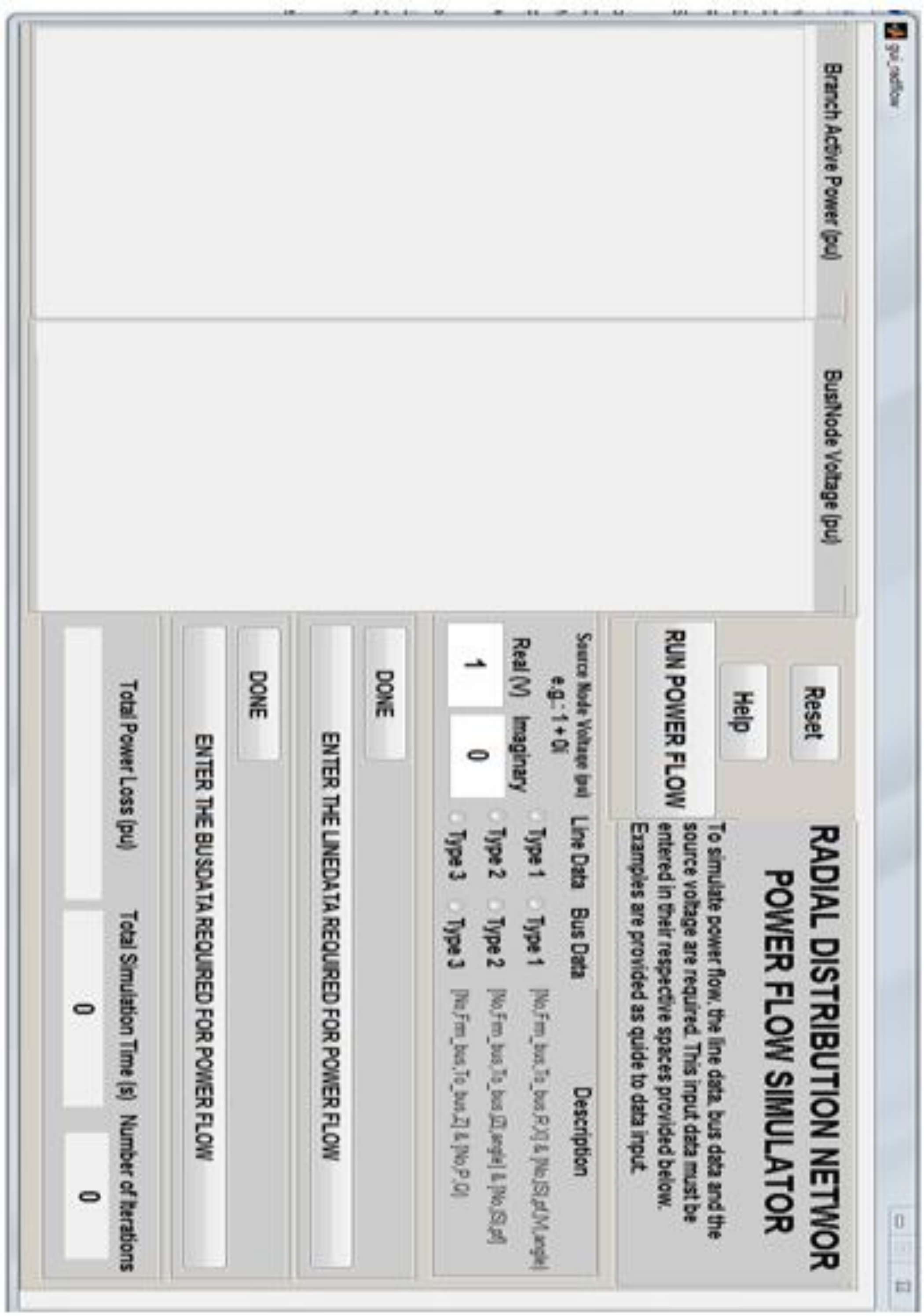

Figure 3.9: The Designed Radial Distribution Network Power Flow Simulation GUI.

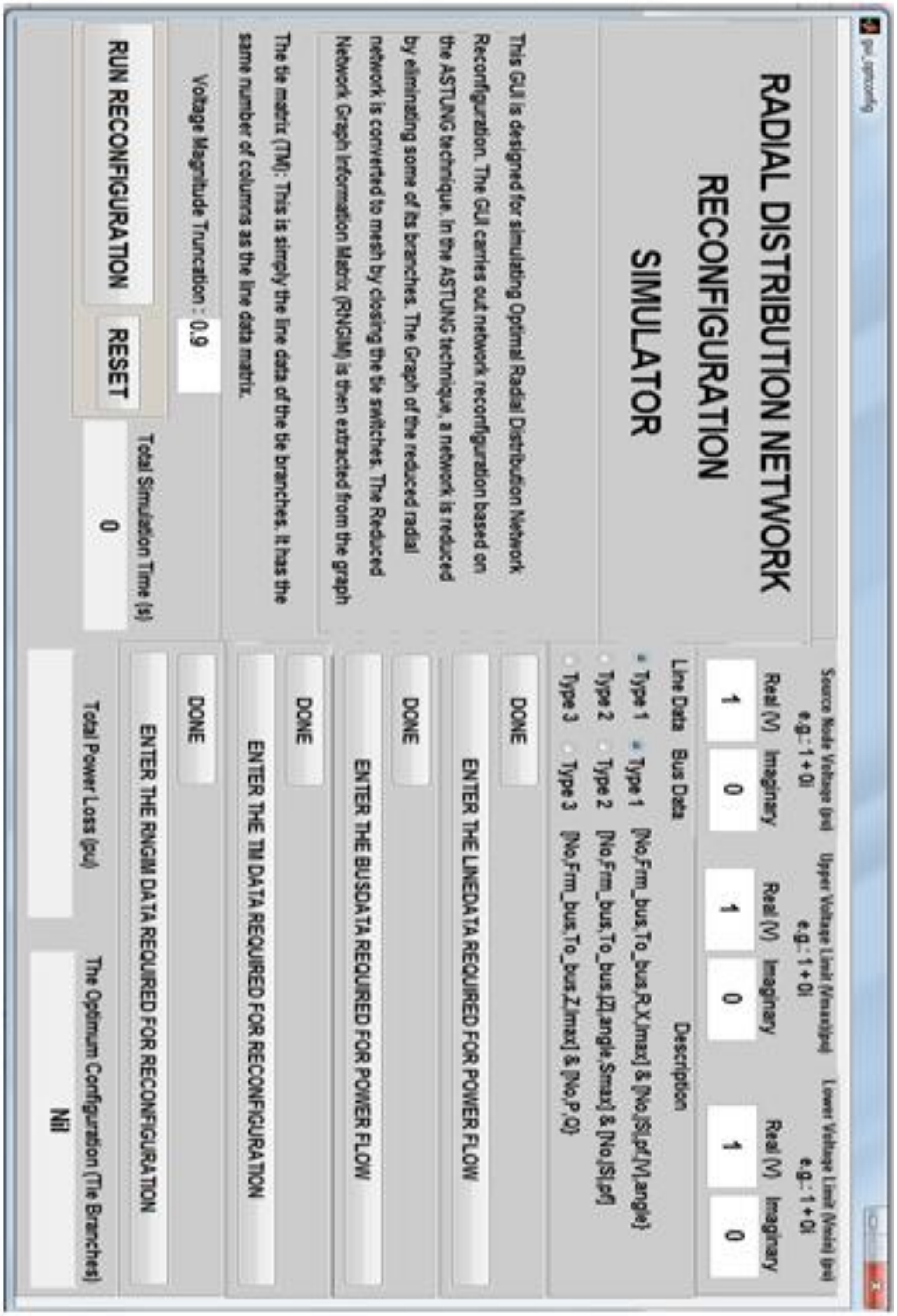

Figure 3.10: The Designed Radial Distribution Network Reconfiguration Simulation GUI

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, power flow and optimal reconfiguration are simulated on the Azare distribution using the developed simulator (MATLAB GUIs); the original and optimum configuration of Azare network are compared; finally, the developed simulators are validated using standard IEEE 30 and 33 buses radial distribution network.

4.2 Simulation

In this work, firstly, a radial distribution power flow of Azare network (original configuration) is simulated using the developed radial distribution network power flow GUI. Secondly, an extensive network reconfiguration was performed using the developed radial distribution network reconfiguration GUI. The output (screen) of the developed simulation programs (power flow and reconfiguration) were captured and shown in Figure 4.1 and 4.2 respectively. The reconfiguration program is designed to automatically determine the optimum configuration and compare it with the original configuration in term of voltage profile, voltage stability index (VSI), system load balancing index (SLBI), total real power loss, etc. using numeric values and charts.

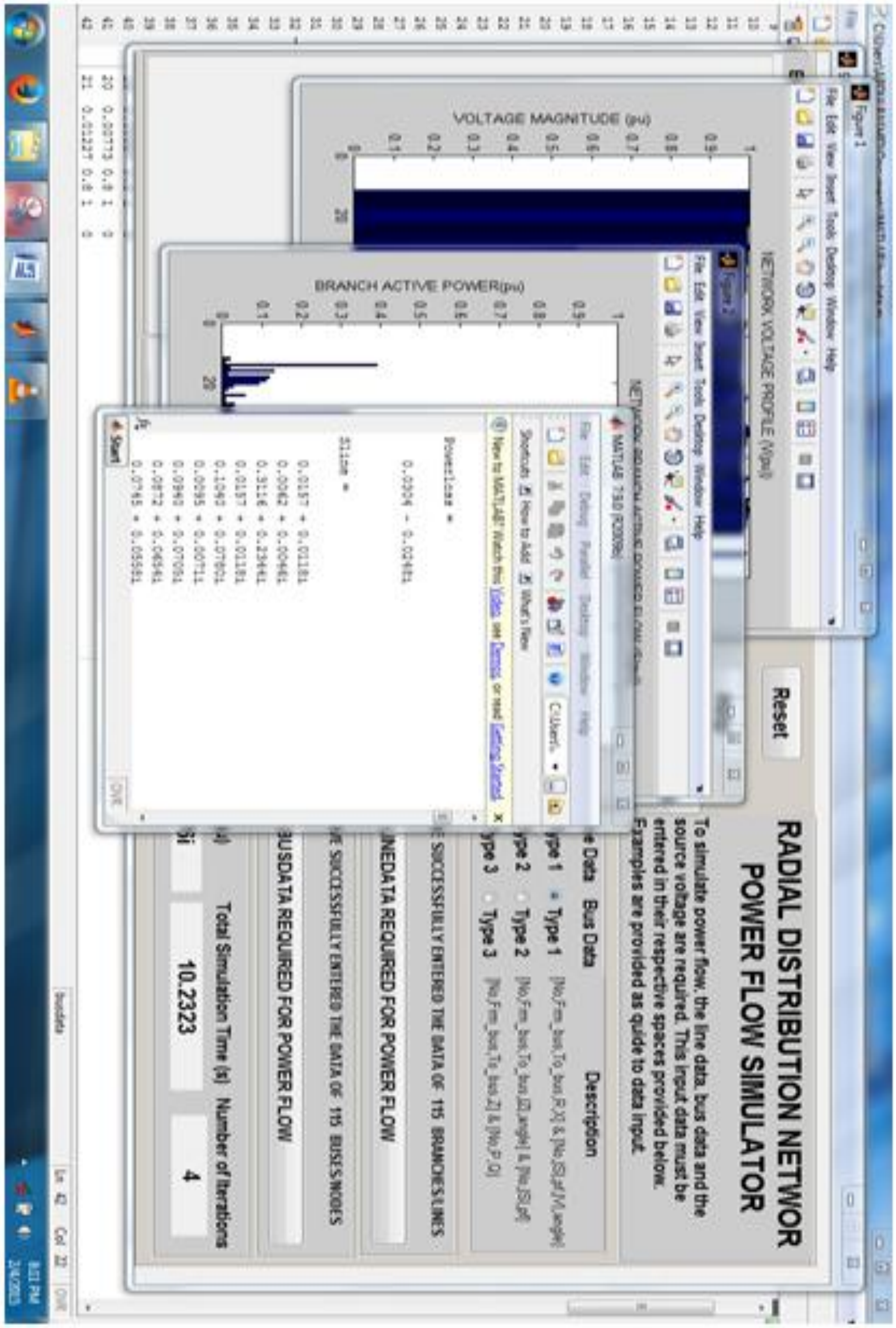

Figure 4.1: Computer Screen Showing the Power Flow Results as Generated by the Developed Power Flow Simulation Program

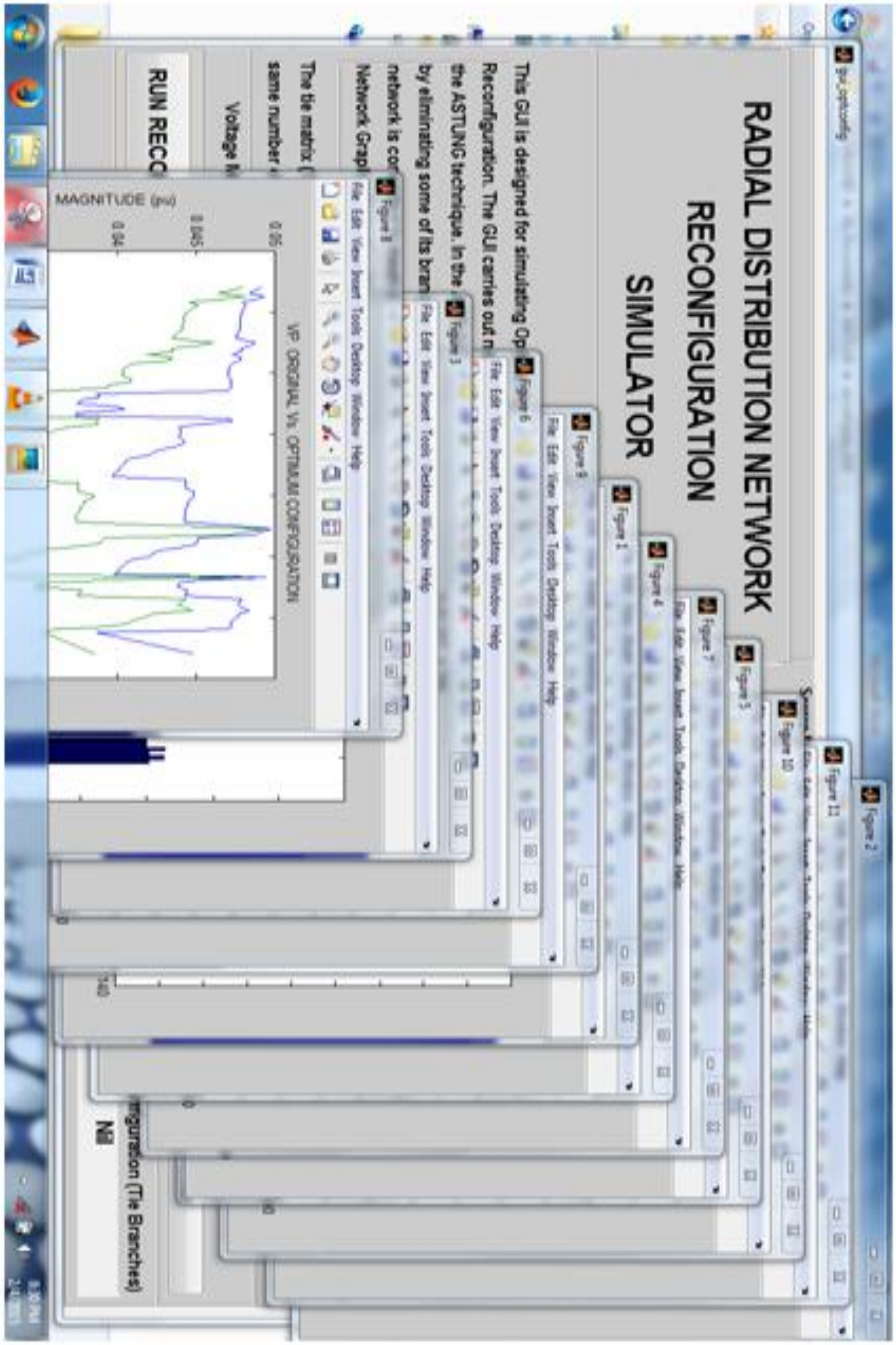

Figure 4.2: Computer Screen Showing the Reconfiguration Results as Generated by the Developed Reconfiguration Simulation

The simulation was carried out using the complete Azare 11kV radial distribution network data (line and bus data shown in Appendix A2 and A3 respectively). With reference to the 11kV network schematic diagram shown in Figure 3.2, the source node (0) has a maximum capacity of 7.5MVA at 11kV. The load (active power) allocated to the various load points were estimated based on the load dispatch data as obtained from the injection substation (at the time in which the entire 11kV network is active). An equivalent single phase representation of the three phase 11kV network is used. Table 4.1 shows the base values which were used in converting the required network parameter values to their respective per unit (pu) values in order to carry out simulation. Appendix M also shows the line data, bus data, tie matrix (TM), and the RNGIM of the original configuration (Azare network) that were used as input to the developed power flow and reconfiguration simulators.

Table 4.1: The Base Values

S/No.	Base Quantity	Value (per phase)
1	Voltage	6.35kV
2	Power	2.5MVA
3	Impedance	16.13Ω
4	Current	393.6A

4.3. Voltage Profile

The variation in node voltages with respect to the source (rated) voltage across the entire network can be described using a voltage profile. The line/branch conductors connecting the nodes in a network are not perfect conductors (conductors with zero resistance and reactance). The resistance and reactance of these conductors causes a voltage drop and power loss when current flow in them. The voltage drop causes a deviation of the node voltages from the rated value (source value). Since power flow in one direction in radial networks (with one source), nodes located on the same feeder experiences voltage drop based on their position and section on that feeder. The closer a node is, to the source node, the higher its voltage magnitude (the lower the voltage drop) and vice versa. Nodes on different feeder experience voltage drop based on the impedance of the path tracing them to the source node; and the current flowing through the branches linking the downstream nodes on that feeder. In this work, the radial distribution network has two main feeders. Therefore the node voltages (voltage drop) are expected to vary in two distinct patterns. Figure 4.3 and 4.4 shows the voltage profile of the original and optimum configuration respectively. In this work, the network nodes are not numbered sequentially. Therefore the two distinct node voltage variations cannot be easily observed in the network voltage profile.

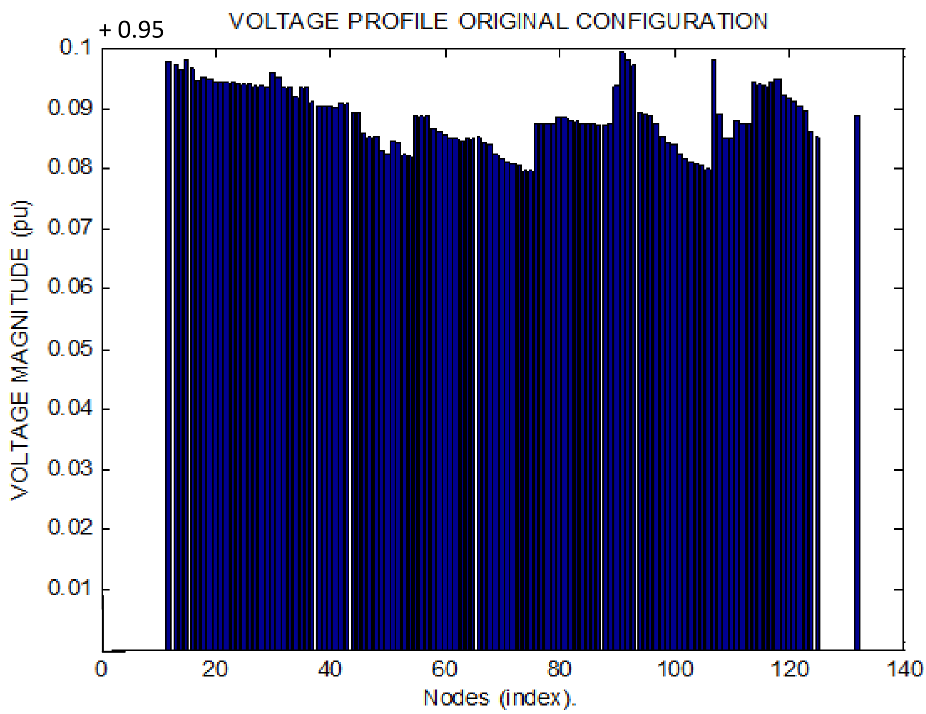

Figure 4.3: Voltage Profile of the Original Configuration.

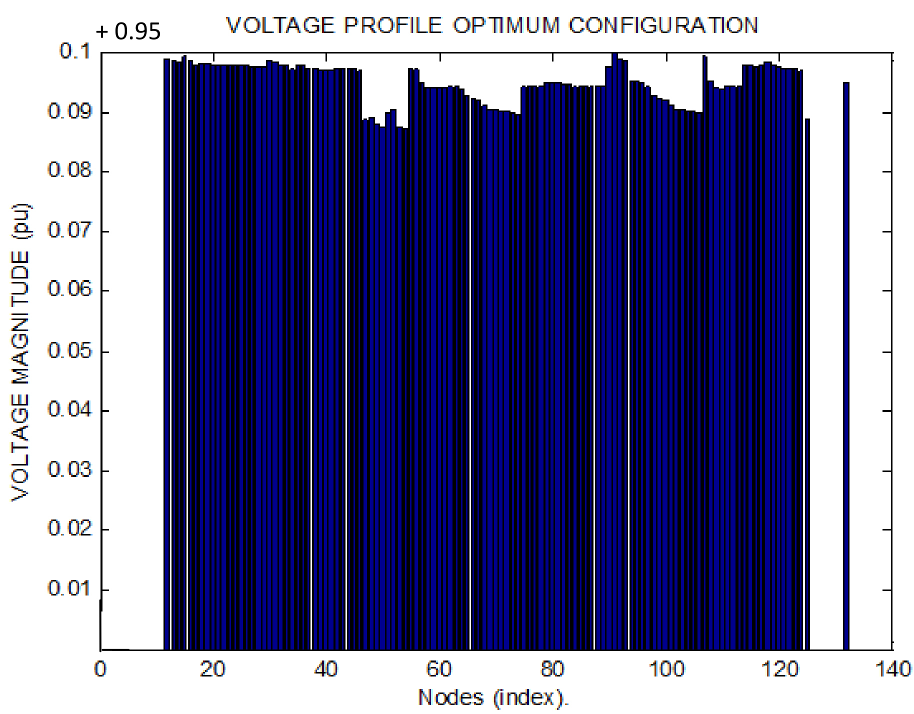

Figure 4.4: Voltage Profile of the Optimum Configuration.

In Figure 4.3 and 4.4, the height of the bars is supposed to decrease gradually as one move from the source node down to the end node, indicating an increasing voltage drop. The gradual decrease in node voltage magnitude can therefore be noticed if the nodes are arranged in a sequence of decreasing voltage magnitude as shown in Figure 4.5. The voltage profile of a network is said to be improved if the voltage magnitude of the network nodes are relatively increased (the voltage drop at the network nodes are decreased). In order to compare the original and the optimum configuration in terms of voltage profile, the network nodes are sorted with decrease in voltage magnitude (increase in voltage drop). Figure 4.5 shows the plot of the sorted nodes voltage magnitude for the original and the optimum configuration. The optimum configuration can be observed to have an improved voltage profile.

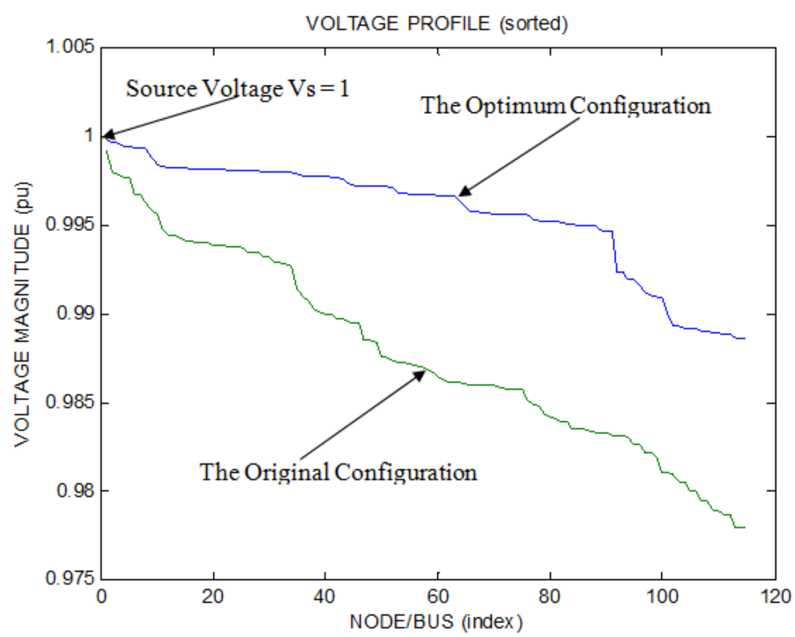

Figure 4.5: Voltage Profile of the Original and Optimum Configurations with Nodes/Buses Arranged in Decreasing Order of Voltage Magnitudes.

4.3.1 Voltage Profile Improvement

The improvement in voltage profile can be measured based on the reduction in total voltage deviation TVD of a given network. Consider a distribution network in which the TVD is reduced from a value TVD_o to TVD_i, the percentage improvement in voltage profile (%VI) can be represented using equation (4.2). If the node voltages are in per-unit (pu), the TVD can be expressed using equation (4.1).

$$TVD = \sum_{k=1}^{n}(1 - V_k) \tag{4.1}$$

$$\%VI = \frac{TVD_o - TVD_i}{TVD_o} x100 \tag{4.2}$$

where:

V_k is the voltage magnitude at the kth bus;
n is the number of buses in a network;

The voltage profile improvement achieved for Azare distribution network at the optimum configuration is estimated as in equation (4.3).

$$VI = \frac{1.4133 - 0.5072}{1.4133} x100 = 64.11\% \tag{4.3}$$

4.4 Voltage Stability Index (VSI).

VSI is a measure of the deviation of the node voltage magnitudes from the rated value (the source voltage magnitude). In electrical power system, VSI can be used for steady or dynamic state analysis. In this research work, the network is assumed to be in steady state, and the loads allocated to the various nodes have lagging power factor. Thus; the deviation in node voltages is largely due to line/branch voltage drop. Since the voltage magnitude of the network nodes depends on the voltage drop (voltage deviation) along the network branches, VSI is a measure of voltage profile. Therefore, the lower the VSI of a network, the better its voltage profile and vice versa. The VSI of the original and optimum configuration are shown Figure 4.6. The designed reconfiguration simulator computes the VSI of each candidate solution while performing reconfiguration. The resulting VSIs of the 4008 candidate solutions were computed and plotted. Figure 4.7 shows the VSIs of the 4008 candidate solutions.

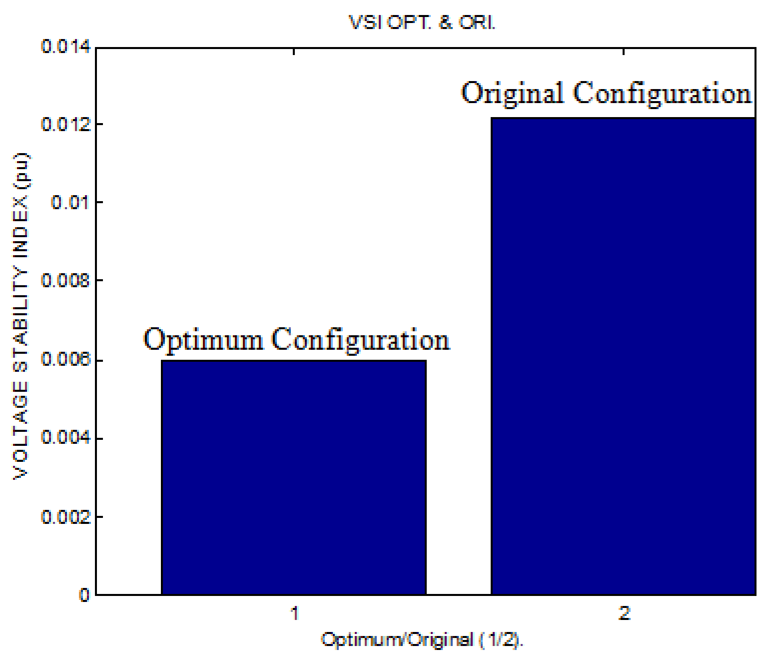

Figure 4.6: VSI of the Original and Optimum Configuration.

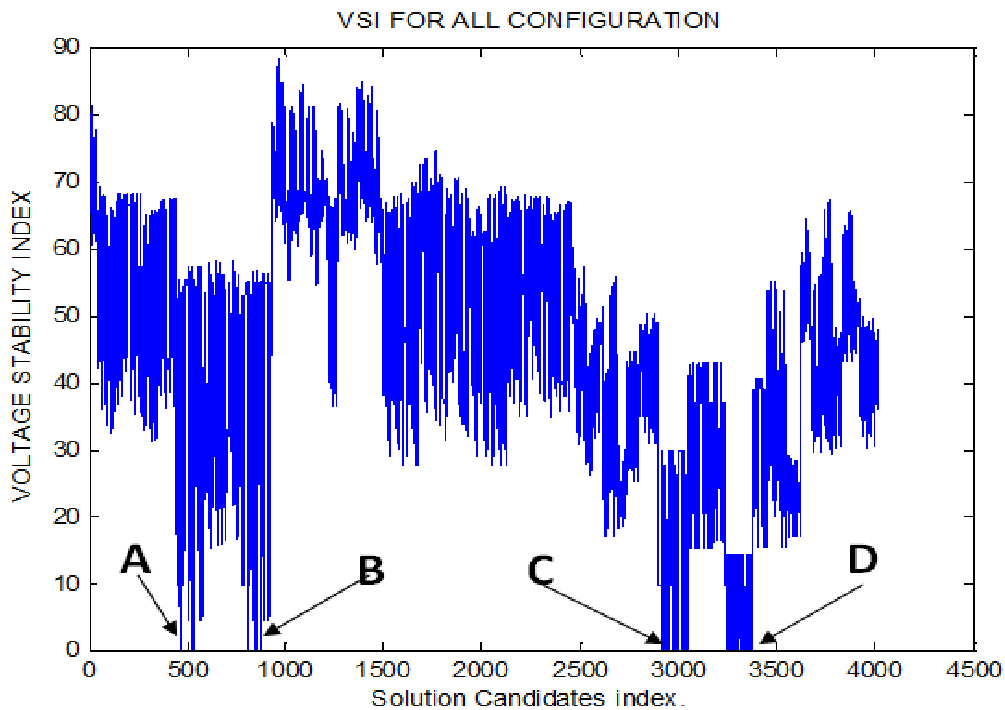

Figure 4.7: VSI of the entire (4008) Candidate Solutions (Possible Configurations)

4.5 Solution Search

In Figure 4.7, it can be observed that the VSI of the candidate solutions varies randomly. Since high VSI indicates low voltage profile (large voltage drop), the optimum configuration solution candidate is located at a point of minimum VSI. Such point can be found on either position A, B, C, or D as shown in Figure 4.7. Where A, B, C and D represents a range of candidate solutions as described by Table 4.2. The candidate solutions can be termed as local optimums.

Table 4.2: Ranges of Local Optimum Candidate Solutions

Position	Range (Candidate Solution number)
A	450-550
B	800-900
C	2900-3100
D	3250-3400

In order to determine the position in which the Global optimum solution lies, a plot of the SLBI of the entire candidate solution is required. The developed program was also designed to estimate and plot the SLBI of each of the 4008 candidate solutions during simulation. Figure 4.8 shows a plot of the SLBI of the entire candidate solutions.

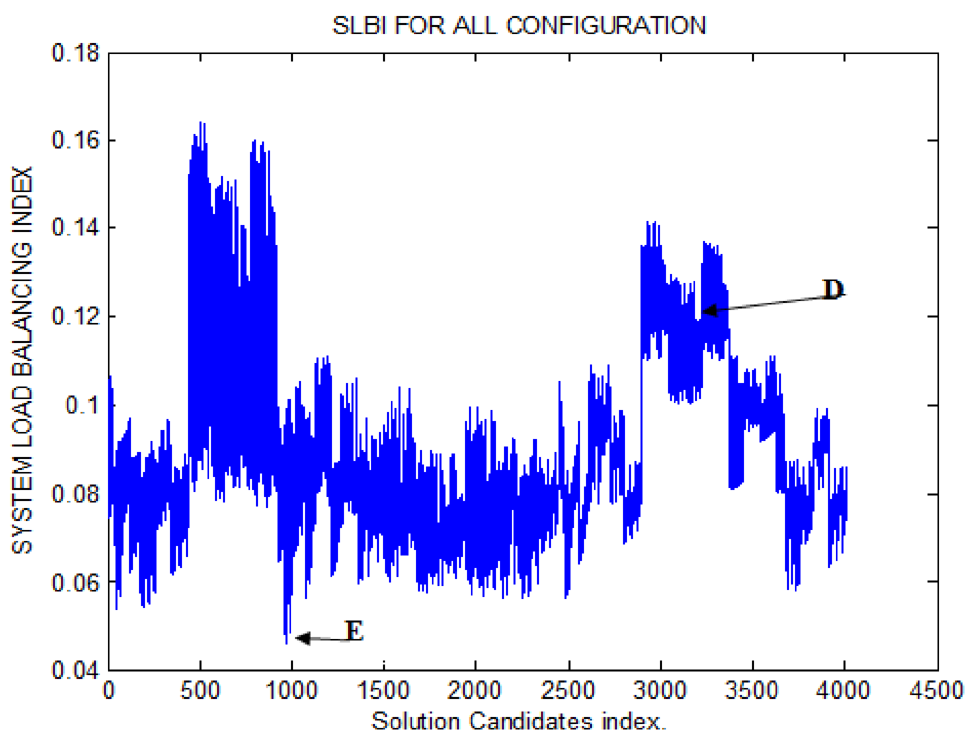

Figure 4.8: SLBI of the entire (4008) Candidate Solutions (Possible Configurations

In Figure 4.8, the solution candidate (configuration) with the minimum SLBI is located within E (950-1000). Comparing Figures 4.7 to 4.8; it can be observed that; between positions B and C, the VSIs are generally high while the SLBI are low. In this research work, more emphasis is given to voltage profile improvement than load balancing. Therefore since E does not lie in any of the positions A, B, C, or D, the global optimum configuration does not lie within E. The global optimum solution (configuration) was found to exist at position D between the 3250th and 3400th solution candidate. It has a VSI of 0.054pu and an SLBI of 0.1175.

4.6 Power Losses

Due to the impedance of the branches that forms a given distribution network, certain percentage of the total active power injected at the source node, get wasted along the network branches. This power wasted (in form of heat) on the branches is termed as power loss. The total power loss of a distribution network is the summation of the individual branch loss across the entire network. This loss has two components, the real and the reactive component. The total real and reactive power losses of the original configuration were found to be 0.0305pu (76.25kW) and 0.0248pu (62kVAR) respectively, while that of the optimum configuration are 34.75kW and 28kVAr respectively. Therefore the total real power loss is reduced by 41.5kW (54.4%) in the optimum configuration. Figure 4.9 shows a bar chart of the total real power loss.

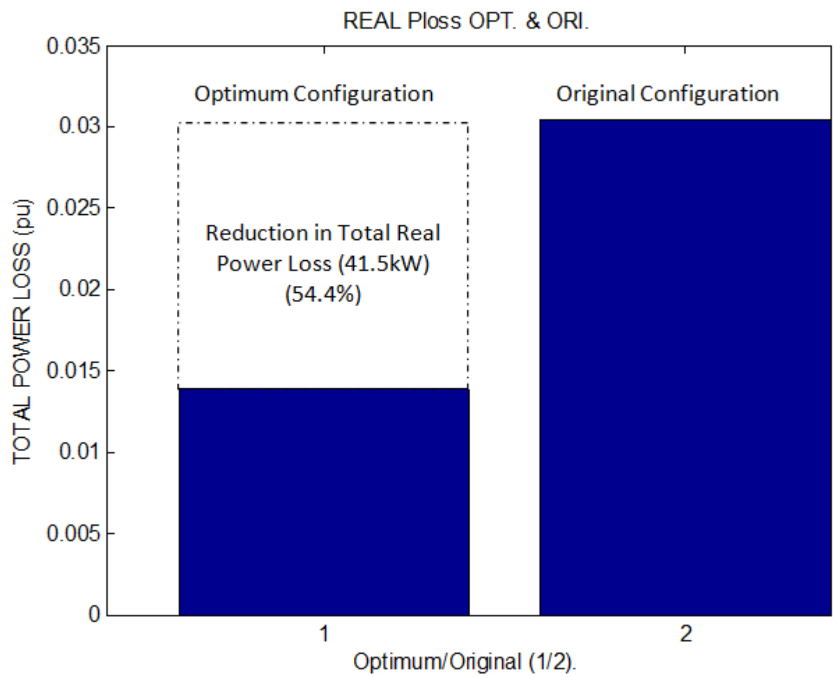

Figure 4.9: Total Real Power Loss of the Original and Optimum Configuration

In order to ascertain the global optimum solution, in terms of total real power loss, the developed reconfiguration simulator was also designed to estimate and plot the total real power loss of the entire local optimum solutions (network configurations that certifies both the bus voltage and branch active power constraints), while performing reconfiguration. Figure 4.10 is a bar chart showing the total real power loss of the entire local optimum solutions.

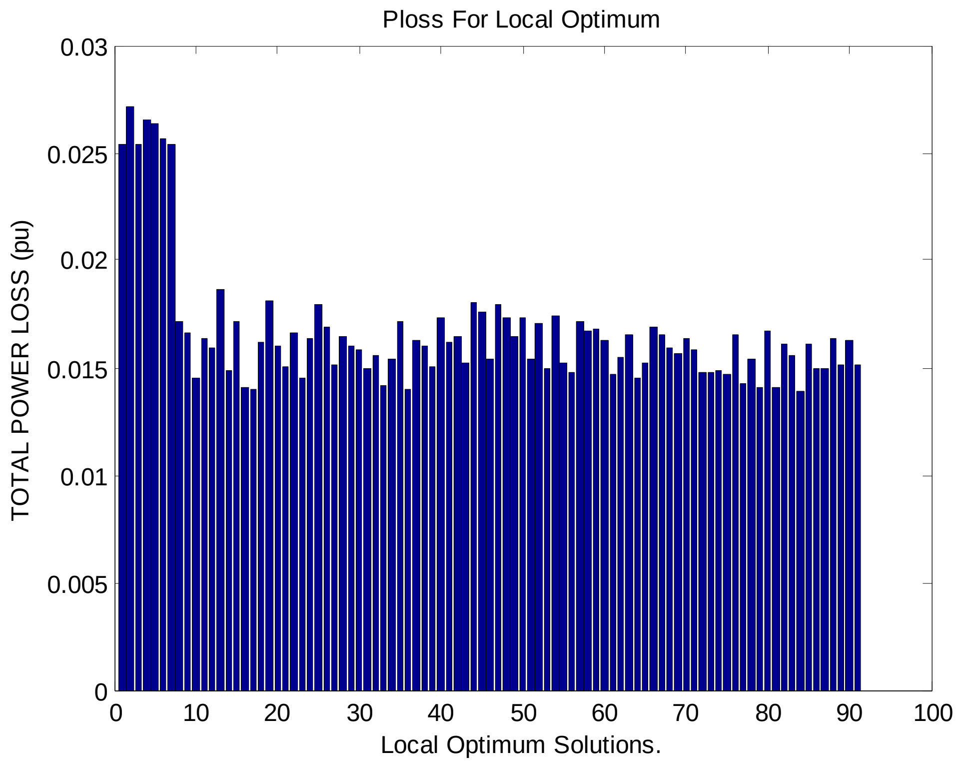

Figure 4.10: Total Real Power Loss of the Entire Local Optimum Solutions

In Figure 4.10, it can be observed that the total real power loss of the local optimum configuration 10 to 90 varies only slightly, which indicates a closely related network operating condition. Between configurations 0 and 10, the power losses are relatively high. In general, power losses are proportion to the square of branch load current.

The optimum configuration of the Azare network can be formed by opening the optimum tie branches (55, 125, 65, 62) in the original configuration of the network (Figure 3.3), while closing the proposed tie branches (85, 70, 56, 80).

The simulation results for the Original and Optimum Configuration of Azare distribution network are summarized in Table 4.3.

Table 4.3: Simulation Results For Azare Distribution Network..

Parameter Name	**Value for Original Configuration**	**Value for Optimum Configuration**
Voltage Profile Improvement	0	64.11%
VSI	0.0135pu	0.0054pu
SLBI	0.114	0.1175
Minimum Voltage magnitude (|V|)	0.9779pu	0.9886pu
Real Power Loss (kW)	76.25	34.75
Reactive Power loss (kVAr)	62	28
Real Power Loss Reduction	0	41.5 kW (54.4%)
Tie Branches	85, 70, 56, 80	55,125,65,62

Appendix N also shows the values of the bus/node voltage magnitude and branch active power for the original and optimum configuration of the Azare distribution network as generated by the developed power flow simulator.

4.7 Validation

In order to validate the proposed models and algorithms, and demonstrate the robustness of the developed MATLAB GUI based simulation programs (power flow and optimal reconfiguration simulators), the power flow analysis of the IEEE standard 30, and 33 buses network is performed using the developed power flow simulator; while the reconfiguration simulator is used in carrying out optimal network reconfiguration on the 33 buses standard IEEE network. The power flow and reconfiguration results are also compared with those obtained in order literatures to ascertain their correctness.

4.7.1 Standard 30 buses IEEE Network

Figure 4.11 shows a schematic diagram for an IEEE standard 30 bus radial distribution network. The associated line and bus data of Figure 4.11 are shown in Appendix O2 and O3 respectively. The voltage profile of Figure 4.11 (as obtained in the work of Majtaba *et al.*, 2014) is shown in Figure 4.12, while that which was generated by the develkoped power flow simulator is shown in Figure 4.13.

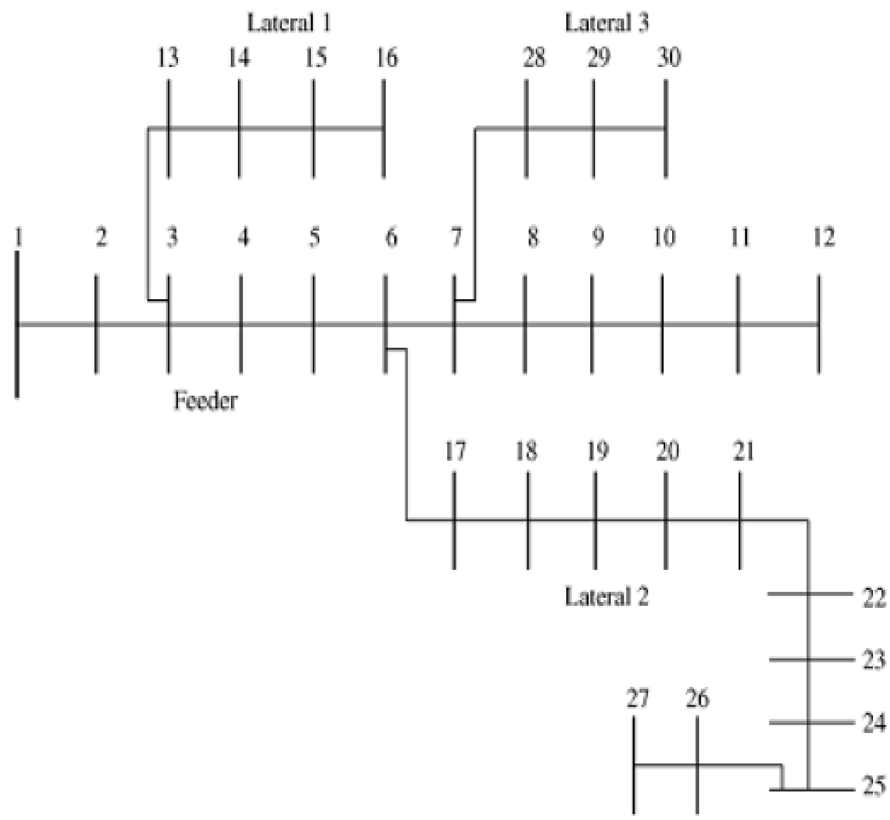

Figure 4.11: 30 Bus Radial Distribution System (Majtaba *et al.*, 2014).

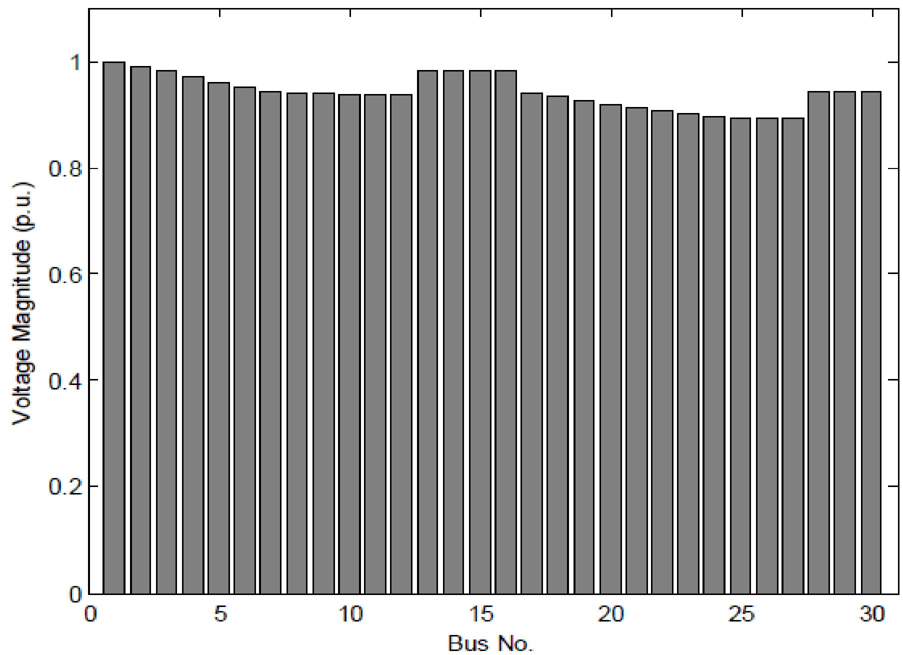

Figure 4..12:Voltage Magnitude Profile for 30 Bus Network
(Majtaba *et al.*, 2014).

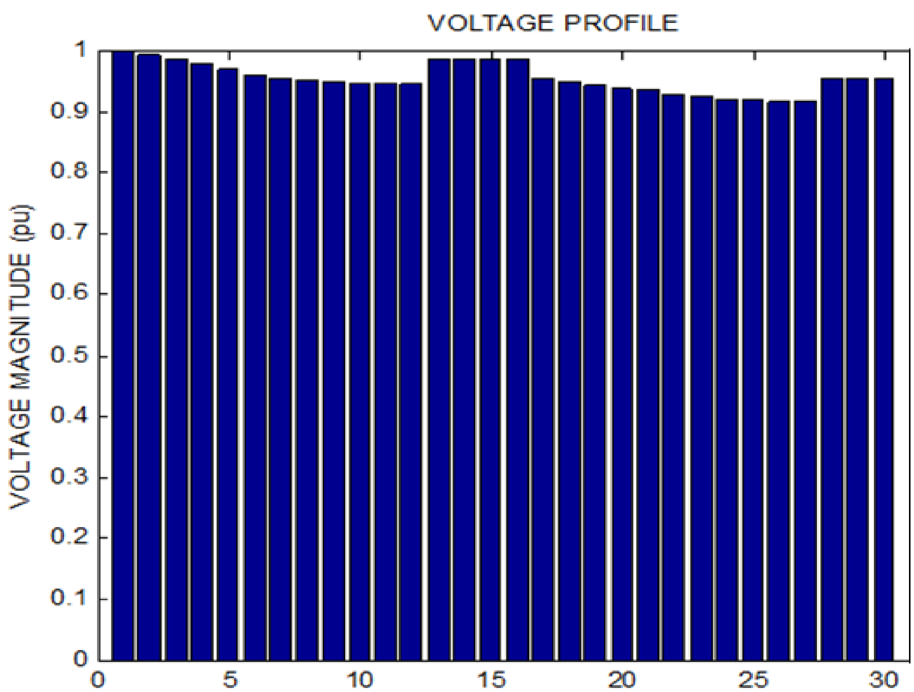

Figure 4.13: Voltage Magnitude Profile (Obtained Using the Developed Power Flow Simulator) for 30 Bus Network

4.7.2 Standard 33 buses IEEE Network

Figure 4.14 shows a schematic diagram for an IEEE standard 33 bus radial distribution network. The associated line and bus data of Figure 4.14 are shown in Appendix O5 and O6 respectively. The voltage and Current profile of Figure 4.14 (as obtained in the work of Rao *et al.,* 2011) are shown in Figure 4.15 and 4.17 respectively, while that which were generated by the developed power flow simulator are shown in Figure 4.16 and 4.18 respectively.

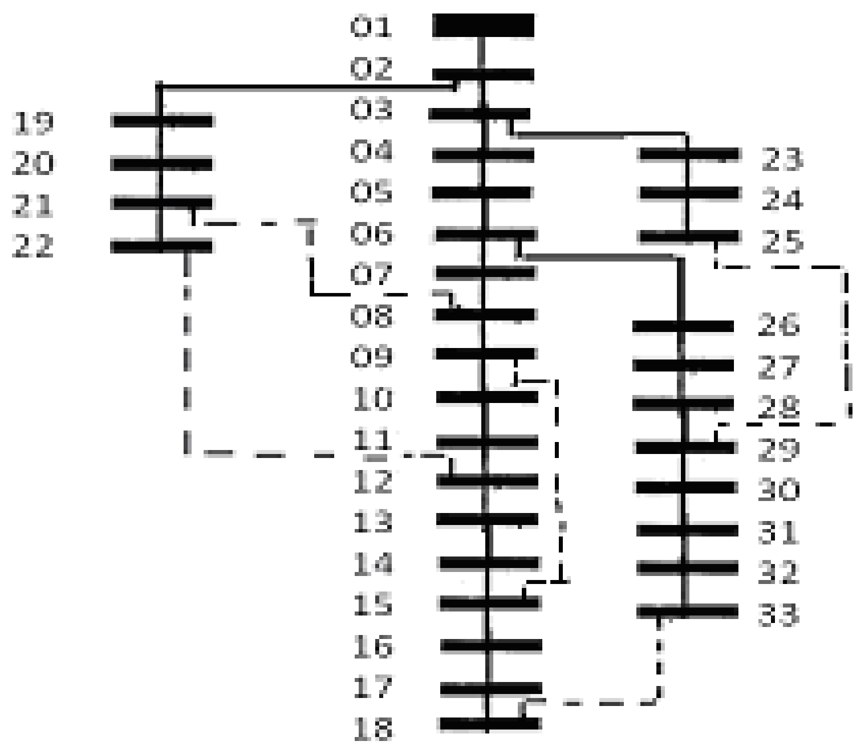

Figure 4.14: Standard 33 Bus IEEE (Rao *et al,* 2011)

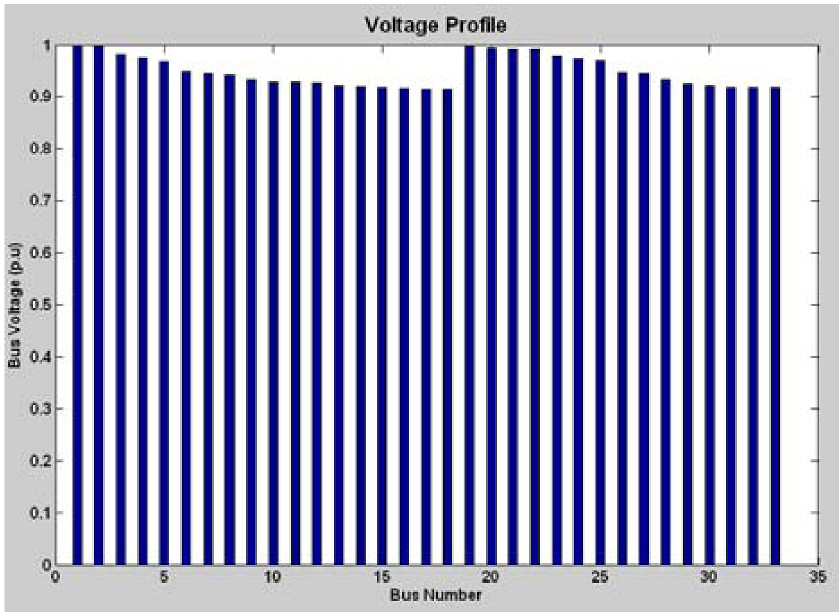

Figure 4.15: Voltage Magnitude Profile for the 33 Bus Network
(Rao *et al.*, 2011).

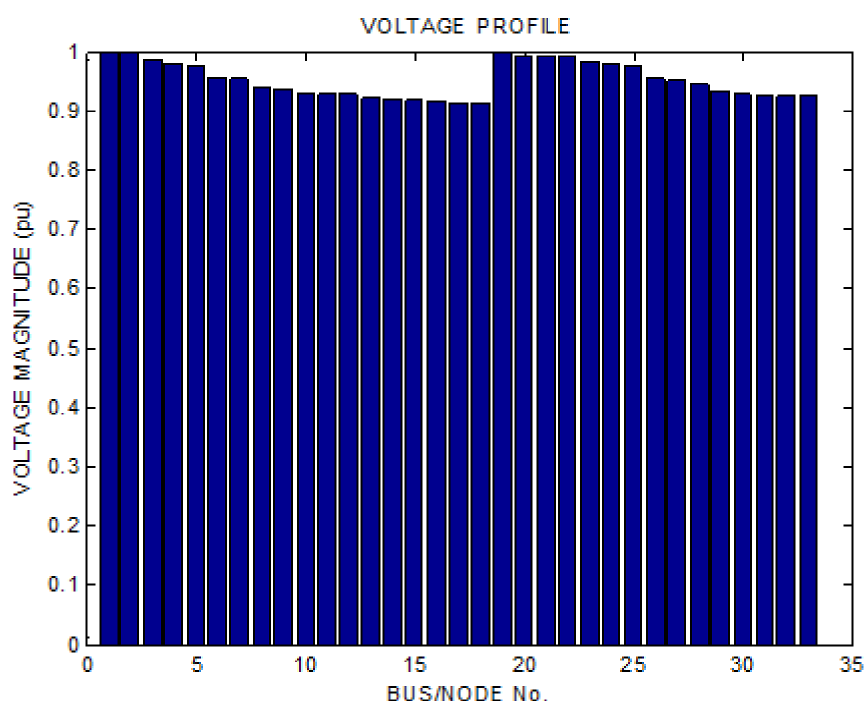

Figure 4.16: Voltage Magnitude Profile (Obtained Using the Developed Reconfiguration Simulator) for the 33 Bus Network

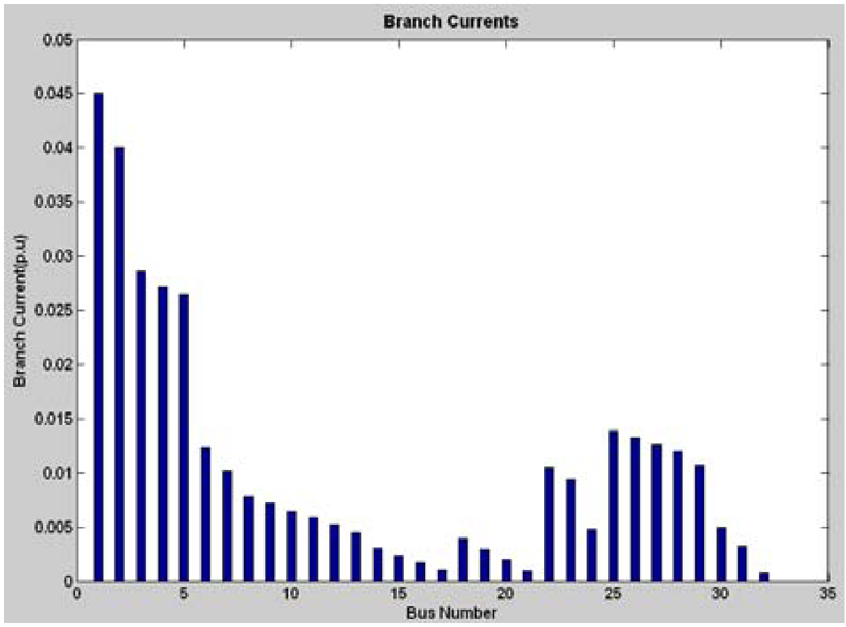

Figure 4.17:Branch Currents Magnitude Profile for the 33 Bus Network (Rao *et al.*, 2011).

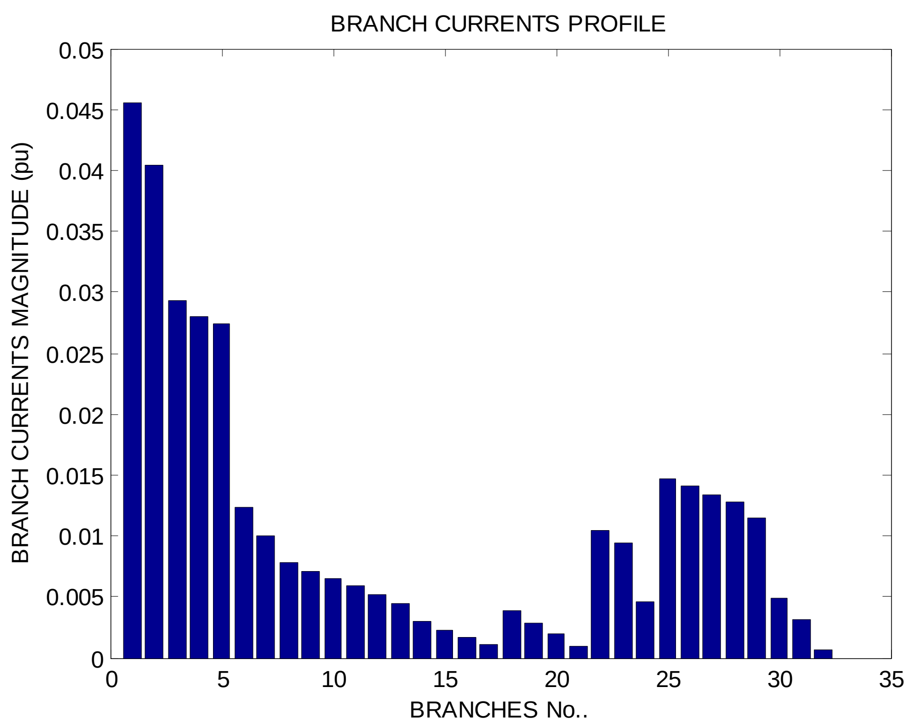

Figure 4.18: Branch Currents Magnitude Profile (Obtained Using the Developed Reconfiguration Simulator) for the 33 Bus Network.

The developed reconfiguration simulator was used in performing optimal reconfiguration on the standard 33 buses IEEE network. The tie matrix TM and the reduce network graph information matrix RNGIM shown in Appendix O7 and O8 respectively are also required in addition to the line and bus data matrices of Appendix O5 and O6. Table 4.4 shows the Comparison optimum configuration results generated by the developed reconfiguration simulator and those presented in the work of Rao *et al.*, 2011

Table 4.4: Comparison of the 33 Bus Network Reconfiguration Results as Obtained Using the Developed Reconfiguration Simulator and in the Work of Rao *et al.*, 2011

Parameter Name	**Developed Simulator**	**Rao *et al.*, 2011**
VSI	0.0195pu	----
SLBI	0.2022	----
Minimum Voltage magnitude (|V|)	0.9689pu	0.9607pu
Real Power Loss (kW)	89	89.473
Reactive Power loss kVAr	42	----
Real Power Loss Reduction	56.17%	55.86%
Tie Branches	36, 8, 29, 12, 15	36,10,28,14,7
Voltage Profile Improvement	65.7%	51.47%

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This Chapter presents a conclusion and summary of the work done so far. Recommendations for further work and some of the limitations encountered are also presented in this chapter.

5.2 Conclusion

In this research work, a GPS based method for tie switch placement (needed for network reconfiguration) has been proposed. Two robust algorithms (power flow and reconfiguration algorithms) have been developed based on improved BFS and ASTUNG techniques respectively. The algorithms reduce power flow and reconfiguration computation complexity by breaking the steps involved into a number of sub-steps represented by MATLAB function blocks. Power flow and reconfiguration simulators (MATLAB GUI) have been developed based on the developed power flow and reconfiguration algorithms respectively. The developed simulators have been used in performing power flow and reconfiguration analysis of Azare distribution network. A total real power loss reduction and voltage profile improvement of 54.4% and 64.11% have been achieved respectively. The developed simulators have been validated by carrying out power flow and reconfiguration on two IEEE standard test networks (30 and 33 buses network) and the reconfiguration yield a total real power loss reduction and voltage profile improvement of 56.17% and 65.7% respectively on the 33 buses network. The results were also compared with those obtained in order literatures (Majtaba *et al.,* 2014 and Rao *et al*., 2011) in order to demonstrate the effectiveness of the developed simulator. Finally, this work provides the future researchers with flexible tools (MATLAB GUI) and techniques for radial distribution network power flow and reconfiguration analysis.

5.3 Recommendation

The future works should consider the following area of research as advancement to this work:

1. The developed power flow model and algorithm can be extended to consider an unbalanced three phase network while incorporating the effect of line capacitance, mutual coupling, and loads that varies with changes in network condition in order to simulate more realistic network.
2. The developed reconfiguration model and algorithm can be extended to consider fast online reconfiguration in the presence of distributed generation (DG) using harmonic differential evolution (HDE) heuristic search technique;
3. The developed simulators (power flow and reconfiguration GUI) can be converted into full software packages with standard interface using Java or C++ programming language to aid users in performing radial distribution network power flow and reconfiguration with little stress.

5.4 Limitation

The following limitations were encountered in the course of this work:

1. Unavailability of installed GIS devices on the network made the network tracing and mapping very difficult and decreased the accuracy of the GPS coordinates;
2. The analysis carried out so far was based on the full network capability. The dynamic nature of the Nigerian electricity introduce uncertainty in the actual values of the power flow parameters on the real network;
3. Some parameters such as the resistance and reactance of network branches were not available at the substation and therefore has to be calculated

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APPENDIX A
Substations Data, Network Data, and GPS Data

Appendix A1:

Table 3.1: The Transformers Data

S/No.	TRANSFORMERS	CAPACITY SEC. kV	PRI. kV	MVA	Z (ohms)	YEAR OF MAN	YEAR OF INST
O	TCN AZARE	33	132	30		2009	
0	AZARE INJECTION SUBSTITION	11	33	7.5	7.69	1991	1996
1	ALHERI BAKERY AZARE	0.415	33	0.3	4	2008	2009
2	ZAIN KAFIN KURA	0.415	33	0.1	4	2008	
3	AZARE MAKARAHUTA	0.415	33	0.5	8.75	2005	2009
4	ANGWAN DANKAWU 11	0.415	33	0.2	5.04	2008	
5	ANGWAN DANKAWU 1	0.415	33	0.2	4.75	2008	
6	FMC 1	0.415	33	0.5	5.71	2005	2008
7	FMC 11	0.415	33	0.5	4.75	2009	
8	RAMAD TABLE WATER	0.415	33	0.2	4.55	2006	2008
9	GILMOR AZARE	0.415	33	0.6	4.94	2007	2009
10	NORTH STAR LTD	0.415	33	0.3	4.75	2008	2011
11	STATION AUXILIARY 1	0.415	33	0.1	3.7	1988	
12	M.O.W	0.415	11	0.5	5.55	2009	
13	M.O.W. PREMISES	0.415	11	0.2	4.59	1998	
14	SULE KATAGIUIM	0.415	11	0.2	3.87	2001	
15	GENERAL HOSPITAL	0.415	11	0.5	4.75	2006	
16	AZARE CLUB	0.415	11	0.3	4.49	1982	
17	CAMSAC 1	0.415	11	0.3	4.3	1982	
18	PROF. GAMBO LARABA	0.415	11	0.2	4.4	1981	
19	SANI HALIRU	0.415	11	0.1	4	2005	
20	FAROUQ MUSTAFA	0.415	11	0.2	3.81	2002	
21	SAMARU	0.415	11	0.3	5.1	1990	
22	AKOMA GONA	0.415	11	0.3	4.58	2003	
23	ABBA HALIRU	0.415	11	0.1	5.25	2002	
24	GOVMT LODGE	0.415	11	0.3	4.8	1977	
25	KASHURI	0.415	11	0.2	4.7	2005	
26	DUHU KURA	0.415	11	0.2	3.81	2002	
27	GADAU MAIN	0.415	11	0.1	3.8	1988	
28	GADAU DANDALI	0.415	11	0.1	4	1990	
29	GADAU UNIVERSITY	0.415	11	0.5	5.3	2000	
30	CAMSAC 11	0.415	11	0.3	4.7	2001	
31	MAGAJIN GARI 1	0.415	11	0.5	4.75	2008	
32	CENTRAL MOSQUE	0.415	11	0.3	4.43	2005	
33	EMIR'S PALACE	0.415	11	0.3	4.75	1991	
34	MAGAJIN GARI 11	0.415	11	0.3	4.2	2009	
35	FIRE SERVICE	0.415	11	0.3	4.3	1990	
36	HOSPITAL	0.415	11	0.5	5.02	2009	
37	ZENITH BANK	0.415	11	0.2	5.01	2006	2010
38	COE 1	0.415	11	0.5	4.6	1982	
39	COE 11	0.415	11	0.5	5.1	1885	
40	MTN COE	0.415	11	0.1	4	2012	
41	COE WORKSHOP	0.415	11	0.3	4.22	2009	
42	CABS	0.415	11	0.5	4.8	1981	
43	PATARA	0.415	11	0.2	4.5	2006	
44	ADAMU ALIYU	0.415	11	0.3	3.92	2001	
45	KAULAHA	0.415	11	0.3	3.7	1998	
46	MATSANGO 1	0.415	11	0.5	5.2	1996	
47	BRC	0.415	11	0.2	4.6	1981	
48	WTC (LEA)	0.415	11	0.2	4.8	1985	1992
49	FGC	0.415	11	0.3	4.5	1981	
50	SILO	0.415	11	0.5	4.6	2007	

Table 3.1: The Transformers Data (Continued)

S/No.	TRANSFORMERS	CAPACITY SEC.	PRI.	MVA	Z (ohms)	YEAR	YEAR OF

		kV	kV			OF MAN	INST
51	MTN MATSANGO	0.415	11	0.1	4	2001	
52	MATSANGO 11	0.415	11	0.3	4.75	1981	
53	RADIO MONITORING	0.415	11	0.2	4.89	1977	
54	NTA	0.415	11	0.5	5.14	1981	
55	SARKIN GIYADE 1	0.415	11	0.3	4.74	1981	
56	SARKIN GIYADE 11	0.415	11	0.2	3.9	1990	
57	SULE DANGOGEL	0.415	11	0.3	4.25	2008	2008
58	MTN STATE LOWCOST	0.415	11	0.1	4	2007	
59	TALBA	0.415	11	0.3	4.9	1990	
60	YAYALLE	0.415	11	0.2	3.9	1990	
61	MTN KASUWAR KAJI	0.415	11	0.1	3.9	2000	
62	KASUWAR KAJI 11	0.415	11	0.3	4.7	1982	
63	KASUWAN KAJI 1	0.415	11	0.5	3.77	2006	
64	ROYAL HOTEL	0.415	11	0.3	4.8	1977	
65	FIRST BANK	0.415	11	0.2	4.15	2007	
66	GGSS	0.415	11	0.3	3.86	2009	
67	WATER BOARD 1	0.415	11	0.1	4.73	1998	
68	WATER BOARD 11	0.415	11	0.1	4.54	1998	
69	STATE LOWCOST	0.415	11	0.3	4.5	2009	2011
70	BIDAWA	0.415	11	0.2	3.82	2005	
71	SPECIAL SCHOOL	0.415	11	0.2	4.8	1985	
72	MTN, KAN TUDU	0.415	33	0.1	3.6	2005	
73	MADANGALA	0.415	11	0.2	3.98	1995	
74	KAURI MILLS	0.415	11	2	5.81	1986	
75	ARMY BARACK	0.415	11	0.2	4.3	1982	
76	GT BANK	0.415	11	0.2	4	2008	
77	INTCON BANK	0.415	11	0.1	4.1		
78	NITEL	0.415	11	0.2	4.8	1982	
79	MTN ALH KUDA	0.415	11	0.1	4	2007	
80	UNITY BANK	0.415	11	0.2	4.4	1981	
81	MTN OPP UNITY BANK	0.415	11	0.1	4	2008	
82	BANK PHB	0.415	11	0.2	4.11	2008	
83	FCMB	0.415	11	0.2	4.51	1975	
84	IGBO QTRS 1	0.415	11	0.2	4.5	1967	
85	IGBO QTRS 11	0.415	11	0.3	4.75	2008	
86	KANKANI FILLING STATION	0.415	11	0.1	4	2008	
87	FEDERAL LAWOCOST 1	0.415	11	0.5	5.7	1977	
88	JIMROSE	0.415	11	0.3	4.48	2004	
89	FEDERAL LOWCOST 11	0.415	11	0.3	6.02	2009	
90	ZAIN GADAU	0.415	11	0.1	4	2008	

Appendix A2

Table 3.5: The Transformers GPS Data.

		LONGITUDE (N)			LATUTUDE (E)		
S/No.	**TRANSFORMERS**	**deg.(o)**	**min.(')**	**sec(")**	**deg.(o)**	**min.(')**	**sec(")**
O	TCN AZARE	10	9	51	11	41	8

0	AZARE INJECTION SUBSTITION	10	11	5	11	41	0
1	ALHERI BAKERY AZARE	10	11	18	11	41	13
2	ZAIN KAFIN KURA	10	11	21	11	41	15
3	AZARE MAKARAHUTA	10	11	37	11	41	12
4	ANGWAN DANKAWU 11	10	11	25	11	41	30
5	ANGWAN DANKAWU 1	10	11	41	11	41	36
6	FMC 1	10	11	52	11	40	32
7	FMC 11	10	12	39	11	40	9
8	RAMAD TABLE WATER	10	10	17	11	40	28
9	GILMOR AZARE	10	10	12	11	40	37
10	NORTH STAR LTD	10	10	30	11	40	45
11	STATION AUXILIARY 1	10	11	6	11	40	59
12	M.O.W	10	11	8	11	40	54
13	M.O.W. PREMISES	10	11	5	11	40	51
14	SULE KATAGIUIM	10	11	13	11	40	40
15	GENERAL HOSPITAL	10	11	0	11	41	2
16	AZARE CLUB	10	11	10	11	41	16
17	CAMSAC 1	10	11	12	11	41	19
18	PROF. GAMBO LARABA	10	11	10	11	41	19
19	SANI HALIRU	10	11	12	11	41	20
20	FAROUQ MUSTAFA	10	11	12	11	41	28
21	SAMARU	10	11	8	11	41	33
22	AKOMA GONA	10	11	2	11	41	33
23	ABBA HALIRU	10	11	4	11	41	38
24	GOVMT LODGE	10	11	7	11	41	43
25	KASHURI	10	11	11	11	41	45
26	DUHU KURA	10	10	57	11	41	45
27	GADAU MAIN	10	11	0	11	42	55
28	GADAU DANDALI	10	10	36	11	43	3
29	GADAU UNIVERSITY	10	10	20	11	43	10
30	CAMSAC 11	10	11	17	11	40	51
31	MAGAJIN GARI 1	10	11	27	11	40	48
32	CENTRAL MOSQUE	10	11	30	11	40	37
33	EMIR’S PALACE	10	11	35	11	40	40
34	MAGAJIN GARI 11	10	11	15	11	40	30
35	FIRE SERVICE	10	11	35	11	40	31
36	HOSPITAL	10	11	38	11	40	33

Table 3.5: The Transformers GPS Data. (Continued)

		LONGITUDE (N)			LATUTUDE (E)		
S/No.	**TRANSFORMERS**	**deg.(o)**	**min.(')**	**sec(")**	**deg.(o)**	**min.(')**	**sec(")**
49	FGC	10	12	18	11	39	45
50	SILO	10	12	25	11	39	35
51	MTN MATSANGO	10	11	38	11	39	45
52	MATSANGO 11	10	11	19	11	39	21
53	RADIO MONITORING	10	12	27	11	39	17
54	NTA	10	12	45	11	39	7

55	SARKIN GIYADE 1	10	11	18	11	40	23
56	SARKIN GIYADE 11	10	11	25	11	40	26
57	SULE DANGOGEL	10	11	11	11	40	9
58	MTN STATE LOWCOST	10	10	55	11	40	8
59	TALBA	10	10	58	11	40	13
60	YAYALLE	10	11	0	11	40	15
61	MTN KASUWAR KAJI	10	10	59	11	40	19
62	KASUWAR KAJI 11	10	10	48	11	40	15
63	KASUWAN KAJI 1	10	10	31	11	40	19
64	ROYAL HOTEL	10	10	49	11	40	22
65	FIRST BANK	10	10	58	11	40	34
66	GGSS	10	11	4	11	39	50
67	WATER BOARD 1	10	11	11	11	39	44
68	WATER BOARD 11	10	11	0	11	39	38
69	STATE LOWCOST	10	10	44	11	39	37
70	BIDAWA	10	11	4	11	39	16
71	SPECIAL SCHOOL	10	10	24	11	39	45
72	MTN, KAN TUDU	10	10	41	11	39	27
73	MADANGALA	10	10	29	11	39	14
74	KAURI MILLS	10	10	11	11	39	26
75	ARMY BARACK	10	9	34	11	38	51
76	GT BANK	10	11	7	11	40	35
77	INTCON BANK	10	11	10	11	40	35
78	NITEL	10	11	11	11	40	31
79	MTN ALH KUDA	10	11	6	11	40	26
80	UNITY BANK	10	10	52	11	40	39
81	MTN OPP UNITY BANK	10	10	51	11	40	33
82	BANK PHB	10	10	44	11	40	33
83	FCMB	10	10	37	11	40	31
84	IGBO QTRS 1	10	10	34	11	40	27
85	IGBO QTRS 11	10	10	28	11	40	24
86	KANKANI FILLING STATION	10	10	24	11	40	33
87	FEDERAL LAWOCOST 1	10	10	23	11	40	39
88	JIMROSE	10	10	19	11	40	44
89	FEDERAL LOWCOST 11	10	10	16	11	40	39
90	ZAIN GADAU	10	10	26	11	43	2

Table 3.5: The Transformers GPS Data. (Continued)

		LONGITUDE (N)			LATUTUDE (E)		
S/No.	**TRANSFORMERS**	**deg.(o)**	**min.(')**	**sec(")**	**deg.(o)**	**min.(')**	**sec(")**
37	ZENITH BANK	10	12	2	11	40	35
38	COE 1	10	13	13	11	40	52
39	COE 11	10	12	48	11	40	55
40	MTN COE	10	12	43	11	41	2
41	COE WORKSHOP	10	12	53	11	41	6
42	CABS	10	13	19	11	40	14
43	PATARA	10	13	28	11	40	26

44	ADAMU ALIYU	10	11	34	11	40	25
45	KAULAHA	10	11	35	11	40	22
46	MATSANGO 1	10	11	41	11	40	2
47	BRC	10	12	1	11	40	2
48	WTC (LEA)	10	12	1	11	39	55

Appendix A3

Table 3.6: The Line Data. (α=0.015515 ohms in^2/1000ft at 25^{o}C, β=0.00404/^{o} C at 25^{o}C)

LINE _No	FRM. BUS	TO-BUS	Length (km)	CSA. (mm2)	R (ohms) 75^{o}C	X (ohms) 75^{o}C	AMPACITY (A)
91	0	91	0.15	150	0.0039474	0.0032887	390
94	14	94	3.62	150	0.0952645	0.0793661	390
18	16	18	2.48	150	0.0652638	0.0543724	390
19	18	19	0.74	150	0.0194736	0.016224	390
17	19	17	2.43	100	0.0959232	0.084212	313
20	19	20	0.83	150	0.0218427	0.0181972	390
114	20	114	0.17	150	0.0044738	0.0037271	390
117	21	117	0.14	150	0.0036841	0.0030694	390
115	24	115	0.11	100	0.0043416	0.0038121	313
116	27	116	0.05	150	0.0013162	0.0010962	390
29	28	29	0.38	100	0.0149998	0.013169	313
31	30	31	0.45	100	0.0177632	0.0155948	313

118	31	118	0.21	150	0.0055268	0.0046041	390
35	32	35	0.14	150	0.0036841	0.0030694	390
32	33	32	0.17	150	0.0044738	0.0037271	390
36	35	36	0.81	100	0.0319744	0.0280707	313
121	37	121	0.48	150	0.0126318	0.0105237	390
40	39	40	0.53	100	0.020922	0.0183672	313
41	40	41	0.36	150	0.0094742	0.0078928	390
43	42	43	0.27	35	0.0304515	0.0182567	175
45	44	45	0.17	50	0.0134215	0.0095912	203
51	48	51	2.09	50	0.1650034	0.1179149	203
50	49	50	2.28	100	0.0900022	0.0790138	313
53	50	53	0.5	100	0.0197368	0.0173276	313
52	51	52	0.71	50	0.0560541	0.0400572	203
54	53	54	0.15	50	0.0118421	0.0084628	203
56	55	56	1.17	50	0.0923701	0.0660098	203
98	58	98	0.57	50	0.0450005	0.0321586	203
60	59	60	0.84	100	0.0331584	0.0291103	313
109	60	109	1.43	100	0.0564483	0.0495569	313
110	61	110	0.96	100	0.0378955	0.033269	313
63	62	63	0.36	35	0.0406024	0.0243423	175
77	76	77	0.29	100	0.0114479	0.01005	313
78	76	78	0.14	75	0.0073683	0.0061163	271
79	78	79	0.2	100	0.0078947	0.006931	313
81	80	81	0.26	100	0.0102639	0.0090103	313
82	81	82	0.81	100	0.0319744	0.0280707	313
83	82	83	0.14	150	0.0036841	0.0030694	390
111	83	111	0.27	100	0.0106581	0.0093569	313
113	86	113	0.33	150	0.0086845	0.007235	390
88	87	88	0.29	100	0.0114479	0.01005	313
92	91	92	0.33	75	0.0173689	0.014417	271
107	91	107	0.35	100	0.0138158	0.0121293	313
93	92	93	0.29	100	0.0114479	0.01005	313
12	92	12	0.14	100	0.0055268	0.0048517	313
14	93	14	0.3	100	0.0118421	0.0103965	313
13	93	13	0.29	100	0.0114479	0.01005	313
95	94	95	0.11	100	0.0043416	0.0038121	313

Table 3.6: The Line Data (Continued)

LINE_No	FRM. BUS	TO-BUS	Length (km)	CSA. (mm2)	R (ohms) 75°C	X (ohms) 75°C	AMPACITY (A)
55	95	55	0.56	70	0.0315789	0.0256783	175
97	96	97	0.2	35	0.0225567	0.0135235	175
57	96	57	0.69	100	0.0272373	0.0239121	313
58	97	58	0.14	35	0.0157895	0.0094665	175
59	97	59	0.62	35	0.0699264	0.0419229	175
99	98	99	0.21	35	0.0236842	0.0141997	175
66	98	66	0.47	100	0.0185529	0.0162879	313
100	99	100	0.18	50	0.0142113	0.0101554	203
67	99	67	0.29	100	0.0114479	0.01005	313
101	100	101	0.41	35	0.0462409	0.0277232	175
68	100	68	0.41	150	0.0107892	0.008989	390
102	101	102	0.66	100	0.0260534	0.0228724	313
69	101	69	0.36	150	0.0094742	0.0078928	390
103	102	103	1.07	150	0.0281581	0.0234591	390
70	102	70	0.41	150	0.0107892	0.008989	390

104	103	104	0.93	150	0.0244739	0.0203896	390
71	103	71	0.35	150	0.0092109	0.0076735	390
105	104	105	0.41	150	0.0107892	0.008989	390
72	104	72	0.18	150	0.0047371	0.0039464	390
106	105	106	1.79	150	0.0471064	0.0392446	390
73	105	73	0.15	150	0.0039474	0.0032887	390
75	106	75	0.5	100	0.0197368	0.0173276	313
74	106	74	0.09	100	0.0035531	0.003119	313
16	107	16	0.66	50	0.0521067	0.0372363	203
15	107	15	0.9	150	0.0236842	0.0197319	390
30	107	30	0.95	100	0.0375012	0.0329224	313
76	108	76	2.34	35	0.2639147	0.158225	175
80	108	132	0.3	50	0.0236842	0.0169256	203
61	109	61	0.71	100	0.028027	0.0246052	313
62	109	62	0.44	100	0.0173689	0.0152483	313
65	110	65	0.59	100	0.02329	0.0204465	313
64	110	64	0.09	100	0.0035531	0.003119	313
84	111	84	0.78	100	0.0307904	0.027031	313
112	111	112	0.12	100	0.0047371	0.0041586	313
85	112	85	0.65	100	0.0256579	0.0225259	313
86	112	86	0.51	100	0.0201323	0.0176741	313
89	113	89	0.59	100	0.02329	0.0204465	313
87	113	87	0.35	100	0.0138158	0.0121293	313
21	114	21	0.15	100	0.0059211	0.0051983	313
24	114	24	0.44	100	0.0173689	0.0152483	313
26	115	26	0.21	100	0.0082902	0.0072776	313
25	115	25	0.36	100	0.0142113	0.0124759	313
27	115	27	0.29	35	0.0327076	0.0196091	175
90	116	90	0.15	100	0.0059211	0.0051983	313
28	116	28	0.33	35	0.0372187	0.0223138	175
23	117	23	0.36	35	0.0406024	0.0243423	175
22	117	22	0.3	35	0.0338351	0.0202853	175
33	118	33	3.3	100	0.1302656	0.114362	313

Table 3.6: The Line Data (Continued)

LINE _No	FRM. BUS	TO-BUS	Length (km)	CSA. (mm2)	R (ohms) 75^{o}C	X (ohms) 75^{o}C	AMPACITY (A)
120	119	120	0.09	35	0.0101509	0.0060856	175
37	120	37	0.18	35	0.0203006	0.0121712	175
123	120	123	0.51	35	0.0575193	0.0344849	175
42	121	42	0.3	100	0.0118421	0.0103965	313
122	121	122	0.21	35	0.0236842	0.0141997	175
38	122	38	0.33	150	0.0086845	0.007235	390
39	122	39	1.23	150	0.0323687	0.0269669	390
44	123	44	0.39	100	0.0153952	0.0135155	313
124	123	124	1.68	50	0.1326335	0.0947833	203
46	124	46	1.04	150	0.0273683	0.0228013	390
125	124	125	1.13	100	0.0446062	0.0391603	313
47	125	47	0.18	150	0.0047371	0.0039464	390
48	125	48	0.27	35	0.0304515	0.0182567	175
49	125	49	1.23	35	0.138724	0.0831695	175
132	65	132	0.05	150	0.0177632	0.0155948	390
133	63	85	0.1	150	0.0055268	0.0046041	390
134	52	70	0.2	150	0.0036841	0.0030694	390

135	34	56	0.1	150	0.0044738	0.0037271	390
132	132	80	0.05	150	0.0177632	0.0155948	390
130	126	130	0.81	35	0.0913556	0.0547702	175
2	127	2	0.44	35	0.0496246	0.0297517	175
1	127	1	0.21	35	0.0236842	0.0141997	175
129	128	129	0.14	100	0.0055268	0.0048517	313
3	128	3	0.93	35	0.1048889	0.0628843	175
5	129	5	0.3	100	0.0118421	0.0103965	313
4	129	4	0.95	100	0.0375012	0.0329224	313
11	130	11	0.38	150	0.0100006	0.0083313	390
10	130	10	0.33	150	0.0086845	0.007235	390
8	131	8	0.39	100	0.0153952	0.0135155	313
9	131	9	0.51	100	0.0201323	0.0176741	313
126	TCN	126	0.6	100	0.0236842	0.0207931	313
6	1	6	0.23	100	0.0090787	0.0079707	313
128	2	128	0.12	100	0.0047371	0.0041586	313
7	6	7	1.92	100	0.0757909	0.0665379	313
131	10	131	0.23	35	0.0259404	0.015552	175
127	126	127	0.23	100	0.0090787	0.0079707	313
108	94	108	0.08	100	0.0031577	0.0027724	313
96	95	96	0.09	100	0.0035531	0.003119	313
119	118	119	1.53	100	0.0603957	0.0530224	313
34	119	34	1.08	35	0.1218071	0.0730269	175

Appendix A4
Table 3.7: The Bus Data.

	LONGITUDE (N)			LATUTUDE (E)			(kVA)	(pf)	(|V|)
S/No.	**deg.(o)**	**min.(')**	**sec(")**	**deg.(o)**	**min.(')**	**sec(")**		**…**	**kV**
TCN	10	9	51	11	41	8	…		33
0	10	11	5	11	41	0	…		11
1	10	11	18	11	41	13	146	0.8	33
2	10	11	21	11	41	15	24	0.8	33
3	10	11	37	11	41	12	242	0.8	33
4	10	11	25	11	41	30	96	0.8	33
5	10	11	41	11	41	36	96	0.8	33
6	10	11	52	11	40	32	242	0.8	33
7	10	12	39	11	40	9	242	0.8	33
8	10	10	17	11	40	28	96	0.8	33
9	10	10	12	11	40	37	306	0.8	33
10	10	10	30	11	40	45	146	0.8	33
11	10	11	6	11	40	59	48	0.8	33
12	10	11	8	11	40	54	147	0.8	11
13	10	11	5	11	40	51	58	0.8	11
14	10	11	13	11	40	40	58	0.8	11
15	10	11	0	11	41	2	147	0.8	11
16	10	11	10	11	41	16	89	0.8	11
17	10	11	12	11	41	19	89	0.8	11
18	10	11	10	11	41	19	58	0.8	11

19	10	11	12	11	41	20	29	0.8	11
20	10	11	12	11	41	28	58	0.8	11
21	10	11	8	11	41	33	92	0.8	11
22	10	11	2	11	41	33	89	0.8	11
23	10	11	4	11	41	38	29	0.8	11
24	10	11	7	11	41	43	92	0.8	11
25	10	11	11	11	41	45	58	0.8	11
26	10	10	57	11	41	45	58	0.8	11
27	10	11	0	11	42	55	29	0.8	11
28	10	10	36	11	43	3	29	0.8	11
29	10	10	20	11	43	10	147	0.8	11
30	10	11	17	11	40	51	89	0.8	11
31	10	11	27	11	40	48	147	0.8	11
32	10	11	30	11	40	37	89	0.8	11
33	10	11	35	11	40	40	89	0.8	11
34	10	11	15	11	40	30	89	0.8	11
35	10	11	35	11	40	31	92	0.8	11
36	10	11	38	11	40	33	147	0.8	11
37	10	12	2	11	40	35	58	0.8	11
38	10	13	13	11	40	52	147	0.8	11
39	10	12	48	11	40	55	147	0.8	11
40	10	12	43	11	41	2	15	0.8	11
41	10	12	53	11	41	6	89	0.8	11
42	10	13	19	11	40	14	147	0.8	11
43	10	13	28	11	40	26	58	0.8	11
44	10	11	34	11	40	25	89	0.8	11
45	10	11	35	11	40	22	89	0.8	11
46	10	11	41	11	40	2	147	0.8	11
47	10	12	1	11	40	2	58	0.8	11
48	10	12	1	11	39	55	58	0.8	11

Table 3.7: The Bus Data (Continued)

	LONGITUDE (N)			LATUTUDE (E)			(kVA)	(pf)	(|V|)
S/No.	deg.(o)	min.(')	sec(")	deg.(o)	min.(')	sec(")		…	kV
49	10	12	18	11	39	45	89	0.8	11
50	10	12	25	11	39	35	147	0.8	11
51	10	11	38	11	39	45	15	0.8	11
52	10	11	19	11	39	21	89	0.8	11
53	10	12	27	11	39	17	58	0.8	11
54	10	12	45	11	39	7	147	0.8	11
55	10	11	18	11	40	23	89	0.8	11
56	10	11	25	11	40	26	58	0.8	11
57	10	11	11	11	40	9	89	0.8	11
58	10	10	55	11	40	8	15	0.8	11
59	10	10	58	11	40	13	92	0.8	11
60	10	11	0	11	40	15	58	0.8	11
61	10	10	59	11	40	19	29	0.8	11
62	10	10	48	11	40	15	89	0.8	11
63	10	10	31	11	40	19	147	0.8	11
64	10	10	49	11	40	22	89	0.8	11
65	10	10	58	11	40	34	58	0.8	11
66	10	11	4	11	39	50	89	0.8	11
67	10	11	11	11	39	44	29	0.8	11
68	10	11	0	11	39	38	29	0.8	11
69	10	10	44	11	39	37	89	0.8	11
70	10	11	4	11	39	16	58	0.8	11

71	10	10	24	11	39	45	58	0.8	11
72	10	10	41	11	39	27	15	0.8	11
73	10	10	29	11	39	14	58	0.8	11
74	10	10	11	11	39	26	590	0.8	11
75	10	9	34	11	38	51	58	0.8	11
76	10	11	7	11	40	35	58	0.8	11
77	10	11	10	11	40	35	29	0.8	11
78	10	11	11	11	40	31	58	0.8	11
79	10	11	6	11	40	26	15	0.8	11
80	10	10	52	11	40	39	58	0.8	11
81	10	10	51	11	40	33	15	0.8	11
82	10	10	44	11	40	33	58	0.8	11
83	10	10	37	11	40	31	58	0.8	11
84	10	10	34	11	40	27	58	0.8	11
85	10	10	28	11	40	24	89	0.8	11
86	10	10	24	11	40	33	29	0.8	11
87	10	10	23	11	40	39	147	0.8	11
88	10	10	19	11	40	44	89	0.8	11
89	10	10	16	11	40	39	89	0.8	11
90	10	10	26	11	43	2	15	0.8	11
91	10	11	8	11	40	59	0	0.8	11
92	10	11	10	11	40	53	0	0.8	11
93	10	11	9	11	40	51	0	0.8	11
94	10	11	11	11	39	97	0	0.8	11

Table 3.7: The Bus Data (Continued)

	LONGITUDE (N)			LATUTUDE (E)			(kVA)	(pf)	(|V|)
S/No.	**deg.(o)**	**min.(')**	**sec(")**	**deg.(o)**	**min.(')**	**sec(")**		**…**	**kV**
99	10	10	52	11	39	57	0	0.8	11
100	10	10	46	11	39	52	0	0.8	11
101	10	10	41	11	39	45	0	0.8	11
102	10	10	35	11	39	41	0	0.8	11
103	10	10	32	11	39	38	0	0.8	11
104	10	10	30	11	39	36	0	0.8	11
105	10	10	29	11	39	34	0	0.8	11
106	10	10	15	11	39	21	0	0.8	11
107	10	11	9	11	40	61	0	0.8	11
108	10	11	8	11	39	96	0	0.8	11
109	10	11	1	11	39	79	0	0.8	11
110	10	11	1	11	39	84	0	0.8	11
111	10	10	32	11	39	94	0	0.8	11
112	10	10	29	11	39	93	0	0.8	11
113	10	10	21	11	39	93	0	0.8	11
114	10	11	7	11	40	96	0	0.8	11
115	10	11	5	11	40	104	0	0.8	11
116	10	10	59	11	42	58	0	0.8	11
117	10	11	4	11	40	96	0	0.8	11
118	10	11	24	11	39	97	0	0.8	11
119	10	11	29	11	39	92	0	0.8	11
120	10	11	36	11	39	92	0	0.8	11
121	10	12	46	11	39	89	0	0.8	11

122	10	12	49	11	40	51	0	0.8	11
123	10	11	40	11	39	85	0	0.8	11
124	10	11	58	11	39	66	0	0.8	11
125	10	12	2	11	39	58	0	0.8	11
126	10	11	8	11	40	81	0	0.8	33
127	10	11	14	11	41	18	0	0.8	33
128	10	11	35	11	41	23	0	0.8	33
129	10	11	30	11	41	30	0	0.8	33
132	10	10	60	11	40	38	0	0.8	11
130	10	11	8	11	41	1	0	0.8	33
131	10	10	17	11	40	33	0	0.8	33
96	10	11	8	11	39	71	0	0.8	11
97	10	10	60	11	39	64	0	0.8	11
98	10	10	58	11	39	63	0	0.8	11

APPENDIX B
m. File: Main Function "RADFLOW"

```
function [P_loss SL Vi]=RADFLOW(linedata,busdata,Vs)
%RADFLOW(linedata,busdata) is a command used in calculating the
power flow
%solution of radial power distribution network.the linedata and
busdata are
%matrices whos column are named as follows:
% linedata=[element_no. Frm_bus To_bus R X];
% busdata=[bus_no. |active power| pf bus_voltage(initial(pu)) angle]
linedata=sortc(linedata,3);% sort the linedata in accending orther
of buses
busdata=sortc(busdata,1);% sort the busdata in accending orther of
buses
S_Load=busdata(:,2).*busdata(:,3)-
1i*busdata(:,2).*sin(acos(busdata(:,3)));% compute the coplex active
power of the load at every bus
Vo=busdata(:,4).*cos(busdata(:,5))+1i*busdata(:,4).*sin(busdata(:,5)
);% compute the complex voltage at every bus
S_line=conj((sortc(sortbus(linedata,S_Load),1)));%compute the active
power flowing in every line
Z=linedata(:,4)+1i*linedata(:,5);% compute the impedance of each
line
V=Vo;% assign the initial voltage to the buses
S_lineflow_bus=S_line(:,2);% assign the initial line flows
S_loss=Z.*(((abs(S_lineflow_bus))./(conj(V))).^2);% compute the line
losses of every line
S_loss=conj((sortc(sortbus(linedata,S_loss),1)));% compute the line
loss of the entire system
S_loss=S_loss(:,2);% assing the new line losses
```

```
S=S_lineflow_bus+conj(S_loss)-
conj(Z.*(((abs(S_lineflow_bus))./(conj(V))).^2));% compute overall
power=floww+loss
[lines,colum]=size(linedata);% obtaining the size of linedata (row X
column)
iter=0;%....................
error=2000000000000;%....................
error2=1;%....................
% define the criteria for loop termination
if Vs>10000
   e=212*Vs/11000;%....................
   else
   e=Vs/12660;%....................
end
if lines>100
    a=3;
else
    a=round(lines/10)+1;
end
while     abs(error2-error)>e
    iter=iter+1;% increment iteration count
    drop=Z.*(S)./conj(V);% compute the drop on each and every line
    Drop=(VDROP(linedata,drop));% estimste the entire system
combined drop
    V1=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
          V=V1;% replace the initial voltage with the new voltage
S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line losses
of every line
S_loss=conj(sortc(sortbus(linedata,S_loss),1));% compute the new
line loss of the entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+conj(S_loss-Z.*(((abs(S))./(conj(V))).^2));%
compute overall power=floww+loss
       iter=iter+1;%....................
  drop=Z.*(S)./conj(V);% compute the drop on each and every line
    Drop=(VDROP(linedata,drop));% estimste the entire system
combined drop
    V2=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
      iter=iter+1;%....................
     V=V2;%....................
S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line losses
of every line
S_loss=conj(sortc(sortbus(linedata,S_loss),1));% compute the new
line loss of the entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+conj(S_loss-Z.*(((abs(S))./(conj(V))).^2));%
compute overall power=floww+loss
    error=max(abs(V1-V2));%....................
   drop=Z.*(S)./conj(V);% compute the drop on each and every line
    Drop=(VDROP(linedata,drop));% estimste the entire system
combined drop
    V3=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
V=V3;
    S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line
losses of every line
S_loss=conj(sortc(sortbus(linedata,S_loss),1));% compute the new
line loss of the entire system
```

```
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+conj(S_loss-Z.*(((abs(S))./(conj(V))).^2));%
compute overall power=floww+loss
        iter=iter+1;%....................
 drop=Z.*(S)./conj(V);% compute the drop on each and every line
    Drop=(VDROP(linedata,drop));% estimste the entire system
combined drop
    V4=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
     V=V4;%....................
S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line losses
of every line
S_loss=conj(sortc(sortbus(linedata,S_loss),1));% compute the new
line loss of the entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+conj(S_loss-Z.*(((abs(S))./(conj(V))).^2));%
compute overall power=floww+loss
    clear i ttt%....................
    error2=max(abs(V3-V4));%....................
end
P_loss=max(S_loss);
SL=round((S)*10000)/10000;
Vi=round((V)*10000)/10000;
Vi=V;
```

APPENDIX C

m. File: Sub-Function "sortbus"

```
function M=sortbus(line,Io)
line=sortc(line,3);
bbb=wizbus(line);
[k,l]=size(bbb);
bb=zeros(k);
Io=Io*100000;
Io=round(Io);
Io=Io/100000;
 for i=1:k
     for j=1:l
         if bbb(i,j)~=0
             for amk=1:k
                 if bbb(amk,1)==bbb(i,j)
                     gotit=amk;
                 end
             end
         bb(i,gotit)=bbb(i,j);
         end
     end
 end
N=bb;
[k,t]=size(N);
for q=1:k*t
    if N(q)~=0
        N(q)=1;
    end
end
II=[];
for e=1:t
    II=[II,Io];
end
II=II*100000;
II=round(II);
II=II/100000;
II=II.*N;
II=II*100000;
II=round(II);
II=II/100000;
II=II';
kkkkk=wizbus(line);
```

```
M=[kkkkk(:,1) II];
```

APPENDIX D
m. File: Sub-Function "sortc"

```
function S=sortc(X,A)
%SORTR(X,A) IS USED TO SORT A GIVEN MATRIX 'X' USING THE COLUMN
ELEMENT GIVEN
%BY 'A'. A, IS A SINGLE VALUE INTEGER RANGING FROM 1 TO N, WHERE 'N'
IS THE
%NUMBER OF COLUMNS IN THE MATRIX.
[a,b]=size(X);
sortee=X;
for m=1:k
n=1;
for i=1:(a-1)
if sortee(n,A)>sortee((n+1),A)
    sortee([n (n+1)],:)=flipud(sortee([n (n+1)],:));
end
n=n+1;
end
end
S=sortee((1:a),(1:b));
```

APPENDIX E
m. File: Sub-Function "wizbus"

```
function Bus=wizbus(line)
% WIZBUS(LINE) IS USED TO GENERATE A MATRIX CONTAINING THE PATH FROM
EACH
% NODE OR LOAD POINT TO THE SORCE BUS. THIS IS USEFELL IN PERFORMING
RADIAL
% DISTRIBUTION POWERFLOW.
line(:,[2 3])=fliplr(line(:,[2 3]));
[v,w]=size(line);
    bus=v;
    x=zeros(bus);
    x(:,[1 2])=line(:,[2 3]);
for i=1:bus
    for j=2:bus
        for k=1:bus
        if line(k,2)==x(i,j)
            x(i,[j j+1])=line(k,[2 3]);
        end
        end
    end
end
X=x;
for l=1:bus
if X(:,l)==del
    [a,b]=size(x);
    x(:,b)=[];
end
end
Bus=sortc(x,1);
```

APPENDIX F
m. File: Sub-Function "VDROP"

```
function Drop=VDROP(linedata,drop)
linedata=sortc(linedata,3);
bus=wizbus(linedata);
kj=k*j;
for jk=1:kj
    for jm=1:k
        if linedata(jj,3)==bus(jk);
            bus(jk)=drop(jj);
        end
    end
end
BUS=sum(bus,2);
Drop=BUS;
```

APPENDIX G
m. File: Sub-Function (New Configuration Line Data Generator)

```
Line_data_original=sortc(line_data_original,3);
 [kl,lk]=size(line_data_original);
sols=CS;
(q,w)=size(sols)
sols=sols';
solss=[];
for breadthsol=1:w
for lentdata=1:kl
    if linedata(lentdata,3)==sols(breadthsol)
solss=[solss;linedata(lentdata,(2:3))];
    end
end
end
chktie=ties(:,(2:3));
chktie=reshape(chktie,1,2*w);
chksol=solss(:,2);
wiz=IM;
[k,l]=size(wiz);
newdata=[];
for i=1:length(chksol)
    tiee=[];
    for j=1:length(chktie)
        for m=1:k
            if wiz(m,1)==chktie(j)
                u=m;
            end
        end
        for n=1:l
            if wiz(u,n)==chksol(i)
                tiee=[tiee,chktie(j)];
                o=n;
                if o~=1
                    while o~=1
                       o=o-1;
                        new=[wiz(u,o),wiz(u,(o+1))];
                        [p,q]=size(newdata);
                        s=2;
                        newdata=[newdata;new];
                    end
                end
            end
        end
    end
end
[p,q]=size(newdata);
hhh=[];
for h=1:p
    for hh=1:p
        if h~=hh
           if newdata(h,:)==newdata(hh,:)
               hhh=[hhh,h];
           end
```

```
        end
    end
end
newdata(hhh,:)=[];
[pp,qq]=size(newdata);
linedat=line_data_original;
newdat=fliplr(newdata);
for hjk=1:kl
    for kjh=1:pp
        if newdat(kjh,:)==linedat(hjk,(2:3))
            linedat(hjk,(2:3))=newdata(kjh,:);
        end
    end
end
eliminate=[];
for hjj=1:w
    for kjh=1:kl
        if solss(hjj,:)==linedat(kjh,(2:3))
           eliminate=[eliminate,kjh];
        end
    end
end
for hjj=1:w
    for kjh=1:kl
        if solss(hjj,:)==fliplr(linedat(kjh,(2:3)))
           eliminate=[eliminate,kjh];
        end
    end
end
linedat(eliminate,:)=[];
tara=[];
[lntd,witd]=size(linedat);
for lntk=1:kl
    k=0;
for lnt=1:lntd
    if linedata(lntk,3)==linedat(lnt,3)
        k=1;
    end
end
if k==0
   tara=[tara,linedata(lntk,3)];
end
end
[k,l]=size(wiz);
tiea=TM;
for s=1:w
    ys=[];
    for ss=2:3
        for ks=1:k
            if wiz(ks,1)==tiea(s,ss)
                ys=[ys;wiz(ks,:)];
            end
        end
    end
    a=0;
    b=0;
        for sa=2:3
```

```
            for ab=1:length(tara)
                if tiea(s,sa)==tara(ab)
                    if sa==2
                        a=1;
                    else
                    if sa==3
                        b=1;
                    end
                    end
                end
            end
        end
    if a==1
        if b==0
            tiea(s,[1 2])=fliplr(tiea(s,[1 2]));
        end
    end
    if a==1
        if b==1
            c=0;
            d=0;
            for z=1:w
                for zz=2:3
                    if TM(z,zz)==TM(s,1)
                        c=c+1;
                    else
                      if TM(z,zz)==TM(s,2)
                        d=d+1;
                      end
                    end
                end
            end
            if d>c
               tiea(s,[1 2])=fliplr(tiea(s,[1 2]));
            end
        end
    end
end
linedat=[linedat;tiea];
line_data_new=linedat;
```

APPENDIX H
m. File: Main Function “optconfig”

```
function optconfig(linedata,busdata,Vs,Vmin,Vmax,ties)
tic;
% objfunctn = 'RADFLOW';
```

```
busdata=sortc(busdata,1);
linedata=sortc(linedata,3);
[ij,ji]=size(busdata);
[kl,lk]=size(linedata);
clc
disp('processing position 1 of the 10 positions in OPTCONFIG......')
feasiblesol=configs;
[q,w]=size(feasiblesol);
Vj=[];
Sj=[];
Plos=[];
for lentsol=1:q
clc
S1=sprintf('PLEASE WAIT WHILE MATLAB PERFORM POWER_FLOW FOR SOLUTION
CANDIDATE NUMBER %d:.......................',lentsol);
disp(S1)
sols=feasiblesol(lentsol,:);
sols=sols';
solss=[];
for breadthsol=1:w
for lentdata=1:kl
    if linedata(lentdata,3)==sols(breadthsol)
solss=[solss;linedata(lentdata,(2:3))];
    end
end
end
chktie=ties(:,(2:3));
chktie=reshape(chktie,1,2*w);
chksol=solss(:,2);
wiz=wizbus(linedata);
[k,l]=size(wiz);
newdata=[];
for i=1:length(chksol)
    tiee=[];
    for j=1:length(chktie)
        for m=1:k
            if wiz(m,1)==chktie(j)
                u=m;
            end
        end
        for n=1:l
            if wiz(u,n)==chksol(i)
                tiee=[tiee,chktie(j)];
                o=n;
                if o~=1
                    while o~=1
                       o=o-1;
                        new=[wiz(u,o),wiz(u,(o+1))];
                        [p,q]=size(newdata);
                        s=2;
                        newdata=[newdata;new];
                    end
                end
            end
        end
    end
end
```

```
[p,q]=size(newdata);
hhh=[];
for h=1:p
    for hh=1:p
        if h~=hh
           if newdata(h,:)==newdata(hh,:)
               hhh=[hhh,h];
           end
        end
    end
end
newdata(hhh,:)=[];
[pp,qq]=size(newdata);
linedat=linedata;
newdat=fliplr(newdata);
for hjk=1:kl
    for kjh=1:pp
        if newdat(kjh,:)==linedat(hjk,(2:3))
            linedat(hjk,(2:3))=newdata(kjh,:);
        end
    end
end
eliminate=[];
for hjj=1:w
    for kjh=1:kl
        if solss(hjj,:)==linedat(kjh,(2:3))
           eliminate=[eliminate,kjh];
        end
    end
end
for hjj=1:w
    for kjh=1:kl
        if solss(hjj,:)==fliplr(linedat(kjh,(2:3)))
           eliminate=[eliminate,kjh];
        end
    end
end
linedat(eliminate,:)=[];
tara=[];
[lntd,witd]=size(linedat);
for lntk=1:kl
    k=0;
for lnt=1:lntd
    if linedata(lntk,3)==linedat(lnt,3)
        k=1;
    end
end
if k==0
   tara=[tara,linedata(lntk,3)];
end
end
[k,l]=size(wiz);
tiea=ties;
for s=1:w
    ys=[];
    for ss=2:3
        for ks=1:k
```

```
                if wiz(ks,1)==tiea(s,ss)
                    ys=[ys;wiz(ks,:)];
                end
            end
        end
        a=0;
        b=0;
            for sa=2:3
                for ab=1:length(tara)
                    if tiea(s,sa)==tara(ab)
                        if sa==2
                            a=1;
                        else
                        if sa==3
                            b=1;
                        end
                        end
                    end
                end
            end
        if a==1
            if b==0
                tiea(s,[2 3])=fliplr(tiea(s,[2 3]));
            end
        end
        if a==1
            if b==1
                c=0;
                d=0;
                for z=1:w
                    for zz=2:3
                        if ties(z,zz)==ties(s,2)
                            c=c+1;
                        else
                          if ties(z,zz)==ties(s,3)
                            d=d+1;
                          end
                        end
                    end
                end
                if d>c
                   tiea(s,[2 3])=fliplr(tiea(s,[2 3]));
                end
            end
        end
    end
    linedat=[linedat;tiea];
    [P_loss SL Vi]=RADFLOW(linedat,busdata,Vs);
     Vj=[Vj,Vi];
     Sj=[Sj,SL];
     Plos=[Plos,P_loss];
    end
    Vi=Vj;
    SL=Sj;
    power_loss=Plos;
    figure
    vsi=(sum((abs(Vs*ones(size(Vi)))-abs(Vi)).^2)/ij).^(0.5);
```

```
Q=1:length(vsi);
plot(Q,vsi);
title('VSI FOR ALL CONFIGURATION')
xlabel('Solution Candidates index.');
ylabel('VOLTAGE STABILITY INDEX');
figure
SLmax=[];
[q,w]=size(feasiblesol);
for lslbi=1:q
    slmax=abs(Vs*linedata(:,6));
    SLmax=[SLmax,slmax];
end
slbi=sum(abs(SL)./SLmax)/ij;
plot(Q,slbi);
title('SLBI FOR ALL CONFIGURATION')
xlabel('Solution Candidates index.');
ylabel('SYSTEM LOAD BALANCING INDEX');
VMIN=min(abs(Vi));
VMAX=max(abs(Vi));
solcandv=[];
solcandl=zeros(size(SL));
solcandll=[];
for lv=1:q
if abs(Vmin)<=VMIN(lv)
    if abs(Vmax)>=VMAX(lv)
    solcandv=[solcandv,lv];
    end
end
for ls=1:kl
    if abs(SL(ls,lv))>SLmax(ls,lv)
    solcandl(ls,lv)=1;
    end
end
sconstr=min(solcandl);
if sconstr(lv)==0
    solcandll=[solcandll,lv];
end
end
solcandlv=[];
for lvv=1:length(solcandll)
    for lsss=1:length(solcandv)
        if solcandll(lvv)==solcandv(lsss)
            solcandlv=[solcandlv,solcandv(lsss)];
        end
    end
end
Plos_local_opt=power_loss(:,solcandlv);
Plos_global_opt=min(real(Plos_local_opt));
for lp=1:length(Plos_local_opt)
    if real(Plos_local_opt(lp))==Plos_global_opt
        best=solcandlv(lp);
    end
end
Vbest=Vi(:,best);
Sbest=SL(:,best);
Plost_best=power_loss(best);
Candsol=feasiblesol(best,:);
```

```
clc
disp('PLEASE WAIT WHILE MATLAB PERFORM POWER_FLOW FOR THE ORIGINAL
CONFIGURATION:.......................')
busdata(1:50,2)=flipud(busdata(1:50,2));
[P_loss SL Vi]=RADFLOW(linedata,busdata,Vs);
Q=linedata(:,3);
figure
bar(Q,(abs(Vbest)-0.9));
title('VOLTAGE PROFILE OPTIMUM CONFIGURATION')
xlabel('Nodes (index).');
ylabel('VOLTAGE MAGNITUDE (pu)');
figure
bar(Q,(abs(Vi)-0.9));
title('VOLTAGE PROFILE ORIGINAL CONFIGURATION')
xlabel('Nodes (index).');
ylabel('VOLTAGE MAGNITUDE (pu)');
figure
blbi=(abs(Sbest)./slmax);
bar(Q,blbi);
title('BLBI OPTIMUM CONFIGURATION')
xlabel('Solution Candidates index.');
ylabel('BRANCH LOAD BALANCING INDEX');
figure
blbi=(abs(SL)./slmax);
bar(Q,blbi);
title('BLBI ORIGINAL CONFIGURATION')
xlabel('Solution Candidates index.');
ylabel('BRANCH LOAD BALANCING INDEX');
figure
plot(Q,(abs(Vbest)-0.95),Q,(abs(Vi)-0.95));
title('VP. ORIGINAL Vs. OPTIMUM CONFIGURATION')
xlabel('Nodes (index).');
ylabel('VOLTAGE MAGNITUDE (pu)');
figure
vsiopt=(sum((abs(Vs*ones(size(Vbest)))-abs(Vbest)).^2)/ij).^(0.5);
vsiold=(sum((abs(Vs*ones(size(Vi)))-abs(Vi)).^2)/ij).^(0.5);
blbiold=sum((abs(SL)./slmax))/ij;
blbiopt=sum((abs(Sbest)./slmax))/ij;
bar(1:2,[vsiopt,vsiold]);
title('VSI OPT. & ORI.')
xlabel('Optimum/Original (1/2).');
ylabel('VOLTAGE STABILITY INDEX (pu)');
figure
bar(1:2,[blbiopt,blbiold]);
title('SLBI OPT. & ORI.')
xlabel('Optimum/Original (1/2).');
ylabel('SYSTEM LOAD BALANCING INDEX');
figure
bar(1:2,[Plost_best,P_loss]);
title('REAL Ploss OPT. & ORI.')
xlabel('Optimum/Original (1/2).');
ylabel('TOTAL POWER LOSS (pu)');
figure
bar(1:length(Plos_local_opt),real(Plos_local_opt));
title('Ploss For Local Optimum')
xlabel('Local Optimum Solutions.');
ylabel('TOTAL POWER LOSS (pu)');
```

```
clc
TIME=toc;
s1=sprintf('                                    SUMARRY OF RESULTS\n');
disp(s1)
s2=sprintf('   The Simulation Time is : %0.6g seconds\n',TIME);
disp(s2)
disp('   The Best Configuration can be Obtained by Removing the
following element(s):')
disp(Candsol)
disp('The Local Optimums are Solutions of Row:')
disp(solcandlv)
s3=sprintf('\n   Parameter Name               Optimum Configuration
Original Configuration\n');
disp(s3)
s4=sprintf('   VSI                                     %0.3g pu
%0.3g.pu\n',vsiopt,vsiold);
disp(s4)
s5=sprintf('   SLBI                                    %0.4g
%0.3g\n',blbiopt,blbiold);
disp(s5)
s6=sprintf('   Minimum Voltage magnitude (|V|)    %0.4g pu
%0.3g pu\n',abs(min(Vbest)),abs(min(Vi)));
disp(s6)
s7=sprintf('   Real Power Loss (pu)                %0.3g
%0.3g\n',real(Plost_best),real(P_loss));
disp(s7)
s8=sprintf('   Reactive Power Loss (pu)            %0.3g
%0.3g\n',abs(imag(Plost_best)),abs(imag(P_loss)));
disp(s8)
s9=sprintf('   X/R Ratio                               %0.3g
%0.3g\n',abs(round(10*imag(Plost_best)/real(Plost_best))/10),abs(rou
nd(10*imag(P_loss)/real(P_loss))/10));
disp(s9)
s10=sprintf('   Real Power Loss Reduction          %0.3g pu
(%0.3g.percent)    0 \n',(real(P_loss)-
real(Plost_best)),(real(P_loss)-
real(Plost_best))*100/(real(P_loss)));
disp(s10)
k3=sprintf('   You Have Successfully Carried Out Network
Reconfiguration!!!\n                                          THANK
YOU!....');
disp(k3)
```

APPENDIX I
m. File: Sub-Function "configs"

```
function A=configs
%CONFIGS is used to generate all the feasible solution candidates of
a
%given network reconfiguration probMem using AMM SPANNING TREE OF
%UNDIRECTED GRAPH TECHNIQUE. The function guide you through
instructions to
%achieve the intended function. the candidate solutions are provided
in the
%matrix A.
clear all
global DATA Data
clc
s1=sprintf('WELCOME TO RECONFIGURATION SOMUTION CANDIDATES
WIZARD....!!!');
disp(s1)
s2=sprintf('........\nPLedit EASE KINDMY NOTE THAT INSTRUTION
ADHERANCE IS CRITICAL\n');
disp(s2)
s3=sprintf('EXAMPLE:\nCONSIDER THE FOLLOWING REDUCED 4 MESH
NETWORK\n\n');
disp(s3)
s4=sprintf('o...1...o...2...o...3...o...4...o\no               :
:\no               6       M2      5\no               :
:\no      M1       o...8...o...9...o\no               :       :
:\no               7  M3  12  M4  14\no               :       :
:\no...10..o...11..o..13...o...15..o\n');
disp(s4)
```

```
s5=sprintf('Where:\n      o = node\n      ...k... = eMement (k)\n
M!,M2,M3,M4 = Meshes.\n\nTHE INPUT DATA MATRIX REQUIRED FOR THE
SOLUTION\nCANDIDATES OF THE ABOVE REDUCED NETWORK IS AS
FOLLOWS..\nIN WHICH EACH BRANCH OF THE NETWORK IS REPRESENTED BY A
\nSUB-MATRIX (1x4).THEREFORE THE OVERALL MATRIX IS 16x16\n');
disp(s5)
s6=sprintf('1  2  10 11 6  0  0  0  7  0  0  0  0   0  0  0\n6  0  0
0  3  4  5  0  8  0  0  0  9   0  0  0\n7  0  0  0  8  0  0  0 13  0
0  0  12  0  0  0\n0  0  0  0  9  0  0  0 12  0  0  0  14 15  0
0\n\nNOTE: The above matrix is termed as DIRECT INPUT DATA');
disp(s6)
selection=input('PLEASE PRESS ONE(1) FOR DIRECT INPUT OR TWO(2) TO
INVOKE THE INPUT WIZARD OR THREE (3) IF YOUHAVE THE
SOLUTIONS...\nWaiting for input : ');
if selection==1
    DATA=input('ENTER THE DATA MATRIX: ');
    [lt,bt]=size(DATA);
    LOOPS=lt;
    clc
end
if selection==2
    LOOPS=input('ENTER THE NUMBER OF LOOPS: ');
    clc
    for loop1=1:LOOPS
        for loop2=1:LOOPS
            clc
        disp('NOTE: IF NO SINGLE ELEMENT EXIST ENTER ZERO(0)')
        if loop1==loop2
        s7=sprintf('ENTER THE SERIAL NUMBER/NUMBERS OF ELEMENTS
BELONGING \nTO ONLY MESH %d AS A SINGLE ROW MATRIX (BRANCH
MATRIX)',loop1);
        disp(s7)
        else
            if loop1<loop2
             s8=sprintf('ENTER THE SERIAL NUMBER/NUMBERS OF ELEMENTS
COMMON TO MESH %d & %d \nAS A SINGLE ROW MATRIX (BRANCH
MATRIX)',loop1,loop2);
             disp(s8)
            else
                s9=sprintf('REENTER THE SERIAL NUMBER/NUMBERS OF
ELEMENTS COMMON TO MESH %d & %d \nAS A SINGLE ROW MATRIX (BRANCH
MATRIX)',loop2,loop1);
             disp(s9)
            end
        end
        elmts=input('BRANCH MATRIX: ');
        lentelmts=length(elmts);
        Data(loop2,1:lentelmts)=elmts;
        end
        [lent,bret]=size(Data);
        DATA((end+1):(lent+end),1:bret)=Data;
        Data=zeros(size(Data));
    end
    [lent1,bret1]=size(DATA);
    disp(lent1);
    DATA=DATA';
    DATA=reshape(DATA,(LOOPS*bret1),LOOPS);
```

```
    DATA=DATA';
end
clc
if selection==1||selection==2
disp('MATLAB HAS SUCCESSFULLY RECIEVED DATA...!')
s10=sprintf('\nTHE RESULTING DATA MATRIX IS:\n\n');
        disp(s10)
        disp(DATA)
s11=sprintf('\nPRESS ONE(1) TO BEGIN SOLUTION CANDIDATE GENERATION
\nOR TWO(2) TO START AFRESH\n');
        disp(s11)
request=input('MATLAB is Waiting for input: ');
clc
if request==2
    configs
end
    Cand1=1:LOOPS;
    Cand2=ones(LOOPS,1);
    Cand12=Cand2*Cand1;
    Cand12=Cand12'*10+Cand12;
    Candown=triu(Cand12);
    Cands=reshape(Candown,1,LOOPS^2);
    Cands=sort(Cands);
    Cands(1:(LOOPS^2-LOOPS)/2)=[];
    Cands=combntns(Cands,LOOPS);
    badsol=[];
    for n=1:LOOPS-1
    for point1=1:LOOPS-n
        for point2=point1+n
            for k=1:n
            bad=[Candown(point1,(point2-
k)),Candown(point1,point2),Candown(point1+k,point2)];
            badsol=[badsol;bad];
            end
        end
    end
    end
   [u,v]=size(Cands);
   [uu,vv]=size(badsol);
   SN1=[];
   see=LOOPS-2;
   for num=1:(LOOPS-2)
   see=see-1;
   SN=[];
   for gi=1:uu
      for gh=1:u
          if Cands(gh,num:(LOOPS-see))==badsol(gi,:)
            SN=[SN,gh];
          end
      end
   end
   SN1=[SN1,SN];
   end
Cands(SN1,:)=[];
L=(length(DATA))/LOOPS;
SN2=[];
for nm=1:LOOPS
```

```
    for mn=1:LOOPS
    if DATA(nm,((L*mn-L+1):(L*mn)))==zeros(1,L)
        elmt=nm*10+mn;
        SN2=[SN2,elmt];
    end
    end
end
 [uv,vu]=size(Cands);
   LL=length(SN2);
   SN3=[];
   for nam=1:LL
   SN4=[];
   for ggg=1:uv
      for hhh=1:vu
          if Cands(ggg,hhh)==SN2(nam)
            SN4=[SN4,ggg];
          end
      end
   end
   SN3=[SN3,SN4];
   end
Cands(SN3,:)=[];
Lent=length(Cands);
SOLDATA=zeros(Lent,length(DATA));
for lsol=1:Lent
    for wsol=1:LOOPS
        LL1=floor((Cands(lsol,wsol))/10);
        LL2=(Cands(lsol,wsol))-LL1*10;
        SOLDATA(lsol,((L*wsol-L+1):(L*wsol)))=DATA(LL1,((L*LL2-
L+1):(L*LL2)));
    end
end
SOLS=combntns((reshape((ones(LOOPS,1)*(1:L)),1,L*LOOPS)),LOOPS);
Checkn=zeros(1,LOOPS);
[cck,ccck]=size(Checkn);
ckk=0;
for Chk=1:length(SOLS)
    for ck=1:cck
        if SOLS(Chk,:)==Checkn(ck,:)
            ckk=ckk+1;
        end
    end
        if ckk==0
            Checkn=[Checkn;SOLS(Chk,:)];
        end
        ckk=0;
        [cck,ccck]=size(Checkn);
end
Checkn(1,:)=[];
CHECKN=[];
for gtb=1:length(Checkn)
    Perm=perms(Checkn(gtb,:));
    CHECKN=[CHECKN;Perm];
end
SOLS=CHECKN;
Checkn=zeros(1,LOOPS);
[cck,ccck]=size(Checkn);
```

```
ckk=0;
for Chk=1:length(SOLS)
    for ck=1:cck
        if SOLS(Chk,:)==Checkn(ck,:)
            ckk=ckk+1;
        end
    end
        if ckk==0
            Checkn=[Checkn;SOLS(Chk,:)];
        end
        ckk=0;
        [cck,ccck]=size(Checkn);
end
Checkn(1,:)=[];
[pp,qq]=size(Checkn);
SOL2=[];
[dddd,ddd]=size(SOLDATA);
for p=1:dddd
    for q=1:pp
        SOL1=[];
        for w=1:qq
            SO=SOLDATA(p,(L*w-L+Checkn(q,w)));
            SOL1=[SOL1,SO];
        end
        SOL2=[SOL2;SOL1];
    end
end
[ww,rr]=size(SOL2);
SOL3=[];
for ee=1:ww
    for te=1:rr
        if SOL2(ee,te)==0
            SOL3=[SOL3,ee];
        end
    end
end
SOL2(SOL3,:)=[];
A=SOL2;
end
if selection==3
   DATA=input('ENTER THE DATA MATRIX: ');
   A=DATA;
end
```

APPENDIX J
m. File: Main Function "gui_radflow"

```
function varargout = gui_radflow(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @gui_radflow_OpeningFcn, ...
                   'gui_OutputFcn',  @gui_radflow_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
 if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
function gui_radflow_OpeningFcn(hObject, eventdata, handles,
varargin)
handles.output = hObject;
guidata(hObject, handles);
set(handles.linedata_type1,'value',1);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',0);
set(handles.busdata_type1,'value',1);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',0);
function varargout = gui_radflow_OutputFcn(hObject, eventdata,
handles)
varargout{1} = handles.output;
function realv_Callback(hObject, eventdata, handles)
function realv_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function linedata_type1_Callback(hObject, eventdata, handles)
set(handles.linedata_type1,'value',1);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',0);
ldt1=get(handles.linedata_type1,'value');
function linedata_type2_Callback(hObject, eventdata, handles)
set(handles.linedata_type1,'value',0);
set(handles.linedata_type2,'value',1);
set(handles.linedata_type3,'value',0);
```

```
ldt2=get(handles.linedata_type2,'value');
function linedata_type3_Callback(hObject, eventdata, handles)
set(handles.linedata_type1,'value',0);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',1);
ldt3=get(handles.linedata_type3,'value');
function busdata_type1_Callback(hObject, eventdata, handles)
set(handles.busdata_type1,'value',1);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',0);
bdt1=get(handles.busdata_type1,'value');
function busdata_type2_Callback(hObject, eventdata, handles)
set(handles.busdata_type1,'value',0);
set(handles.busdata_type2,'value',1);
set(handles.busdata_type3,'value',0);
bdt2=get(handles.busdata_type2,'value');
function busdata_type3_Callback(hObject, eventdata, handles)
set(handles.busdata_type1,'value',0);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',1);
bdt3=get(handles.busdata_type3,'value');
function SL_CreateFcn(hObject, eventdata, handles)
function Vi_CreateFcn(hObject, eventdata, handles)
function sim_time_CreateFcn(hObject, eventdata, handles)
function iterations_CreateFcn(hObject, eventdata, handles)
function linedata_info_CreateFcn(hObject, eventdata, handles)
function linedata_done_Callback(hObject, eventdata, handles)
LD=linedata;
[lld,bld]=size(LD);
ld=sprintf('YOU HAVE SUCCESSFULLY ENTERED THE DATA OF  %d
BRANCHES/LINES',lld);
set(handles.linedata_info,'string',ld)
function busdata_info_CreateFcn(hObject, eventdata, handles)
function imagv_Callback(hObject, eventdata, handles)
function imagv_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function busdata_build_Callback(hObject, eventdata, handles)
set(handles.linedata_info,'string','')
edit busdata
function busdata_done_Callback(hObject, eventdata, handles)
BD=busdata;
[lbd,bbd]=size(BD);
bd=sprintf('YOU HAVE SUCCESSFULLY ENTERED THE DATA OF  %d
BUSES/NODES',lbd);
set(handles.busdata_info,'string',bd)
function linedata_build_Callback(hObject, eventdata, handles)
edit linedata
set(handles.busdata_info,'string','')
function heading1_CreateFcn(hObject, eventdata, handles)
function heading2_CreateFcn(hObject, eventdata, handles)
function SL_No_CreateFcn(hObject, eventdata, handles)
function V_No_CreateFcn(hObject, eventdata, handles)
function Simulate_Callback(hObject, eventdata, handles)
bdt3=get(handles.busdata_type3,'value');
```

```
bdt2=get(handles.busdata_type2,'value');
bdt1=get(handles.busdata_type1,'value');
ldt3=get(handles.linedata_type3,'value');
ldt2=get(handles.linedata_type2,'value');
ldt1=get(handles.linedata_type1,'value');
imagv=str2double(get(handles.imagv,'string'));
realv=str2double(get(handles.realv,'string'));
Vs=realv+1i*imagv;
linedatas=linedata;
busdatas=busdata;
[a,b]=size(linedatas);
if a<=30
if ldt1==1
LD=linedatas;
end
if ldt2==1
    LD=zeros(size(linedatas));
    LD(:,(1:3))=linedatas(:,(1:3));
    LD(:,4)=cosd(linedatas(:,5)).*linedatas(:,4);
    LD(:,5)=sind(linedatas(:,5)).*linedatas(:,4);
end
if ldt3==1
    LD=zeros(size(linedatas));
    LD(:,(1:3))=linedatas(:,(1:3));
    LD(:,4)=real(linedatas(:,4));
    LD(:,5)=imag(linedatas(:,4));
end
if bdt1==1
BD=busdatas;
end
if bdt2==1
    BD=zeros(size(busdatas));
    BD(:,(1:3))=busdatas(:,(1:3));
    BD(:,4)=ones(size( BD(:,4)));
    BD(:,5)=zeros(size( BD(:,5)));
end
if bdt3==1
    BD=zeros(size(busdatas));
    BD(:,1)=busdatas(:,1);
    BD(:,2)=abs(busdatas(:,2)+1i*busdatas(:,3));
    BD(:,3)=cosd(angle(busdatas(:,2)+1i*busdatas(:,3)));
    BD(:,4)=ones(size( BD(:,4)));
    BD(:,5)=zeros(size( BD(:,5)));
end
y=floor(a/24);
if y>1
    y=1;
end
n=14-y*ceil((a-24)/3);
set(handles.SL,'fontsize',n)
set(handles.Vi,'fontsize',n)
set(handles.SL_No,'fontsize',n)
set(handles.V_No,'fontsize',n)
[SimT,Itr,Powerloss,Sline,Vbus]=RADFLOW(LD,BD,Vs)
Ld=sortc(LD,3);
No=Ld(:,1);
no=Ld(:,3);
```

```
No=[No,no];
No=sortc(No,2);
No=No(:,1);
Vbus=[No,Vbus];
Vbus=sortc(Vbus,1);
Sline=[No,Sline];
Sline=sortc(Sline,1);
No=Sline(:,1);
Sline=Sline(:,2);
Vbus=Vbus(:,2);
Powerloss=num2str(Powerloss);
Sline=num2str(Sline);
Vbus=num2str(Vbus);
set(handles.SL,'string',Sline)
set(handles.Vi,'string',Vbus)
set(handles.P_loss,'string',Powerloss)
SimT=num2str(SimT);
Itr=num2str(Itr);
set(handles.iterations,'string',Itr)
set(handles.sim_time,'string',SimT)
No=num2str(No);
set(handles.SL_No,'string',No)
set(handles.V_No,'string',No)
else
if ldt1==1
LD=linedatas;
end
if ldt2==1
    LD=zeros(size(linedatas));
    LD(:,(1:3))=linedatas(:,(1:3));
    LD(:,4)=cosd(linedatas(:,5)).*linedatas(:,4);
    LD(:,5)=sind(linedatas(:,5)).*linedatas(:,4);
end
if ldt3==1
    LD=zeros(size(linedatas));
    LD(:,(1:3))=linedatas(:,(1:3));
    LD(:,4)=real(linedatas(:,4));
    LD(:,5)=imag(linedatas(:,4));
end
if bdt1==1
BD=busdatas;
end
if bdt2==1
    BD=zeros(size(busdatas));
    BD(:,(1:3))=busdatas(:,(1:3));
    BD(:,4)=ones(size( BD(:,4)));
    BD(:,5)=zeros(size( BD(:,5)));
end
if bdt3==1
    BD=zeros(size(busdatas));
    BD(:,1)=busdatas(:,1);
    BD(:,2)=abs(busdatas(:,2)+1i*busdatas(:,3));
    BD(:,3)=cosd(angle(busdatas(:,2)+1i*busdatas(:,3)));
    BD(:,4)=ones(size( BD(:,4)));
    BD(:,5)=zeros(size( BD(:,5)));
end
[SimT,Itr,Powerloss,Sline,Vbus]=RADFLOW(LD,BD,Vs)
```

```
Ld=sortc(LD,3);
No=Ld(:,1);
no=Ld(:,3);
No=[No,no];
No=sortc(No,2);
No=No(:,1);
Vbus=[No,Vbus];
Vbus=sortc(Vbus,1);
Sline=[No,Sline];
Sline=sortc(Sline,1);
No=Sline(:,1);
Sline=Sline(:,2);
Vbus=Vbus(:,2);
Powerloss=num2str(Powerloss);
Sline=num2str(Sline);
Vbus=num2str(Vbus);
set(handles.SL,'fontsize',20)
set(handles.Vi,'fontsize',20)
set(handles.SL,'string','TOO MANY ARGUMENTS!!! PLEASE REFFER TO THE
COMMAND WINDOW FOR THE BRANCH ACTIVE POWER ')
set(handles.Vi,'string','TOO MANY ARGUMENTS!!! PLEASE REFFER TO THE
COMMAND WINDOW FOR THE BUS/NODE VOLTAGE ')
set(handles.P_loss,'string',Powerloss)
SimT=num2str(SimT);
Itr=num2str(Itr);
set(handles.iterations,'string',Itr)
set(handles.sim_time,'string',SimT)
No=num2str(No);
set(handles.SL_No,'string','')
set(handles.V_No,'string','')
end
function Reset_Callback(hObject, eventdata, handles)
set(handles.linedata_info,'string','')
set(handles.busdata_info,'string','')
set(handles.P_loss,'string','')
set(handles.sim_time,'string','')
set(handles.iterations,'string','')
set(handles.realv,'string','')
set(handles.imagv,'string','')
set(handles.linedata_type1,'value',1);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',0);
set(handles.busdata_type1,'value',1);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',0);
set(handles.SL,'string','')
set(handles.Vi,'string','')
set(handles.SL_No,'string','')
set(handles.V_No,'string','')
function Vi_Callback(hObject, eventdata, handles)
function Help_Callback(hObject, eventdata, handles)
set(handles.SL,'fontsize',10)
set(handles.Vi,'fontsize',10)
set(handles.SL_No,'fontsize',10)
set(handles.V_No,'fontsize',10)
set(handles.SL,'string','This GUI is design to help users
(especially those that are less familiar with MATLAB coding) in
```

```
performing radial distribution power flow simulation based on the
BSF algorithm. This can be achieved by entering the required data in
the provided spaces and clicking the simulate button. The line data
and bus data can be entered by clicking the 'enter line data' and
'enter bus data' button. The 'done' button is used to view the
number of ranches or node in the line data and bus data
respectively. The 'reset' button will clear all the previous
information generated by a user, except the line and bus data. The
source voltage is the complex rated voltage at no load. When the
number of nodes and branches exceed 30, the line power flows and the
node voltages can only be viewed on the command window. The BFS
technique for radial distribution power flow analysis can be
successfully carried out by logically executing the following set of
instructions. These set of instructions forms the BFS Algorithm. The
BFS algorithm is as follows: Construct the network's line data
matrix, bus data matrix, and define the source voltage and the
voltage error limit (e); ')
set(handles.Vi,'string','Execute the backward sweep, by logically
tracing each and every node back to the source while computing the
power flowing on the network branches and their respective branch
power losses. This can be achieved using the MATLAB function
'sortbus'; Execute the forward sweep, by logically tracing the
source to every other node while computing the voltage drop along
the branches (based on the results obtained from the second
instruction (2) above). This can be achieved using the MATLAB
Function 'VDROP'; Update the node voltages using the results
obtained from the third instruction (3) above, and store the updated
node voltages as VF1; Execute instructions two (2) and three (3)
above; re-update the updated node voltages (as in four (4) above);
and store the re-updated node voltages as VF2; Compute the change in
node voltage between two successive forward sweeps (which represents
the absolute voltage error (|V_F1-V_F2 |)); Repeat instructions two
(2) to six (6), as long as the maximum absolute voltage error is
greater than the error limit (e). Print the results, if the
condition in instruction seven (7) is violated.')
set(handles.heading1,'string','HELP!!!')
set(handles.heading2,'string','HELP CONT...!!!')
set(handles.SL_No,'string','')
set(handles.V_No,'string','')
```

APPENDIX K
m. File: Main Function "gui_optconfigs"

```
function varargout = gui_optconfig(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                  'gui_OpeningFcn', @gui_optconfig_OpeningFcn, ...
                   'gui_OutputFcn',  @gui_optconfig_OutputFcn, ...
```

```
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
function gui_optconfig_OpeningFcn(hObject, eventdata, handles,
varargin)
handles.output = hObject;
guidata(hObject, handles);
set(handles.linedata_type1,'value',1);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',0);
set(handles.busdata_type1,'value',1);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',0);
function varargout = gui_optconfig_OutputFcn(hObject, eventdata,
handles)
varargout{1} = handles.output;
function linedata_type1_Callback(hObject, eventdata, handles)
set(handles.linedata_type1,'value',1);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',0);
ldt1=get(handles.linedata_type1,'value');
function linedata_type2_Callback(hObject, eventdata, handles)
set(handles.linedata_type1,'value',0);
set(handles.linedata_type2,'value',1);
set(handles.linedata_type3,'value',0);
ldt2=get(handles.linedata_type2,'value');
function linedata_type3_Callback(hObject, eventdata, handles)
set(handles.linedata_type1,'value',0);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',1);
ldt3=get(handles.linedata_type3,'value');
function busdata_type1_Callback(hObject, eventdata, handles)
set(handles.busdata_type1,'value',1);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',0);
bdt1=get(handles.busdata_type1,'value');
function busdata_type2_Callback(hObject, eventdata, handles)
set(handles.busdata_type1,'value',0);
set(handles.busdata_type2,'value',1);
set(handles.busdata_type3,'value',0);
bdt2=get(handles.busdata_type2,'value');
function busdata_type3_Callback(hObject, eventdata, handles)
set(handles.busdata_type1,'value',0);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',1);
bdt3=get(handles.busdata_type3,'value');
function RNGIM_build_Callback(hObject, eventdata, handles)
edit RNGIM
set(handles.RNGIM_info,'string','')
function RNGIM_done_Callback(hObject, eventdata, handles)
```

```
[LD,bd]=RNGIM;
[lld,bld]=size(LD);
ld=sprintf('YOU HAVE ENTERED THE RNGIM OF A NETWORK GRAPH WITH %d
MESHES',lld);
set(handles.RNGIM_info,'string',ld)
function TM_build_Callback(hObject, eventdata, handles)
edit TM
set(handles.TM_info,'string','')
function TM_done_Callback(hObject, eventdata, handles)
LD=TM;
[lld,bld]=size(LD);
ld=sprintf('YOU HAVE ENTERED THE TM OF A NETWORK WITH %d TIE-
LINES/BRANCHES',lld);
set(handles.TM_info,'string',ld)
function busdata_build_Callback(hObject, eventdata, handles)
set(handles.linedata_info,'string','')
edit busdata
function busdata_done_Callback(hObject, eventdata, handles)
BD=busdata;
[lbd,bbd]=size(BD);
bd=sprintf('YOU HAVE SUCCESSFULLY ENTERED THE DATA OF  %d
BUSES/NODES',lbd);
set(handles.busdata_info,'string',bd)
function linedata_build_Callback(hObject, eventdata, handles)
edit linedata
set(handles.busdata_info,'string','')
function linedata_done_Callback(hObject, eventdata, handles)
LD=linedata;
[lld,bld]=size(LD);
ld=sprintf('YOU HAVE SUCCESSFULLY ENTERED THE DATA OF  %d
BRANCHES/LINES',lld);
set(handles.linedata_info,'string',ld)
function linedata_info_CreateFcn(hObject, eventdata, handles)
function busdata_info_CreateFcn(hObject, eventdata, handles)
function TM_info_CreateFcn(hObject, eventdata, handles)
function RNGIM_info_CreateFcn(hObject, eventdata, handles)
function sim_time_CreateFcn(hObject, eventdata, handles)
function P_loss_CreateFcn(hObject, eventdata, handles)
function Best_solution_CreateFcn(hObject, eventdata, handles)
function realVs_Callback(hObject, eventdata, handles)
function realVs_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function imagVs_Callback(hObject, eventdata, handles)
function imagVs_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function realVmax_Callback(hObject, eventdata, handles)
function realVmax_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function imagVmax_Callback(hObject, eventdata, handles)
function imagVmax_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function realVmin_Callback(hObject, eventdata, handles)
function realVmin_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function imagVmin_Callback(hObject, eventdata, handles)
function imagVmin_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function simulate_Callback(hObject, eventdata, handles)
bdt3=get(handles.busdata_type3,'value');
bdt2=get(handles.busdata_type2,'value');
bdt1=get(handles.busdata_type1,'value');
ldt3=get(handles.linedata_type3,'value');
ldt2=get(handles.linedata_type2,'value');
ldt1=get(handles.linedata_type1,'value');
imagv=str2double(get(handles.imagVs,'string'));
realv=str2double(get(handles.realVs,'string'));
Vs=realv+1i*imagv;
imagvmax=str2double(get(handles.imagVmax,'string'));
realvmax=str2double(get(handles.realVmax,'string'));
Vmax=realvmax+1i*imagvmax;
imagvmin=str2double(get(handles.imagVmin,'string'));
realvmin=str2double(get(handles.realVmin,'string'));
VMT=str2double(get(handles.VMT,'string'));
Vmin=realvmin+1i*imagvmin;
linedatas=linedata;
busdatas=busdata;
tm=TM;
[rn1 rn2]=RNGIM;
rngim=rn1;
rngim_choice=rn2;
if ldt1==1
LD=linedatas;
end
if ldt2==1
    LD=zeros(size(linedatas));
    LD(:,(1:3))=linedatas(:,(1:3));
    LD(:,4)=cosd(linedatas(:,5)).*linedatas(:,4);
    LD(:,5)=sind(linedatas(:,5)).*linedatas(:,4);
end
if ldt3==1
    LD=zeros(size(linedatas));
    LD(:,(1:3))=linedatas(:,(1:3));
    LD(:,4)=real(linedatas(:,4));
    LD(:,5)=imag(linedatas(:,4));
end
if bdt1==1
```

```
BD=busdatas;
end
if bdt2==1
    BD=zeros(size(busdatas));
    BD(:,(1:3))=busdatas(:,(1:3));
    BD(:,4)=ones(size( BD(:,4)));
    BD(:,5)=zeros(size( BD(:,5)));
end
if bdt3==1
    BD=zeros(size(busdatas));
    BD(:,1)=busdatas(:,1);
    BD(:,2)=abs(busdatas(:,2)+1i*busdatas(:,3));
    BD(:,3)=cosd(angle(busdatas(:,2)+1i*busdatas(:,3)));
    BD(:,4)=ones(size( BD(:,4)));
    BD(:,5)=zeros(size( BD(:,5)));
end
[TIME CSOL
Plost_best]=optconfig(LD,BD,Vs,Vmin,Vmax,tm,rngim,rngim_choice,VMT);
Plost_best=num2str(Plost_best);
set(handles.P_loss,'string',Plost_best)
TIME=num2str(TIME);
set(handles.sim_time,'string',TIME)
CSOL=num2str(CSOL);
set(handles.Best_solution,'string',CSOL)
function reset_Callback(hObject, eventdata, handles)
set(handles.P_loss,'string','')
set(handles.sim_time,'string','')
set(handles.Best_solution,'string','')
set(handles.realVs,'string','')
set(handles.imagVs,'string','')
set(handles.realVmin,'string','')
set(handles.imagVmin,'string','')
set(handles.realVmax,'string','')
set(handles.imagVmax,'string','')
set(handles.linedata_type1,'value',1);
set(handles.linedata_type2,'value',0);
set(handles.linedata_type3,'value',0);
set(handles.busdata_type1,'value',1);
set(handles.busdata_type2,'value',0);
set(handles.busdata_type3,'value',0);
set(handles.linedata_info,'string','')
set(handles.busdata_info,'string','')
set(handles.RNGIM_info,'string','')
set(handles.TM_info,'string','')
set(handles.VMT,'string','')
function VMT_Callback(hObject, eventdata, handles)
function VMT_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

APPENDIX L
Conductor Ampacity and GMD Factor

Estimating of resistance and reactance of a conductor

$$R=\frac{211.67\alpha L}{A}(1+\beta(T_c-T_0))$$

$$X=\frac{0.1735fL}{60}\log(\frac{8.6}{k\,A})$$

Where: R, α, L, A, β, T_c, and T_0 represents the resistance of a line (ohms); the resistivity of a line at 25°C (ohms in^2/1000ft); length of a line (km); cress-sectional area of a conductor (mm^2); temperature coefficient of resistivity (/° C); conductor temperature and the initial temperature respectively. T_c, and T_0 were chosen to be 75 and 25°C respectively. Also X, f, and k represent the reactance of the line; the operating frequency; and a factor of geometric mean distance (GMD) respectively.

The GMD factor (k) depends on the number of strands in a conductor.

Table 3.8: GMD Factor

Number of Strands	GMD Factor
1	0.7788
3	0.6778
7	0.7256
19	0.7577
37	0.7678
61	0.7722

Table 3.9: Conductor Amapacities

CSA (mm2)	Conductor temperature =75^{o}C			
	Ambient =25^{o}C		Ambient = 40^{o}C	
	No Wind	Wind	No Wind	Wind
150	325	479	243	390
100	254	383	190	313
75	216	331	162	271
50	157	243	118	203
35	134	214	101	175

APPE999999999NDIX M
Line, Bus, Tie Data Matrices and RNGIM

1. Line Data Matrix:

91	0	91	2.447E-03	2.039E-03	0.9906
94	14	94	5.906E-02	4.921E-02	0.9906
18	16	18	4.046E-02	3.371E-02	0.9906
19	18	19	1.207E-02	1.006E-02	0.9906
17	19	17	5.947E-02	5.221E-02	0.7950
20	19	20	1.354E-02	1.128E-02	0.9906
114	20	114	2.774E-03	2.311E-03	0.9906
117	21	117	2.284E-03	1.903E-03	0.9906
115	24	115	2.692E-03	2.363E-03	0.7950
116	27	116	8.160E-04	6.797E-04	0.9906
29	28	29	9.300E-03	8.165E-03	0.7950
31	30	31	1.101E-02	9.669E-03	0.7950
118	31	118	3.427E-03	2.855E-03	0.9906
35	32	35	2.284E-03	1.903E-03	0.9906
32	33	32	2.774E-03	2.311E-03	0.9906
36	35	36	1.982E-02	1.740E-02	0.7950
121	37	121	7.832E-03	6.525E-03	0.9906
40	39	40	1.297E-02	1.139E-02	0.7950
41	40	41	5.874E-03	4.894E-03	0.9906
43	42	43	1.888E-02	1.132E-02	0.4445
45	44	45	8.321E-03	5.947E-03	0.5156
51	48	51	1.023E-01	7.311E-02	0.5156

50	49	50	5.580E-02	4.899E-02	0.7950
53	50	53	1.224E-02	1.074E-02	0.7950
52	51	52	3.475E-02	2.484E-02	0.5156
54	53	54	7.342E-03	5.247E-03	0.5156
56	55	56	5.727E-02	4.093E-02	0.5156
98	58	98	2.790E-02	1.994E-02	0.5156
60	59	60	2.056E-02	1.805E-02	0.7950
109	60	109	3.500E-02	3.073E-02	0.7950
110	61	110	2.350E-02	2.063E-02	0.7950
63	62	63	2.517E-02	1.509E-02	0.4445
77	76	77	7.098E-03	6.231E-03	0.7950
78	76	78	4.568E-03	3.792E-03	0.6883
79	78	79	4.895E-03	4.297E-03	0.7950
81	80	81	6.364E-03	5.586E-03	0.7950
82	81	82	1.982E-02	1.740E-02	0.7950
83	82	83	2.284E-03	1.903E-03	0.9906
111	83	111	6.608E-03	5.801E-03	0.7950
113	86	113	5.384E-03	4.486E-03	0.9906
88	87	88	7.098E-03	6.231E-03	0.7950
92	91	92	1.077E-02	8.939E-03	0.6883
107	91	107	8.566E-03	7.520E-03	0.7950
93	92	93	7.098E-03	6.231E-03	0.7950
12	92	12	3.427E-03	3.008E-03	0.7950
14	93	14	7.342E-03	6.446E-03	0.7950

Line Data Matrix (Continued):

96	95	96	2.203E-03	1.934E-03	0.7950
55	95	55	1.958E-02	1.592E-02	0.4445
97	96	97	1.399E-02	8.385E-03	0.4445
57	96	57	1.689E-02	1.483E-02	0.7950
58	97	58	9.789E-03	5.869E-03	0.4445
59	97	59	4.335E-02	2.599E-02	0.4445
99	98	99	1.468E-02	8.804E-03	0.4445
66	98	66	1.150E-02	1.010E-02	0.7950
100	99	100	8.811E-03	6.296E-03	0.5156
67	99	67	7.098E-03	6.231E-03	0.7950
101	100	101	2.867E-02	1.719E-02	0.4445
68	100	68	6.689E-03	5.573E-03	0.9906
102	101	102	1.615E-02	1.418E-02	0.7950
69	101	69	5.874E-03	4.894E-03	0.9906
103	102	103	1.746E-02	1.454E-02	0.9906
70	102	70	6.689E-03	5.573E-03	0.9906
104	103	104	1.517E-02	1.264E-02	0.9906
71	103	71	5.711E-03	4.758E-03	0.9906
105	104	105	6.689E-03	5.573E-03	0.9906
72	104	72	2.937E-03	2.447E-03	0.9906
106	105	106	2.921E-02	2.433E-02	0.9906
73	105	73	2.447E-03	2.039E-03	0.9906
75	106	75	1.224E-02	1.074E-02	0.7950
74	106	74	2.203E-03	1.934E-03	0.7950
16	107	16	3.231E-02	2.309E-02	0.5156
15	107	15	1.468E-02	1.223E-02	0.9906
30	107	30	2.325E-02	2.041E-02	0.7950
76	108	76	1.636E-01	9.810E-02	0.4445
80	108	132	1.468E-02	1.049E-02	0.5156

61	109	61	1.738E-02	1.526E-02	0.7950
62	109	62	1.077E-02	9.454E-03	0.7950
65	110	65	1.444E-02	1.268E-02	0.7950
64	110	64	2.203E-03	1.934E-03	0.7950
84	111	84	1.909E-02	1.676E-02	0.7950
112	111	112	2.937E-03	2.578E-03	0.7950
85	112	85	1.591E-02	1.397E-02	0.7950
86	112	86	1.248E-02	1.096E-02	0.7950
89	113	89	1.444E-02	1.268E-02	0.7950
87	113	87	8.566E-03	7.520E-03	0.7950
21	114	21	3.671E-03	3.223E-03	0.7950
24	114	24	1.077E-02	9.454E-03	0.7950
26	115	26	5.140E-03	4.512E-03	0.7950
25	115	25	8.811E-03	7.735E-03	0.7950
27	115	27	2.028E-02	1.216E-02	0.4445
90	116	90	3.671E-03	3.223E-03	0.7950
28	116	28	2.308E-02	1.383E-02	0.4445
23	117	23	2.517E-02	1.509E-02	0.4445
22	117	22	2.098E-02	1.258E-02	0.4445
33	118	33	8.076E-02	7.090E-02	0.7950
119	118	119	3.745E-02	3.287E-02	0.7950
34	119	34	7.552E-02	4.528E-02	0.4445

Line Data Matrix (Continued):

123	120	123	3.566E-02	2.138E-02	0.4445
42	121	42	7.342E-03	6.446E-03	0.7950
122	121	122	1.468E-02	8.804E-03	0.4445
38	122	38	5.384E-03	4.486E-03	0.9906
39	122	39	2.007E-02	1.672E-02	0.9906
44	123	44	9.545E-03	8.380E-03	0.7950
124	123	124	8.223E-02	5.877E-02	0.5156
46	124	46	1.697E-02	1.414E-02	0.9906
125	124	125	2.766E-02	2.428E-02	0.7950
47	125	47	2.937E-03	2.447E-03	0.9906
48	125	48	1.888E-02	1.132E-02	0.4445
49	125	49	8.601E-02	5.157E-02	0.4445
136	132	80	2.774E-03	2.311E-03	0.9906
13	93	13	7.098E-03	6.231E-03	0.7950
95	94	95	2.692E-03	2.363E-03	0.7950
108	94	108	1.958E-03	1.719E-03	0.7950
120	119	120	6.294E-03	3.773E-03	0.4445
37	120	37	1.259E-02	7.546E-03	0.4445

2. Tie Matrix (TM)

133	63	85	3.427E-03	2.855E-03	0.9906
134	52	70	2.284E-03	1.903E-03	0.9906
135	34	56	2.774E-03	2.311E-03	0.9906
136	132	80	2.774E-03	2.311E-03	0.9906

3. Bus Data Matrix:

12	0.01960	0.8	1	0
13	0.00773	0.8	1	0
14	0.00773	0.8	1	0
15	0.01960	0.8	1	0
16	0.01187	0.8	1	0
17	0.01187	0.8	1	0
18	0.00773	0.8	1	0
19	0.00387	0.8	1	0
20	0.00773	0.8	1	0
21	0.01227	0.8	1	0
22	0.01187	0.8	1	0
23	0.00387	0.8	1	0
24	0.01227	0.8	1	0
25	0.00773	0.8	1	0
26	0.00773	0.8	1	0
27	0.00387	0.8	1	0
28	0.00387	0.8	1	0
29	0.01960	0.8	1	0
30	0.01187	0.8	1	0
31	0.01960	0.8	1	0
32	0.01187	0.8	1	0
33	0.01187	0.8	1	0
34	0.01187	0.8	1	0
35	0.01227	0.8	1	0
36	0.01960	0.8	1	0
37	0.00773	0.8	1	0
38	0.01960	0.8	1	0
39	0.01960	0.8	1	0
40	0.00200	0.8	1	0
41	0.01187	0.8	1	0
42	0.01960	0.8	1	0
43	0.00773	0.8	1	0
44	0.01187	0.8	1	0
45	0.01187	0.8	1	0
46	0.01960	0.8	1	0
47	0.00773	0.8	1	0

48	0.00773	0.8	1	0
49	0.01187	0.8	1	0
50	0.01960	0.8	1	0
51	0.00200	0.8	1	0
52	0.01187	0.8	1	0
53	0.00773	0.8	1	0
54	0.01960	0.8	1	0
55	0.01187	0.8	1	0
56	0.00773	0.8	1	0
57	0.01187	0.8	1	0
58	0.00200	0.8	1	0
59	0.01227	0.8	1	0
60	0.00773	0.8	1	0
61	0.00387	0.8	1	0
62	0.01187	0.8	1	0

Bus Data Matrix (Continued):

63	0.01960	0.8	1	0
64	0.01187	0.8	1	0
65	0.00773	0.8	1	0
66	0.01187	0.8	1	0
67	0.00387	0.8	1	0
68	0.00387	0.8	1	0
69	0.01187	0.8	1	0
70	0.00773	0.8	1	0
71	0.00773	0.8	1	0
72	0.00200	0.8	1	0
73	0.00773	0.8	1	0
74	0.07867	0.8	1	0
75	0.00773	0.8	1	0
76	0.00773	0.8	1	0
77	0.00387	0.8	1	0
78	0.00773	0.8	1	0
79	0.00200	0.8	1	0
80	0.00773	0.8	1	0
81	0.00200	0.8	1	0
82	0.00773	0.8	1	0
83	0.00773	0.8	1	0
84	0.00773	0.8	1	0
85	0.01187	0.8	1	0
86	0.00387	0.8	1	0
87	0.01960	0.8	1	0
88	0.01187	0.8	1	0
89	0.01187	0.8	1	0
90	0.00200	0.8	1	0
91	0.00000	0	1	0
92	0.00000	0	1	0
93	0.00000	0	1	0
94	0.00000	0	1	0
95	0.00000	0	1	0
96	0.00000	0	1	0
97	0.00000	0	1	0
98	0.00000	0	1	0
99	0.00000	0	1	0
100	0.00000	0	1	0
101	0.00000	0	1	0

102	0.00000	0	1	0
103	0.00000	0	1	0
104	0.00000	0	1	0
105	0.00000	0	1	0
106	0.00000	0	1	0
107	0.00000	0	1	0
108	0.00000	0	1	0
109	0.00000	0	1	0
110	0.00000	0	1	0
111	0.00000	0	1	0
112	0.00000	0	1	0
113	0.00000	0	1	0

Bus Data Matrix (Continued):

114	0.00000	0	1	0
115	0.00000	0	1	0
116	0.00000	0	1	0
117	0.00000	0	1	0
118	0.00000	0	1	0
119	0.00000	0	1	0
120	0.00000	0	1	0
121	0.00000	0	1	0
122	0.00000	0	1	0
123	0.00000	0	1	0
124	0.00000	0	1	0
125	0.00000	0	1	0
132	0.00000	0	1	0

4. Reduced Network Graph Information Matrix (RNGIM)

18	119	93	94	34	56	55	0	95	0	0	0	0	0	0	0
34	56	55	0	123	125	99	102	96	97	0	0	0	0	0	0
95	0	0	0	96	97	0	0	109	108	132	60	61	110	65	0
0	0	0	0	0	0	0	0	61	110	65	0	111	112	85	62

APPENDIX N
Values of the Node Voltages and Branch Currents

Voltage/active power of the network nodes/lines as obtained in the original and optimum configuration power flow simulation respectively.

Comparison of the Optimum and Original Configuration of Azare Distribution Network

Bus S/ No.	Original Config. Voltage (pu)	Optimum Config. Voltage (pu)	Original Config. Power (pu)	Optimum Config. Power(pu)
12	0.9976 - 0.0082i	0.9996 - 0.0017i	0.0157 + 0.0118i	0.0157 + 0.0118i
13	0.9966 - 0.0117i	0.9994 - 0.0023i	0.0062 + 0.0046i	0.0062 + 0.0046i
14	0.9957 - 0.0152i	0.9993 - 0.0028i	0.3117 + 0.2126i	0.1582 + 0.1165i
15	0.9978 - 0.0083i	0.9993 - 0.0031i	0.0157 + 0.0118i	0.0157 + 0.0118i
16	0.9962 - 0.0127i	0.9988 - 0.0044i	0.1040 + 0.0757i	0.1030 + 0.0765i
17	0.9940 - 0.0213i	0.9982 - 0.0070i	0.0095 + 0.0071i	0.0095 + 0.0071i
18	0.9946 - 0.0187i	0.9984 - 0.0062i	0.0940 + 0.0690i	0.0933 + 0.0695i
19	0.9942 - 0.0204i	0.9983 - 0.0067i	0.0872 + 0.0648i	0.0870 + 0.0650i
20	0.9938 - 0.0220i	0.9981 - 0.0072i	0.0745 + 0.0555i	0.0743 + 0.0556i
21	0.9937 - 0.0224i	0.9981 - 0.0073i	0.0224 + 0.0168i	0.0224 + 0.0168i
22	0.9935 - 0.0227i	0.9981 - 0.0074i	0.0095 + 0.0071i	0.0095 + 0.0071i
23	0.9936 - 0.0225i	0.9981 - 0.0074i	0.0031 + 0.0023i	0.0031 + 0.0023i
24	0.9935 - 0.0231i	0.9981 - 0.0075i	0.0457 + 0.0342i	0.0457 + 0.0342i
25	0.9935 - 0.0233i	0.9980 - 0.0076i	0.0062 + 0.0046i	0.0062 + 0.0046i
26	0.9935 - 0.0233i	0.9980 - 0.0076i	0.0062 + 0.0046i	0.0062 + 0.0046i
27	0.9932 - 0.0239i	0.9980 - 0.0077i	0.0235 + 0.0176i	0.0235 + 0.0176i
28	0.9929 - 0.0245i	0.9979 - 0.0079i	0.0188 + 0.0141i	0.0188 + 0.0141i
29	0.9929 - 0.0247i	0.9979 - 0.0080i	0.0157 + 0.0118i	0.0157 + 0.0118i
30	0.9954 - 0.0176i	0.9982 - 0.0075i	0.2638 + 0.1839i	0.4049 + 0.2901i
31	0.9942 - 0.0220i	0.9977 - 0.0095i	0.2519 + 0.1789i	0.3937 + 0.2844i
32	0.9924 - 0.0292i	0.9971 - 0.0119i	0.0350 + 0.0262i	0.0350 + 0.0262i
33	0.9924 - 0.0291i	0.9972 - 0.0119i	0.0448 + 0.0331i	0.0446 + 0.0333i
34	0.9903 - 0.0355i	0.9954 - 0.0177i	0.0095 + 0.0071i	0.0521 + 0.0389i
35	0.9923 - 0.0293i	0.9971 - 0.0120i	0.0255 + 0.0191i	0.0255 + 0.0191i
36	0.9922 - 0.0298i	0.9971 - 0.0121i	0.0157 + 0.0118i	0.0157 + 0.0118i
37	0.9895 - 0.0372i	0.9956 - 0.0172i	0.0707 + 0.0527i	0.0706 + 0.0528i
38	0.9889 - 0.0390i	0.9954 - 0.0177i	0.0157 + 0.0118i	0.0157 + 0.0118i
39	0.9887 - 0.0397i	0.9954 - 0.0179i	0.0268 + 0.0201i	0.0268 + 0.0201i
40	0.9886 - 0.0399i	0.9954 - 0.0180i	0.0111 + 0.0083i	0.0111 + 0.0083i
41	0.9886 - 0.0400i	0.9954 - 0.0180i	0.0095 + 0.0071i	0.0095 + 0.0071i
42	0.9892 - 0.0382i	0.9955 - 0.0175i	0.0219 + 0.0164i	0.0219 + 0.0164i
43	0.9892 - 0.0384i	0.9955 - 0.0175i	0.0062 + 0.0046i	0.0062 + 0.0046i
44	0.9876 - 0.0413i	0.9944 - 0.0198i	0.0190 + 0.0142i	0.0190 + 0.0142i
45	0.9875 - 0.0414i	0.9944 - 0.0199i	0.0095 + 0.0071i	0.0095 + 0.0071i

46	0.9834 - 0.0518i	0.9920 - 0.0265i	0.0157 + 0.0118i	0.0157 + 0.0118i
47	0.9826 - 0.0546i	0.9915 - 0.0287i	0.0062 + 0.0046i	0.0062 + 0.0046i

Comparison of the Optimum and Original Configuration of Azare Distribution Network

Bus S/. No.	Original Config. Voltage (pu)	Optimum Config. Voltage (pu)	Original Config. Power (pu)	Optimum Config. Power(pu)
48	0.9824 - 0.0550i	0.9911 - 0.0296i	0.0173 + 0.0129i	0.1172 + 0.0862i
49	0.9800 - 0.0599i	0.9907 - 0.0303i	0.0475 + 0.0350i	0.0472 + 0.0352i
50	0.9790 - 0.0634i	0.9905 - 0.0314i	0.0377 + 0.0280i	0.0376 + 0.0281i
51	0.9818 - 0.0566i	0.9893 - 0.0345i	0.0111 + 0.0083i	0.1109 + 0.0816i
52	0.9816 - 0.0571i	0.9887 - 0.0362i	0.0095 + 0.0071i	0.1087 + 0.0809i
53	0.9789 - 0.0638i	0.9904 - 0.0315i	0.0219 + 0.0164i	0.0219 + 0.0164i
54	0.9788 - 0.0640i	0.9904 - 0.0315i	0.0157 + 0.0118i	0.0157 + 0.0118i
55	0.9863 - 0.0439i	0.9951 - 0.0187i	0.0157 + 0.0118i	0.0364 + 0.0272i
56	0.9861 - 0.0444i	0.9954 - 0.0178i	0.0062 + 0.0046i	0.0425 + 0.0318i
57	0.9862 - 0.0443i	0.9950 - 0.0190i	0.0095 + 0.0071i	0.0095 + 0.0071i
58	0.9839 - 0.0489i	0.9949 - 0.0191i	0.1186 + 0.0852i	0.0173 + 0.0130i
59	0.9830 - 0.0509i	0.9971 - 0.0119i	0.0604 + 0.0446i	0.0098 + 0.0074i
60	0.9825 - 0.0525i	0.9971 - 0.0118i	0.0504 + 0.0374i	0.0160 + 0.0120i
61	0.9817 - 0.0556i	0.9973 - 0.0107i	0.0188 + 0.0141i	0.1043 + 0.0776i
62	0.9817 - 0.0555i	0.9970 - 0.0120i	0.0252 + 0.0189i	0.0850 + 0.0635i
63	0.9814 - 0.0560i	0.9967 - 0.0128i	0.0157 + 0.0118i	0.0754 + 0.0564i
64	0.9815 - 0.0562i	0.9976 - 0.0095i	0.0095 + 0.0071i	0.0095 + 0.0071i
65	0.9815 - 0.0563i	0.9978 - 0.0087i	0.0062 + 0.0046i	0.1201 + 0.0893i
66	0.9820 - 0.0537i	0.9949 - 0.0194i	0.0095 + 0.0071i	0.0095 + 0.0071i
67	0.9810 - 0.0556i	0.9948 - 0.0194i	0.0031 + 0.0023i	0.0031 + 0.0023i
68	0.9805 - 0.0570i	0.9948 - 0.0194i	0.0031 + 0.0023i	0.0031 + 0.0023i
69	0.9786 - 0.0608i	0.9885 - 0.0367i	0.0095 + 0.0071i	0.0095 + 0.0071i
70	0.9779 - 0.0631i	0.9886 - 0.0363i	0.0062 + 0.0046i	0.0990 + 0.0739i
71	0.9772 - 0.0654i	0.9883 - 0.0373i	0.0062 + 0.0046i	0.0062 + 0.0046i
72	0.9766 - 0.0672i	0.9882 - 0.0378i	0.0016 + 0.0012i	0.0016 + 0.0012i
73	0.9763 - 0.0680i	0.9881 - 0.0381i	0.0062 + 0.0046i	0.0062 + 0.0046i
74	0.9753 - 0.0714i	0.9878 - 0.0391i	0.0629 + 0.0472i	0.0629 + 0.0472i
75	0.9753 - 0.0713i	0.9878 - 0.0391i	0.0062 + 0.0046i	0.0062 + 0.0046i
76	0.9848 - 0.0466i	0.9977 - 0.0083i	0.0171 + 0.0128i	0.0171 + 0.0128i
77	0.9848 - 0.0466i	0.9977 - 0.0084i	0.0031 + 0.0023i	0.0031 + 0.0023i
78	0.9848 - 0.0466i	0.9977 - 0.0084i	0.0078 + 0.0058i	0.0078 + 0.0058i
79	0.9848 - 0.0466i	0.9977 - 0.0084i	0.0016 + 0.0012i	0.0016 + 0.0012i
80	0.9859 - 0.0447i	0.9979 - 0.0081i	0.0739 + 0.0549i	0.0140 + 0.0105i
81	0.9857 - 0.0454i	0.9979 - 0.0081i	0.0677 + 0.0503i	0.0078 + 0.0058i
82	0.9852 - 0.0475i	0.9979 - 0.0082i	0.0661 + 0.0491i	0.0062 + 0.0046i
83	0.9851 - 0.0478i	0.9966 - 0.0133i	0.0597 + 0.0446i	0.0062 + 0.0046i
84	0.9849 - 0.0485i	0.9966 - 0.0133i	0.0062 + 0.0046i	0.0062 + 0.0046i
85	0.9848 - 0.0488i	0.9967 - 0.0129i	0.0095 + 0.0071i	0.0597 + 0.0447i
86	0.9847 - 0.0493i	0.9966 - 0.0135i	0.0378 + 0.0283i	0.0378 + 0.0283i
87	0.9845 - 0.0500i	0.9965 - 0.0137i	0.0252 + 0.0189i	0.0252 + 0.0189i
88	0.9845 - 0.0501i	0.9965 - 0.0137i	0.0095 + 0.0071i	0.0095 + 0.0071i
89	0.9845 - 0.0499i	0.9965 - 0.0137i	0.0095 + 0.0071i	0.0095 + 0.0071i
90	0.9932 - 0.0239i	0.9980 - 0.0078i	0.0016 + 0.0012i	0.0016 + 0.0012i

Comparison of the Optimum and Original Configuration of Azare Distribution Network

Bus S/ No.	Original Config. Voltage (pu)	Optimum Config. Voltage (pu)	Original Config. Power (pu)	Optimum Config. Power(pu)
94	0.9867 - 0.0425i	0.9982 - 0.0071i	0.3045 + 0.2089i	0.1519 + 0.1119i
95	0.9864 - 0.0434i	0.9950 - 0.0189i	0.2052 + 0.1480i	0.0268 + 0.0201i
96	0.9862 - 0.0441i	0.9950 - 0.0190i	0.1893 + 0.1364i	0.0268 + 0.0201i
97	0.9846 - 0.0474i	0.9950 - 0.0190i	0.1797 + 0.1294i	0.0173 + 0.0130i
98	0.9820 - 0.0536i	0.9949 - 0.0193i	0.1168 + 0.0842i	0.0157 + 0.0118i
99	0.9810 - 0.0556i	0.9948 - 0.0193i	0.1067 + 0.0775i	0.0062 + 0.0046i
100	0.9805 - 0.0569i	0.9948 - 0.0194i	0.1033 + 0.0753i	0.0031 + 0.0023i
101	0.9786 - 0.0607i	0.9885 - 0.0366i	0.1001 + 0.0731i	0.0095 + 0.0071i
102	0.9779 - 0.0631i	0.9885 - 0.0366i	0.0901 + 0.0663i	0.0928 + 0.0693i
103	0.9772 - 0.0654i	0.9883 - 0.0373i	0.0837 + 0.0618i	0.0833 + 0.0621i
104	0.9766 - 0.0672i	0.9882 - 0.0378i	0.0774 + 0.0573i	0.0770 + 0.0576i
105	0.9763 - 0.0680i	0.9881 - 0.0381i	0.0756 + 0.0562i	0.0754 + 0.0564i
106	0.9753 - 0.0712i	0.9879 - 0.0390i	0.0694 + 0.0516i	0.0692 + 0.0518i
107	0.9979 - 0.0079i	0.9993 - 0.0030i	0.3853 + 0.2698i	0.5246 + 0.3774i
108	0.9866 - 0.0428i	0.9982 - 0.0072i	0.0912 + 0.0676i	0.1513 + 0.1124i
109	0.9818 - 0.0550i	0.9971 - 0.0116i	0.0441 + 0.0328i	0.1011 + 0.0754i
110	0.9815 - 0.0562i	0.9976 - 0.0095i	0.0157 + 0.0118i	0.1139 + 0.0847i
111	0.9849 - 0.0483i	0.9966 - 0.0133i	0.0536 + 0.0400i	0.0124 + 0.0093i
112	0.9849 - 0.0486i	0.9966 - 0.0133i	0.0473 + 0.0354i	0.0502 + 0.0376i
113	0.9846 - 0.0496i	0.9965 - 0.0136i	0.0347 + 0.0260i	0.0347 + 0.0260i
114	0.9937 - 0.0223i	0.9981 - 0.0073i	0.0682 + 0.0510i	0.0681 + 0.0510i
115	0.9935 - 0.0232i	0.9980 - 0.0076i	0.0359 + 0.0269i	0.0359 + 0.0269i
116	0.9932 - 0.0239i	0.9980 - 0.0078i	0.0204 + 0.0153i	0.0204 + 0.0153i
117	0.9937 - 0.0224i	0.9981 - 0.0073i	0.0126 + 0.0094i	0.0126 + 0.0094i
118	0.9938 - 0.0232i	0.9975 - 0.0101i	0.2352 + 0.1680i	0.3772 + 0.2734i
119	0.9908 - 0.0345i	0.9961 - 0.0161i	0.1901 + 0.1351i	0.3324 + 0.2402i
120	0.9901 - 0.0360i	0.9958 - 0.0168i	0.1786 + 0.1298i	0.2784 + 0.2030i
121	0.9893 - 0.0380i	0.9956 - 0.0174i	0.0644 + 0.0481i	0.0644 + 0.0482i
122	0.9889 - 0.0388i	0.9954 - 0.0177i	0.0425 + 0.0318i	0.0425 + 0.0318i
123	0.9876 - 0.0410i	0.9945 - 0.0198i	0.1075 + 0.0773i	0.2076 + 0.1503i
124	0.9835 - 0.0514i	0.9920 - 0.0264i	0.0879 + 0.0634i	0.1879 + 0.1365i
125	0.9827 - 0.0545i	0.9915 - 0.0287i	0.0712 + 0.0524i	0.1709 + 0.1257i
132	0.9860 - 0.0444i	0.9979 - 0.0081i	0.0740 + 0.0548i	0.1342 + 0.0997i
91	0.9992 - 0.0027i	0.9998 - 0.0008i	0.7235 + 0.4949i	0.7055 + 0.5096i
92	0.9976 - 0.0081i	0.9996 - 0.0017i	0.3363 + 0.2267i	0.1803 + 0.1327i
93	0.9966 - 0.0117i	0.9994 - 0.0023i	0.3189 + 0.2163i	0.1645 + 0.1210i

APPENDIX O
Standard 30 and 33 Bus Networks and their Data (Validation)

Appendix O2
Line data matrix for the 30 bus network shown in Figure 4.11:

Line. Number	Source Bus	Sin Bus	Impedance (pu)
1.0000	0	2.0000	0.0967 + 0.0397i
2.0000	2.0000	3.0000	0.0886 + 0.0364i
3.0000	3.0000	4.0000	0.1359 + 0.0377i
4.0000	4.0000	5.0000	0.1236 + 0.0343i
5.0000	5.0000	6.0000	0.1236 + 0.0343i
6.0000	6.0000	7.0000	0.2598 + 0.0446i
7.0000	7.0000	8.0000	0.1732 + 0.0298i
8.0000	8.0000	9.0000	0.2598 + 0.0446i
9.0000	9.0000	10.0000	0.1732 + 0.0298i
10.0000	10.0000	11.0000	0.1083 + 0.0186i
11.0000	11.0000	12.0000	0.0886 + 0.0149i
12.0000	3.0000	13.0000	0.1299 + 0.0223i
13.0000	13.0000	14.0000	0.1732 + 0.0298i
14.0000	14.0000	15.0000	0.0886 + 0.0149i
15.0000	15.0000	16.0000	0.0433 + 0.0074i
16.0000	6.0000	17.0000	0.1483 + 0.0412i
17.0000	17.0000	18.0000	0.1359 + 0.0377i
18.0000	18.0000	19.0000	0.1718 + 0.0391i
19.0000	19.0000	20.0000	0.1562 + 0.0355i
20.0000	20.0000	21.0000	0.1562 + 0.0355i
21.0000	21.0000	22.0000	0.2165 + 0.0372i
22.0000	22.0000	23.0000	0.2165 + 0.0372i
23.0000	23.0000	24.0000	0.2598 + 0.0446i
24.0000	24.0000	25.0000	0.1732 + 0.0298i
25.0000	25.0000	26.0000	0.1083 + 0.0186i
26.0000	26.0000	27.0000	0.0886 + 0.0149i
27.0000	7.0000	28.0000	0.1299 + 0.0223i
28.0000	28.0000	29.0000	0.1299 + 0.0223i
29.0000	29.0000	30.0000	0.1299 + 0.0223i

Appendix O3

Bus data matrix for the 30 bus network shown in Figure 4.11:

Bus No.	P (pu)	Q (pu)
1.0000	0.0042	0.0026
2.0000	0	0
3.0000	0.0042	0.0026
4.0000	0.0042	0.0026
5.0000	0	0
6.0000	0	0
7.0000	0.0042	0.0026
8.0000	0.0042	0.0026
9.0000	0.0041	0.0025
10.0000	0.0042	0.0026
11.0000	0.0025	0.0015
12.0000	0.0011	0.0007
13.0000	0.0011	0.0007
14.0000	0.0011	0.0007
15.0000	0.0002	0.0001
16.0000	0.0044	0.0027
17.0000	0.0044	0.0027
18.0000	0.0044	0.0027
19.0000	0.0044	0.0027
20.0000	0.0044	0.0027
21.0000	0.0044	0.0027
22.0000	0.0044	0.0027
23.0000	0.0044	0.0027
24.0000	0.0044	0.0027
25.0000	0.0044	0.0027
26.0000	0.0026	0.0016
27.0000	0.0017	0.0011
28.0000	0.0017	0.0011
29.0000	0.0017	0.0011

Appendix O5

Line Data Matrix of the Standard 33 bus network shown in Figure 4.14:

Line No.	Source	Sink	R(pu)	X(pu)	I-max (pu)

2.0000	0	2.0000	0.0575	0.0293	0.0494
3.0000	2.0000	3.0000	0.3076	0.1567	0.0494
4.0000	3.0000	4.0000	0.2284	0.1163	0.0289
5.0000	4.0000	5.0000	0.2378	0.1211	0.0494
6.0000	5.0000	6.0000	0.5110	0.4411	0.0494
7.0000	6.0000	7.0000	0.1168	0.3861	0.0289
8.0000	7.0000	8.0000	1.0678	0.7706	0.0494
9.0000	8.0000	9.0000	0.6427	0.4617	0.0190
10.0000	9.0000	10.0000	0.6514	0.4617	0.0494
11.0000	10.0000	11.0000	0.1227	0.0406	0.0289
12.0000	11.0000	12.0000	0.2336	0.0772	0.0289
13.0000	12.0000	13.0000	0.9160	0.7207	0.0289
14.0000	13.0000	14.0000	0.3379	0.4448	0.0253
15.0000	14.0000	15.0000	0.3688	0.3282	0.0289
16.0000	15.0000	16.0000	0.4657	0.3401	0.0289
17.0000	16.0000	17.0000	0.8043	1.0738	0.0289
18.0000	17.0000	18.0000	0.4567	0.3581	0.0494
19.0000	2.0000	19.0000	0.1023	0.0976	0.0494
20.0000	19.0000	20.0000	0.9385	0.8457	0.0494
21.0000	20.0000	21.0000	0.2555	0.2985	0.0253
22.0000	21.0000	22.0000	0.4423	0.5848	0.0190
23.0000	3.0000	23.0000	0.2815	0.1924	0.0494
24.0000	23.0000	24.0000	0.5603	0.4424	0.0494
25.0000	24.0000	25.0000	0.5591	0.4374	0.0289
26.0000	6.0000	26.0000	0.1267	0.0645	0.0494
27.0000	26.0000	27.0000	0.1773	0.1613	0.0494
28.0000	27.0000	28.0000	0.0903	0.6080	0.0494
29.0000	28.0000	29.0000	0.6608	0.6009	0.0494
30.0000	29.0000	30.0000	0.5826	0.1937	0.0494
31.0000	30.0000	31.0000	0.5018	0.2258	0.0494
32.0000	31.0000	32.0000	0.4371	0.2128	0.0494
33.0000	32.0000	33.0000	0.3167	0.3308	0.0289

Appendix O6

Bus Data Matrix of the Standard 33 bus network shown in Figure 4.14:

Bus_No.	P(pu)	Q(pu)
2.0000	0.0010	0.0006
3.0000	0.0009	0.0004
4.0000	0.0012	0.0008

5.0000	0.0006	0.0003
6.0000	0.0006	0.0002
7.0000	0.0020	0.0010
8.0000	0.0020	0.0010
9.0000	0.0006	0.0002
10.0000	0.0006	0.0002
11.0000	0.0004	0.0003
12.0000	0.0006	0.0004
13.0000	0.0006	0.0004
14.0000	0.0012	0.0008
15.0000	0.0006	0.0001
16.0000	0.0006	0.0002
17.0000	0.0006	0.0002
18.0000	0.0009	0.0004
19.0000	0.0009	0.0004
20.0000	0.0009	0.0004
21.0000	0.0009	0.0004
22.0000	0.0009	0.0004
23.0000	0.0009	0.0004
24.0000	0.0042	0.0020
25.0000	0.0042	0.0020
26.0000	0.0006	0.0003
27.0000	0.0006	0.0003
28.0000	0.0006	0.0002
29.0000	0.0012	0.0007
30.0000	0.0020	0.0060
31.0000	0.0015	0.0007
32.0000	0.0021	0.0010
33.0000	0.0006	0.0004

Appendix O7
Tie Matrix (TM) for the Standard 33 bus network shown in Figure 4.14:

34.0000	9.0000	15.0000	1.2477	1.2477	0.0494
33.0000	21.0000	8.0000	1.2477	1.2477	0.0494
35.0000	12.0000	22.0000	1.2477	1.2477	0.0494
37.0000	25.0000	29.0000	0.3119	0.3119	0.0494

Appendix O8
Reduced Network Graph Information Matrix (RNGIM) for the Standard 33 bus network shown in Figure 4.14:

$$\begin{pmatrix}
19 & 20 & 21 & 3 & 7 & 8 & 0 & 4 & 5 & 6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
4 & 5 & 6 & 0 & 0 & 0 & 0 & 23 & 24 & 25 & 29 & 28 & 27 & 26 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 22 & 9 & 0 & 0 & 0 & 0 & 0 & 10 & 11 & 12 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 11 & 12 & 0 & 0 & 0 & 0 & 13 & 14 & 15 & 0 & 0 & 0 & 0
\end{pmatrix}$$