Development of an Optimal Reconfiguration Algorithm for Radial Distribution Electrical Power Networks
(A Case Study of Zaria Distribution Network)

By

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A THESIS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING OF AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc) DEGREE IN ELECTRICAL ENGINEERING (POWER SYSTEMS).

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DECLARATION

I Adamu Abubakar Saidu declare that this thesis entitled “Development of an optimal Reconfiguration Algorithm for a Radial Distribution Network (A case study of Zaria Distribution Network)” has been carried out by me in the Department of Electrical and Computer Engineering. The information derived from literature cited are dully acknowledge in the text and a list of references provided. No part of this thesis was previously presented for the award of degree at this or any other institution.

ABUBAKAR ADAMU SAIDU _________________________ _____________________

(Signature) **Date**

CERTIFICATION

This thesis entitled “DEVELOPMENT OF AN OPTIMAL RECONFIGURATION ALGORITHM FOR A RADIAL DISTRIBUTION NETWORK (A CASE STUDY OF ZARIA DISTRIBUTION NETWORK)” by ADAMU SAIDU ABUBAKAR meets the requirements for the award of Master of Science (M.Sc.) Degree in Electrical Engineering Ahmadu Bello University, Zaria and it is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to God Almighty for his guidance, kindness, mercy and sympathy.

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My profound gratitude to God Almighty for sparing my life and health he has bestowed on me throughout the course of this research work.

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List of Abbreviation

Acronyms	Definition
DG	Distributed Generation
DNRC	Distribution Network Reconfiguration Configuration
PQ	Constant Active and Reactive Power Load Model
PV	Constant Active Power and Voltage Load
NC	Normally Closed
NO	Normally Open
NSGA II	Non-dominated Sorting Genetic Algorithm
N	Number of Node

ABSTRACT

This worked aimed at developing an optimal reconfiguration algorithm for a radial distribution network using fast and elitist non-dominated sorting genetic algorithm (NSGA II), considering distributed generation. The work models the reconfiguration using a pragmatic multi-objective approach considering active power loss and total voltage deviation, so as to determine the optimum locations of the tie and sectionalizing switches within the distribution network. The model was validated using standard IEEE 33-Bus network and extended to a subsection of Zaria distribution network. The active power loss and total voltage deviation was estimated for Gaskiya, Railway, Sabo and Canteen distribution network as 55.32kW, 0.22V, 17.22kW, 0.2340V, 120.08kW, 0.9949V and 508.0kW, 4.7482V respectively, prior to reconfiguration. With distributed generation placed at different location based on the computed voltage stability index of the nodes. The active power loss for Gaskiya, Railway, Sabo and Canteen distribution network was recorded to be 26.19%, 19.22%, 10.23% and 8.01% reduction respectively as compared to the initial configuration with distributed generation placed at strategic locations. The optimal location of the tie and sectionalizing switches for Gaskiya, Railway, Sabo and Canteen distribution network was found to be 12 14, 14 16 18, 25 20 11 and 23 16 43, respectively after reconfiguration. A reduction in active power loss and reductions in total voltage deviation for Gaskiya, Railway, Sabo and Canteen distribution network was found to be 37.64%, 28.94%, 18.2%, 8.12%, 39.21%,37.8% and 23.42%, 10.72% respectively as compared to the active power loss and total voltage deviation of the initial configuration.

CHAPTER ONE

INTRODUCTION

1.1 Background

The concept of distribution system automation has capture the attention of researchers and utility companies over the last decade. Even though, a lot of research have been undertaken and many works are still ongoing at the moment on "distribution system automation", due to technological innovations and increasing connection of distributed energy source in to existing distribution network. The research is aimed at developing an optimal reconfiguration model for a radial distribution network using Zaria distribution network as a case study.

The problem of minimizing distribution systems losses has received a global attention due to high cost of electrical energy, need for better quality of service, efficient utilization of available energy and high power loss in power networks (Charlangsut *et al,* 2012). Under normal operating conditions, any distribution network must supply electrical power to all its customer connected to it, while simultaneously avoiding overloading, feeder thermal overload and abnormal voltage across the line, as well as minimizing active power loss and maintaining radial topology (Carcamo-Gallardo *et al,* 2008) etc. There are different techniques for reducing losses within the distribution level which include reconfiguration, capacitor placement, load balancing, introduction of higher voltage level and reconductoring (Abdelaziz *et al,* 2010; Sarfi *et al,* 1994). These methods of reducing losses are quite numerous but the major concern is about their technical implications on the network. Introduction of new equipment at distribution level offers tremendous financial burden on the utilities that cannot be justified by the potential saving. The use of fixed compensators offers optimal reduction in losses for specific demand condition, but the control systems required are very expensive (Sarfi *et al,* 1994).

The choice of reconductoring is not an option due to the cost associated with relaying the feeder, while the introduction of higher voltage level requires upgrading the rating of the transformer and other equipment in the network (Sarfi *et al,* 1994). The problem of reconfiguration of distribution network has been explored in this work due to its flexibility, ability to use existing equipment and other pragmatic approaches to offer dynamic means of reducing losses within the distribution level.

Distribution systems are designed as radial systems in which tie (NO) and sectionalizing switches(NC) play a critical role in determining the configuration of the system (Rashtchi and Pashai, 2012). Therefore reconfiguration of the distribution network is the process of altering the topology of the distribution network implemented via maneuvering the position of both switches (normally closed and normally open). Due to the candidate switching combinations in the distribution system, reconfiguration is a complicated combinatorial, non-differentiable constrained optimization problem (Abdelaziz *et al,* 2010).

The reconfiguration problem is one of the multi criteria and multi objective optimization types, where the solution is chosen after the evaluation of some indices such as active power loss, reliability indices, branch load limit and voltage drop limit which represent multiple functions. These criteria can be grouped into objective functions that can be minimized and the constraints that must be included with some bounds while some criteria are often modeled along with their objective functions (Tomoigo *et al,* 2013). The earlier reconfiguration problems were mostly represented by a single objective function (Abdelaziz *et al,* 2010; Baran and Wu 1989; Nara *et al*, 1992). The growing demand and increasing connection of smart devices in to the existing network offers a great advantage but increases the burden and complexity of distribution network.

Clearly, single-shot optimization is not an effective solution to the problem due to the changes in power demand of the customer over time. This is because an operating topology obtained at a specific operating condition may no longer be optimal under new operating conditions (Carcamo-Gallardo *et al,* 2008). There is the need to constantly evolve efficient techniques of reducing active power losses within the distribution system in order to enhance the network performance while improving the continuity of electricity delivery to consumer. The early works on reconfiguration of radial distribution network were centralized in planning of distribution system with the aim of reducing system cost. Distribution network planning requires feeder reconfiguration on a seasonal and annual basis, with the potential to provide required benefit, since the load varies continuously as the network expands. This potential can be exploited by distribution management system where the switches can be opened and closed on a real-time basis (Roytelman *et al,* 1996). The concept of reconfiguration of radial distribution network is aimed at improving the system performance under different operating conditions.

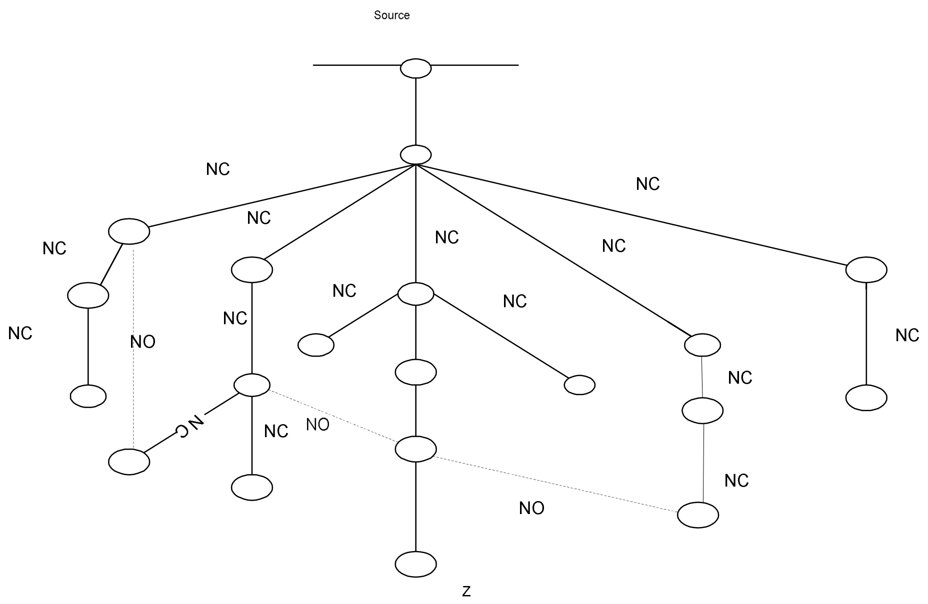


Figure 1.1 Diagram of Typical Radial Distribution Network (Zhang *et al,* 2012)

Generally, distribution networks are built as interconnected networks, while in operation they are arranged in a radial tree structure. This means that a distribution system is divided into subsystems of radial feeders, which contain a number of normally closed (NC) switches and normally open (NO) switches as in Figure 1.1. According to the graph theory (Zhu, 2009), a distribution network can be represented with a graph of G (N, B) that contains a set of N nodes and a set of B branches. Every node represents either a source node (supply transformer) or a sink node (customer load point), while a branch represents a feeder section that can either be energized or de-energized. The typical radial distribution network of Figure 1.1 is such that the feeder section forms a set of trees where each sink node is supplied from exactly one source node. The distribution network reconfiguration problem then is to find a radial operating structure that minimizes the system power loss while satisfying critical operating constraints.

Many techniques such as branch and bound, analytic approach, heuristic, expert system, linear programming etc were presented by different researchers aimed at addressing the problem of reconfiguration of radial distribution network considering active power loss (Zhu, 2009). Fewer addressed the problem of optimal reconfiguration using multi-objective approach (Hung, 2002; Prasad *et al.,* 2009; Kumar *et al.,* 2006; Tomoiga, 2013). This research work developed a pragmatic multi objective genetic algorithm approach in addressing the problem of reconfiguration of distribution system in order to minimize active power loss and reduce total voltage deviation.

1.2 Statement of the Problem

Most of the literatures reviewed addressed the problem of reconfiguration using single objective function considering active power loss as the optimization parameter. Fewer researchers addressed the problem using multi-objective optimization approach by transforming the multi-objective function into a single objective function by using some user parameters which are subjective. The advent and increasing connection of distributed energy sources to distribution network, has necessitated the need to consider other parameters (such as total voltage deviation, reliability index, load balancing, energy not served etc) so as to increase the complexity of the system. This research work addressed the problem of distribution network reconfiguration using an enhanced non-dominated sorting genetic algorithm (NSGA-II) considering active power loss and total voltage deviation as the objective functions, within a reasonable convergence time.

1.3 Aim and Objectives

The aim of this research is to develop an optimal reconfiguration algorithm for radial distribution networks, using non-dominated sorting genetic algorithm (NSGA-II) with a view to improving the performances of a radial distribution system through minimizing its active power loss and reduce total voltage deviation.

The objectives of this research are itemized as follows:

i. Development of an optimal reconfiguration algorithm using fast and elitist non-dominated sorting genetic algorithm (NSGA-II) to determine the optimal location of tie and sectionalizing switches.
ii. Determination of the location and size distributed generation for the distribution network.
iii. Investigation of the effect of distributed generation placement on the power quality for the distribution network.
iv. Comparison of the results obtained from the normal and reconfigured network in order to determine the extent of reductions in both active power loss and total voltage deviation
v. Comparison of the efficiency of the proposed model with existing model as a means of validation.

1.4 Methodology

The following methodology are adopted in carrying out this research and are itemized as follows;

i. Collection of data for radial distribution network of Zaria distribution
ii. Establishment of the most suitable method for performing power flow analysis for the radial distribution network
iii. Based on ii, a power flow analysis is carried out to estimate the initial configuration for distribution network.
iv. Determination of the optimal location and size of distributed generation placement based on computed voltage stability index.
v. Development of an enhanced non-dominated sorting genetic algorithm (NSGA-II) model used to determine the optimal location of tie and sectionalizing switches considering active power loss and total voltage deviation.
vi. Testing and validation of the developed model

vii. A comparison of the reconfigure system with the original system is carried out, to determine the extent of loss reduction.

1.5 Significant Contribution

The significance of this research are itemized as follows:

i. Development of a multi-objective based reconfiguration model using enhanced Non-dominated Sorting Genetic Algorithm (NSGA-II) to obtain optimal switching state (open branch).

ii. A reduction in active power loss (2.8%) was recorded when tested on a standard 33-bus IEEE network as compared with active power loss of other developed model.

1.6 Thesis Organization

The general introduction has been presented in Chapter One. The rest of the chapter are as follows: A detailed of the fundamental concepts of reconfiguration and review of the relevant literatures is carried out in Chapter Two. Mathematical derivation of reconfiguration equations and formulation of the problem are presented in Chapter Three. Analysis and discussions of the results are presented in Chapter Four. Conclusion and recommendation are presented in Chapter Five.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is divided into two parts. The first part discussed the fundamental concepts relevant to the study and the second part provides a review of related works.

2.2 Conventional Approach

This section presents an overview of some of the conventional approaches and fundamental concept critical to the concept of network reconfiguration.

2.2.1 Determination of Radial Configuration

The number of possible radial structure for a distribution network can be obtained for a given configuration. The number of branches needed to maintain a radial network with redundant connections is fixed and can be obtained using (Chicco, 2013):

$$D = B - N + S \tag{2.1}$$

Where:

B : Number of branches

N : Number of nodes

S : Number of supplies

D : Number of redundant connection

A typical distribution network is a complete graph, with N nodes and a single point source. The number of radial configuration (trees) that can be extracted using (Chicco, 2013):

$$\phi = \frac{B!}{N!(B-N)!} \qquad 2.2$$

The number of branches can be obtained using:

$$B = \frac{N(N-1)}{2} \qquad 2.3$$

The number of open branches can be obtained using:

$$D = 1 + N(N-3)/2 \qquad 2.4$$

A complete distribution network (graph), with 14 nodes, the number of possible radial configurations are 1.07× 10^{16}. A practical distribution system has a number of branches that is far less than the complete graph, as such the number of possible configuration can be obtained using Kirchhoff matrix tree theorem.

2.1.2 Kirchhoff Matrix Tree Theorem

Kirchhoff matrix theorem can be applied to determine the number of radial configuration extracted from a weakly structure of an electrical distribution system (Chicco, 2013). The number of possible radial configuration can be obtained by using the determinant of the Laplacian matrix. The Laplacian matrix is a square matrix and can be obtained using (Chicco, 2013):

$$I_{ij} = \begin{cases} \textit{no of branches connected to node. for } i = j \\ -1 \quad \textit{if } (i \neq j) \textit{ and node } i \textit{ adjacent to node } j \\ 0 \quad \textit{otherwise} \end{cases} \qquad 2.5$$

The number of possible radial configuration can be obtained using:

$$\phi = \det(I_{ij}) \qquad 2.6$$

For real network, the exploration can be quite complex and time consuming or even impossible reasonable computational times. As such, the need to discuss other possible approaches to distribution network reconfiguration.

2.1.3 Heuristic Approach to Distribution Network Reconfiguration

This section presents an overview of some of the heuristic approaches used in network reconfiguration.

2.1.3.1 Branch-and-Bound Technique

Branch-and-Bound technique is a general algorithm for finding optimal solutions of various optimization problems, especially in discrete optimization. It consists of a systematic enumeration of all candidate solutions, while discarding infeasible solution based on the upper and lower bound of the optimized quantities. The concept of branch-and-bound technique is to search into the graph of the distribution network, with a view to obtaining the minimal loss configuration, while satisfying radial constraint by using:

$$P_T = Min. \sum_{j=1}^{n} P_j x_j \tag{2.7}$$

Where:

$$x_j = \begin{cases} 1 \\ 0 \end{cases}$$ Status of the branch

P_j : Branch power loss

The basic idea of the heuristic branch exchange is to compute the change of power losses by operating a pair of switches with the aim of achieving reduction in system active power loss (Zhu, 2009). The main advantage of the Branch-and-bound is its simplicity and ease of comprehension, while its disadvantages are:

i. Final system configuration depends on the initial configuration.

ii. It is time consuming for selecting and operating each pair of switches i.e 2^n is the possible switching combinations.

iii. The solution is a local optimal, rather than a global optimal one.

2.1.3.2 Optimal Flow Pattern

If the impedance of all branches in the loop network is replaced by their branch resistances, the load flow distribution that satisfies the Kirchhoff current law and Kirchhoff voltage law is called an optimal flow pattern. When the load flow distribution in a loop is an optimal flow, the corresponding network power losses will be minimal. The steps of the heuristic algorithm based on optimal flow pattern are itemized as follows (Zhu, 2009):

i. Compute load flow of the initial network.

ii. Close all normal open switches to produce loop network.

iii. Compute the equivalent currents at all nodes.

iv. Replace all branch impedances by their corresponding branch resistance and run a power flow.

v. Open a switch of the branch that has minimal current value in the loop. Recompute the load flow for the remaining network.

2.1.3.3 Ruled-Based Comprehensive Approach

This method combines both the branch and exchange methods and a set of rules. The rules used to select the optimal reconfiguration of the distribution network are formed based on system operation experiences (Zhu, 2009). The rule based method can be expressed by the use of the following (Zhu, 2009):

$$PI_{swi} = \frac{W_i \Delta PL_i}{\sum_{i}^{n} W_i \Delta PL_i} \qquad 2.8$$

Where:

ΔPL_i : Change in system loss before and after the branch switch

W_i : Weighting coefficient of the different type of switching branches whose value can be determine by the knowledge of the operator

PI_{swi} : Performance index of the switching branch i

n: is the total number of branches

2.1.4 Graph Theory Concept and Application to Reconfiguration

A graph of a network is a collection of set of point or nodes interconnected by some links. For a power network, the buses may be represented by node or vertices and links that connect pair of nodes are called edge or branch.

The characteristic of a graph can be represented by its adjacency matrix, which shows the various interconnections between node and vertices in the network. The adjacency matrix of a graph is a square matrix (Sakar *et al.,* 2010).

In this approach, the optimum switching state for a given operating condition is obtained by using the concept of graph theory. A binary bit code is generated for each network configuration, which serves as the switching vector state of the network. The adjacent matrix of the overall network is developed based on the switching state vector. The adjacent matrix is searched by depth first search algorithm to ensure radial structure of the network. The configuration that produces the minimal active power losses is taken as the optimal operating point of the network (Sarkar *et al.,* 2010).

2.1.5 Mixed Integer Linear Programming Approach

The problem of reconfiguration of distribution network is nonlinear in nature. For this reason application of non-linear optimization and heuristic techniques is preferred. The linearization of the problem is equally possible. This is done by performing a linearization of both the objective function and constraint, thereby transforming the non-linear formulation into mixed integer linear optimization problem (Zhu, 2009). This approach can be modeled using a simplified mathematical model as contained in the next subsection.

2.1.5.1 Simplified Mathematical Model of Distribution Network Reconfiguration

The mathematical model of reconfiguration can be written as (Zhu, 2009):

$$\text{Min } f = \sum_{i=1}^{NL} R_i \left(\frac{P_i^2 + Q_i^2}{V_i^2} \right) \qquad 2.9$$

$$\sum_{j \to i} P_{Gj} + \sum_{l \to i} P_l + \sum_{k \to i} P_{Dk} = 0 \qquad 2.10$$

$$\sum_{j \to i} Q_{Gj} + \sum_{l \to i} Q_l + \sum_{k \to i} Q_{Dk} = 0 \qquad 2.11$$

$$P_i^2 + Q_i^2 \le S_{i\max}^2 \qquad 2.12$$

$$\Delta V_i \leq \Delta V_{i\max} \qquad 2.13$$

$$\sum_{p\in\pi_n^i} K_p^i = 1 \qquad \forall\ node\ \mathrm{i} \qquad 2.14$$

$$\mathrm{K}_p^i \leq K_l^i \qquad \forall\ \pi_l^i \subset \pi_p^i \qquad 2.15$$

The power flow P_i and Q_i comprises the real and reactive load demanded downstream from node j plus the real and reactive losses of the respective branches. For the sake of simplicity the real and reactive losses are omitted. Therefore, the real and reactive power flow is the sum of load located at downstream of the node (Zhu, 2009).

$$P_i = \sum_{p\in\pi_{NL}^i} K_p^i P_{Di} \qquad 2.16$$

$$Q_i = \sum_{p\in\pi_{NL}^i} K_p^i Q_{Di} \qquad 2.17$$

Substituting equations (2.16) and (2.17) into equation (2.9) and taking V=1.0 per unit

$$\mathrm{Min}\ f = \sum_{i=1}^{NL} R_i \left[\left(\sum_{p\in\pi_{NL}^i} K_p^i P_{Di} \right)^2 + \left(\sum_{p\in\pi_{NL}^i} K_p^i Q_{Di} \right)^2 \right] \quad \mathrm{i} \in \mathrm{NL} \qquad 2.18$$

The network connectivity is incorporated in the binary variable K_p^i .

Substituting equation (2.16) into (2.17)

$$\left[\left(\sum_{p\in\pi_{NL}^i} K_p^i P_{Di} \right)^2 + \left(\sum_{p\in\pi_{NL}^i} K_p^i Q_{Di} \right)^2 \right] \leq S_{i\max}^2 \qquad \mathrm{i} \in \mathrm{NL} \qquad 2.19$$

According to Baran and Wu (1989), the voltage drop without considering power losses can be expressed as follows:.

$$V_l^2 - V_i^2 \approx 2(R_i P_i + X_i Q_i) \qquad 2.20$$

The total voltage drop through a path can be expressed as:

$$V_l^2 - V_i^2 \approx 2\sum_{i}^{NL}(R_i P_i + X_i Q_i) \qquad 2.21$$

The voltage constraint can be obtained using equation (2.13)

$$2\sum_{i\in\pi_p^i}\left[R_i\left(\sum_{p\in\pi_{NL}^i} K_p^i P_{Di}\right) + X_i\left(\sum_{p\in\pi_{NL}^i} K_p^i Q_{Di}\right)\right] \le \Delta V_{\max} \qquad 2.22$$

Where:

K_p : Status of the switch

P_i : Active power at node i

P_{Di} : Active power demand at node i

Q_i : Reactive power at node i

Q_{Di} : Reactive power demand at node i

NL: Number of branches

R_i : Branch resistance

X_i : Branch reactance

V_i: Branch voltage

$\Delta V_{i\max}$: Change in maximum branch voltage

$S_{i\max}$: Maximum branch apparent power

2.1.5.2 Mixed-Integer Linear Model

The distribution network model described in equation (2.18) is simplified, in which the branch losses and bus voltages are removed from the model. The resulting equation (2.18) is still quadratic in nature. By applying the piecewise linear function, equation (2.18) is transformed in to a standard mixed integer linear model (Zhu, 2009):

$$\text{Min } f = \sum_{i=1}^{NL} R_i \left[\left(\sum_{i \in tp} C_p^{p(t)} \sum_{p \in \pi_{NL}^i} K_p^i P_{Di} \right) + \left(\sum_{i \in tp} C_p^{p(t)} \sum_{p \in \pi_{NL}^i} K_p^i Q_{Di} \right) \right] \quad \text{i} \in \text{NL} \qquad 2.23$$

Such that

$$P_i^{(\text{t})} = \sum_{p \in \pi_{NL}^i} K_p^i P_{Di} \quad \text{t} \in \text{tp} \qquad 2.24$$

$$Q^{(\text{t})}{}_i = \sum_{p \in \pi_{NL}^i} K_p^i Q_{Di} \quad \text{t} \in \text{tp} \qquad 2.25$$

$$\left(\sum_{i \in tp} C_p^{p(t)} \sum_{p \in \pi_{NL}^i} K_p^i P_{Di} \right) + \left(\sum_{i \in tp} C_p^{p(t)} \sum_{p \in \pi_{NL}^i} K_p^i Q_{Di} \right) \le S_{i\max}^2 \qquad 2.26$$

$$\begin{cases} 0 \le P_i^{(1)} \le \bar{P}_i^{(1)} \\ 0 \le P_i^{(2)} \le (\bar{P}_i^{(2)} - \bar{P}_i^{(1)}) \qquad \text{i} \in \text{NL} \\ \dots\dots\dots\dots\dots\dots \\ 0 \le P_i^{(tp)} \le (\bar{P}_i^{(tp)} - \bar{P}_i^{(tp-1)}) \end{cases} \qquad 2.27$$

$$\begin{cases} 0 \le Q_i^{(1)} \le \bar{Q}_i^{(1)} \\ 0 \le Q_i^{(2)} \le (\bar{Q}_i^{(2)} - \bar{Q}_i^{(1)}) \qquad \text{i} \in \text{NL} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ 0 \le Q_i^{(tp)} \le (\bar{Q}_i^{(tp)} - \bar{Q}_i^{(tp-1)}) \end{cases} \tag{2.28}$$

Where:

K_p : Status of the switch

P_i : Active power at node i

Q_i : Reactive power at node i

NL: Number of branches

C_p : Piece wise linear constant

To reduce the problem size and speed up the computation, some additional features are considered as follows:

i. The path whose electrical length exceeds a certain threshold is discarded.
ii. If the set of path associated with a branch j comprise of a single element π_l^i, then the power flow P_j is constant provided the weighting coefficient is 1

2.1.6 Application of Genetic Algorithm to Network Reconfiguration

Genetic algorithm is an optimization and search technique based on the principle of genetics and natural selection. A genetic algorithm allows a population composed of many individuals to evolve under specified selection rules to a state that maximized the fitness. Genetic algorithms are considered when conventional techniques cannot achieve the desired speed, accuracy and efficiency (Haupt and Ellen, 2002).

The key steps of a genetic algorithm are itemized as follows (Haupt and Ellen, 2002):

i. Initialization and selecting of variable

   The first step in genetic algorithm implementation is the selection of chromosome or an array of variable, where each individual represents a binary string. Each individual corresponds to a fitness value and the population corresponds to a set of fitness.

ii. Fitness function

   Evaluation of the cost function using the random generated individual or chromosome.

iii. Selection

   Selecting a pair of chromosome or individual from the population as a parent. Survival of the fittest translates into discarding the individuals with the highest cost. Generally, an individual with a bigger fitness has a higher probability to be selected.

iv. Crossover

   The purpose of the cross over is to exchange information fully among individual. There are many cross over methods such as one point cross over and multi-point cross over

v. Mutation

   Mutation provides a medium in which the genetic algorithm can explore its cost surface. It introduces the trait not in the original population and keeps the algorithm from converging too fast before sampling the entire cost surface. Good mutations are to be kept, while bad mutations are to be discarded.

vi. Convergence check

The algorithm stops if an acceptable solution has been reached or a certain number of iterations has been met.

In application of genetic algorithm to distribution system, the network contains a number of normally closed and normally opened switches. For a large distribution network, it is not efficient to represent every switch or branch in the network using binary strings. In this approach the position of the tie or open switch is known so as to simplify the problem. The number of open switches determine the length of the strings (Zhu, 2009). The implementation of genetic algorithm is largely dependent on the fitness function.

(A) Fitness Function

The fitness should be capable of reflecting the objective and direct the search towards the optimal solution. The fitness function L is formed by combining the objective function and the penalty function to form the optimization equation (Nara *et al,* 1992):

$$f = \max\ (1/L) \tag{2.29}$$

Where

$$L = \sum_i I^2{}_i k_i R_i + \beta_1 \max\left\{0, (I_i - I_{i\max})^2\right\} + \beta_2 \max\left\{0, (\mathrm{V}_{\mathrm{i}\min} - V_i)^2\right\} + \beta_3 \max\left\{0, (\mathrm{V}_i - V_{i\max})^2\right\} \tag{2.30}$$

β_i : Large constant

k_i : Status of the switch at branch i

R_i : Resistance at branch i

I_i : Current at branch i

V_i : Voltage at branch i

2.1.7 Spanning Tree

A graph consists of a set of vertices and the link between these vertices is called the edge. The concept of minimum spanning tree is used to obtain the shortest possible path, with all vertices connected (Zhu, 2009).

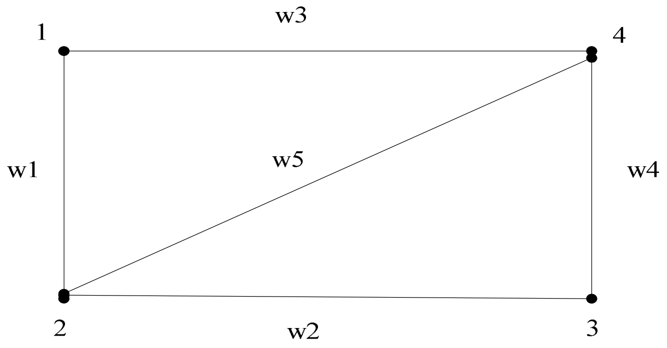


Figure 2.1. A Four Bus Distribution Network (Zhu, 2009)

Figure 2.1 shows a typical 4-bus distribution network (graph). The concept of minimal spanning is used to obtain the shortest possible path that results in a minimal loss with all nodes connected. The active power loss can be expressed as follows:

$$P_T = \sum_{i=1}^{n} w(n) \qquad 2.31$$

Where:

$W(n)$: Branch active power loss

2.1.8 Matroid Theory to Reconfiguration

The reconfiguration problem tries to find the optimal spanning tree among all the sub-graphs of the distribution network in Figure 2.2 for a given objective function (Zhu, 2009):

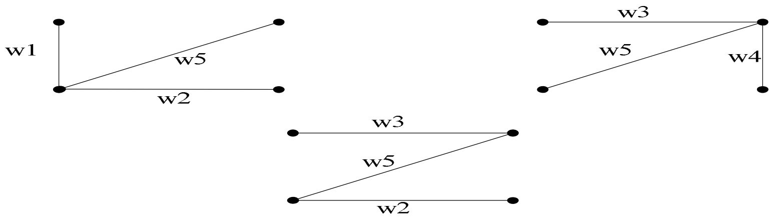


Figure 2.2 Possible Spanning Tree for the 4-Bus Distribution Network (Zhu, 2009)

A matroid theory exploits the characteristic and the collection of spanning tree as shown in Figure 2.2. A matroid is a collection of all the possible spanning trees of a graph. Therefore, branch exchange between the spanning trees of the same graph is possible (Zhu, 2009). From an electrical perspective, branch exchange between spanning trees can be seen as load transfer between two supply points.

$$P_T = \sum_{i=1}^{n} w(n) \qquad 2.32$$

Where:

$w(n)$: Branch active power loss

2.1.9 Depth First Search Algorithm

The depth first search algorithm also uses the concept of determining the shortest path (spanning tree). The search starts from any arbitrary node usually the parent node and progresses until all nodes are visited. If in the process a node visited twice is encountered, the presence of a loop is detected. Also the presence of an unvisited node, signifies the presence of islanded node (Sarkar *et al,* 2010). This approach is adopted to solve the problem of distribution network reconfiguration.

2.1.10 Overview of Meta-Heuristic Technique for Network Reconfiguration

This subsection presents the application of several meta-heuristic techniques to distribution network reconfiguration. Some of the meta-heuristic techniques are discussed as follows:

2.1.10.1 Application Ant Colony Optimization for Network Reconfiguration

This approach can be used to solve the problem of reconfiguration of distribution network. The basic steps of this approach are itemized as follows (Srinivasa *et al,* 2013):

i. Probability

The selection of any switch or path in the first iteration are of equal chances. While in the next iteration, the selections are based on the intensity of pheromone that relate to the switch or path. The probability of path selection is given by (Srinivasa *et al.,* 2013).

$$P_i = \frac{T_i}{\sum_{i=1}^{n} T_i} \qquad 2.33$$

Where:

T_i: Intensity of pheromone that belong to switch i

ii. Evaporation

When one group finished their tour, the ant will have its location list and fitting evaluation. The trail intensity can be updated by (Srinivasa *et al.,* 2013):

$$T_i = (1-\rho)T_i \qquad 2.34$$

Where:

ρ : Heuristically defined parameter

iii. Global updating rule

The ant with the best solution at this iteration level will provide the greatest amount of pheromone at the edges represented by (Srinivasa *et al,* 2013):

$$T_i = T_i + (\mathrm{x}-\mathrm{y})\,\mathrm{a} \qquad 2.35$$

Where:

T_i: Intensity of pheromone that belong to switch i

ρ : Heuristically defined parameter

x and y are the cost in the recent and previous tour respectively (Srinivasa *et al,* 2013)

2.1.10.2 Application of Particle Swarm Optimization for Network Reconfiguration

Particle swarm optimization was formulated by Edward and Kennedy in 1995. The thought behind the algorithm was inspired by the social behavior of animal such as bird flocking or fish schooling (Haupt and Ellen, 2002). The basic particle swarm optimization technique is a real value optimization whereby each dimension can take on any real value number.

For each dimension search space, the velocity and position for each particle and the best position for all particles are presented by vectors and described by the equations (2.36) through (2.39) respectively (Khalil *et al,* 2012):

$$\mathrm{X}_i = [X_{i1,} ......X_{id}] \tag{2.36}$$

$$V_i = [V_{i1,} .....V_{id}] \tag{2.37}$$

$$Pb_i = [Pb_{i1} ......Pb_{in}] \tag{2.38}$$

$$Gb_i = [gb_{i1} ....gb_{in}] \tag{2.39}$$

At each iteration, the velocity and position of the particle in d-dimensional are updated by using (Khalil *et al,* 2012):

$$\mathrm{V}_{id}^{k+1} = wV_{id}^{k} + C_1 r_1 (Pb_{id}^{k} - X_{id}^{k}) + \mathrm{C}_2\, r_2 (gb_{id}^{k} - X_{id}^{k}) \tag{2.40}$$

$$\mathrm{X}_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \tag{2.41}$$

Where:

n : Set particle swarm population

V_i: Velocity of particle

Pb_i : Position of particle

Gb_i : Best position of particle

$pop = [\mathrm{X}_1 .....X_n]$

w: Inertia weight

$\mathrm{C}_1\, C_2$: Acceleration constant

$r_1 r_2$: Random values

The velocity vectors for each particle are updated and added to the velocity of the particle position or values. The updated velocity is influenced by the best solution associated with the lowest cost (Haupt and Ellen, 2002). This concept can be applied to solve the problem of reconfiguration in distribution network. The basic steps are itemized as follows **(**Abdel-aziz *et al,* 2010**):**

i. Input data and initialize the parameter of each particle position and velocity based on network parameter
ii. Measure the fitness function and store the best fitness value
iii. Update velocity and position according to equations (2.40) and (2.41)
iv. Perform violation check, if violation detected apply the repair algorithm
v. Decrease the inertia weight and repeat the process until (iv) is satisfied

2.1.11 Application of Multi Objective Evolutional Programming for Network Reconfiguration

Minimization of the power loss is the primary aim of network reconfiguration strategy. Thus power loss is generally selected as the objective function in reconfiguration problem. In multi-objective approach two or more objective functions such as power loss, energy not served, and voltage profile are considered. There is no single best solution with respective to all the cost functions in a multi-objective optimization approach (Zhu, 2009). Therefore, this multi objective evolution approach to reconfiguration can be solved by either using the concept of non-inferiority or Pareto and the weighted cost function.

2.1.11.1 Sum of Weighted Cost Function

The most straightforward approach to multi objective optimization is the weight cost function approach (Haupt and Ellen, 2002).

$$\cos t = \sum_{n=1}^{NL} W_n f_i \qquad i = 1,2,3 \qquad 2.42$$

Where

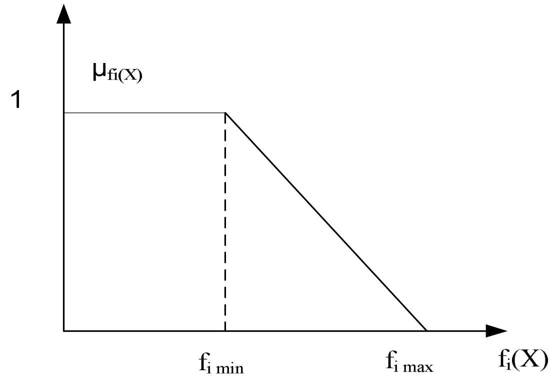
f_i : is the objective function

W_n : weighting factor

The problem with this approach is how to specify the appropriate weighting factor. This approach is not computationally intensive and results in a single best solution which depends on the value of the weighting factor (Haupt and Ellen, 2002).

2.1.11.2 Multi objective Evolution Programming Using Fuzzy Objective Function

A fuzzy set is typically represented by a membership function. A higher member function signifies greater satisfaction with the solution. A typical membership function is the triangular one shown in Figure 2.3



.

Figure 2.3. Fuzzy Membership Function (Zhu, 2009)

The triangular membership function consists of lower and upper boundaries, together with a strictly monotonically decreasing membership function.

$$\mu_{f1(x)} = \begin{cases} 1 & \text{if } f_i \le f_{imin} \\ \dfrac{f_{i\max} - f_i}{f_{i\max} - f_{i\min}} & \text{if } f_{imin} \le f_i \le f_{i\max} \\ 0 & \text{if } f_i \ge f_{i\max} \end{cases} \qquad 2.43$$

$$C(\bar{X}) = \frac{1}{1 + F(\bar{X})} \qquad 2.44$$

$$F(\bar{X}) = Min\{\max[\mu_{fi} - \mu_{fi(x)}]\} \qquad 2.45$$

Where:

μ_{fi}: Expected values of the objective function

$\mu_{fi(x)}$: The actual values of the objective function

$C(\bar{X})$: The fitness function

The state variable x contained in equation (2.44) represents a chromosome of which each gene represent an open switch in the network reconfiguration. The fitness function of x can be defined using equation (2.45). The function $F(X)$ is to minimize the objective with a maximum distance away from its expected value among the multiple objective functions, until the solution reaches the optimum as the fitness value increases Zhu (2009).

2.1.11.3 Pareto Optimal Concept

In multi-objective optimization, there is usually no single solution that is optimum with respect to all the objectives. As such additional information about all the solution can be equally considered satisfactory. If reallocation of resources cannot improve one cost without raising another cost, then the solution is a Pareto optimal one (Haupt and Ellen, 2002).

A pareto-genetic algorithm returns a population with a number front. The population is ordered based on dominance. Solution A dominates B if A has a lower cost than B for at least one objective function and is not worse with respect to the other objective functions. Mathematically x_1 dominates x_2 if and only if $f_1(x_1) < f_1(x_2)$ and $f_2(x_1) \leq f_2(x_2)$ (Haupt and Ellen, 2002).

A solution is Pareto optimal if no other solution dominates that solution with respect to the objective function. Once the solution is found the user can select a single solution based on the post optimization trade-offs rather than weighting the cost (Haupt and Ellen, 2002).

2.1.11.4 Fast and Elitist Non-Dominated Sorting Genetic Algorithm (NSGA II)

The non-dominated sorting genetic approach has a better sorting algorithm incorporating elitism and the use of crowding distance to ascertain its closeness to its neighbor solution (Deb *et al.*, 2002). The population is initialized and sorted based on non-domination into each front. The first front being the completely non-dominated solution in the current population and the second front being dominated by individuals in the first front and so on. Each individuals in the front are assigned fitness values based on the front in which it belongs (Deb *et al*, 2002; Seshadri, 2002). In addition to the fitness values, a parameter called crowding distance is calculated for each individual. Large average crowding distance will result in better diversity in the population (Seshadri, 2002).

Parents are selected from the population via binary tournament selection based on the fitness values and crowding distances. The selected population generates offspring from crossover and mutation operations. The offspring population is combined with the current generation population and selection is performed to set the individual of the next generation. Since all individuals are added in the population, elitism is ensured.

Against the backdrop that non-dominated sorting algorithm is a modified form of conventional genetic algorithm, the key steps are itemized as follows (Kumar *et al,* 2005; Moshtag and Ghasemi, 2013):

i. A random parent population (P_o) of size N is generated (N is the number of solution in P_o).

ii. Generating offspring population (Q_o) of size N by applying usual genetic algorithm operators.

iii. Assign the parent and offspring population at the ith generation.

iv. Create a combined population of both parent and offspring R_t.

v. Perform non-dominated sorting on the combined population R_t. Non-dominated sorting divides the population into different fronts. The solutions in R_t, which do not constraint-dominate each other but constraint-dominate all the other solutions of R_t are kept in the first front or best front (F1). Among the solutions not in the first front, the solutions which do not constraint-dominate each other but constraint-dominate all the solutions are kept in the second front (F2) and so on. The solutions in F1 are assigned rank 1 and so on.

vi. The parent population in the next $(i+1)^{th}$ generation is generated. The solutions belonging to the first front (F1) are considered. If the size of F1 is smaller than N, then all solutions in F1 are included in the parent population (P_{t+1}), while the remaining solution in P_{t+1} are filled up from the rest of the non-dominated fronts in order of their ranks. Thus, if after including all the solutions in F1, the size of parent population (P_{t+1}) is less than N, the solutions belonging to F2 are included in P_{t+1}. The process is repeated until the total number is greater than N. To make the size of parent population (P_{t+1}) exactly equal to N, solutions from the last front are discarded from P_{t+1}. The solution to be discarded are chosen based on the solutions with the lowest crowding distances.

vii. Create the offspring population (Q_{t+1}) by applying crowding tournament selection operator and mutation operator on the current parent population (P_{t+1}). In crowding tournament selection operator, the better solution is selected by comparing two solutions based on their ranks and crowding distances. The solution with the least rank is regarded as the best solution. If both solutions have equal rank, the solution with the highest crowding distance is declared as the best solution. To generate the offspring population, two solutions from the parent population and subsequently the winner are collected. The process is repeated until the number of solutions is less than the population.

viii. Test for convergence.

2.2 REVIEW OF SIMILAR WORKS

The following subsection presents a review of literature with respect to reconfiguration.

Nara *et al.* (1992) developed a minimum loss reconfiguration model using genetic algorithm. The study formulated the problem as complex mixed inter programming problem considering all the constraint in to a single objective function. The effect of constraint violation was added to the objective function to form a penalized function, with constraint multiplier. This multiplier is user defined and leads to the presence of residual violation as such an optimum solution is not guaranteed.

Sarfi *et al.* (1994), developed an approach to loss reduction using set of quantified heuristic rules. The work assigned the candidate switching options numerical index relative to its performance by linearizing the mathematical relation between the line parameters and the relative worth of its operation. The work assigned high weighted factor to the switching option that result in least amount power loss. The work fails to capture the non-linearities of the problem and the use of weighted factor which are highly subjective.

Roytelman *et al.* (1996), presented a multi-objective approach to distribution management system based on two stage. The work adopted the use of branch exchange scheme based on power flow type to determine the suboptimal solution which act the initial starting point. The work fails to acknowledge that incorrect suboptimal solution may lead to local optimal solution. The use of weighted parameter which are highly subjective, thus making it unsuitable for addressing a multi-objective problem. This approach is highly dependent on the initial starting point.

Huang (2002) proposed a fuzzy enhanced genetic algorithm model to reconfiguration. The work transformed the multi-objective functions into a single objective function by using user defined parameters (weighting factor) which are highly subjective. This approach to solving reconfiguration is not suited for a multi-objective problem, because it requires fine tuning the weighted parameter.

Gomes *et al* (2005) presented an algorithm based on heuristic strategy, in which a meshed system was obtained by closing all the tie switches. The switches were then opened successively based on minimum real power loss increase determined by the execution of a power flow scheme. A branch exchange procedure was applied in the neighbor load of the open switch in order to refine the solution. This method required performing successive power flow which added to the computational burdening. The solution also did not guarantee a global optimum solution.

Prasad *et al* (2005) presented a fuzzy mutated genetic algorithm for radial distribution system reconfiguration with multi objective optimization constraints that used the features of basic genetic algorithm with the aim of reducing the system losses. The constraint is formulated into the objective function. The method was based on reducing the multi objective function into a single objective function which tended to avoid the complexity involved in solving a multi objective problem, and getting the solution stuck into a local minimum. This technique is suitable for a convex Pareto front.

Prasad *et al.* (2007) presented a methodology of solving network reconfiguration problem for load balancing, using genetic algorithm. The model was achieved by transferring load from a heavily loaded feeder to a lightly loaded feeder to as to achieve loss reduction. They adopted network branch load balance index, a measure of how a branch can be loaded without exceeding the rated capacity of the branch and the balancing index that indicated load on the entire system. The work tried to set branch load balancing indices be more or less the same value and equal to the entire load balancing index. Its major limitation was that it was impossible to transfer load on a feeder to another without violating the feeder constraint.

Srinivasa and Narasimham (2009) developed a new search approach based on heuristic technique to distribution network reconfiguration. The work computed the voltage difference for all the tie switches in the network and checked to determine if the voltage difference was greater than a specified value. The major limitation of this work was that it required continuous power flow for every switching configuration, thus making this approach time consuming especially for large distribution network and the solution did not guarantee an optimum one.

Kaiyu (2010) presented a study of an economic operation and planning of distribution system sources in a radial distribution network. The work adopted the use of forward/backward technique to perform power flow and employ minty algorithm to reduce the number of spanning trees and thus reduced the computational time. It used the minty algorithm to determine the optimal location of switches and also to determine the size and placement of capacitor, distributed generation within a radial distribution network with aim of minimizing system losses and planning for distribution network expansion. The model was developed for a static distribution network, with a view to determining location of various substation in order to minimal loss.

Zhang *et al.* (2012) presented oilfield distribution network reconfiguration with distributed generation. The work employed the use of simulated annealing and vaccine based algorithm to determine the optimum location of tie and sectionalizing switch within a radial network to minimize loss. The work adopted the use of Boltzmann simulating annealing operator to select new solutions with the advantage of joining some inferior solution in to the evolution and diversity population remained preferably in order to avoid local optimum solution. It used vaccine immune algorithm to obtain estimate of optimal individual gene, which is obtained by prior knowledge of evolution. Its major setback was that the vaccine extraction method did not consider all genes, as such some information of the global solution still existed in other genes, and did not guarantee an effective solution. The algorithm is highly sensitive to the control parameter and shows poor correlation between the control parameter and the objective function.

Kiran *et al.* (2012) presented particle swarm optimization approach to reconfiguration of a radial distribution network with the aim of achieving minimal loss. The works considered local best particle point as well as its neighboring particle value before arriving at the best particle. The work adopted the use of a socio-cognitive learning, where each particle learns from the experience of neighboring particles that have a better fitness than itself. Though the rationale for considering local best was to widen the solution search space through temporary worsening the solution, with aim of achieving a better solution. This approach led to several local optimal solutions and was not suited for large distribution networks.

Rashtchi *et al.* (2012) presented network reconfiguration using ant colony search algorithm for radial distribution system with objective of loss minimization in the presence of operational constraints. The work developed an algorithm based on natural behavior of ant and how they search for food, to determine the optimal position of tie and sectionalizing switches to achieved minimal loss. This algorithm employed a positive feedback that ensure rapid search of a global solution and distributed computation. Each switch in a group is selected, other subsequent switch selection depends on the intensity of pheromone that relate to the switch. Also fitting evaluation is performed on the switch option and the possible switch option will provide the greatest pheromone. This model did not guarantee an optimum solution due to its high dependency on the intensity pheromone.

Cheraghi *et al.* (2012) presented an efficient fast method for determining minimal loss configuration base on sensitivity analysis for minimal loss. They developed an algorithm based on real power loss sensitivities with respect to the impedance of the candidate branch. The optimization was formulated as a non-linear optimization problem with real and integer variable. After calculating the sensitivities the candidate branch which can be opened were ranked based on their sensitivity and are arranged in ascending order. The top rank branch is first opened and all the remaining switches were closed. If any violation is detected the switch configuration is considered infeasible and so on. This algorithm failed to acknowledge that there are a lot of branches in a typical distribution network. This approach to solving reconfiguration problem could require constantly running power flow, high infeasible configuration and the solution did not guarantee an optimal solution.

Yang *et al.* (2012) developed an approach to reconfiguration using multi-objective model considering reliability index. The work adopted a decoding process based on random spanning tree strategy to minimize the chance of unfeasible solution and a network reduction technique so as to simplify the problem and to reduce the computation time. The drawback of this approach is that this technique employed the use of other search based algorithm as such this add to the complexity of the model.

Tomoiaga *et al.* (2013) developed a multi-objective approach to reconfiguration considering the active power loss and system average interruption frequency index of the network. The work adopted the use of binary string to represent each and every branch or switch, thus adding to the computational burden and was not suited for a distribution network with a high amount of branches.

To overcome the identified limitations as stated in the literature review and to capture the real essence of a typical distribution system, an algorithm will be developed to solve the problem of network reconfiguration for a typical radial distribution network using a multi-objective optimization technique (NSGA II) considering active power loss and total voltage deviation with the aim of achieving loss reduction and improving voltage profile. The algorithm considered only the open switch (tie switch) in order to reduce the search space and enhance the convergence time.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter present a details mathematical model equation for computing parameters of the distribution network, load model, model of the distributed generation, problem formulation and a detail of the developed non-dominated sorting genetic algorithm (NSGA II).

3.2 Model Equation of the Two Bus Distribution Network

Considered a n bus distribution network, reduced to a two bus distribution network as contained in Figure 3.1.

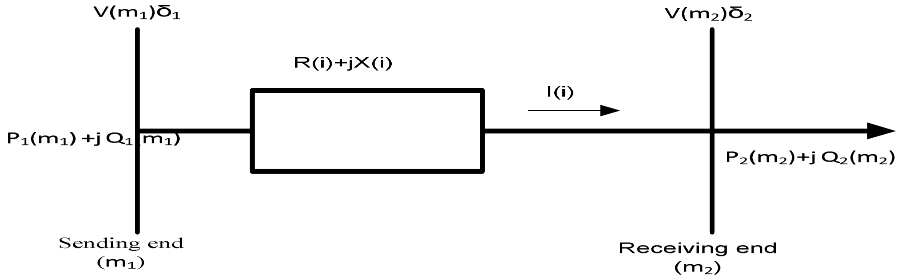


Figure 3.1 Single-Line of a Two Bus Distribution Network

Applying Kirchhoff's law

$$|V(m_2)|\angle\delta_2 = |V(m_1)|\angle\delta_1 - I(i)(R(i) + jX(i)) \qquad 3.1$$

$$I(i) = \frac{P_2(m_2) - jQ_2(m_2)}{V^*(m_2)} \qquad 3.2$$

Let

$$V(m_2) = |V(m_2)| \angle \delta_2 \qquad 3.3$$

$$V(m_1) = |V(m_1)| \angle \delta_1 \qquad 3.4$$

$$Z(i) = |Z(i)| \angle -\phi = R(i) + jX(i) \qquad 3.5$$

$$I(i) = |I(i)| \angle -\theta \qquad 3.6$$

Substituting equations (3.3), (3.4), (3.5) and (3.6) into equation (3.1)

$$|V(m_2)|(\cos\delta_2 + j\sin\delta_2) = |V(m_1)|(\cos\delta_1 + j\sin\delta_1) - |I(i)|(\cos\theta + j\sin\theta)(R(i) + jX(i)) \qquad 3.7$$

$$|V(m_2)|\cos\delta_2 + j|V(m_2)|\sin\delta_2 = |V(m_1)|\cos\delta_1 + j|V(m_1)|\sin\delta_1 - (|I(i)|\cos\theta + j|I(i)|\sin\theta)(R(i) + jX(i)) \qquad 3.8$$

$$\begin{aligned}|V(m_2)|\cos\delta_2 + j|V(m_2)|\sin\delta_2 = |V(m_1)|\cos\delta_1 + j|V(m_1)|\sin\delta_1 - [|I(i)|R(i)\cos\theta + j|I(i)|X(i)\cos\theta + \\ j|I(i)|R(i)\sin\theta - |I(i)|X(i)\sin\theta]\end{aligned} \qquad 3.9$$

Separating equation (3.9) into real and imaginary part

$$|V(m_2)|\cos\delta_2 = |V(m_1)|\cos\delta_1 - |I(i)|(R(i)\cos\theta + X(i)\sin\theta) \qquad 3.10$$

$$|V(m_2)|\sin\delta_2 = |V(m_1)|\sin\delta_1 - |I(i)|(X(i)\cos\theta - R(i)\sin\theta) \qquad 3.11$$

Taking the square of equation (3.10) and (3.11) and adding the equation yields:

$$\begin{aligned}|V(m_2)|^2 = |V(m_1)|^2 - 2|I(i)||V(m_1)|\cos\delta_1(R(i)\cos\theta + X(i)\sin\theta) - \\ 2|I(i)||V(m_1)|\sin\delta_1(X(i)\cos\theta - R(i)\sin\theta) + |I(i)|^2 Z^2(i))\end{aligned} \qquad 3.12$$

$$\begin{aligned}|V(m_2)|^2 = |V(m_1)|^2 - 2|I(i)||V(m_1)|[R(i)(\cos\delta_1\cos\theta - \sin\delta_1\sin\theta) + \\ X(i)(\cos\delta_1\cos\theta + \sin\delta_1\sin\theta)] + I(i)^2 Z^2(i)\end{aligned} \qquad 3.13$$

Substituting equation (3.5) into equation (3.13)

$$|V(m_2)|^2 = |V(m_1)|^2 - 2|V(m_1)||I(i)||Z(i)|[\cos(\delta_1 + \theta)\cos\phi + \sin(\delta_1 + \theta)\sin\phi] + |I(i)|^2|Z(i)|^2 \qquad 3.14$$

Since ϕ is small and upon simplification

$$\text{Cos}\ (\phi - \delta_1 - \theta) \approx 1 \qquad 3.15$$

From equation (3.2), the branch current can be expressed as:

$$|I(i)|^2 = \frac{\{P_2(m_2)\}^2 + \{Q_2(m_2)\}^2}{|V(m_2)|^2} \qquad 3.16$$

Substituting equations (3.15), (3.16) into (3.14) and simplifying the expression yields:

$$\left|V(m_2)\right|^4 = \left|V(m_1)\right|^2 \left|V(m_2)\right|^2 - 2\left|V(m_1)\right|\left|V(m_2)\right|\left|Z(i)\right|\sqrt{P_2^2(m_2) + Q_2^2(m_2)} + (P_2^2(m_2) + Q_2^2(m_2))(R(i)^2 + X(i)^2) \qquad 3.17$$

Upon simplification of equation (3.17), the receiving-end bus (Bhujel *et al.,* 2012):

$$\left|V(m_2)\right| = \sqrt{\left[\{(P_2(m_2)R(i) + Q_2X(i) - 0.5|V(m_1)|^2)^2 - |Z(i)|^2 (P_2^2(m_2) + Q_2^2(m_2)\}^{1/2} - (P_2(m_2)R(i) + Q_2(m_2)X(i) - 0.5|V(m_1)|^2\right]}$$

3.18

Equation (3.18) is used to obtain voltage magnitude for a distribution network taking two nodes (n-1 and n) at a time.

The branch active and reactive power loss is as follows:

$$P(i) = \left|I(i)\right|^2 R(i) \qquad 3.19$$

$$Q(i) = \left|I(i)\right|^2 X(i) \qquad 3.20$$

Substituting equation (3.16) into equation (3.19) and (3.20)

$$P(i) = \frac{\{P_2(m_2)\}^2 + \{Q_2(m_2)\}^2}{|V(m_2)|^2} * R(i) \qquad 3.21$$

$$Q(i) = \frac{\{P_2(m_2)\}^2 + \{Q_2(m_2)\}^2}{|V(m_2)|^2} * X(i) \qquad 3.22$$

The total branch active and reactive power of the network can be obtained using:

$$P_t = \sum_{i=1}^{n-1} \frac{\{P_2(m_2)\}^2 + \{Q_2(m_2)\}^2}{|V(m_2)|^2} * R(i) \qquad 3.23$$

$$Q_t = \sum_{i=1}^{n-1} \frac{\{P_2(m_2)\}^2 + \{Q_2(m_2)\}^2}{|V(m_2)|^2} * X(i) \qquad 3.24$$

The voltage stability index for each node in the network can be obtained using:

$$VI_{index} = \sqrt{\frac{(V_{rate} - V_i)^2}{n}} \tag{3.25}$$

The total voltage deviation for the network can be obtained using:

$$TVD = \sum_{i=1}^{n} (V_{rate} - V_i) \tag{3.26}$$

3.3 Load Model

A balanced load can be modeled as either a constant power, constant current, constant impedance or an exponential load. The general expression for the composite type of load are given by equations (3.27) - (3.28) (Ghosh and Sonam, 2008).

$$P(m_2) = P_n\left[a_0 + a_1V(m_2) + a_2V^2(m_2) + a_3V^{e1}(m_2)\right] \tag{3.27}$$

$$Q(m_2) = Q_n\left[b_0 + b_1V(m_2) + b_2V^2(m_2) + b_3V^{e2}(m_2)\right] \tag{3.28}$$

For all load type, the equation (3.27) and (3.28) are modelled using:

$$a_0 + a_1 + a_2 + a_3 = 1.0 \tag{3.29}$$

$$b_0 + b_1 + b_2 + b_3 = 1.0 \tag{3.30}$$

3.3.1 Constant Power Load (CP)

Substituting, $a_0 = b_0 = 1$ and $a_i = b_i = 0$, for $i = 1,2,3$, the equations (3.27) and (3.28), yield an expression for constant power load model given by equation (3.31) – (3.32).

$$P(m_2) = P_n \qquad 3.31$$

$$Q(m_2) = Q_n \qquad 3.32$$

3.3.2 Constant Current Load (CI)

Substituting $a_1 = b_1 = 1$, and $a_i = b_i = 0$, for $i = 0,2,3$, the equations (3.27) and (3.28), yields the expression for the constant current load model given by equation (3.33)-(3.34).

$$P(m_2) = P_n V(m_2) \qquad 3.33$$

$$Q(m_2) = Q_n V(m_2) \qquad 3.34$$

3.3.3 Constant Impedance Load (CZ)

Substituting $a_2 = b_2 = 1$, and $a_i = b_i = 0$, for $i = 0,1,3$, the equations (3.27) and (3.28), yields the expression for the constant impedance load model given by equation (3.35)-(3.36).

$$P(m_2) = P_n V^2(m_2) \qquad 3.35$$

$$Q(m_2) = Q_n V^2(m_2) \qquad 3.36$$

3.3.4 Composite Load

Composite load model is a combination of either CP, CI or CZ. For exponential load model, substituting $a_3 = b_3 = 1$, and $a_i = b_i = 0$, for $i = 0,1,2$, the equations (3.27) and (3.28), yields the expression for an exponential load model given by equation (3.37)-(3.38).

$$P(m_2) = P_n[V^{e1}(m_2)] \tag{3.37}$$

$$Q(m_2) = Q_n[V^{e2}(m_2)] \tag{3.38}$$

3.4 Modelling of Distributed Generation

The inclusion of a distributed generation to the radial system results in a network that may not be strictly radial (weakly meshed network) and their feeders may carry power whose direction changes as a function of the loading and distributed generation levels. In distribution system power flow analysis, distributed generation are model as either constant active and reactive power (PQ) or constant active power and voltage (PV) model.

3.4.1 Constant Active and Reactive Power Model

The constant active and reactive power models are identified with a constant power load model except that the current is injected into the bus. (Eminoglu and Hocaoglu, 2008). In this model the distributed generation is modelled as a negative load which alters the direction of flow of current in the radial system (acting as generator). In this model the total load at the bus where the distributed generation is situated is increased, but its challenge is its ability to handle or control their reactive power output in order to maintain a specific terminal voltage. The constant active and reactive power models are expressed using:

$$P(m_2) = -P_n \tag{3.39}$$

$$Q(m_2) = -Q_n \tag{3.40}$$

Where:

P_n : Active load at node n

Q_n : Reactive load at node n

3.4.2 Constant Active Power and Constant Voltage Model

Distributed generation should have the capability of controlling their reactive power within some limit, so as to be able to control their voltage within the bus in which they are located (Bhujel *et al*, 2012). When modeled as a constant active power and constant voltage source, the total reactive power to keep the voltage at specific value can be computed by using:

$$Q_{gen}(m_2) = Q_{ref} - Q_n \qquad 3.41$$

Where:

$Q_{gen}(m_2)$: Generated reactive power

Q_{ref} : Reference reactive power

Q_n : load reactive power to maintain specific terminal voltage

For a bus in which a distributed energy source is connected, the reactive power is checked to ensure that it is within a specified limit. If the reactive power is greater than the stated limit the reactive power of the distributed generation is set as the maximum reactive power of the bus and the distributed generation is set as a constant load bus (Bhujel *et al*, 2012; Eminoglu and Hocaoglu, 2008). As contained in the work of Chowdhury *et al,* (2009), for practical distributed energy source connected to distribution network, they are normally modelled as a constant active power and reactive power (PQ) node owing to the fact that in this mode, the bus voltage and frequency are controlled solely by the network. Upon disconnection from the network, the energy sources are capable of operating in an independent power island, having full control of their frequency and voltage. This work adopt the use of distributed generation (DG) model as constant PQ load as contain in the work of Chowdhury *et al,* (2009).

3.5 Distributed Generation Placement

The best possible location of distributed generation placement can be obtained by injecting at most 20% of the distributed energy source at each bus until the node with the least voltage stability index is taken as the best possible location for siting distributed generation in the network (Subrahmanyam *et al*, 2009). The node with the least voltage stability index is taken as the best node for distributed generation placement for maximal benefit. For this work the size of distributed generation placed on the network is less 10% of the total capacity of the feeder.

3.6 Developed Approach

The methodology adopted is divided into three phases. This includes collection of data, determination of the initial configuration and the reconfiguration process.

3.6.1 Data Collection

Data was collected from Power Holding Company of Nigeria Sabo Business unit. The data captures the network diagram, rating of each transformer, capacity of each feeder and span length between each connected transformer. The load data that was utilized was based on the following assumption:

i. The real and reactive demand at each node is taken as (0.8*kVA and 0.6*kVA) of the transformer rating respectively

ii. The network was assume to be a balance system with a power factor of 0.8

iii. Effect of line charging capacitance was neglected due to short nature of distribution network

The line and load data was converted into case data as contained in Appendix A1-A4.

3.6.2 Determination of Initial Configuration

Certain applications, particularly in distribution automation and optimization of a power system (reconfiguration), require load flow solution and in these applications, it is very important to solve the load flow problem as efficiently as possible (Eminoglu *et al,* 2007). Several approaches such as Gauss-Seidel, Newton-Raphson, Fast decoupled methods were employed to solve the problem of load flow for a network. These methods were criticized due to fact a distribution network has some characteristic such as radial structure, high resistance to reactance ratio, large number of nodes, ill-conditioned and unbalanced nature of loads. These features need to be taken into account while carrying out the power flow analysis of a distribution system (Bhutad *et al,* 2003).

Due to the radial structure of the distribution network, conventional methods may provide inaccurate results and may not converge (Subrahmanyam *et al,* 2010).The high number of buses and branches of the distribution network makes the direct use of the aforementioned techniques unsuitable and inefficient for load flow analysis of distribution systems as such this work adopted the use of forward and backward sweep process, with a sequential numbering scheme (Ghosh and Ddas *et al,* 1994; Ghosh and Sonam, 2008). The forward/backward sweep based approach adopted the use of an algorithm to determine the number of node belonging to main lines, lateral, sub-lateral and minors similar to the methods of Ddas *et al,* (1994) and Ghosh and Das, (1999).

The forward sweep is mainly used for the node voltage calculation from the sending end to the receiving end of the feeder, while backward sweep is primarily used for the branch current or power summation from the receiving end to the sending end of the feeder (Eminoglu and Hacaoglu, 2008). The initial configuration entails performing power flow with and without distributed generation. The details of the steps in determining the initial configuration are contained in Figure 3.1

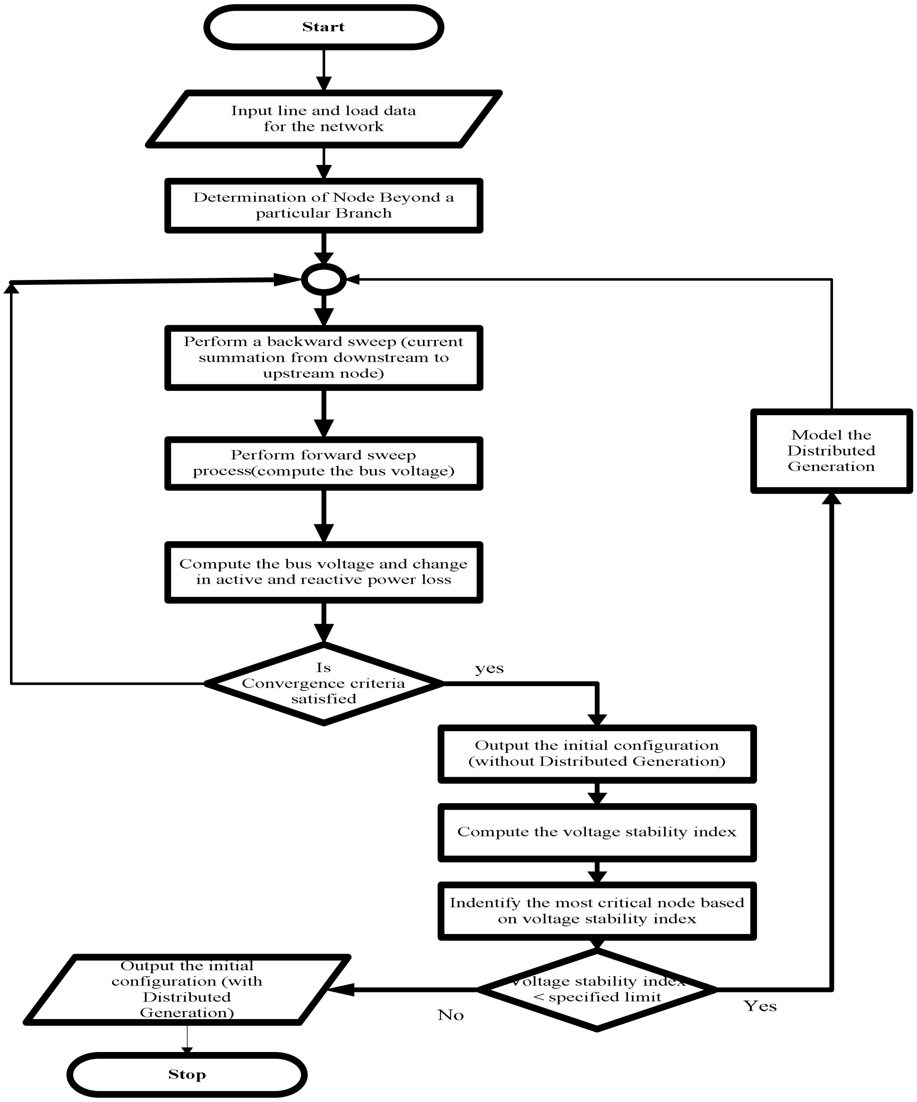


Figure 3.2 Sequential Steps for Determining the Initial Configuration (with and without DG)

The details of the developed Matlab code are contain in Appendix B1-B2.

3.6.2 Formulation of the Problem

In this work the following two objective functions are considered:

i. Minimization of total power losses,

ii. Minimization of total voltage deviation

(A). Minimization of Total Power Losses

The power loss reduction is the primary aim of the reconfiguration of the distribution system. Hence it is considered as the first objective function. The power loss reduction can either be expressed in terms of current variable by using:

$$P_{Loss} = \min \sum_{i=1}^{N-1} kI^2(i)R(i) \qquad 3.41$$

(B). Minimization of Total Voltage Deviation

This bus voltage describes the security and service quality indices for the distribution system. The total voltage deviation is described by:

$$TVD = \min \sum_{i=1}^{N} (V_{rate} - V_i) \qquad 3.42$$

Lower TVD , indicate a higher quality voltage profile and better security of the considered network configuration. These objective functions are subjected to constraint, which must be satisfied (Yang *et al.,* 2012):

i. Branch current limit

$$I_{\min}(i) \le I(i) < I_{\max}(i) \qquad 3.43$$

ii. Power Flow constraint

$$g(P_i, Q_i, V_i, \theta_i) = 0 \tag{3.44}$$

iii. Radial structure constraint

Presence of no loop and islanding in the distribution network.

The methodology adopted for this research work is based on enhanced non-dominated sorting genetic algorithm (NSGA II), due to its better sorting algorithm, crowding distance and its ability to generate sets of solution (Deb *et al*,2002; Seshadri, 2002). The developed NSGA II was implemented using Matlab power simulation package (Matpower 4.2) developed by Zimmerman and David (1997). The detail steps are outlined as follows:

i. Close all tie switches or normally open switches to form a loop or mesh network.
ii. Determination of possible branches that constitute each loop
iii. Generation of random population based on the numbers of loop and branches in the network.
iv. Constraint checking is perform to ensure that generated population are void from loops and islanding. The constraint check comprises of checking for loops, islanding, searching the network to ensure that generated population have radial structure and evaluating to ensure load flow solution.
v. Evaluation of the objective functions as contained in equation (3.41) and (3.42). The details of the program is contained in Appendix C1.
vi. The non-dominated sorting of is performed on individual based on principle of non-domination. The non-dominated sorting ranks this individuals based on the value of it

computed crowding distance and placing each individual into different fronts. The crowding distance of each individuals in same front is sorted and compared based on their objective function. A crowded comparison operator was adopted for this work.

vii. Selection operation is performed. Once individual are sorted based on non-domination and crowding distance, the selection operator adopted is based on tournament selection crowded comparison operator.

viii. Recombination and crossover operators: The individual population is combined with the current generation population and selection is performed to set the individuals of the next generations.

ix. Test for convergence

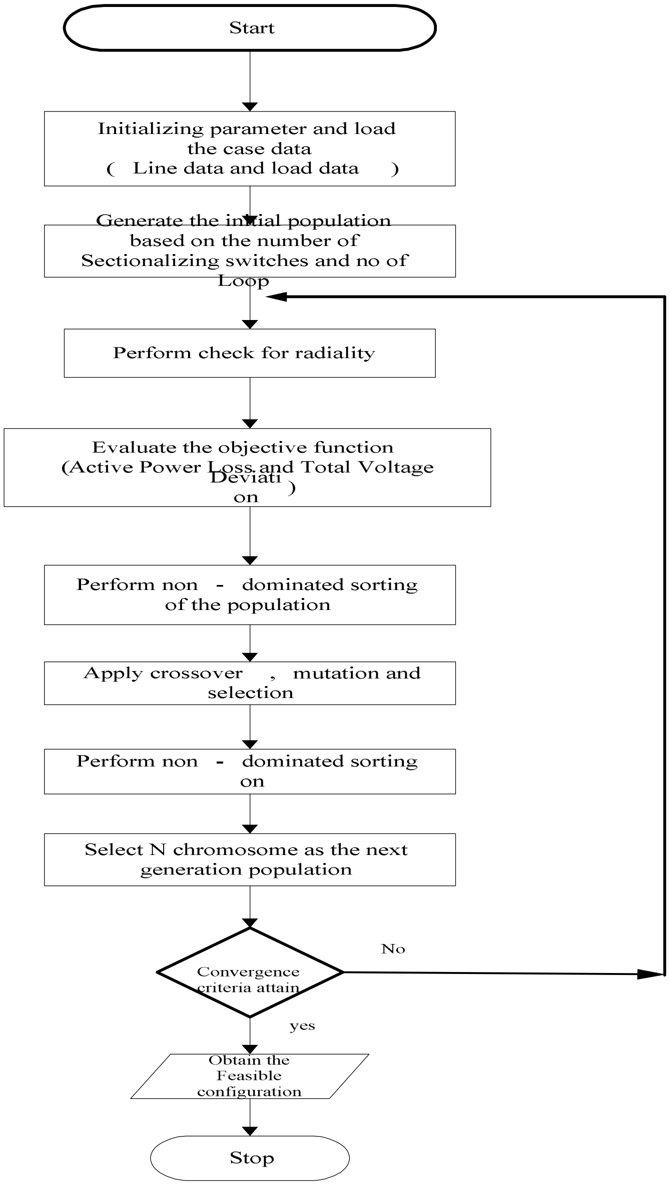


Figure 3.3 Flowchart of the Developed Non-dominated Sorting Genetic Algorithm II

The details of the Matlab implementation of this steps are contained in Appendix C1-C7.

3.7 Conclusion

This chapter has shown the mathematical model of a two bus distribution network, load and distributed generation model, development of a power flow based on forward/backward, problem formulation and development of reconfiguration model based on the enhanced non-dominated sorting genetic algorithm.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This section discusses the results obtained from the standard IEEE network before and after reconfiguration. The results obtained after application of reconfiguration model on the Zaria distribution network are also analyzed and discussed.

4.2 Comparative Study Before and After the Application of Reconfiguration

The developed reconfiguration model was validated using a standard 33-Bus distribution network with line and load data as contained the works of Baran and Wu (1989) and Srinivasa *et al.,* (2009). The 33 IEEE bus test feeder comprises of 33 nodes, with 5 tie switches, 32 sectionalizing switches as shown in Figure 4.1.

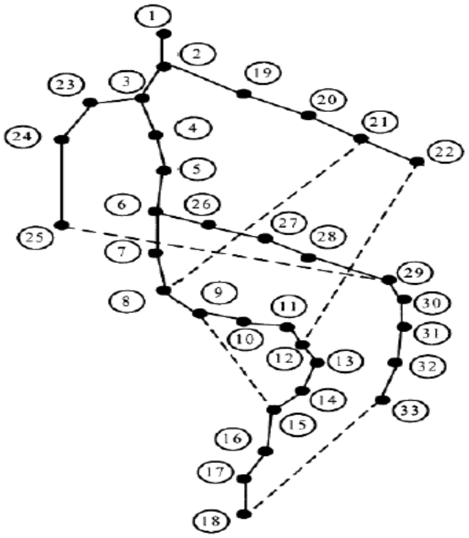


Figure 4.1 Standard 33 Bus Distribution Network (Baran and Wu, (1989); Le-Roux, 2013)

By closing the five tie switches, the five loops are formed in the network and the number of branches in the loop constitute the search space as contained in Table 4.1.

Table 4.1 Meshed loop of the Standard 33 Bus Network

Loop Number	Branches
Loop1	2, 3, 4, 5, 6, 7, 33, 20, 19, 18
Loop2	8, 9, 10, 11, 35, 21, 20, 19, 18, 2, 3, 4, 5, 7
Loop3	37, 28, 27, 26, 25, 5, 4, 3, 22, 23, 24
Loop4	9, 34, 14, 13, 12, 11, 10
Loop5	25, 26, 27, 28, 29, 30, 31, 32, 36, 17, 16, 15, 34, 8, 7, 6

The comparative studies of the standard IEEE network before and after reconfiguration are discussed based on the results obtained in Table 4.2.

Table 4.2 Comparison of the Proposed Approach with Other Algorithms

33 Bus System	Switching state	Base Power Loss (kW)	Active power Loss (kW)	% Reduction in Power Loss
Initial configuration	33 34 35 36 37	202.8	202.8	――
Proposed Approach	8 14 25 33 32	204.68	139.4	31.89
Baran and Wu, (1989)	7 9 14 32 37	202.2	139.5	31.01
Srinivasa *et al.,*2009	33 14 8 32 28	202.71	135.78	33.01
Moshtagh and Ghasemi, (2013)	37 32 14 9 7	203.45	140.17	31.10
Rashtchi and Pashai (2012)	32 14 9 37 7	199.3	136.5	31.51

Table 4.2 shows a comparison of the developed non-dominated sorting genetic algorithm with other developed algorithm. The empirical result shows that the developed approach is in conformity with other algorithm. The optimal location of the tie switches was found to be 8, 14, 25, 33, and 32, with reduction of 31.89% in active power loss as compare to the active power loss of the initial configuration after reconfiguration.

4.2.1 Gaskiya 16-Bus Network

Reconfiguration was implemented on Gaskiya feeder extracted from Zaria distribution network as contain in Figure 4.2. The network consist of 16 nodes, with 2 tie switches, 15 sectionalizing switches. The network data is contained in Appendix A1. By closing the tie switches, the two loops are formed in the network and the number of loops formed the search space. Table 4.3 contains the branches that forms the loop. The details of this result are discussed in section 4.2.5

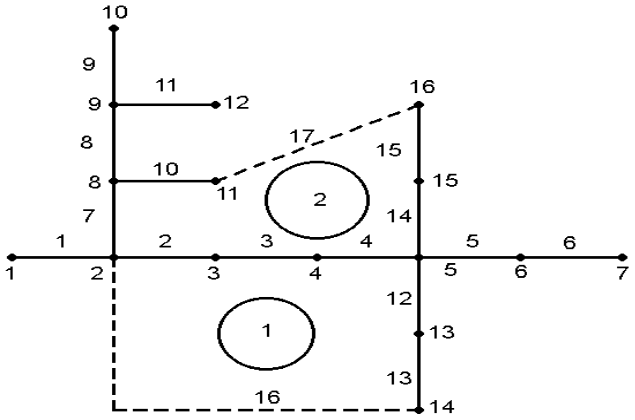


Figure 4.2 Single-Line Diagram of Gaskiya 16-Bus Distribution Network

Table 4.3 Meshed Loop of the 16-Bus Network

Loop Number	Branches
Loop1	2, 3, 4, 14, 15, 16, 10, 7
Loop2	2, 3, 4, 12, 13. 17

4.2.2 Railway 19-Bus Network

The network consists of 19 buses, with 18 sectionalizing and 3 tie switches as shown in Figure 4.3. The network data is contained in Appendix A2. Closing the tie switches forms three loops in the distribution and this forms the search space (number of branches to be open) as seen in Table 4.4.

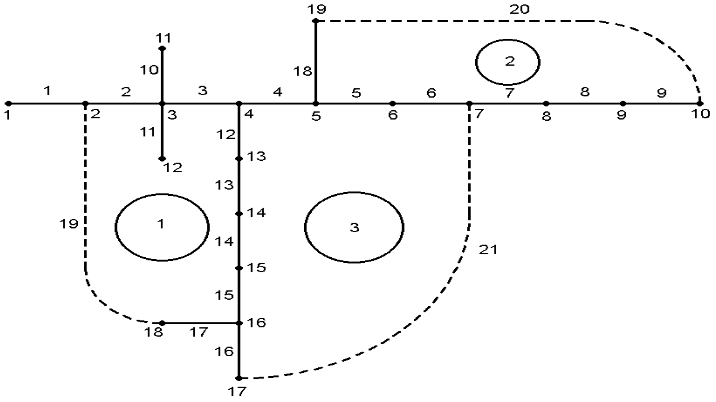


Figure 4.3 Single-Line Diagram of Railway 19-Bus Distribution Network

Table 4.4 Meshed Loop of the 19-Bus Network

Loop Number	Branches
Loop 1	2, 3, 12, 13, 14, 15, 17, 19
Loop 2	4, 5, 6, 20, 16, 15, 14, 13, 12
Loop 3	5, 6, 7, 8, 9, 21, 18

4.2.3 Sabo 29-Bus Distribution Network

The network consist of 29 nodes, with 3 tie switches, 28 sectionalizing switches as shown in Figure 4.4. The network data is contained in Appendix A3 By closing the three tie switches, the three loops are formed in the network and the number of branches form the search space or possible switches to be opened as seen in Table 4.5.

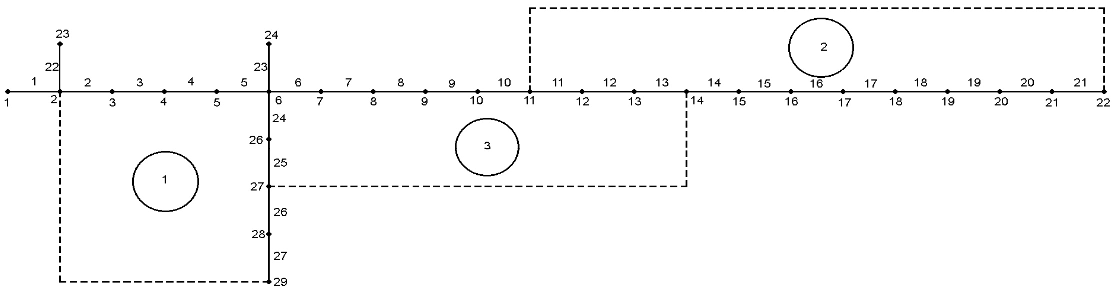


Figure 4.4 Single-Line Diagram of Sabo 29-Bus Distribution Network

Table 4.5 Meshed Loop of the 29-Bus Network

Loop Number	Branches
Loop1	2, 3, 4, 5, 24, 25, 26, 27, 28, 29
Loop2	11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 30
Loop3	6, 7, 8, 9, 10, 11, 12, 13, 31, 25, 24

4.2.4 Canteen 50-Bus Network

The network consists of 50 nodes, with 3 tie switches, 49 sectionalizing switches as shown in Figure 4.5. The network data is contained in Appendix A4. By closing the three tie switches, the three loops are formed in the network and the number of branches in the loop constitute the search space (possible switches to be open) as contained in Table 4.6.

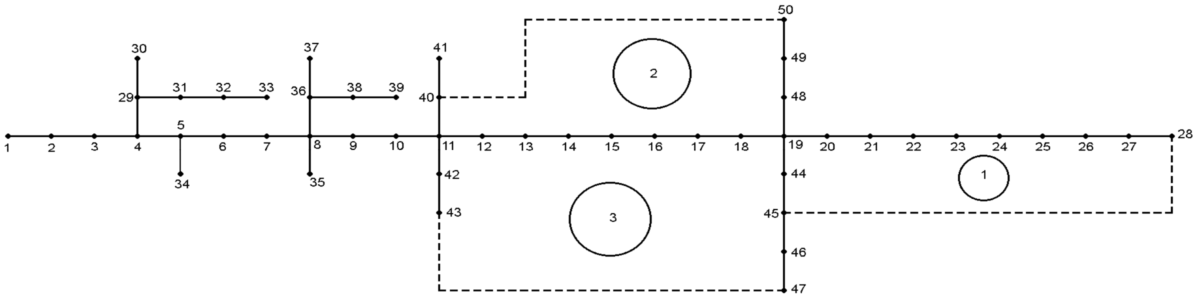


Figure 4.5 Single-Line Diagram of Canteen 50-Bus Distribution Network

Table 4.6 Meshed Loop of the 50-Bus Network

Loop Number	Branches
Loop1	19, 20, 21, 22, 23, 24, 25, 26, 27, 50, 44, 43
Loop2	11, 12, 13, 14, 15, 16, 17, 18, 47, 48, 49, 51, 39
Loop3	11, 12, 13, 14, 15, 16, 17, 18, 43, 44, 45, 46, 52, 42, 41

4.2.5 Discussions

Comparative studies of the distribution networks before and after reconfiguration are discussed based on optimization result obtained as contained in Table 4.7. Based on empirical results obtained from the analysis carried out on the Gaskiya 16-Bus distribution network. The location of tie switches was found to be 12 and 14 with an reduction of 37.64% and 28.84% in both active power loss and total voltage deviation respectively as compared to the active power loss and total voltage deviation of the initial system (initial configuration) after reconfiguration. For Railway 19-Bus distribution network, the optimal location of tie switches was found to be 14. 16 and 18 with a reduction of 18.12% and 9.02% in active power loss and total voltage deviation respectively as compared to the active power loss and total voltage of the initial system (initial configuration) after reconfiguration. For Sabo distribution network, the location of tie switches was found to be 25, 20 and 11 with a reduction of 39.12% and 37.81% in active power loss and total voltage deviation respectively as compared to that of the initial configuration after reconfiguration. While for the 50-Bus network, the optimal location of tie switches was obtained to be 16, 23 and 43, with a reduction in both 23.42% and 10.72% in active power loss and total voltage deviation respectively as compared to the active power loss and total voltage of the initial configuration.

Table 4.7 Summary of the Results Obtained Before and After Reconfiguration

	Gaskiya 16 Bus Network			Railway 19 Bus Network			Sabo 29 Bus Network			Canteen 50 Bus Network		
	Prior to Reconfiguration	With DG	After Reconfiguration	Prior to Reconfiguration	With DG	After Reconfiguration	Prior to Reconfiguration	With DG	After Reconfiguration	Prior to Reconfiguration	With DG	After Reconfiguration
Tie Switches	16, 17	16,17	12, 14	19, 20, 21	19, 20, 21	14, 16, 18	29, 30, 31	29, 30, 31	25, 20, 11	50, 51, 52	50, 51, 52	23, 16, 43
Active Power Loss(kW)	55.32	40.83	33.05	17.22	13.90	14.0	120.08	107.8	73.0	508.0	466.95	389.0
Reactive Power (kVAR)	29.47	29.0	20.5	10.11	9.88	9.88	90.0	80.0	71.0	330.3	290.0	272.0
Total Voltage Deviation (pu)	0.220	0.2063	0.1577	0.2340	0.2150	0.2152	0.9949	0.883	0.6188	4.7482	4.412	4.6410
Minimal Voltage (pu)	0.975	0.98	0.9840	0.983	0.986	0.985	0.938	0.941	0.980	0.8170	0.836	0.8950
% reduction in active power Loss(kW)	___	26.19	37.64	___	19.22	18.12	___	10.23	39.21	___	8.01	23.42
% Reduction Total voltage deviation	___	6.22	28.96	___	8.12	8.12	___	11.25	37.81	___	7.10	10.72

4.3 Analysis of the Voltage Profile

The voltage profile before and application of reconfiguration is discussed based on the results of the power flow obtained for the distribution network.

4.3.1 Gaskiya 16-Bus Network

The voltage profile of the 16-Bus distribution network prior to reconfiguration is shown in Figure 4.6 (a). The voltage drops as the number of buses (node) increases this is as a result of increase in load across the feeder. The sudden rise in voltage across nodes 8-12, is as result of proximity (lateral) to node 3. With a 300kW DG model as a constant PQ load placed at node 11, an improvement in voltage profile was obtain for the network due to reduction in active power loss as shown in Table 4.7. The noticeable improvement is as result of reduction in active power loss.

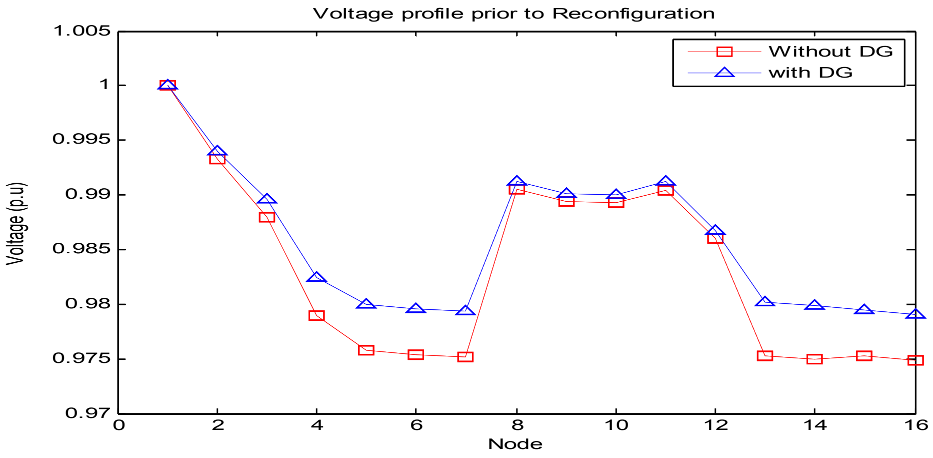


Figure 4.6 (a) Voltage profile for Gaskiya 16-Bus Network, Prior to Reconfiguration

With reconfiguration, the voltage profile is shown in Figure 4.6 (b), the following observation were realized on the Gaskiya 16-Bus distribution network. A noticeable improvement in voltage was recorded across the network due to considerable reduction of 37.64% in active power loss as compare to the active power loss initial configuration. The slight degradation in voltage across nodes 8-12, is as a result of slight increase in the branch active power loss as compare to the branch active power loss of the initial configuration.

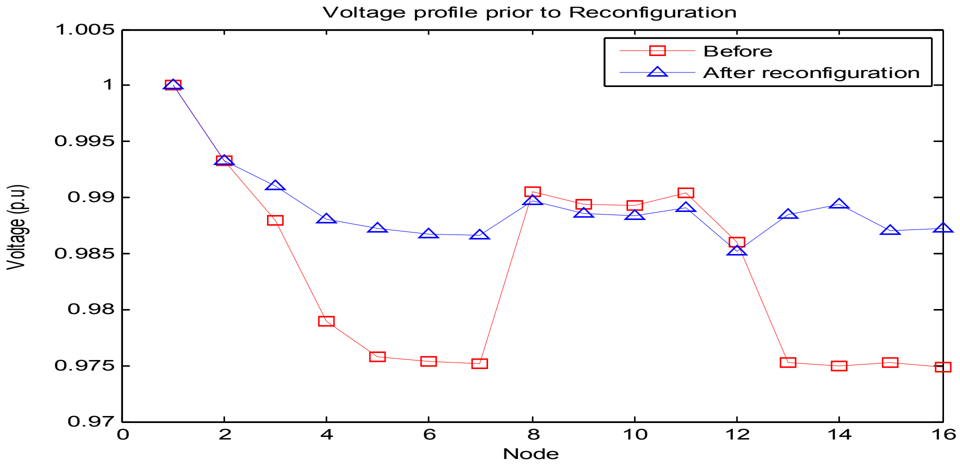


Figure 4.6 (b).Voltage Profile for Gaskiya 16-Bus Distribution Network Before and after Reconfiguration

4.3.2 Railway 19-Bus Network

The voltage profile of the 19-Bus distribution network prior to reconfiguration is shown in Figure 4.7 (a), shows that the voltage decreases as the number of buses (node) in the network increases. The sudden rise in voltage across nodes 11-12 and 13-15 are as a result of proximity (lateral) to node 3 and 4 respectively. With 120kW DG model as a PQ load, placed at node 13, an improvement in the voltage was recorded which was as a result of reduction in active power loss due to the introduction of distributed generation.

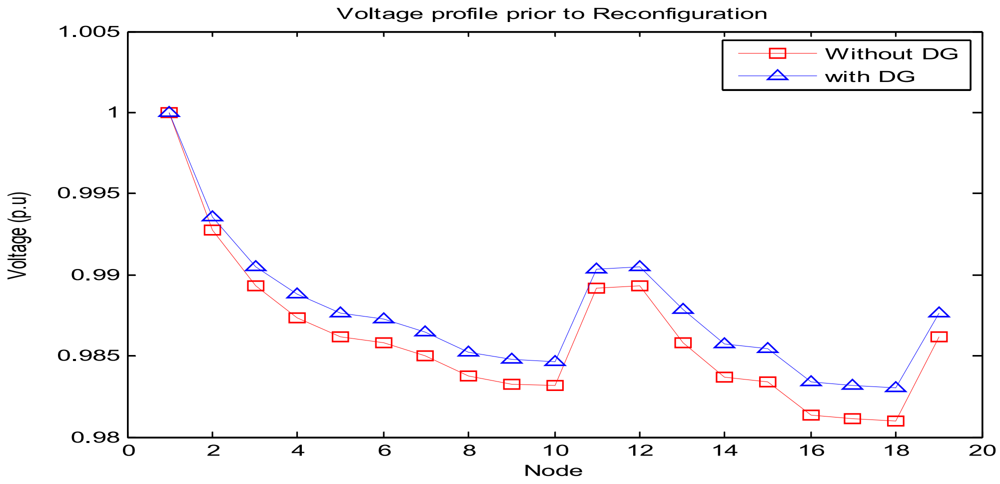


Figure 4.7 (a). Voltage profile for Railway 19-Bus Network, Prior to Reconfiguration

With reconfiguration, the voltage profile obtained is shown in Figure 4.7(b), the following observation were realized on the Railway 19-Bus distribution network. A noticeable improvement in voltage was recorded across the network due to considerable reduction of 18.22% in active power loss as compared to the active power loss initial configuration.

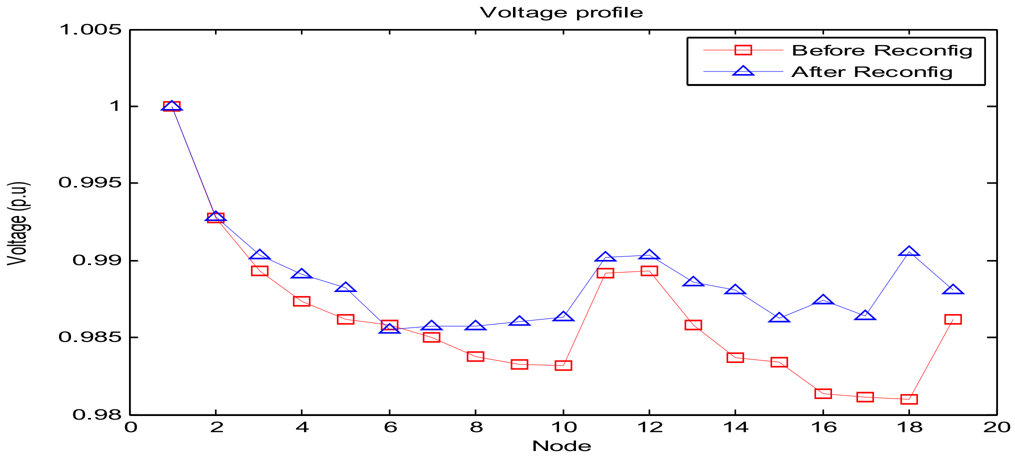


Figure 4.7 (b). Voltage profile for Railway 19-Bus Network, Before and After Reconfiguration

4.3.3 Sabo 29-Bus Network

The voltage profile of the 29-Bus distribution network prior to reconfiguration is shown in Figure 4.8 (a), shows that the voltage decreases as the number of buses (node) in the network increases. The sudden rise in voltage across node 24-39 is as a result of proximity (lateral) to node 6. With 300kW DG model as a constant PQ load, placed at node 24, an slight improvement in the voltage was recorded which was as a result of reduction in active power loss brought about due to the introduction of distribution generation.

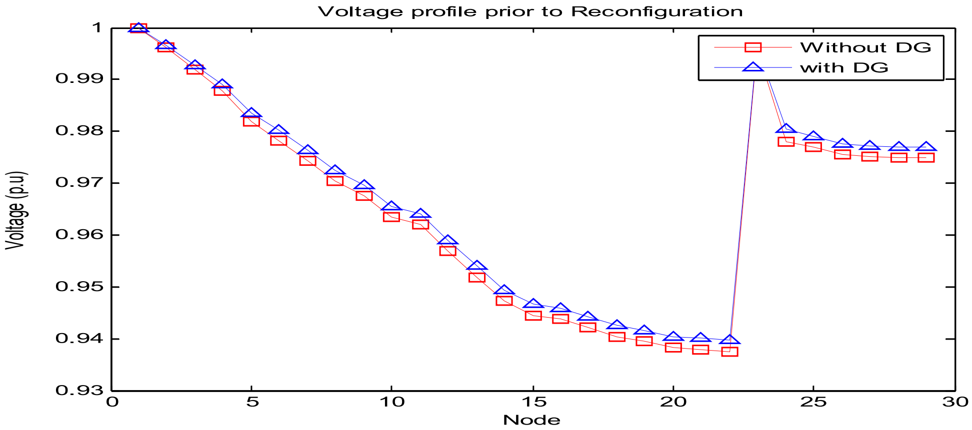


Figure 4.8 (a) Voltage profile for Sabo 29-Bus Network, Prior to Reconfiguration

With reconfiguration, the voltage profile obtained is shown in Figure 4.8 (b), the following observation were realized on the Sabo 29-Bus distribution network. A noticeable improvement in voltage was recorded across the network due to considerable reduction of 39.21% in active power loss as compared to the active power loss initial configuration.

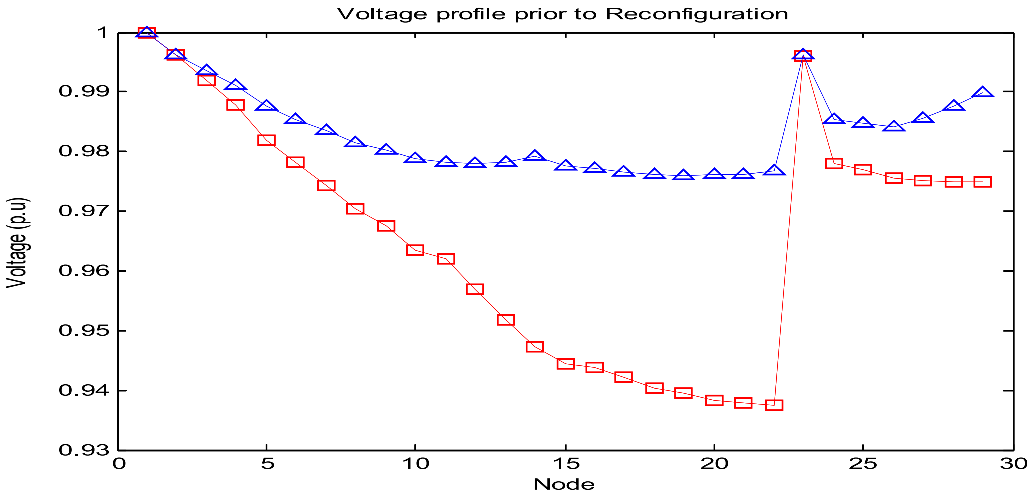


Figure 4.8 (b). Voltage profile for Sabo 29-Bus Network, Before and After Reconfiguration

4.3.4 Canteen 50-Bus Network

The voltage profile of the 50-Bus distribution network prior to reconfiguration is shown in Figure 4.9 (a). The voltage decreases as the number of buses (node) in the network increases. The sudden rise in voltage across node 24-39 is as a result of proximity (lateral) to node 6. With 300kW DG model as constant PQ load, placed at node 33, a slight improvement in the voltage was recorded due to the introduction of distributed generation.

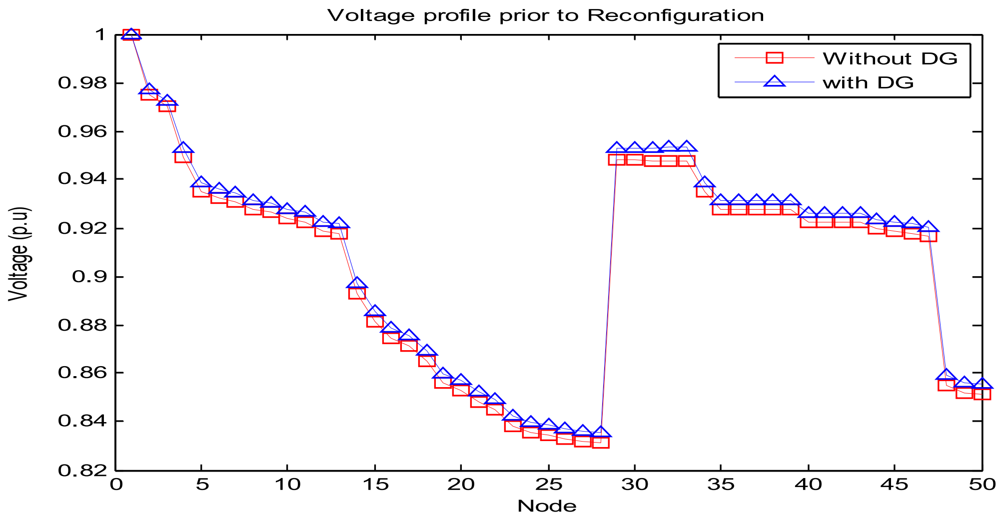


Figure 4.9 (a). Voltage profile for Canteen 50-Bus Network, Prior to Reconfiguration

With reconfiguration, the voltage profile obtained is shown in Figure 4.9 (b), the following observation were realized on the Canteen 50-Bus distribution network. A noticeable improvement in voltage was recorded across the network due to considerable reduction of 23.42% in active power loss as compared to the active power loss initial configuration.

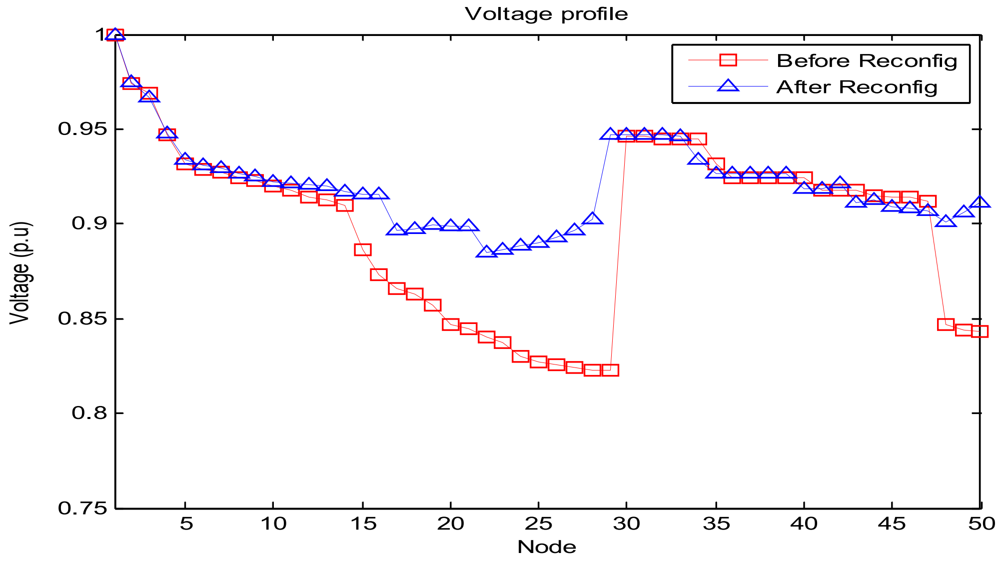


Figure 4.9 (b). Voltage profile for Canteen 50-Bus Network, Before and After Reconfiguration

4.4 Conclusion

A comparative study on the distribution network before and after reconfiguration was carried out, results shows that with reconfiguration was used to reduced the active power loss and improve the voltage profile of the stated network. Based on the results obtained, certain limitations were observed and areas for further works were discussed in the next chapter.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This section present the limitation, conclusion and recommendation for further work.

5.2 Conclusion

The research has developed an approach to distribution network reconfiguration using enhance non-dominated sorting genetic algorithm (NSGA-II) multi-objective based, considering active power loss and total voltage deviation as the main objective function. The developed algorithm was tested using sample of data extracted from Zaria distribution network. The result revealed several feasible switching state for the various distribution system as compared to the normal network. Optimal locations of tie switches (open branches) were found to be at branches 12, 14 and locations 14, 16, 18 and 25, 20, 10 and 23, 16, 43 for Gaskiya, Railway, Sabo and Canteen distribution network respectively. An improvement in active power loss reduction of 37.14%, 18.22%, 39.21% and 23.42% as compared to the active power loss of the normal network (55.32kW, 17.22kW, 120.08kW and 508.3kW) for Gaskiya, Railway, Sabo and Canteen distribution network respectively. While a reduction in total voltage deviation of 9.43%, 9.02%, 37.81% and 10.72% as compared to the total voltage deviation of the normal network (0.2672V, 0.2340V, 0.9949V and 4.7482V) for Gaskiya, Railway, Sabo and Canteen distribution network respectively. Based on the result obtained, it can be concluded that the total active power and total voltage deviation has been estimated for different switching state, using non-dominated sorting genetic algorithm (NSGA II). Also a noticeable reduction in active power loss and improvement voltage profile were recorded for all the sample of distribution network, with the introduction of distributed generation.

5.3 Limitations

During the course of this work, certain limitation were observed which are itemized as follows:

1. The scope of this work was limited to a balanced network, hence the effect of unbalanced nature of the distribution network were not captured.
2. The enhance dominated sorting genetic algorithm explore the search space and performs best at a high generation, as such increase the computation burden consequently affecting the convergence time.
3. The dynamic nature of load for a typical distribution network was not considered.

5.4 Recommendation for Further Work

Future works should consider the following areas:

i. This algorithm can be developed and extended to an unbalanced distribution network, so as to capture the exact nature of a distribution system.

ii. The use of hybrid algorithm can be adopted to enhance the convergence time, while simultaneously exploring the search space.

Reference

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Appendix A1

```
function mpc = case16

%% MATPOWER Case Format : Version 2
mpc.version = '2';

%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 100;

%% bus data
%   bus_i   type    Pd   Qd   Gs   Bs   area    Vm   Va   baseKV  zone    Vmax
Vmin
mpc.bus = [
    1   3   0.0000  0.0000  0   0   1   1.00    0   11  1   1.00    0.90;
    2   1   0.2736  0.2052  0   0   1   1.00    0   11  1   1.00    0.90;
    3   1   0.2736  0.2052  0   0   1   1.00    0   11  1   1.00    0.90;
    4   1   0.1824  0.1368  0   0   1   1.00    0   11  1   1.00    0.90;
    5   1   0.456   0.342   0   0   1   1.00    0   11  1   1.00    0.90;
    6   1   0.1824  0.1368  0   0   1   1.00    0   11  1   1.00    0.90;
    7   1   0.0912  0.0684  0   0   1   1.00    0   11  1   1.00    0.90;
    8   1   0.0912  0.0684  0   0   1   1.00    0   11  1   1.00    0.90;
    9   1   0.0912  0.0684  0   0   1   1.00    0   11  1   1.00    0.90;
    10  1   0.0912  0.0684  0   0   1   1.00    0   11  1   1.00    0.90;
    11  1   0.0456  0.0342  0   0   1   1.00    0   11  1   1.00    0.90;
    12  1   0.456   0.342   0   0   1   1.00    0   11  1   1.00    0.90;
    13  1   0.0456  0.0342  0   0   1   1.00    0   11  1   1.00    0.90;
    14  1   0.1824  0.1368  0   0   1   1.00    0   11  1   1.00    0.90;
    15  1   0.1824  0.1368  0   0   1   1.00    0   11  1   1.00    0.90;
    16  1   0.1824  0.1368  0   0   1   1.00    0   11  1   1.00    0.90;
];
 %% generator data
%   bus Pg  Qg  Qmax    Qmin    Vg  mBase   status  Pmax    Pmin    Pc1 Pc2
Qc1min  Qc1max  Qc2min  Qc2max  ramp_agc    ramp_10 ramp_30 ramp_q  apf
mpc.gen = [
    1   0   0   0   0   1.00    100 1   0   0   0   0   0   0   0   0   0   0
0   0   0;
];

%% branch data
%   fbus    tbus    r   x   b   rateA   rateB   rateC   ratio   angle
status  angmin  angmax
mpc.branch = [
    1   2   0.1580  0.1002  0   0   0   0   0   0   1   -360        360;
    2   3   0.1975  0.1253  0   0   0   0   0   0   1   -360        360;
    3   4   0.3950  0.2506  0   0   0   0   0   0   1   -360        360;
    4   5   0.1580  0.1002  0   0   0   0   0   0   1   -360        360;
    5   6   0.1185  0.0751  0   0   0   0   0   0   1   -360        360;
    6   7   0.1185  0.0751  0   0   0   0   0   0   1   -360        360;
    2   8   0.2370  0.1504  0   0   0   0   0   0   1   -360        360;
    8   9   0.1185  0.0751  0   0   0   0   0   0   1   -360        360;
    9   10  0.1185  0.0751  0   0   0   0   0   0   1   -360        360;
    8   11  0.1185  0.0751  0   0   0   0   0   0   1   -360        360;
    9   12  0.4938  0.3133  0   0   0   0   0   0   1   -360        360;
    5   13  0.1580  0.1002  0   0   0   0   0   0   1   -360        360;
```

```
    13  14  0.1185  0.0751  0   0   0   0   0   0   1   -360         360;
    5   15  0.0988  0.0627  0   0   0   0   0   0   1   -360         360;
    15  16  0.1382  0.0877  0   0   0   0   0   0   1   -360         360;
    16  11  0.5000  0.3000  0   0   0   0   0   0   1   -360         360;
    14  2   0.400   0.1500  0   0   0   0   0   0   1   -360         360;
];
```

Appendix A2

```
function mpc=case19
mpc.version = '2';

%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 100;

%% bus data
%   bus_i   type    Pd  Qd  Gs  Bs  area    Vm  Va  baseKV  zone    Vmax
Vmin
mpc.bus = [
    1   3   0.0000  0.0000  0   0   1   1.00    0   11  1   1.00    0.93;
    2   1   0.04557 0.0342  0   0   1   1.00    0   11  1   1.00    0.93;
    3   1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    4   1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    5   1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    6   1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    7   1   0.03038 0.0228  0   0   1   1.00    0   11  1   1.00    0.93;
    8   1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    9   1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    10  1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    11  1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    12  1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    13  1   0.03038 0.0228  0   0   1   1.00    0   11  1   1.00    0.93;
    14  1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    15  1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    16  1   0.07595 0.0569  0   0   1   1.00    0   11  1   1.00    0.93;
    17  1   0.03038 0.0228  0   0   1   1.00    0   11  1   1.00    0.93;
    18  1   0.03038 0.0228  0   0   1   1.00    0   11  1   1.00    0.93;
    19  1   0.03038 0.0228  0   0   1   1.00    0   11  1   1.00    0.93;
];

%% generator data
%   bus Pg  Qg  Qmax    Qmin    Vg  mBase   status  Pmax    Pmin    Pc1 Pc2
Qc1min  Qc1max  Qc2min  Qc2max  ramp_agc    ramp_10 ramp_30 ramp_q  apf
mpc.gen = [
    1   0   0   0   0   1.00    100 1   0   0   0   0   0   0   0   0   0   0
0   0   0;
];

%% branch data
%   fbus    tbus    r   x   b   rateA   rateB   rateC   ratio   angle
status  angmin  angmax
mpc.branch = [
    1   2   0.4345    0.2757    0   0   0   0   0   0   1   -360     360;
    2   3   0.2173    0.1378    0   0   0   0   0   0   1   -360     360;
    3   4   0.1580    0.1002    0   0   0   0   0   0   1   -360     360;
```

```
    4   5   0.1778    0.1129    0   0   0   0   0   0   1   -360     360;
    5   6   0.079     0.0501    0   0   0   0   0   0   1   -360     360;
    6   7   0.1975    0.1253    0   0   0   0   0   0   1   -360     360;
    7   8   0.3752    0.2381    0   0   0   0   0   0   1   -360     360;
    8   9   0.1975    0.1253    0   0   0   0   0   0   1   -360     360;
    9   10  0.1185    0.0751    0   0   0   0   0   0   1   -360     360;
    3   11  0.1383    0.0877    0   0   0   0   0   0   1   -360     360;
    3   12  0.0197    0.0125    0   0   0   0   0   0   1   -360     360;
    4   13  0.316    0.2005   0   0   0   0   0   0   1   -360        360;
    13  14  0.4937   0.3138   0   0   0   0   0   0   1   -360        360;
    14  15  0.0988   0.0627   0   0   0   0   0   0   1   -360        360;
    15  16  0.9875   0.6265   0   0   0   0   0   0   1   -360        360;
    16  17  0.5135   0.3258   0   0   0   0   0   0   1   -360        360;
    16  18  0.7505   0.4762   0   0   0   0   0   0   1   -360        360;
    5   19  0.0395   0.0251   0   0   0   0   0   0   1   -360        360;

    18  2   0.500    0.3000   0   0   0   0   0   0   1   -360        360;
    10  19  0.500    0.3000   0   0   0   0   0   0   1   -360        360;
    7   17  0.500    0.3000   0   0   0   0   0   0   1   -360        360;
```

Appendix A3

```
function mpc = case29
%% MATPOWER Case Format : Version 2
mpc.version = '2';

%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 100;

%% bus data
%   bus_i   type    Pd  Qd  Gs  Bs  area    Vm  Va  baseKV  zone    Vmax
Vmin
mpc.bus = [
    1   3   0.0000  0.0000  0   0   1   1.00    0   11  1   1.00     0.90;
    2   1   0.1123  0.0842  0   0   1   1.00    0   11  1   1.00     0.90;
    3   1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    4   1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.0      0.90;
    5   1   0.0748  0.0561  0   0   1   1.00    0   11  1   1.00     0.90;
    6   1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    7   1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    8   1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    9   1   0.1122  0.0842  0   0   1   1.00    0   11  1   1.00     0.90;
    10  1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    11  1   0.0374  0.0281  0   0   1   1.00    0   11  1   1.00     0.90;
    12  1   0.1123  0.0842  0   0   1   1.00    0   11  1   1.00     0.90;
    13  1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    14  1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    15  1   0.0748  0.0561  0   0   1   1.00    0   11  1   1.00     0.90;
    16  1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
    17  1   0.1123  0.0842  0   0   1   1.00    0   11  1   1.00     0.90;
    18  1   0.0748  0.0561  0   0   1   1.00    0   11  1   1.00     0.90;
    19  1   0.0374  0.0281  0   0   1   1.00    0   11  1   1.00     0.90;
    20  1   0.0374  0.0281  0   0   1   1.00    0   11  1   1.00     0.90;
    21  1   0.1123  0.0842  0   0   1   1.00    0   11  1   1.00     0.90;
    22  1   0.1123  0.0842  0   0   1   1.00    0   11  1   1.00     0.90;
    23  1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00     0.90;
```

```
    24  1   0.0374  0.0281  0   0   1   1.00    0   11  1   1.00    0.90;
    25  1   0.1123  0.0842  0   0   1   1.00    0   11  1   1.00    0.90;
    26  1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00    0.90;
    27  1   0.1871  0.1404  0   0   1   1.00    0   11  1   1.00    0.90;
    28  1   0.0187  0.0140  0   0   1   1.00    0   11  1   1.00    0.90;
    29  1   0.0374  0.0281  0   0   1   1.00    0   11  1   1.00    0.90;
];

%% generator data
%   bus Pg  Qg  Qmax    Qmin    Vg  mBase   status  Pmax    Pmin    Pc1 Pc2
Qc1min  Qc1max  Qc2min  Qc2max  ramp_agc    ramp_10 ramp_30 ramp_q  apf
mpc.gen = [
    1   0   0   0   0   1.00    100 1   0   0   0   0   0   0   0   0   0   0
0   0   0;
];

%% branch data
%   fbus    tbus    r   x   b   rateA   rateB   rateC   ratio   angle
status  angmin  angmax
mpc.branch = [
    1   2   0.0671   0.0501     0   0   0   0   0   0   1   -360    360;
    2   3   0.0840   0.0627     0   0   0   0   0   0   1   -360    360;
    3   4   0.084    0.0627     0   0   0   0   0   0   1   -360    360;
    4   5   0.1344   0.1003     0   0   0   0   0   0   1   -360    360;
    5   6   0.084    0.0627     0   0   0   0   0   0   1   -360    360;
    6   7   0.1176   0.0877     0   0   0   0   0   0   1   -360    360;
    7   8   0.1343   0.1003     0   0   0   0   0   0   1   -360    360;
    8   9   0.1176   0.0877     0   0   0   0   0   0   1   -360    360;
    9   10  0.1679   0.1253     0   0   0   0   0   0   1   -360    360;
    10  11  0.06718  0.0501     0   0   0   0   0   0   1   -360    360;
    11  12  0.2519   0.188      0   0   0   0   0   0   1   -360    360;
     12  13  0.2687   0.2005     0   0   0   0   0   0   1   -360    360;
    13  14  0.3023   0.2256     0   0   0   0   0   0   1   -360    360;
    14  15  0.2183   0.1629     0   0   0   0   0   0   1   -360    360;
    15  16  0.06718  0.05012    0   0   0   0   0   0   1   -360    360;
    16  17  0.20154  0.1502     0   0   0   0   0   0   1   -360    360;
    17  18  0.2855   0.2130     0   0   0   0   0   0   1   -360    360;
    18  19  0.16795  0.1253     0   0   0   0   0   0   1   -360    360;
    19  20  0.3023   0.2256     0   0   0   0   0   0   1   -360    360;
    20  21  0.06718  0.0501     0   0   0   0   0   0   1   -360    360;
    21  22  0.21834  0.16291    0   0   0   0   0   0   1   -360    360;
    2   23  0.06718  0.0501     0   0   0   0   0   0   1   -360    360;
    6   24  0.06718  0.0501     0   0   0   0   0   0   1   -360    360;
    6   25  0.1344   0.1003     0   0   0   0   0   0   1   -360    360;
    25  26  0.21834  0.16291    0   0   0   0   0   0   1   -360    360;
    26  27  0.1008   0.0751     0   0   0   0   0   0   1   -360    360;
    27  28  0.1176   0.0877     0   0   0   0   0   0   1   -360    360;
    28  29  0.1344   0.1003     0   0   0   0   0   0   1   -360    360;

    29  2   0.4000   0.2000     0   0   0   0   0   0   1   -360    360;
    22  11  0.4000   0.2000     0   0   0   0   0   0   1   -360    360;
    14  26  0.4000   0.2000     0   0   0   0   0   0   1   -360    360;
];
```

Appendix A4

```
function mpc = case50
%% MATPOWER Case Format : Version 2
mpc.version = '2';

%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 100;

%% bus data
%   bus_i   type    Pd  Qd  Gs  Bs  area    Vm  Va  baseKV  zone    Vmax
Vmin
mpc.bus = [
    1   3   0.0000  0.0000  0   0   1   1.00    0   11  1   1.00    0.80;
    2   1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    3   1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    4   1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    5   1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    6   1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    7   1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    8   1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    9   1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    10  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    11  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    12  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    13  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    14  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    15  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    16  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    17  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    18  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    19  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    20  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    21  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    22  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    23  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    24  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    25  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    26  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    27  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    28  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    29  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    30  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    31  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    32  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    33  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    34  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    35  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    36  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    37  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    38  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    39  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    40  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    41  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    42  1   0.0648  0.0486  0   0   1   1.00    0   11  1   1.00    0.80;
    43  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
```

```
    44  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    45  1   0.0324  0.0243  0   0   1   1.00    0   11  1   1.00    0.80;
    46  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    47  1   0.1620  0.1215  0   0   1   1.00    0   11  1   1.00    0.80;
    48  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    49  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    50  1   0.0972  0.0729  0   0   1   1.00    0   11  1   1.00    0.80;
    ];

%% generator data
%   bus Pg  Qg  Qmax    Qmin    Vg  mBase   status  Pmax    Pmin    Pc1 Pc2
Qc1min  Qc1max  Qc2min  Qc2max  ramp_agc    ramp_10 ramp_30 ramp_q  apf
mpc.gen = [
1   0   0   0   0   1.00    100 1   0   0   0   0   0   0   0   0   0   0   0
0   0
];

%% branch data
%   fbus    tbus    r   x   b   rateA   rateB   rateC   ratio   angle
status  angmin  angmax
mpc.branch = [
    1   2   0.3871  0.2456      0   0   0   0   0   0   1   -360    360;
    2   3   0.0829  0.0526      0   0   0   0   0   0   1   -360    360;
    3   4   0.3318  0.2105      0   0   0   0   0   0   1   -360    360;
    4   5   0.2489  0.1579      0   0   0   0   0   0   1   -360    360;
    5   6   0.0553  0.0351      0   0   0   0   0   0   1   -360    360;
    6   7   0.0277  0.0175      0   0   0   0   0   0   1   -360    360;
    7   8   0.0553  0.0351      0   0   0   0   0   0   1   -360    360;
    8   9   0.0277  0.0175      0   0   0   0   0   0   1   -360    360;
    9   10  0.0553  0.0351      0   0   0   0   0   0   1   -360    360;
    10  11  0.0277  0.0175      0   0   0   0   0   0   1   -360    360;
    11  12  0.1106  0.0702      0   0   0   0   0   0   1   -360    360;
    12  13  0.0277  0.0175      0   0   0   0   0   0   1   -360    360;
    13  14  0.7742  0.4912      0   0   0   0   0   0   1   -360    360;
    14  15  0.3871  0.2456      0   0   0   0   0   0   1   -360    360;
    15  16  0.2212  0.1403      0   0   0   0   0   0   1   -360    360;
    16  17  0.1106  0.0701      0   0   0   0   0   0   1   -360    360;
    17  18  0.2212  0.1403      0   0   0   0   0   0   1   -360    360;
    18  19  0.3871  0.2456      0   0   0   0   0   0   1   -360    360;
    19  20  0.1659  0.1052      0   0   0   0   0   0   1   -360    360;
    20  21  0.3318  0.2105      0   0   0   0   0   0   1   -360    360;
    21  22  0.1936  0.1228      0   0   0   0   0   0   1   -360    360;
    22  23  0.6083  0.3859      0   0   0   0   0   0   1   -360    360;
    23  24  0.3318  0.2105      0   0   0   0   0   0   1   -360    360;
    24  25  0.1659  0.1052      0   0   0   0   0   0   1   -360    360;
    25  26  0.3318  0.2105      0   0   0   0   0   0   1   -360    360;
    26  27  0.3595  0.2281      0   0   0   0   0   0   1   -360    360;
    27  28  0.4701  0.2982      0   0   0   0   0   0   1   -360    360;
    4   29  0.2212  0.1403      0   0   0   0   0   0   1   -360    360;
    29  30  0.1935  0.1228      0   0   0   0   0   0   1   -360    360;
    29  31  0.1935  0.1228      0   0   0   0   0   0   1   -360    360;
    31  32  0.0277  0.0175      0   0   0   0   0   0   1   -360    360;
    32  33  0.1106  0.0701      0   0   0   0   0   0   1   -360    360;
    5   34  0.2212  0.1403      0   0   0   0   0   0   1   -360    360;
    8   35  0.0553  0.0351      0   0   0   0   0   0   1   -360    360;
    8   36  0.0553  0.0351      0   0   0   0   0   0   1   -360    360;
```

```
36  37  0.0553  0.0351          0 0   0   0   0   0   1   -360    360;
36  38  0.0553  0.0351          0 0   0   0   0   0   1   -360    360;
38  39  0.0277  0.0175          0 0   0   0   0   0   1   -360    360;
11  40  0.1382  0.0877          0 0   0   0   0   0   1   -360    360;
40  41  0.0277  0.0175          0 0   0   0   0   0   1   -360    360;
11  42  0.1106  0.0702          0 0   0   0   0   0   1   -360    360;
42  43  0.0277  0.0175          0 0   0   0   0   0   1   -360    360;
11  44  0.4148  0.2631          0 0   0   0   0   0   1   -360    360;
44  45  0.1659  0.1053          0 0   0   0   0   0   1   -360    360;
45  46  0.1382  0.0877          0 0   0   0   0   0   1   -360    360;
46  47  0.4977  0.3158          0 0   0   0   0   0   1   -360    360;
19  48  0.1383  0.1000          0 0   0   0   0   0   1   -360    360;
48  49  1.0000  0.5000          0 0   0   0   0   0   1   -360    360;
49  50  0.5000  0.3000          0 0   0   0   0   0   1   -360    360;
];
```

Appendix B1

```
m-file
% Extracted from the work of Gosh and das,1994
% Code for identifying the node beyond a particular branch
% the input to this file is loaded from a bus data
function [IE,IB] = funx22(IR,IS)
LN1=length (IR); % length of node
LL=zeros(1,LN1);IK=zeros(1,LN1);KK=zeros(1,LN1);
IE=zeros(LN1,LN1);IB=zeros(LN1,LN1);N=zeros(1,LN1);
j=1;
while (j<=(LN1-1)) %while 1
k=j+1;ip=0;iq=0;
while (iq<=ip)  % while 2
i=k;
while (i<=LN1)  % while 3
nc=0;
if (IR(j)==IS(i))
if (ip~=0)
for in=1:ip,
if or((IR(i)==KK(ip)),(IR(i)==LL(ip)))
nc=1;
end;end
if (nc==1)
i=i+1;continue;
end;else
IE(j, ip + 1) = IR(j);
IB(j, ip + 1) = IS(j);end
ip = ip + 1;IK(ip) = i;
LL(ip) = IS(i);KK(ip) = IR(i);
IE(j, ip + 1) = IR(i);IB(j, ip + 1) = IS(i);
N(j) = ip + 1  ;
end
i=i+1;
end   %while 3 closed
if (ip==0)
IE(j,ip+1)=IR(j);IB(j,ip+1)=IS(j);N(j)=ip+1;
break;end
iq=iq+1;
if(iq>ip)
break;end
IR(j)=KK(iq);k=IK(iq)+1;
end   % while 2 closed here
j=j+1; %ip,KK,LL,IE,IB
end
for i=1:LN1
IE(i);IB(i)
end
```

Appendix B2

```
% Matlab code developed based on forward/Backward sweep algorithm
% to perform load flow analysis for a typical radial distribution network
clear all
clc
X= load('load bus.m');
IR=X(:,2);IS=X(:,1);
LN1=length(IR);
[IE,IB]=funx22(IR,IS): %Calling function
IE(LN1, 1) = IR(LN1);
IB(LN1, 1) = IS(LN1);
N(LN1) = 1;
R=X(:,3)X=X(:,4)
BASEKVA=100KVA;BASEKV=11kV;
ND=load('loaddata.m');% loading data from load file
PL=ND(:,2);QL=ND(:,3);
Node=ND(:,1);
LN2=length(PL);
for i=1:LN1
R(i)=R(i)*BASEKVA/(BASEKV*BASEKV*1000);%converting to pu
X(i)=X(i)*BASEKVA/(BASEKV*BASEKV*1000);%convertin to pu
end
for i=1:LN2
PL(i)=PL(i)/BASEKVA;QL(i)=QL(i)/BASEKVA;
end
P=zeros(1,LN2);Q=zeros(1,LN2);
m1=zeros(1,LN2);m2=zeros(1,LN2);
L1=zeros(1,LN2);L2=zeros(1,LN2);
IT=1;
SLP=0.0; SLQ=0.0;PLOSS=0.0;QLOSS=0.0;
DP=0.1;DQ=0.1;LK=0;
LP=zeros(1,LN2);LQ=zeros(1,LN2);
A=zeros(1,LN2);B=zeros(1,LN2);V=zeros(1,LN2);
L=load('load bus.m');
IR=L(:,2);IS=L(:,1);
while (and((DP > 0.0001),(DQ>0.0001)))
PLOSS=0.0;QLOSS=0.0;
j=1;
while j<=LN1
LK=N(j);i=1;
while i<=LK
if IB(j,i)==IS(j)
L1=IB(j,i);L2=IE(j,i);
m1=IS(j);m2=IR(j);
P(m2)=PL(L2);Q(m2)=QL(L2);
i=i+1;
continue;
else
L1=IB(j,i);L2=IE(j,i)
in=1;
while in<=LN1
if and(L1==IS(in),L2==IR(in))
%display('output in else');
P(m2)=P(m2)+PL(L2)+LP(in);%active node power loss
Q(m2)=Q(m2)+QL(L2)+LQ(in);%reactive node power loss
```

```
else in=in+1;
continue;
end
in=in+1; continue;
end;end
i=i+1;end
if (m1==1)
V(m1)=1.0;% setting slack bus parameter
Y(m1)=0;%setting slack bus parameter
end
A(j)=(((P(m2)*R(j)+Q(m2)*X(j))-0.5*((V(m1))^2)));
B(j)=((A(j)^2)-((R(j)^2)+(X(j)^2))*((P(m2)^2)+((Q(m2)))^2))^0.5;
V(m2)=((B(j)-A(j))^0.5); %calculation of node voltage
Y(m2)=Y(m1)-atan((P(m2)*X(j)-
Q(m2)*R(j))/((abs(V(m2))^2)+P(m2)*X(j)+Q(m2)*R(j)));% angle in radian
LP(j)=(R(j)*(P(m2)^2 + Q(m2)^2)/(V(m2)^2)); %branch active power losses
LQ(j)=(X(j)*(P(m2)^2 + Q(m2)^2)/(V(m2)^2));%branch reactive power losses
PLOSS=PLOSS+LP(j);%  total active power loss
QLOSS=QLOSS+LQ(j);%  total reactive power loss
VI(m2)=((1-V(m2))^2/m2)^0.5 % calculation of voltage stability index
j=j+1;
end
DP=(PLOSS-SLP);%convergence criteria
DQ=(QLOSS-SLQ);%convergence criteria
IT=IT+1;
SLP=PLOSS;SLQ=QLOSS;
End
fprintf('Node  Magnitude Voltage [p.u.] angle[p.u]\n')
dev=1-V
disp[V, dev]
```

Appendix C1

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Development of an optimal Reconfiguration Algorithm for a radial
% Distribution Network submitted to the Department of Electrical and
% Computer Engineering of Ahmadu Bello University, Zaria.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This code is developed  to solve the problem of distribution
% network reconfiguration using Enhance non-dominated sorting genetic
% algorithm considering active power loss and profile.
% ADAMU ABUBAKAR SAIDU. Msc/Eng/542/2011-2012
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Initialization of NSGA II parameter
tic;
D=2;   % Numbers of Loops in the network (dimesion of search space)
lb= ones(D,1);           % Lower bound
ub= [8;6];               % Upper bound setting based on the number of element
in each loops
generation  = 20;        % number of generation
penality = 100000;       % setting the upper fitness function
L = 30;
mu = 30;
sigma = 5;
ub_sigma= 8;
lb_sigma= 1;
Global_T =1/sqrt(2*D); %Computing global learning rate
Local_T =1/sqrt(2*sqrt(D)); %Local Learning rate
% Initilization of iterative sum
y1=zeros(L,generation); y2=zeros(L,generation);y3=zeros(D,L, generation);
y11=zeros(1,generation);y12=zeros(1,generation);y13=zeros(D,generation);
y4=zeros(L,generation);y5=zeros(generation);y51=zeros(D,generation);
y6=zeros(D,L);y7=zeros(D,L);y8=zeros(1,L);
x=zeros(D,mu);x1=zeros(mu,1); x2=zeros(mu,1);x3=sigma;
% Generating the initial population via Initialization function
x=initilization(L,D,lb,ub);
for i=1:mu
f=0;
while f==0;
x(:,i)=initilization(1,D,lb,ub); % generating chromosome
f=constraint_checking(x(:,i))    % constraint check
if f == 1;
[temp_power,temp_voltage]=objective_function(x(:,i)); % Evaluating objective
function
x1(i,1) = temp_power;x1(i,2) = temp_voltage; end;
end;end
x_parent=x;
f_parent=x1;
last_pareto=f_parent(fndpareto(x1'),:); %  return non-dominated individual
%based on principle of pareto optimal
stop=1;
g=0;         % counter no improvement
while stop<=generatio
 [xr, sigmar] = recombination(D, mu,L, x_parent, x3);% perform crossover
 % Perform Mutation
[xm, sigma_m] = mutation(xr,D,L, sigmar, ub_sigma, lb_sigma, Global_T,
Local_T, lb, ub)
 for i = 1:L
```

```
y4(i,1:17) = constraint_checking(xm(:,i));
if y4(i,stop) == 1
[temp_power,temp_voltage]= objective_function(xm(:,i));
y1(i,stop)= temp_power;
y2(i,stop)= temp_voltage;
else
y1(i,stop)= penality;
y2(i,stop)= penality;
end
end
fitness = [y1(:,stop),y2(:,stop)]
% selection
[offspring, fitness_offspring, sigma_offsrping] = selection(xm,
x_parent,fitness,f_parent,sigma_m,sigma,mu,L,D);
x_parent = offspring;
sigma= sigma_offsrping;
f_parent = fitness_offspring;
current_pareto = f_parent(fndpareto(f_parent'),:);

[m_last,n_last] = size(last_pareto);
[m_current,n_current] = size(current_pareto);
if m_last == m_current
if all(last_pareto == current_pareto) ==1
 g = g+ 1;
 if g == 5
 sigma = sigma / 1.2;
  g= 0;
 end
else
 g = 0;
last_pareto = current_pareto;
 end
 else
g = 0;
last_pareto = current_pareto;
end

    y3(:,:,stop) = xm
    y11(1,stop)= f_parent(1,1)
    y13(:,stop)= x_parent(:,1)
    y5(:,:,stop)= sigma_m
    y51(:,stop)= sigma_m(:,1)
stop=stop+1;
 toc;
end
```

```
%.........................................................................%
%% This function generate a random chromosomes
function offspring =initilization(L,D,lb,ub)
  offspring = zeros(D,L);
  for i = 1:D
  offspring(i,:) = randi([lb(i,1), ub(i,1)], 1,L);% Generate random
chromosome
 % between the upper and lower bound of length L
end
end

%..............................................................................................................................................%

%% This function check constraint to ensure that radilaity is preserve
function [power_loss,min_v,f] = constraint_checking(chorm)
power_loss = 0; %initialize the active power loss
min_v = 0;      % initialize the voltage
test_1 = 1;     % test
test_2 = 0;     % test 2, to recomfirm test 1
ub = [8;6];     % Number of branch in each loop
D=2;            % Number of loops
for i=1:D
    if chorm(i,1) > ub(i,1)
        f=0;
       test_1 = 0;
    end
    if chorm(i,1) < 1
        f=0;
        test_1 = 0;
    end
end
if test_1== 1
X1=loadcase(case16);  % load case data
branch_data=X1.branch; % select the case branch data
Loop = [
2 3 4 14 15 16 10 7
2 3 4 12 13 17 0 0
];% Enter the branches Belonging to each Loop
delete_branch = zeros(D,1); % initialization
for i = 1:D
    delete_branch(i,1) = Loop(i,chorm(i));
end
branch_data(delete_branch-1,:)=[]; % delete the branch
[m_branch_data, n_branch_data] = size(branch_data);
if m_branch_data >15
    f = 0;
else
    test_2 = 1;
end
if test_2 ==1
node_searched = zeros(16,2); % initialization
for i = 1:16
    node_searched(i,1)  =  i;
end
node_searched(1,2)  =   1;
%Find the original source, node No. 1
```

```
num_row_1= find(branch_data(:,1)==1);
[m_1,n_1] = size(num_row_1);
% node_next
% The next nodes information of the current line segment, this number is a
matrix
node_next= ones(m_1,n_1);
for i = 1:m_1
node_next(i,1)= branch_data(num_row_1(i,1), 2);
node_searched(node_next(i,1),2) =  1;
end
% Delete the processed data(The line segment of first node is No. 1 )
branch_data(num_row_1,:) = [];
% Size the matrix of the branch
[m_branch,n_branch] = size(branch_data);
clear m_1;
clear n_1;
f=1;
% Loop when all the data is not complete
% When find a loop or a isolate island, set m_branch = 0 and flag = 0;
while (m_branch ~=0)
current_node= node_next;
clear node_next;
[m_c, n_v]= size(current_node);
 if m_c == 0
 m_branch = 0;
 break;
 end
%   Find in the first line
 num_row_next=find(branch_data(:,1)==current_node(1,1));
 for i = 2:m_c

num_row_next=[num_row_next;find(branch_data(:,1)==current_node(i,1))];
 end
[m_n1,n_n1]= size(num_row_next);
 node_next = ones(m_n1,n_n1);
 for i =1:m_n1
 node_next(i,1)=branch_data(num_row_next(i,1),2);
 node_searched(node_next(i,1),2) =  1;
 end
 % Find in the second line
 for i = 1:m_c
 num_row_next=[num_row_next;find(branch_data(:,2)==current_node(i,1))];
        end

 [m_n2,n_n2]=size(num_row_next);

 for i =(1+m_n1):m_n2
 node_next(i,1)  =   branch_data(num_row_next(i,1),1);
 node_searched(node_next(i,1),2) =  1;
 end
 % Delete all the current information
 branch_data(num_row_next,:) = [];
 clear current_node;
 clear num_row_next;
 % Calculate the size of the branch
[m_branch,n_branch] = size(branch_data);
```

```
 end
f=all(node_searched(:,2)==1);
if f== 1
[power_loss,min_v,] = objective_function(chorm);% Evaluating objective
function
end
end
end
%.....................................................................%
%% This function evaluate the objective function
% its output active power loss and minimal voltage at each node
function [power_loss,min_v,success] = objective_function(chorm)
D=2;
X1=loadcase(case16);  % load case data for the Gaskiya (16 Bus network)
mpc.bus=X1.bus; % load the node data
mpc.branch=X1.branch; % load the line data
Loop = [
2 3 4 14 15 16 10 7
2 3 4 12 13 17 0 0
];
delete_branch = zeros(D,1); % initialization
for i = 1:D
    delete_branch(i,1) = Loop(i,chorm(i));
end
mpc.branch(delete_branch-1,:)=[];
ko=runpf(X1)
[power_loss,min_v] = runpf(X1)
power_loss = real(sum(ko.branch(:,14))+(ko.branch(:,16)))*1000 % Active power
Loss
dev = 1-real(ko.bus(:,8))%Node deviation
TVD=sum(dev)
%.......................................................................%
function [xx, ss]=recombination(n,mu,L,xi,x3)
% function that performs crossover
xx=zeros(n,L)% Allocating memory space
ss=zeros(n,L)% Allocating memry space
i = 1;
while (i <=L)
 fixed = randsample(1:mu,1);
 for k = 1:mu
 for j = 1:n
 tmp= randsample(1:mu,1);
 idx = randsample([fixed tmp],1);
 xx(j,i)  = xi(j,idx);
 end
 end
 i = i+1;
 end; clear ss; ss = x3;
 %........................................................................%
```

```
%.............................................................................%
function [par] = fndpareto(fobj)
%FNDPARETO Returns the indexes of non-dominated individual
nobj = size(fobj,1)
nind = size(fobj,2)
par = [];
%-----------------------------------------------------------------------
for i = 1:nind,
    lme = zeros(nobj,nind);
    leq = zeros(nobj,nind);
    for j = 1:nobj,
        lme(j,:) = (fobj(j,:) <= fobj(j,i));
        leq(j,:) = (fobj(j,:) == fobj(j,i));
    end
    if isempty(find(sum(lme) == nobj & sum(leq) < nobj,1)),
        lid = find(sum(lme) == nobj & sum(leq) == nobj);
        if isempty(lid),
            par = [par i];
        else
            if i <= min(lid),
                par = [par i];
            end
        end
        clear lid
    end
    clear lme leq
end
%-----------------------------------------------------------------------
[a b] = sort(fobj(1,par));
par = par(b);
clear a b
%-----------------------------------------------------------------------

function
[xm,sigma_m]=mutation(offspring,N,L,sigma,ub_sigma,lb_sigma,Global_T,Local_T,
lb,ub)
    globalRandnZ = repmat(randn(1,L), N, 1);
    offspringStepsizeZ = sigma * exp(globalRandnZ .* Local_T);

    if offspringStepsizeZ < lb_sigma
        offspringStepsizeZ = 1;
    else if offspringStepsizeZ > ub_sigma
            offspringStepsizeZ = ub_sigma;
        end
    end
    sGeo = offspringStepsizeZ;
    pGeo = 1 - ((sGeo/N) ./ (1 + sqrt(1 + (sGeo/N).^2)));
    u1 = rand(N,L);
    geo1 = floor((log(1 - u1)./ log(1 - pGeo)));
    u2 = rand(N,L);
    geo2 = floor((log(1 - u2)./ log(1 - pGeo)));
    offspringZ = offspring + (geo1 - geo2);


    a   = repmat(lb, 1,L);
```

```
    b   = repmat(ub, 1,L);
    y   = a + (b - a).*(2/pi).*asin(abs(sin((pi/2 *((offspringZ - a) ./ (b -
a))))));
    offspringZ = round(y);
  sigma_m = offspringStepsizeZ(1,1);
  xm = offspringZ; end
%.............................................................%
function [x_selection,fitness_selection,sigma_selection] =
selection(offspring, x_parent, fitness, f_parent, sigma_offsrping,
sigma_parent, mu, L, N)
% selection based on tournament selection type
selection_pool_x = [offspring, x_parent];
selection_pool_sigma= [sigma_offsrping,sigma_parent];
selection_pool_f = [fitness; f_parent];
temp_sorting_number= nsga2sort(selection_pool_f);
selection_sort_number= temp_sorting_number(1:mu);
x_selection = selection_pool_x(1:N, selection_sort_number);
fitness_selection= selection_pool_f(selection_sort_number,1:2);
sigma_selection = sigma_offsrping;
end
%.............................................................%
```