APPLICATION OF BAT ALGORITHM-BASED METHOD FOR MULTI-OBJECTIVE OPTIMAL NETWORK RECONFIGURATION AND DISTRIBUTED GENERATION PLACEMENT IN RADIAL DISTRIBUTION NETWORK

BY

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A DISSERTATION SUBMITTEDTO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, AHMADUBELLOUNIVERSITYZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc.) IN ELECTRICAL POWER SYSTEM ENGINEERING

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DECLARATION

I Muhammad Magaji declare that this dissertation entitled **“APPLICATION OF BAT ALGORITHM-BASED METHOD FOR MULIT-OBJECTIVEOPTIMAL NETWORK RECONFIGURATION AND DISTRIBUTED GENERATION PLACEMENTIN RADIALDISTRIBUTION NETWORK”** has been carried out by me in the Department of Electrical Engineering, Ahmadu Bello University Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma atAhmadu Bello University, Zaria or any other Institution.

______________________ ____________________

Signature Date

Muhammad MAGAJI

CERTIFICATION

This dissertation entitled **“APPLICATION OF BAT ALGORITHM-BASED METHOD FOR MULTI-OBJECTIVE OPTIMAL NETWORK RECONFIGURATION AND DISTRIBUTED GENERATION PLACEMENT IN RADIAL DISTRIBUTION NETWORK”**by Muhammad MAGAJImeets the regulations governing the award of degree of Master of Science (M.Sc.) in Electrical Power System of the Ahmadu Bello University, Zara and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I Muhammad MAGAJI dedicate this work to Prophet Muhammad Bn Abdullah (S.A.W) and his Companions, thentomyparentsfor their support and prayers.

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ABSTRACT

This dissertation presents an Application of Bat Algorithm-Based Method (BA) forMulti-Objective Optimal Network Reconfiguration andDistributed Generation placement in Radial Distribution Network. The BA approach presented in this work enables the reconfiguration of the network as well as the optimal distributed generation(DG) placement in one seamless algorithm. This would minimize errors encountered in using analytical approaches and also improve on the accuracy of the results obtained. In the developed method, the base case active and reactive power losses for the standard IEEE 33-bus were first determined using forward-backward algorithm as 208.46kW and 111.67kW respectively. Then, the developed BA method was applied on the IEEE-33 to determine the optimal DG sizes and the location as well as the optimal reconfiguration of the network.The DGssizes and locations were determined as 957kW, 870kW, 822kW as well as 593kVar, 539kVar, 509kVar at buses 29, 31 and 12 respectively. The total active and reactive power loss obtained after the DG placement as well as network reconfiguration were 15.2353kW and 12.0593kVAr respectively.Thus, the developed method recorded a loss reduction of 92.6915% and 53.56% for active and reactive power loss respectively over the base case, while the voltage profile of 0.91075*pu* for base casewas improved to 0.9918*pu*.Furthermore, the results were compared with the work of Syahputra*et al*., wherethe developed method recorded an improvement of 6.32% on active power loss reduction and 1.04% on voltage profile improvement over the results of Syahputra. The developed method was also implemented on a simulated feeder of Sabon-Gari at Zaria distribution network with the view to optimize the synchronous DG placement as well as network reconfiguration. The results indicated that active and reactive power losses were reduced by 88.77% and 88.18% respectively, while the voltage profile has beenimproved to 4.1% over the base case.All simulations were implemented on MAT LAB 2013b environment.

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LIST OF ABBREVIATIONS

Abbreviations	Definition
A	Loudness
AC	Alternating Current
CB	Circuit Breaker
DC	Direct Current
DN	Distribution Network
DNR	Distribution Network Reconfiguration
DG	Distributed Generation
DSTATCOM	Distribution Synchronous Static Compensator
ri.	Emission rate
fi	Frequency
IEA	International Energy Association
IEEE	Institute of Electrical Electronics Engineers
I_{DG}	LossSaving Current of DG
kW	Kilo-Watt
kVar	Kilo-Reactive Volt-Ampere
BA	Bat Algorithm

MW	Mega-Watt
MATLAB	Matrix Laboratory
NPF	Number of Pareto Fronts
P	Active Power
P_{DG}	Active Power of DG
PLR	Power Loss Ratio
Q	Reactive Power
Q_{DG}	Reactive Power of DG
Syn DG	Synchronous DG
VSC	Voltage Source Converter
Vi	Velocity of Bats
Xi	Position of Bats
λi	Wavelength

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Distribution network (DN) is the final stage of electric power delivery. The system conveys electrical energy from transmission system to electrical energy consumers. Generally, distribution networks are configured in a radial pattern against meshed configuration used in transmission networks, which makes power flow unidirectional. This often results in power and voltage reduction delivered at the consumer load points where the demand is high. Distribution networks normally have much power loss and poor voltage regulation due to high load current and low voltage in the distribution network (Nguyen *et al.*,2016)

Thus, the performance improvement of the radial distribution network is usually premised on minimization of power loss and voltage deviation. Many efforts have been put in place to mitigate power losses and improve voltage stability in distribution network such as distribution synchronous static compensator (DSTATCOM), voltage source converter (VSC) such DC link Capacitors placement, network reconfiguration, DG placement and many others (Shamsuddin *et al.*, 2014)

However, excessive power loss and voltage deviation in the distribution network may further require combination of network reconfiguration and placement of distributed generation, so as to reduce high power losses, poor voltage regulation and improve loading capacity margin (Ali *et al.*, 2015)

Distribution Network Reconfiguration (DRN) is the process of varying the topology of distribution network by changing the closed/open condition of sectionalizing and tie switches while abiding by distribution system constraints (Rao *et al*., 2013).

On the other hand, Distributed Generation (DG) as defined by the International Energy Association (IEA), as a generating plant serving customers on-site or providing support to distribution network connected to the grid at distribution voltage level (Kansal *et al*., 2011)

The current drive towards power loss reduction, voltage deviation minimization and load balance enhancement tend to favor the introduction of distributed generations (DGs) at distribution load centers, in view of the advantages of the DGs over the expansion of large central power generation plants. Some of these advantages include reduction in line losses, reduction in overall operation costs due to improved efficiency, peaking shaving, improvement of voltage profile, system reliability, ease of finding sites for smaller generators, availability of modular generating plant, proximity to heavy loads and security (Prakash & Khatod, 2016)

There are several types of DG technologies in modern power system generation. These include, solar PV, wind power, small hydro, pumped hydro and synchronous diesel or gas generators. Because solar PV and wind generate power intermittently and require expensive energy storage systems, they are often employed as off-grid DGs, since their unit cost of electricity generation is much higher than the central grid system. The hydro and diesel/gas synchronous generators on the other hand, have been preferred as grid connected DGs due to their ability to generate fairly constant power as well as their ability to provide both active and reactive power at relatively comparative cost with the central grid system. In addition, the synchronous DGs ensure local generation of reactive power and reduces the import of reactive power from the feeder, thus reduces the associated losses and improves the voltage profile. As a result, voltage security is improved (Prakash & Sujatha, 2016)

The placement of the DG in the distribution network, however, is often constrained by the size and location of the DG on the distribution network, which if not optimally located and sized, their deployment in distribution network could pose serious technical challenges that may affect the stability of the power system as well as its quality (Buaklee & Hongesombut, 2014).

Similarly, the distribution network reconfiguration requires some optimization schemes to help fashion out the optimal network topology that would ensure minimum power loss and voltage deviation in the network. The recent approaches to network reconfiguration involved numerical methods as in (Merlin & Back, 1975), analytical methods as in (Baran & Wu, 1989) and heuristics methods as in (Li *et al.*, 2016).

On the other hand, the recent approaches to network reconfiguration and DG placement in the distribution network have been mostly meta-heuristics approaches as in (Syahputra *et al.*, 2015) where extended particle swarm optimization (PSO) was employed (Hivziefendić *et al.*, 2016)

In this research work, an application of Bat Algorithm (BA) based method is presented for multi-objective optimal network reconfiguration and distributed generation placement in radial distribution network considering Sabo-Feeder in Zaria distribution network as a case study.

1.2 Motivation

The incessant power loss and poor voltage level due to varying loads in the distribution network has prompted the power utility to search a quicker and relatively less expensive approach for reducing power loss, improve voltage profile as well as relieving the load among the distribution feeders. This has brought about the choice of distribution network reconfiguration with DG deployment technique to solve the stated problem, hence a motivation for this research work

1.3 PROBLEM DEFINITION

Minimum power loss and voltage deviation in conventional radial distribution network could not achieved for a fixed network configuration due to varying loads, which increases load current drawn from the network .This effect makes the network inefficient, owing to voltage magnitude reduction and increase in network losses. Hence, there is a need for reconfiguration of the network from time to time for optimal network performance. In addition, the total load is more than the system generation capacity due to dynamic nature of the load as such eliminating the load on the feeder could not be possible, hence DG units could be further installed to meet the required level of voltage profile improvement and power loss minimization for overall distribution network performance improvement. The recent approaches to network reconfiguration involved heuristics as in Li *et – al, (2016)* and Meta heuristics methods as in Kunya *et – al (2016)*, On the other hand, the recent approaches to DG placement in the distribution network have been mostly Meta heuristics approaches as in Prakash & Sujatha.

In most of the past research efforts, the framework for optimal network reconfiguration of the distribution network and DG placement considered the two optimization problems independently. However, attempts were made recently to consider the two optimization problems simultaneously by employing multi-objective modeling framework using extended particle swarm optimization (PSO) algorithm as in Syahputra*et al* and a multi-objective approach using a harmony search algorithm as in Rao *et al*. However, in view of the need to further improve accuracy and speed of computation, other meta-heuristic approaches, such as bat algorithm could be explored to achieve better DNR and DG deployment.

Hence, this research work, presented an application of multi-objective bat algorithm-based method for optimal network reconfiguration and DG placement in a radial distribution network. The results obtained from this work have been compared with works of Syahputra 2015 to validate the research work.

1.4 Aim and Objectives

The aim of this dissertation is the application of Bat algorithm-based method for multi-objective optimal network reconfiguration and distributed generation placement in radial distribution network to minimize total power loss, voltage deviation and enhance load balancing in distribution feeders, considering Zaria (Sabo-Feeder) distribution network as a case study.

To attain the aim, the set objectives are given as follows,

1. Determination of Base Case Network Parameters Using Backward-Forward Algorithm
2. Application of Bat Algorithm (BA) Method for Multi-Objective Optimal Network Reconfiguration and DG Placement
3. Validation of the developed method on standard IEEE-33 bus system by comparing with the Work of Syahputra*et al.*, 2015 on MATLAB Platform.
4. Implementation of the developed method on Sabo feeder in Zaria distribution network

1.5 Methodology

The following approach was adopted in order to achieve the stated aim and objectives.

1. Adoption of IEEE-33 bus data and Zaria distribution network data

   The following data have been obtained and analyzed:

i. Line data; impedance data (resistance and reactance) of each line
ii. Bus data ; active and reactive power demand at each bus with the exception of slack bus
iii. Network base voltage
iv. Sending and receiving end buses data

2. Determination of Base Case Network Parameters using backward-forward algorithm

The following steps could be followed;

i. Formulation of forward-backward sweep equations

ii. Loading of the line and bus data for base case

iii. Computation of the load current and bus voltages at each bus

3. Application of BA for optimal reconfiguration and DGs placement

The following steps were followed for optimal DNR and DG Deployment

i. Initialization of the Bat algorithm
ii. Initialization of the population
iii. Selecting the appropriate tuning parameters

4 Validation of the Bat algorithm on IEEE-33 Bus System

i. Loading of line and bus data of IEEE-33 bus
ii. Analysis of base power flow
iii. Initialization the Bat parameters
iv. Application of bat algorithm with the formulated objective functions
v. Analysis of final power flow for reconfiguration and DGs at critical buses
vi. Validation of the developed Method by comparing with the work of Syahputra*et al.*, (2015)

5 Implementation of the Developed Method on Zaria (Sabo-feeder) Distribution Network

i. Load the line and bus data of Zaria distribution network

ii. Analysis of base power flow for Zaria distribution network

iii. Initialization of the Bat parameters for Zaria distribution network

iv. Application of the BA with the formulated objective functions

v. Simulation of final power flow analysis for reconfiguration and DGs incorporated at the optimum buses of Zaria distribution network.

1.6 Dissertation Organization

In chapter one, a general background introduction of distribution network reconfiguration and DG placement concepts were presented accordingly. Chapter two provides a concise review of the fundamental concepts and review of similar works on distribution network reconfiguration and DG placement. The research methods and materials, which include determination of radial network reconfiguration, placement and sizing of DGs were presented in chapter three. In chapter four, the results and discussions based on network reconfiguration and DG deployment were presented, while chapter five discussed on the significance contribution of the research work, conclusion, limitations of the research work and recommendation for further work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter consists of two parts; the review of fundamental concepts relevant to the research work and the review of similar works. In the review of fundamental work, some of the existing research works and fundamental theories relevant to this research work were reviewed for the success of the work

2.2 Review of the fundamental concepts

In this section, fundamental concepts of the research work such as electrical power system, distribution networks, network reconfiguration, synchronous distributed generator, different DGs and many others were reviewed.

2.2.1 Electrical power system

The electrical power systems are classified as large technical systems due to their complex nature characterized by large number of technical components and area coverage. It consists of three major components; generation, transmission and distribution systems as presented in Figure: 2.1. The production, transmission as well as distribution of electrical energy is usually efficient, though unlike other forms of energy production, electrical energy could not be stored easily as such electrical energy must be consumed as it is being generated (Ackermann *et al.*, 2001)

The hierarchical order of power transfer starts from generation via transmission and terminated at various load centers through the DN as shown in Figure 2.1

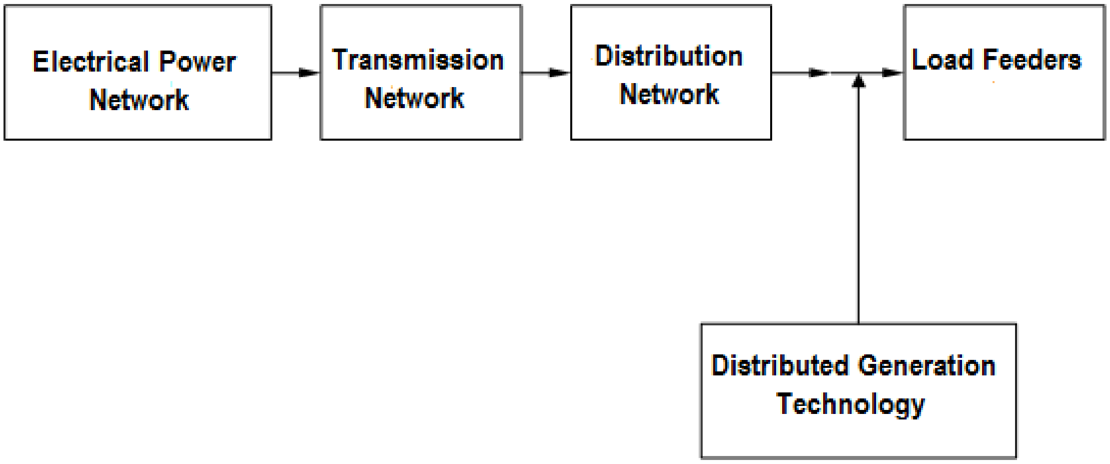

Figure: 2.1 Components of Electric Power Sys. With DG Integration (Ackermann *et al.*, 2001)

2.2.2 Electrical Power Generation

Power generation in modern power system consists of central grid generation systems and the distributed generation systems which can be as follows;

2.2.2.1 Central Grid Generation (Smart Grid)

This is the modern method of power generation which transformed electricity transmission as well as distribution network by allowing robust two-ways communication, advanced sensors and distributed computers in order to improve the efficiency, reliability and safety of power delivery and use (Bari *et al.*, 2014)

Central grid generation brings all elements of the electricity system production, delivery, and consumption closer together to improve overall system operation for the benefit of consumers and the environment. Smart grid can also augment the present electric grid system by including renewable energy resources like solar, wind biomass, synchronous distributed generators that are environmentally cleaned as compared to non-renewable energy resources like fossil fuels technologies that include sterling engine, reciprocating engine, for power generation.

a. Benefits of Smart Grid Application

i. It enable informed participation in buying and selling of electricity by consumers
ii. It optimizes asset utilization and efficient power system operation
iii. It accommodates all generation and storage option
iv. It operates resiliently against all hazards

b. Limitation of Smart Grid Application

i. Energy generators protection is challenging in smart grid
ii. Energy consumers' privacy protection in smart grid
iii. Power houses can be attractive to terrorists targets
iv. Smart grid devices protection in the buildings (Bari *et al.*, 2014)

2.2.3 Distributed Generation (DG): According to International Energy Association (IEA), is a generating plant serving customers on-site or providing support to distribution network connected to the grid at distribution voltage level (Kansal *et al.*, 2011)

Generally, distributed generation refers to small-scale electric power generators (typically 1kW-50MW) that produce electricity at a site close to customer or that are tied to an electric distribution system.

Distributed generation include but not limited to synchronous generators, induction generators, reciprocating engines, micro turbines, combustion gas turbines, fuel cells, solar photovoltaic, wind turbines etc. (Lai & Chan, 2008)

2.2.3.1 Application of Distributed Generation

Distributed generation can be used to generate a customer's entire electricity for peak shaving, for standby or emergency generation, for green power source, or for increased reliability. In some remote locations, distributed generation can be less costly, as it eliminates the need for expensive construction of generation system (Kansal *et al*., 2011)

The benefits of distributed generation can be considered in three fold: economic, technical and environmental as expressed in Figure 2.2

a. Economic Benefits of distributed generations (DGs)

i. DGs provide power generation, transmission, distribution investment deferment

ii. DGs have low operation and maintenance costs to peak shaving

iii. DGs reduce power losses in the distribution network

iv. DGs increase generation diversity on the grid

a. Technical Benefits of distributed generations

i. DGs provide voltage profile improvement

ii. DGs relieve transmission and distribution congestion

iii. DGs increase security for critical loads

iv. DGs lessen physical and cyber-attacks impact

b. Environmental Benefits of distributed generation

i. DGs help in removal of refuse through the use of biomass

ii. DGs help in reduction of pollutant’s emission

iii. DGs help to reduce land use for power generation

iv. DGs help to lessen radiation from transmission lines (Kansal *et al*., 2011)

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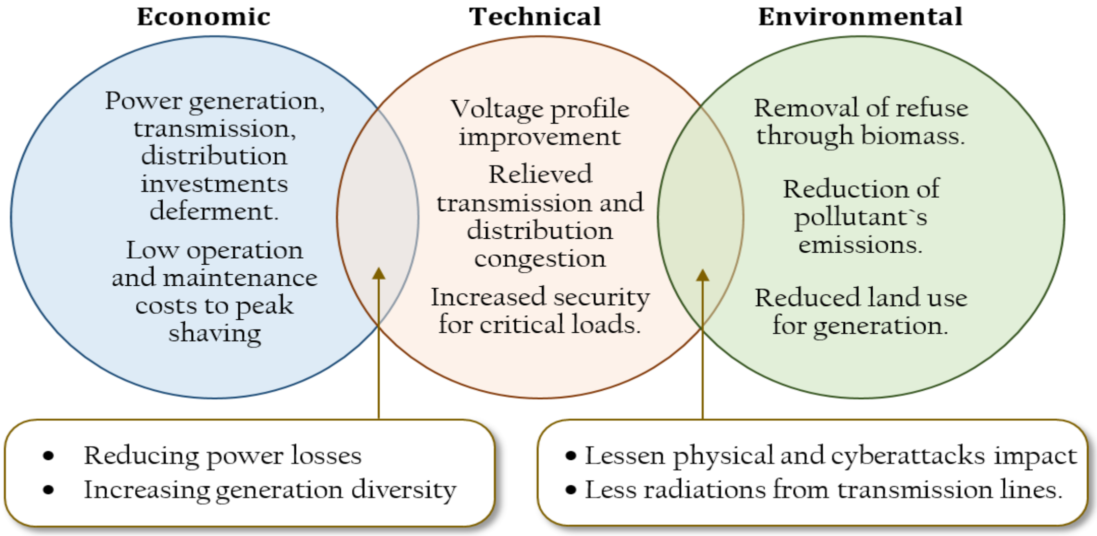


Figure: 2.2 Economic, Technical and Environmental DGs Benefits (Kunya *et al*., 2016)

Distributed generations can be classified based on the reactive power and active power injection or absorption into electrical distribution network as given in Table 2.1:

i.Type 1 DG: This type of DG is having the ability in delivering the real power only in the distribution network and the DG operates at unity power factor. These types of DGs are photovoltaic cells, fuel cells and many others

ii. Type 2 DG: This type of DG is having the ability in delivering both active and reactive power in the distribution network. This type of DG includes synchronous generators

iii.Type 3 DG: This is the type of DG capable of injecting active power (P), but consumes reactive power (Q) from the grid. This type of DG includes induction generators used as in wind turbine.

iii. Type 4 DG: This is the type of DG capable of injecting reactive power (Q) only into distribution network. This type of DG includes synchronous compensator such as in gas turbine (Mehta *et al*., 2015)

The Table 2.1 shows the summary of DG classification in tabular form

Table 2.1: Classification of DGs

Type of DG	**Model of DG**	**Real power of DG** P_{DG}	**Reactive power of DG** Q_{DG}	**Example**
Type I	Constant Real Power	P_{DGi}	0	Solar photovoltaic cells
Type II	Constant Power Factor	$P_{DGi} = S_{DGi}\cos\phi$	$Q_{DGi} = S_{DGi}\sin\phi$	Sync. generators
Type III	Variable Reactive Power	P_{DGi}	$Q_{DGi} = -(0.5 + 0.04(P_{DGi})^2)$	Induction generators
Type IV	Constant Reactive Power	0	Q_{DGi}	Synchronous compensators

2.2.3.2Synchronous Distributed Generator (DG)

This is the DG that generates a three-phase AC voltage output from its stator windings. Synchronous generators consist of a magnetic field on the rotor that rotates and a stationary stator containing multiple windings that supply the generated power to the loads

The rotor's magnetic field system is created by using either permanent magnet mounted directly onto the rotor or energized electro-magnetically by an external DC current flowing in the rotor field windings. Synchronous Generators are capable of generating both active and reactive power. Therefore, the use of DGs utilizing overexcited synchronous generators will allow on-site production of reactive power. The local generation of reactive power reduces its import from the feeder, thus reduces the associated losses and improves the voltage profile. As a result, the voltage security is also improved (Hedayati *et al.*, 2008)

2.2.3.3 Main Components of a Synchronous Generator (DG)

1. **The Stator:** The stator carries the three separate phases, electrically displaced from each other by 120 degrees producing an AC voltage output

2. **The Rotor:** The rotor carries the magnetic field either permanent magnets or wound field coils connected to an external DC power source via slip rings and carbon brushes

2.2.3.4 Excitation of Synchronous DGs

The excitation of synchronous DGs have a power impact on synchronous DGs dynamic performance and availability, as it ensures quality of synchronous DGs voltage and reactive power which means quality of delivered power to energy consumers (Prakash & Khatod, 2016)

2.2.3.5 Synchronous Distributed Generator Model (DG)

This DG model is modelled as PQ^+ type, the DG is usually small in size and normally 2MW with 085*p.f.* Synchronous distributed generator based model has the capability to maintain its terminal voltage constant by varying the reactive power it generates. Given that P_{sg} is real power of the DG and the minimum power factor at which the DG is to operates is $Cos\theta_{\min}$, then the reactive power Q_{sg} with an upper bound Qmax can be determined as maximum and lower reactive power bound; Qmin as follows (Sheng *et al* 2015)

$$Q_{Max} = P_{SG} \tan\theta_{Max} \tag{2.1}$$

$$Q_{Min} = -P_{SG} \tan\theta_{Min} \tag{2.2}$$

Where: P_{SG} ; The real power of DG, Q_{SG} ; The reactive power of DG

Q_{Max} ; The upper limit of reactive power, Q_{Min} ; The lower limit of reactive power

$Cos\theta_{Max}$; The maximum power factor, $Cos\theta_{Min}$; The minimum power factor

In view of the above, it shows that the synchronous distributed generator operates between the upper and lower limit of the reactive power that is

$$-Q_{Min} \leq Q_{SG} \leq Q_{Max} \tag{2.3}$$

Synchronous distributed generators are classified as type 2 DGs for having the capability of delivering both real and reactive power as stated earlier. The power factor of DGs are fixed at a specified value (Hivziefendić *et al.*, 2016)

Considering, the reactive power output of DGs, $\alpha = (\text{sign})\tan(\cos^{-1}(PF_{DG}))$ is expressed as

$$Q_i = \alpha P_{DGi} \qquad (2.4)$$

In this type, $Q_i = Q_{DGi} - Q_{Di} \pm$ *(2.5)*

Where; Q_i = net reactive power of node i

Sign= +1; DG supplying reactive power

Sign =-1; DG absorbing reactive power

PF_{DG} = power factor of DG (Sheng *et al* 2015)

2.2.4 Electrical Power Distribution Networks

Distribution network system is the final point in the delivery of electrical power system. The distribution network carries electricity from the transmission system to different consumers. There are two different distribution stages: Primary distribution and secondary distribution stage, the primary distribution lines carry the medium voltage to distribution transformers which are located near the consumer's areas. The Secondary distribution line's transformers lower the voltage further to the consumption voltage of household electrical appliances such as electric pressing iron, electric blending machines and many others. Distribution network systems are divided into two types namely ring and radial networks;

2.2.4.1 Ring Main Distribution Network

The Ring main distribution network's primaries distribution transformers form a loop. The loop circuit starts from the sub-station bus bars, makes a loop through the area to be served and returns to the sub-station (Sunisith & Meena, 2014)

The distributors are tapped from different points of the feeder through distribution transformers. The schematic diagram of the ring main distribution network is as shown in Figure 2.3

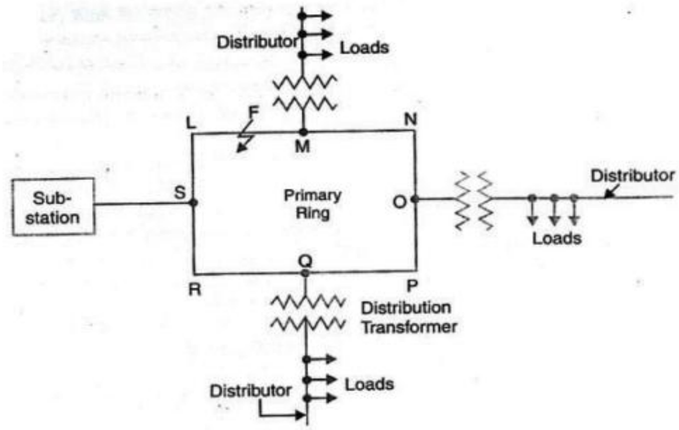


Figure: 2.3 Ring Main Distribution Network (Sunisith & Meena, 2014)

2.2.4.2 Merit of Ring Distribution Network

i. The feeder can be fed at one or more feeding points

ii. The fault cannot interrupt the supply of electricity to consumers

2.2.4.3 Demerit of Ring Main Distribution Network

i. The ring main is more expensive than the radial distribution network

ii. The ring main is not good when the generation is at low voltage

iii. The ring main has a high construction costs (Mehta *et al*., 2015)

2.2.4.4 Radial Distribution Network

The radial distribution network has separate feeders that radiate from a single sub-station and feed the radial distributors. The power is delivered from the main branch to the sub-branches and then radiate out from the main branches again. In summary the radial distribution network leaves the station and passes through the network area with no connection to any other supply. The schematic diagram of the radial distribution network is shown in Figure 2.4, while the schematic diagram showing the power flow equations is as shown in Figure 2.5

2.2.4.5 Merit of Radial Distribution Network

i. The radial distribution network is simple in term of construction

ii. The radial distribution network has low initial cost

iii. The radial distribution network is useful when the generation is at low voltage

iv. The radial distribution network is important when the station is located at the center of the load.

The Figure 2.4 below shows the radial distribution network with the DG connection

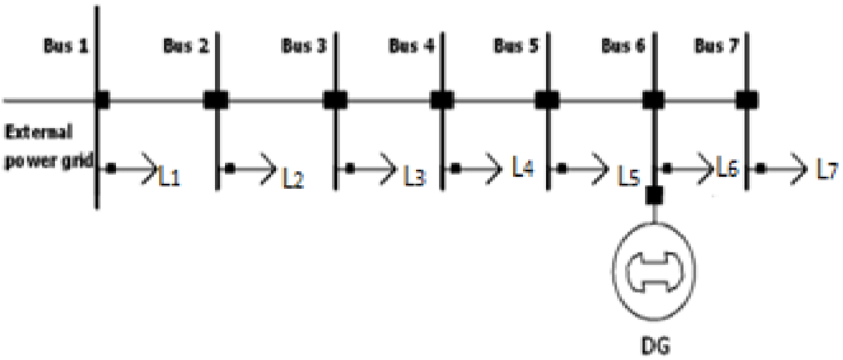


Figure: 2.4 Radial Distribution Network with the DG Connection (Nadhir *et al*., 2013)

2.2.4.6 Demerit of Radial Distribution Network

i. The end of the radial distributor nearest to the feeding point will be heavily loaded

ii. The consumers are dependent on a single feeder and single distributor. If there is fault no voltage supply to the consumers of that feeder until the fault is rectified.

iii. The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes, but with the present distributed generation penetration in the distribution network near the consumer premises, the problem of voltage fluctuations has been adequately addressed (Rupa & Ganesh, 2014)

In view of the above mentioned factors, the radial distribution network is usually used in the distribution network system than the ring main distribution network system.

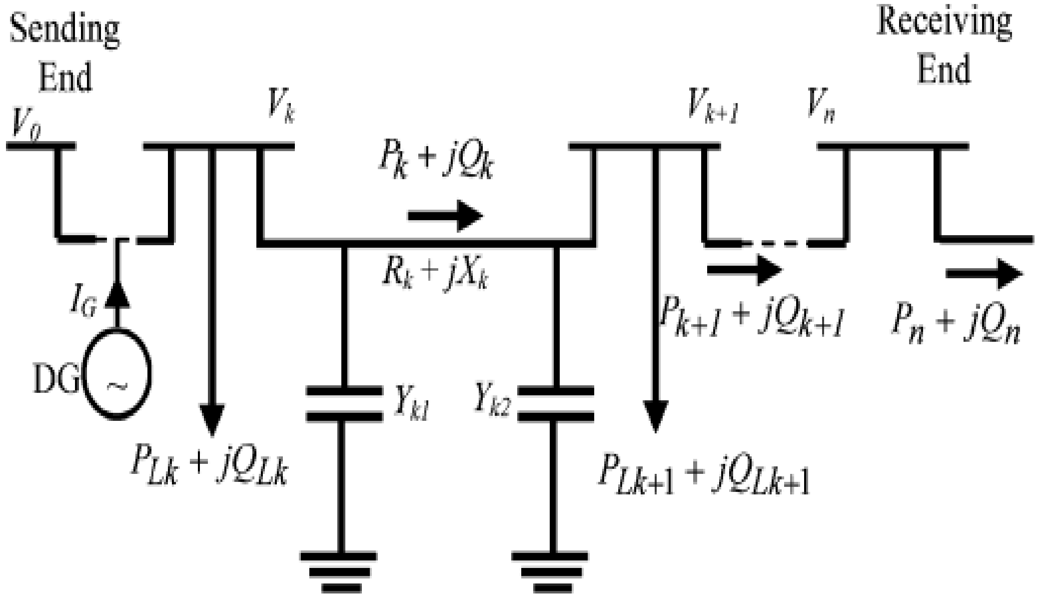


Figure: 2.5 Radial Distribution Network Power Flow Equations with DG (Nadhir *et al.*, 2013)

2.2.4.7 Placement and Sizing of Distributed Generation in the Radial Network

The power flows in the radial network can be calculated by the following number of simplified recursive equations derived from Figure: 2.5 (Nadhir *et al.*, 2013)

$$P_{i+1}=P_i-P_{Loss,i}-P_{Li+1}=P_i-\frac{R_i}{|V|_i^2}(P_i^2+(Q_i+Y_i|V|)_i^2)-P_{Li+1} \qquad (2.5)$$

$$Q_{i+1}=Q_i-Q_{Loss,i}-Q_{Li+1}=Q_i-\frac{R_i}{|V|_i^2}(P_i^2+(Q_i+Y_{i1}|V|)_i^2)-Y_{i1}|V|_i^2-Y_{i2}|V|_{i+1}^2-Q_{Li+1} \qquad (2.6)$$

$$|V|_{i+1}^2=|V|_i^2+-\frac{R_i^2+X_i^2}{|V|_i^2}(P_i^2+Q_i'^2)-2(R_iP_i+X_iQ_i)=|V|_i^2-\frac{R_i^2+X_i^2}{|V|_i^2}(P_i^2+(Q_i+Y_i|V|)_i^2)-2(R_iP_i+X_i(Q_i+Y_i|V|_i^2)) \qquad (2.7)$$

The loss in the line section connecting buses, i and i+1can be calculated as (Nadhir*et al.*, 2013)

$$P_{Loss(\mathrm{i,i+1})}=R_i*\frac{\left(P^2{}_i+Q^2{}_i\right)}{|V|^2{}_i} \qquad (2.8)$$

The total power loss of the network, $P_{T,\,Loss}$ can be determined by summing up the losses of all line sections of the network is given by (Nadhir *et al.*, 2013)

$$P_{\mathrm{T,Loss}}=\sum_{i=1}^{n}P_{LOSS(\mathrm{i,i+1})} \qquad (2.9)$$

The DG location can be determined by considering the difference of the power loss before and after the installation of DG in the network as given below

$$PowerLoss\,\mathrm{Re}\,ductionValue=P_{Loss(\mathrm{i,i+1})}-P'_{Loss(\mathrm{i,i+1})} \qquad (2.10)$$

Where;

PLR: The power loss reduction value

$P_{LOSS:}$ The power loss before DG installation in the network

$P'_{LOSS:}$ The power loss after DG installation in the network

Therefore, the network bus that gives the highest value of PLR will be considered as the optimal DG location in the network.

The DG size can be computed by considering equation (2.11) which means calculating the product of maximum loss saving DG current and voltage magnitude of the network bus as indicated by (Nadhir *et al*., 2013)

$$P_{DG} = I_{DG} V_i \qquad (2.11)$$

Where; $P_{DG:}$ The active power of the DG

$I_{DG:}$ The maximum loss saving current of DG

$V_{i:}$ The voltage magnitude of bus i where the DG is to be installed.

2.2.5 Distribution Network Reconfiguration of Radial Network

Distribution networks are usually operated as radial network but the topology of the network is changed during operation by altering the state of some sectionalizing switches hence called network reconfiguration. For instance in Figure: 2.6, the switches CB7 (circuit breaker7) and CB8 can be closed and CB3 and CB6 can be opened to transfer load from one feeder to another (Li *et al*., 2016).

There are two type of switches in distribution networks: normally closed switches connecting the line sections (CB1 to CB6), and normally open switches on the tie lines connecting either two distribution feeders (CB7) or two sub-stations (CB8), or loop-type laterals (Baran & Wu, 1989) as shown in Figure 2.6

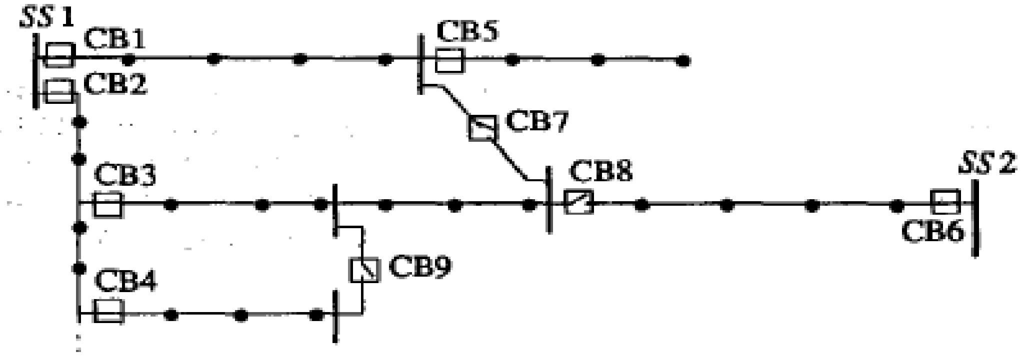


Figure:2.6 Network Reconfiguration Schematic Diagram (Baran & Wu, 1989)

2.2.5.1 Determination of Radial Configuration in the distribution network

The distribution network can be regarded as a function of G (N, B) where G represents a graph that contains a set of N nodes and a set of B branches. The node represents either a source node or a sink node while a branch represents a feeder section that can either be energized or de-energized. The distribution network reconfiguration is to find a radial structure that minimizes the network power loss and relieve the load among feeders while satisfying distribution network operating constraints.

The possible number of radial structure for a distribution network could be obtained for a given configuration. The number of branches needed to maintain a radial network with redundant connections is fixed and could be obtained using (Coroamă *et al.*, 2013)

$D = B - N + S$ *(2.12)*

Where; B is the number of branches

N is the number of nodes

S is the number of supplies

D is the number of redundant connections (Abubakar, 2014)

2.2.5.2 Reconfiguration of Standard IEEE-33 Distribution Network with DG Deployment

The standard IEEE-33 distribution network has a total active and reactive load demand of 3.72MW and 2.30 Mvar respectively. The system also has 37 branches, 32 sectionalizing switches and 5 tie switches respectively.

The Figure: 2.7 shows the reconfiguration of the standard IEEE-33 distribution network,

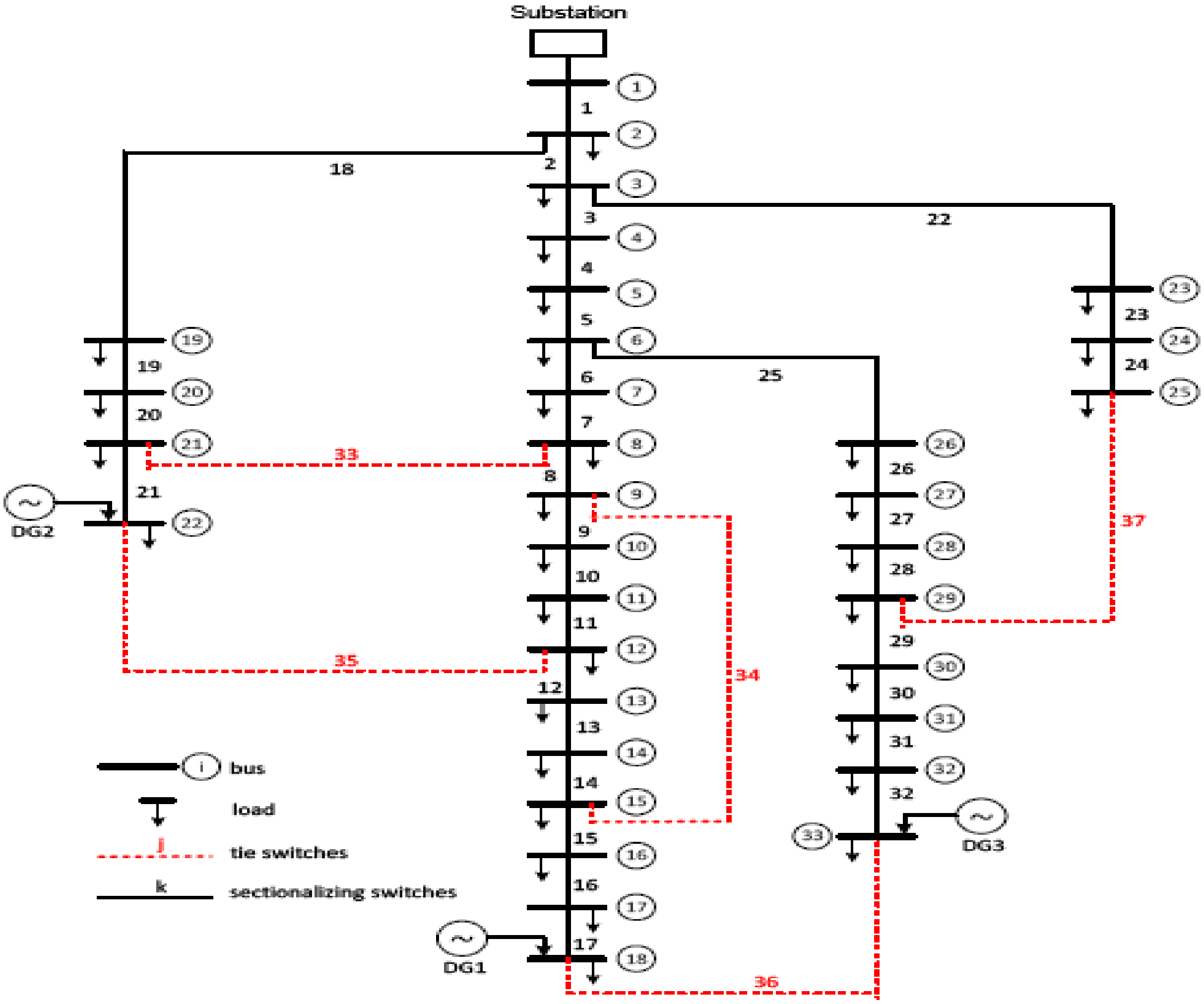


Figure:2.7 Shows the Reconfiguration of Std IEEE-33 System and DGs (Syahputra *et al.*, 2015)

2.2.5.3 Reconfiguration of Zaria (Sabo) Distribution Network with DGs Deployment

The Zaria distribution network has total active and reactive load demand of 1.84MW, 0.82 Mvar and 11kV base voltage respectively. The system also has 31 branches, 29 nodes, 3 tie switches and 28 sectionalizing switches in Figure 2.8. The network data is shown in Appendix B. The three loops were formed by closing the three tie switches and also the number of branches form the possible switches to be opened in the system

The Figure: 2.8 shows the network reconfiguration of Zaria distribution network

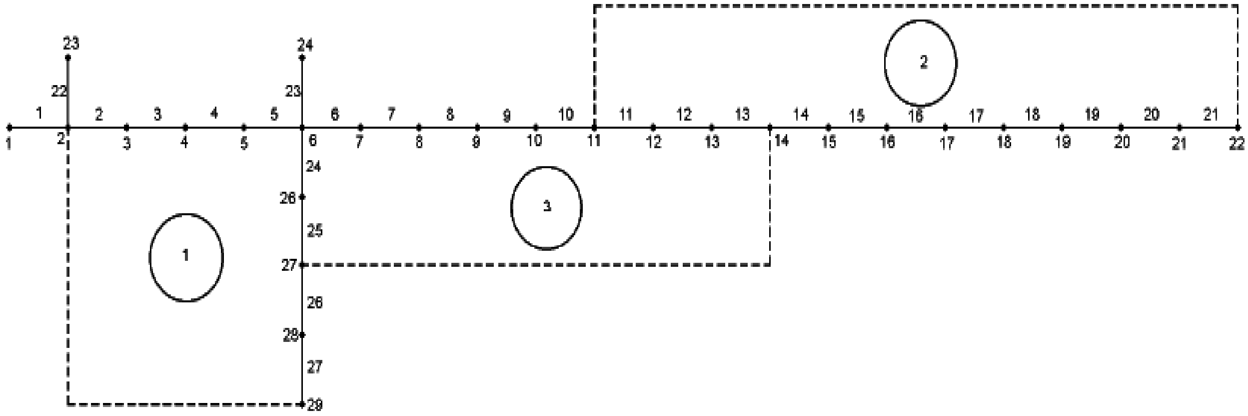


Figure:2.8 Reconfiguration of Zaria Distribution Network Schematic Diagram(Abubakar, 2014)

2.2.6 The Standard IEEE Radial Distribution Network

Different standard IEEE distribution tests networks have been considered and also used by different researchers to verify the effectiveness of their research works. Most of the literatures so far reviewed have employed one or more standard IEEE distribution networks for analysis and validation of research works. The line and bus data for 33-bus standard IEEE radial distribution networks was used in this research work

2.2.6.1 Standard IEEE 33-Bus Distribution Network

This is a medium voltage radial distribution network with 33-buses and 32-branches, line data and bus data as shown in Appendix A. The line and bus data for 33-bus standard IEEE radial distribution networks was used in this research work. The line voltage, base MVA, real and reactive power demands of the radial distribution network are 12.66kV, 10MVA, 3.72MW and 2.30MVAr, respectively (Yuvaraj *et al.*, 2015)

Figure 2.9 shows the single line diagram of the distribution network.

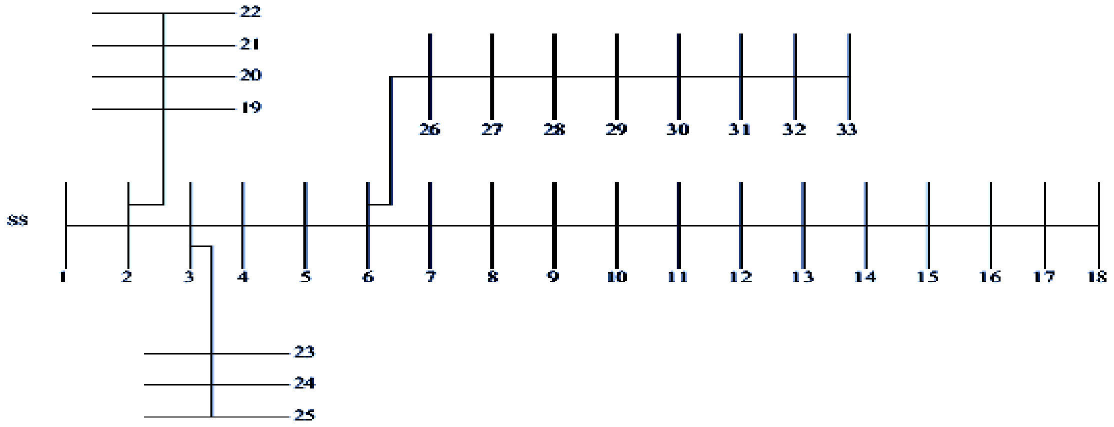


Figure: 2.9 Single Line Diagram of IEEE 33-Bus System (Yuvaraj *et al.*, 2015)

2.2.6.2 Zaria Distribution Network

The Zaria distribution network is a real distribution network interconnected with 8 (eight) distribution feeders that include; Gaskiya feeder, Canteen feeder, Zaria-city feeder, RLY/NTC feeder, Sabon- Gari feeder, G.R.A. feeder, Kofar-Kibo as well as Zaria Teaching hospital feeder. All the above mentioned feeders have 11kV as their base voltage.

This research work opted for Sabon-Gari feeder to be considered as a case study for the implementation of the presented research work.

The line and bus data are shown in appendix B. The line voltage, base MVA, real as well as reactive power demands of Sabon-Gari radial distribution network are 11kV, 10MVA, 1.84MW and 0.82MVar respectively.

The Figure 2.10 shows the single line diagram of the Sabo feeder of Zaria distribution network

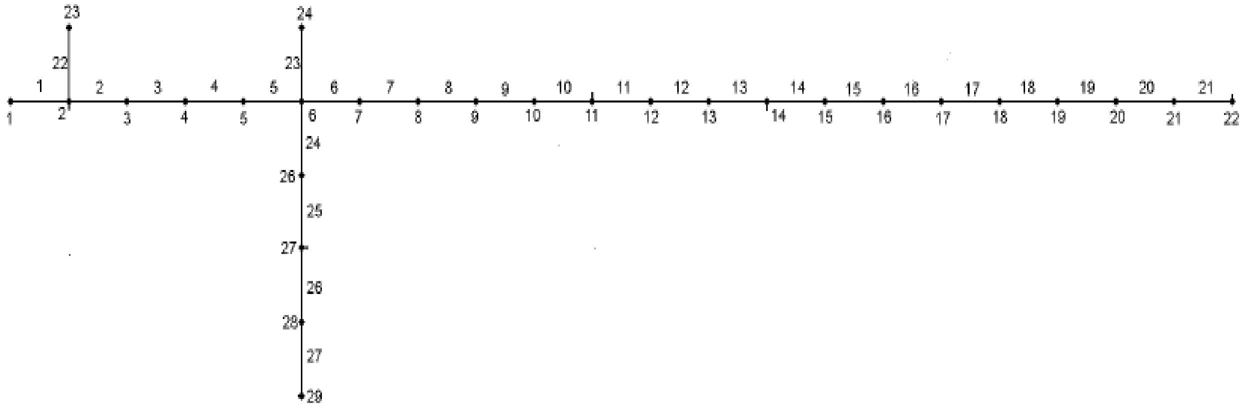


Figure: 2.10 Sabon-Gari Distribution Network (Abubakar, 2014)

2.2.6.3 Load Flow Analysis in Distribution Network

Conventional load flow methods such as Newton-Raphson, Gauss-Seidal or fast Decoupled which are typically designed for electrical transmission networks are not suitable for power distribution networks load flow analysis. Distribution networks are typically radial in nature and the feeders have high R/X ratio, hence ill-conditioned for such load flow

The backward forward sweep (FBS) technique assumed the network to be balanced so that the distribution network could be represented in a single line diagram. The analysis follows from one branch to another in a logical approach until all the branches in the network have been considered (Nadhir *et al.*, 2013)

First, the voltage at all the buses is assumed to be one pu at angle zero except the slack bus. Therefore, based on the above information, the voltage, the specified active power, the reactive power and the branch currents are computed and saved simultaneously, from the end buses to the source buses (Backward Sweep) (Sunisith & Meena, 2014)

Then, the branch currents are calculated in order to find the active and reactive power losses in the distribution network. The current at the source end is now computed iteratively. The calculation starts from source to the end of the distribution network feeders to find the voltage drop, current, real and reactive power losses respectively (Forward Sweep) (Kumar *et al*., 2011)

The flow chart of backward-forward sweep algorithm for determining the base case of the stated objective functions in the distribution network is shown in Figure: 2.11

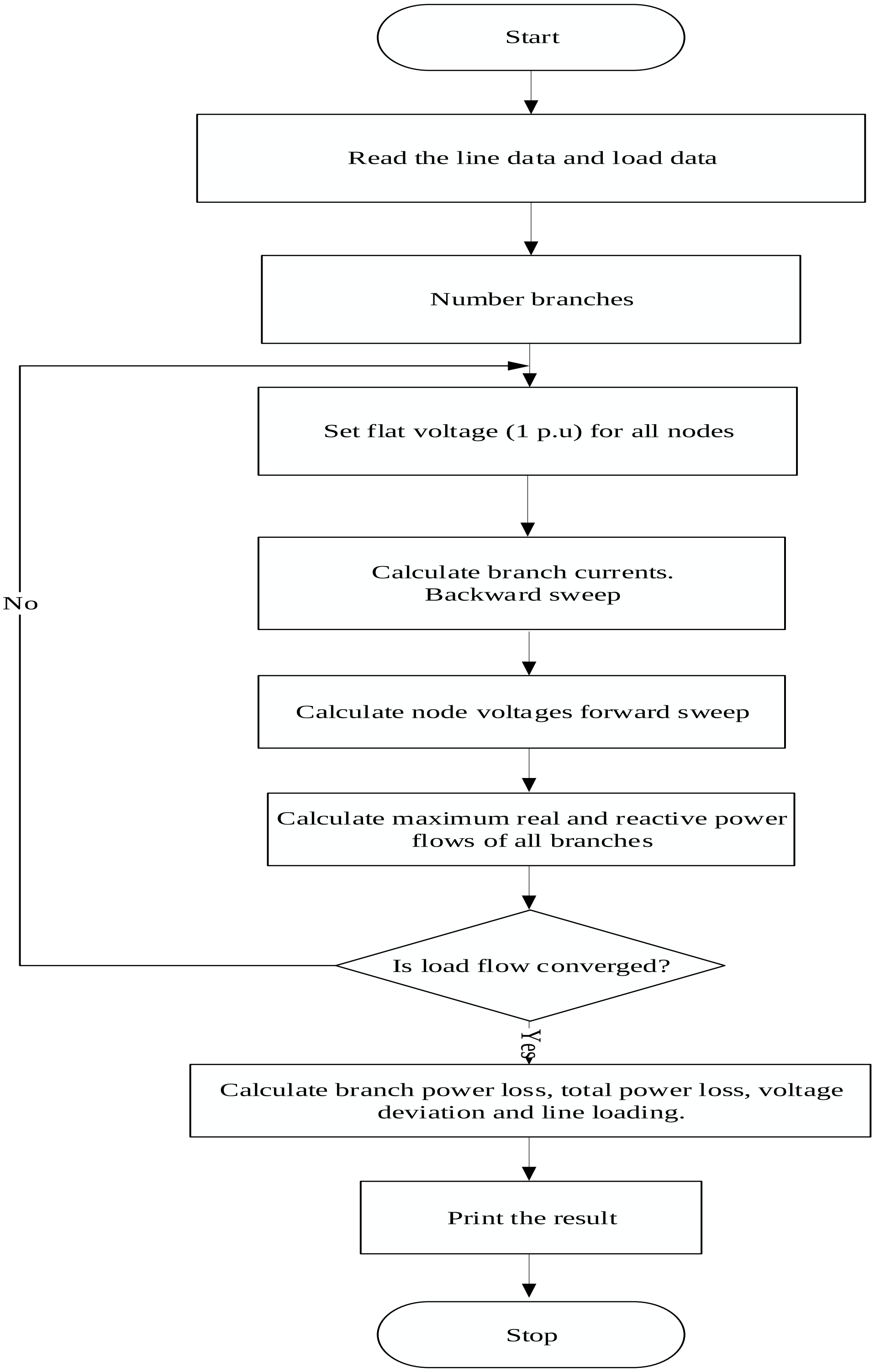


Figure: 2.11 Backward-forward Algorithm of the DN (Rupa & Ganesh, 2014)

The equations for forward/backward sweep technique used for the work were given in Figure: 2.13 and Figure: 2.19

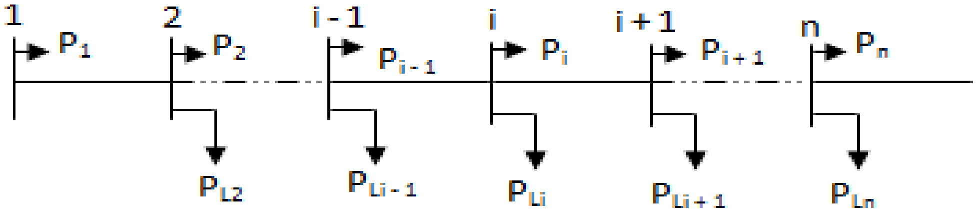


Figure: 2.12 Single Line Diagram of Radial Distribution Network (Nadhir *et al*., 2013)

Consider Figure 2.13 with bus i. as sending bus and bus i+1 as receiving bus

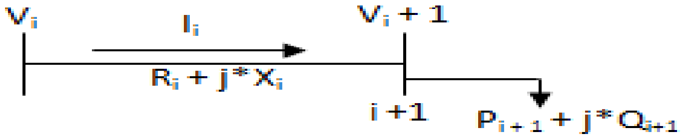


Figure: 2.13 Electrical Equivalent of Single Radial Network (Nadhir *et al*., 2013)

$$P_i = P_{i-1} - P_{L_i} - R_{i-1}\frac{\left(P^2{}_{i-1} + Q^2{}_{i-1}\right)}{|V|^2{}_{i-1}} \tag{2.13}$$

The equations (2.13) and (2.14) were used to determine base case results

$$P_i = P_{i+1} + P_{L_i} + R_{i+1}\frac{\left(P^2{}_i + Q^2{}_i\right)}{|V|^2{}_i} \tag{2.14}$$

The equation (2.15) is used for the computation of branches currents

$$I_i = \frac{|V_i|\angle\delta_i - |V_{i+1}|\angle\delta_{i+1}}{R_i + jX_i} \tag{2.15}$$

The equation (2.16) is used to determine the capacities of the DGs used

$$P_{i+1} - jQ_{i+1} = V^*_{i+1} \times I_i \tag{2.16}$$

The equation (2.17) is used for the determination of voltage deviation

$$|V|_{i-1}^{2} = |V|_{i}^{2} - 2\left(R_{i-1,i} * P_{i}^{1} + X_{i-1,i} * Q_{i}^{1}\right) + \left(R_{i-1,i}^{2} + X_{i-1,i}^{2}\right) * \frac{\left(P^{2}{}_{i} + Q^{2}{}_{i}\right)}{|V|^{2}{}_{i}} \qquad (2.17)$$

The power loss of any line connecting the buses i and i+1 can be calculated as;

$$P_{Loss(\mathrm{i,i+1})} = R_{i,i+1} \frac{\left(P^{2}{}_{i} + Q^{2}{}_{i}\right)}{|V|^{2}{}_{i}} \qquad (2.18)$$

The total power loss in all the buses $P_{T,Loss}$ can be determined by summing up the losses of all line sections of the power feeders (Nadhir *et al.*, 2013) which is given by;

$$P_{T,Loss} = \sum_{i=1}^{n-1} P_{Loss(\mathrm{i,i+1})} \qquad (2.19)$$

Where; n is the number of buses in the distribution network

i.is the number of branches in the distribution network

P_{TLOSS} is the total active power loss in the distribution network

The objective function of minimizing power loss is given by

$$F_{obj} = Min \sum_{i=1}^{line} P_{Loss} \qquad (2.20)$$

The reactive power loss $Q_{T\,LOSS}$ is given by

$$Q_{T,Loss} = \sum_{i=1}^{n-1} Q_{Loss(\mathrm{i,i+1})} \qquad (2.21)$$

Where; n is the number of buses in the distribution network

i.is the number of branches in the distribution network

Q_{TLOSS} is the total reactive power loss in the distribution network

2.2.6.4 Optimal Network Reconfiguration, Placement and Sizing of Distributed Generation

Distribution network reconfiguration and DGs deployment are the good option to improve distribution network performance, but due to complex combinatorial, non-differential nature of the problem, the conventional or classical optimization techniques such as Linear Programming, Gradient Search are not suitable for this optimization problems (Rao *et al*., 2013)

Many methods from different researchers have been introduced for optimal network reconfiguration and DGs deployment in a radial distribution system. Previous methods presented include the analytical approach as proposed by (Merlin and Back, 1975), (Baran & Wu, 1989), (Li *et al*., 2016) and (Hung *et al., 2013)*, the numerical method as presented by (Atwa *et al*., 2010) and (Hung *et al*., 2014). Other methods used were the heuristic approach as proposed in the Work of (Kunya *et al*.), (Abubakar, 2014). The choice is mostly based on the general problem statement, objectives and constraints considered. Generally, some methods used for optimal network reconfiguration and DGs deployment are as follows;

1. Numerical method: This method involves the use of numerical analysis in searching for an optimal solution. Its main advantage lies in the ability to guarantee finding global optimum; however, it is mostly not suitable for large scale systems. The different types of numerical methods that have been used for optimal network reconfiguration and DGs deployment include Gradient search, linear programming, Non-linear programming, Sequential quadratic programming, Exhaustive search and many others (Syahputra *et al*., 2014)

2. Analytical method: This method originated from the 2/3 rule and is mostly executed based on the exact power loss formula for active power loss in the system. Analytical methods are easy to implement and execute, but their results are only indicative, since they make simplified

assumptions including the consideration of only one power system loading snapshot (Hung *et al.*, 2013)

3. Heuristic and Meta-heuristic method: This method involves creating a minimization or maximization objective function in finding the optimal DG placement and size. It could either be an experienced-based technique i.e. heuristic or higher–level i.e. meta-heuristic method that does not require training in searching for the iterative optimal solution. Generally, meta-heuristic methods require high computational effort that is why they can be trapped into local minima. Some types of heuristic and meta-heuristic solution methods used in optimal network reconfiguration and DGs deployment include Genetic Algorithm (GA), Taboo search, particle swarm optimization (PSO), Ant colony Optimization (ACO), Artificial Fish Swarm Algorithm (AFSA), Harmony Search, Fuzz- logic, Firefly Algorithm (FA), Cuckoo search algorithm (CSA) and many others(Nguyen *et al*., 2016)

Hence, application of meta-heuristic techniques known as Bat algorithm (BA) is considered as impetus for distribution network performance improvement through multi-objective optimal network reconfiguration and DG technology placement to achieve the defined objectives of the research work.

2.2.7 Bat Algorithm

Bat Algorithm (BA) is a nature inspired Meta heuristic algorithm developed by Xing-She Yang in 2010. Bat algorithm is based on echolocation that is important feature of the bat behavior. Bats are fascinating group of mammals that rely on echolocation to detect obstacles in flight, finding their way into roosts and forage for food/prey (Buaklee & Hongesombut, 2014)

The principle of operation of this algorithm is as follows; Bats emit a very loud sound pulse and listen for the echo that bounces back from surrounding objects, thus the loud pulse can determine the distance between bats and also can distinguish obstacles and prey(Heraguemi*et al.*, 2016)

Based on that behavior of bats; the ability to compute the distance between them and object echolocation can be used in such a way that it can be associated with the objective function to be optimized (Prakash & Sujatha, 2016)

To model bat algorithm Yang has set some rules as follows;

All bats use echolocation to sense distance and they also guess the difference between food/prey and background barriers in some magical way

Bats fly randomly with velocity v_i at position χ_i with a fixed frequency $f_{\min}$ and varying wavelength λ and loudness A_0 to search for prey (Yang & He, 2013)

They can automatically adjust the wavelength or frequency of their emitted pulses and adjust the rate of pulse emission r ∈ [0, 1], depending on the proximity of their target.

Although the loudness can vary in many ways, we assume that the loudness varies from a large positive A_0 to a minimum constant value $A_{\min}$. For each bat b_i, the position χ_i, the velocity v_i and the frequency f_i are initialize. For each step t, the maximum number of iterations, the movement of the virtual bats is given by updating their velocity and position (Prakash & Sujatha, 2016).

2.2.7.1 Population of Bats

The initial population i.e. the virtual number of bats for BA (n) is generated randomly. The number of bats can be between 20 and 40. After finding the initial fitness of the population for the given objective function, the values are updated based on movement, loudness and pulse rate (Yang, 2011)

2.2.7.2 Movement of Bats

The movement of bats can be demonstrated by the preceding equations as indicated below. All the Bats parameters are updated based on the following equations (Injeti *et al.*, 2015)

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \quad (2.22)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*) f_i \quad (2.23)$$

Where β is a random number between [0, 1], f_i is used to control the pace and range of the bat’s movement, χ_* is a current best location. Then the new solution or position for the bat can be generated by the equation given below

$$v_i^t = x_i^{t-1} + v_i^t \quad (2.24)$$

One solution is selected among the current best solutions and then the random walk is used to obtain a new solution.

$$x^{new} = x^{old} = A_i^t \partial \quad (2.25)$$

∂ is the average loudness of all bats, a random number between [0 1], the local search is launched depending on the pulse rate r_i, it should be noted that when bat finds prey the rate of pulse emission r_i increases and the loudness A_i decreases (Behera *et al.*, 2015)

2.2.7.3 Loudness and Pulse Emission

For each iteration the loudness A_i and the emission pulse rate r_i are updated as follows

$$A_i^{t+1} = \alpha A_i^t \quad (2.26)$$

$$r_i^t = r^o[1 - \exp(-\gamma\, t)] \quad (2.27)$$

Where ∝ and γ are constants. At the first step of the algorithm the values of these two parameters are chosen randomly, generally loudness and pulse rate are chosen within the ranges as indicated in equation (2.28)

$$A_i[0] \in [1,2] \, and \, r_i[0] \in [0,1] \quad (2.28)$$

Based on the above approximations and idealization, the pseudo- code of the Bat algorithm can be summarized as follows:

Step 1: Initialize the bat population or their position r_i and their velocity v_i, define pulse frequency f_i at χ_i. Initialize pulse rate r and loudness A

Step 2: Generate new solutions by adjusting frequency and updating velocities and location /solutions.

Step: 3 If (rand > r) select a solution among the best solutions. Generate a local solution; the selected best solution

Step: 4 Else generate a new solution by flying randomly

Step 5: If (rand $> A_i$) and $f(\chi_i) A_i^t$ accept the new solutions, increase r and reduce A.

Step 6: Rank the bats and find the current best χ_*

Step 7: while (iteration < max number of iterations), post process results and visualization. The algorithm stops with the total best solution. (Yang, 2011)

The flow chart of basic bat algorithm showing the steps involved for DNR and DG deployment

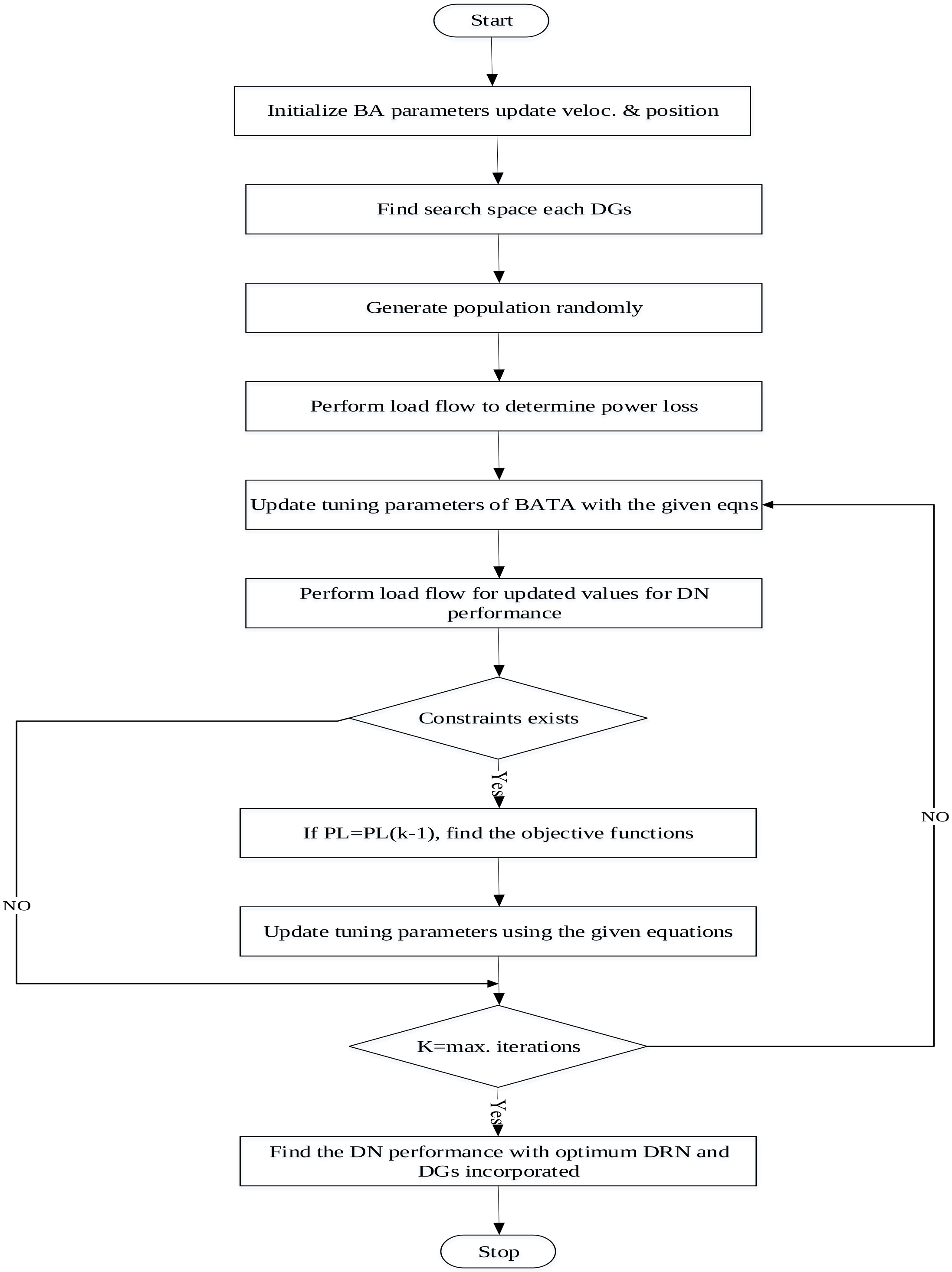


Figure: 2.14 Bat Algorithm Flow Chart (Buaklee*et al.*, 2014)

2.3 Review of Similar Work

In this section, a review of some literatures relevant to this developed method was consulted accordingly.

Kumar *et al*., (2011) proposed a new optimization technique that employed a heuristic based Fuzzy algorithm for optimal network reconfiguration on IEEE-33, 69 and 70adistribution network with the objectives of real power loss minimization, bus voltage deviation minimization and branch current violation for load balancing among feeders, subject to a radial network structure in which all loads were kept energized. The heuristic algorithm was also applied to minimize the number of tie- switch operations in the proposed distribution network.

However, the proposed technique was easy to implement in smaller networks but would take longer time to converge for complex distribution networks. So also the criteria for choosing the operational switches for optimal switching were not clearly elaborated in the work. More, so the improved Fast Decoupled load flow algorithm was not suitable for distribution networks, as the technique was suitable for transmission system where R/X ratio was very minimal.

Dahalan & Mokhlis, (2012)presented a particle swarm optimization (PSO) algorithm for network reconfiguration with distributed generation in order to reduce the real power loss and improve bus voltage profile in the system. The technique considered IEEE33-Bus System for simultaneous reconfiguration with DG placement in the system to achieve the stated objectives. However, in the proposed technique there was no specification of the types of DG considered. More so, the proposed technique considered has low exploration capacity.

Rao *et al*., (2013) extended a new optimization technique that employed Harmony Search Algorithm (HSA) for network reconfiguration with distributed generation placement in order to minimize real power loss and improve voltage profile in the distribution network. The technique had been tested on IEEE-33 and IEEE-69 buses at different load levels to demonstrate the performance and effectiveness of the technique. However, in the proposed technique the use of sensitivity analysis to obtain the optimal location of DGs was complex and time consuming.

Shamsudin*et al*., (2014) proposed a new optimization technique that employed a heuristic algorithm known as Selection Improvement in Genetic Algorithm (SIGA) in consideration of genetic operator probabilities that include cross-over and mutation parameters that would be adjusted in order to determine the objective functions of power loss reduction and voltage profile improvement using optimal network reconfiguration in the distribution network.

The proposed research work applied on IEEE-33 bus system, considered eight cases of the optimization processes, where four cases for cross-over occurrence probabilities and four cases for mutation occurrence probabilities to determine the stated objective functions. The highest percentage of total power loss reduction was 23.65% produced by case 6 with possible tie switches of 14, 28, 11, 7 and 16 using SIGA. The result was the best when compared with other cases and GA as well. However, the proposed method was simple and faster but cannot be suitable for population based solution technique where large iterations were required.

Syahputra*et al*., (2014) presented a new optimization technique that employed an extended fuzzy-objective approach for optimal network reconfiguration with integration of distributed energy resources (DERs) for achieving minimum active power loss, improve voltage profile and enhancing load balancing among feeders of a radial distribution network on standard IEEE 77-Bus distribution network and 60-Bus real distribution network of Yogyakarta province of Indonesia. The proposed work considered solar photovoltaic and wind farms DERs. However, the considered DERs output power was usually affected by weather condition; likewise, the DERs occupy large space, especially wind farms generators. More so the determination of weighting factors combination in the extended fuzzy logic was not clearly stated in the proposed work.

Ali *et al*., (2015) extended a new optimization technique that employed a Meta-heuristic algorithm known as Harmony Search Algorithm for optimal network reconfiguration and DG installation with the objectives of real power loss minimization and voltage profile improvement in the distribution network systems. The proposed work was tested on standard IEEE-33 bus and standard IEEE-69 bus systems respectively. In the analysis of the work three different loads levels were considered i.e heavy load level, nominal load level and light load level respectively. The result obtained indicated that better result was at the nominal load level.

However, the proposed work did not give the details of the DGs types used in the work, likewise the proposed algorithm had a tendency of being trapped in local minima during the optimization process as the algorithm usually converged quickly.

Abdur-Rahman *et al*., (2015) proposed hybridization of analytical-firefly algorithm for optimal DG placement and sizing of non-conventional distributed generations in order to minimizes total power loss and improve voltage profile in distribution network. The proposed work was tested on IEEE-30 bus of radial distribution network and the results obtained showed a better location and sizing. However, the proposed work takes longer time for convergence due to low exploration capacity of the proposed method.

Syahputra*et al*., (2015) suggested a new optimization technique that employed an Extended Particle Swarm Optimization (EPSO) technique for optimal network reconfiguration and distributed generation integration simultaneously, in order to reduce power loss and improve voltage profile in the distribution network. The proposed research work was tested on IEEE-33 and 71 bus system respectively. However, the proposed work did not consider load balance as an objective function rather a constraint. More so, the proposed technique will have the capability of being trapped in local minima.

Nguyen *et al*., (2016) presented a new optimization technique that employed Cuckoo Search Algorithm for network reconfiguration and distributed generation on the IEEE-33, 69 and 119 bus system in the distribution network in order to reduce real power loss and enhance voltage stability in the system. The graph theory was used to determine search space which reduced configuration and reconfiguration processes. However, the proposed graph theory will not yield better result as the approach was computationally complex and time demanding

Kunya *et al*., (2016) extended an optimization technique that employed Binary Particle Swarm Optimization (BPSO) for optimal network reconfiguration using IEEE-16, 33 and 69 test beds, in order to minimize the total active power loss and voltage deviation in the distribution network.

However, the proposed technique might not guarantee optimal location for closed or normally opened switches as the searching space will be dissimilar for different dimensions. More so, the technique may not be suitable for complex distribution networks.

Hivziefendic*et al*., (2016) proposed an optimization technique that employed NSGAII for optimal network reconfiguration with distributed generation installation on the IEEE-213 bus system, in order to minimize real power loss and energy not supplied function in the distribution network. However, the technique was complex for operational improvement conditions of the distribution network. More so, the test bed system was complex and only suitable for planning purpose.

Sudabattula and Kowsalya, (2016) proposed a new optimization technique that employed the Bat algorithm for optimal placement and sizing of DGs on IEEE-33 bus system, in order to maximize annual energy loss reduction and maintain better node voltage profile under a piece-wise linear variable load pattern using a penalty factor. However, the DG was a weather dependent as the output of the DGs depends on temperature and weather conditions, therefore the optimization will not be efficient and reliable.

Prakash and Sujatha, (2016) presented an optimization technique that employed bat algorithm to exploit the DG benefits by choosing optimal location and capacity of DGs in the radial distribution network simultaneously. The technique was applied on the IEEE-69 bus system for multi-objective function of total real power losses minimization and maximum voltage stability index within the range of voltage constraint. However, the technique did not elaborate the criteria for weighting factor selection for optimal DG placement and sizing in the stated objectives of the proposed network.

2.3.1 Summary of Literature

It is apparent that from the literature review, an analytical technique is not suitable for optimal network reconfiguration and DGs deployment in complex distribution networks as it is being impaired due to large computations and time consumption. It is usually applied to simple electrical network problems. Meta-heuristic methods on the other hand are characterized by high computational speed, high handling capacity of complex solutions as well as exploration ability. However, some meta-heuristic algorithms have the possibility of being trapped in local minima, which is considered as a limitation. From the reviewed literatures, it could be said that the optimal network reconfiguration and DG deployment of different types of DGs had been adequately addressed using the PSO, HS, SIGA and Fuzzy approaches. However, optimal network reconfiguration and distributed generation placement using Bat Algorithm-Based method has not been addressed.

CHAPTER THREE

MATRIALS AND METHODS

Introduction

This chapter discussed the detailed materials and methods employed in achieving the aim and objectives of this researched work. This includes application of Bat algorithm based- method for multi-objective optimal network reconfiguration and DG installation in a radial distribution network.

3.1Materials

The materials employed for the realization of this research work are as follows;

3.1.1 Personal Computer

All simulation analyses were carried out using Compact/HP Presario CQ61 with the following specifications:

i. AMD Athlon (tm) 2Duo CPU M320;

ii. 2.10 GHz 64-based processor;

iii. 320GB installed memory (RAM) and;

iv. 64-bit Operating system (OS)

v. 4.1 Windows Experience Index

3.1.2 MATLAB 2013b Software

Simulations were performed under virtual platform using MATLAB 2013b for analysis of the research work. The details of the programs developed are provided in the appendices.

3.1.3Distribution Network Parameters

The standard IEEE-33 and a dedicated 29-bus Sabo-Feeder in Zaria distribution network with the following network parameters: slack bus, active and reactive powers and bus voltages have been adopted for this research work

3.2 Methodology

The following approach was adopted in order to achieve the stated aim and objectives.

3.2.1 Acquisition of IEEE-33 Bus Data and Zaria distribution Network Data

This is a medium voltage radial distribution network with 33-buses and 32-branches, line data and bus data as shown in Appendix A. The Zaria distribution network is the simulated distribution network interconnected with 8 (eight) distribution feeders that include; Gaskiya feeder, Canteen feeder, Zaria-city feeder, RLY/NTC feeder, Sabon- Gari feeder, G.R.A. feeder, Kofar-Kibo as well as Zaria Teaching hospital feeder. The line and bus data are shown in appendix B. The data acquired for IEEE 33 and Zaria distribution network was shown in Table 3.1.The data was obtained from Kaduna Distribution Company at injection sub-station, Zaria main office. The Figure 2.10 in chapter 2 section (2.2.6.2) shows the single line diagram of the given network. Table 3.1 shows the network parameters of IEEE-33 Bus and Zaria Distribution network.

Table 3.1: Data Acquired for IEEE 33 and Zaria distribution network

S/N	Parameter	IEEE 33	Zaria Distribution network
1	line voltage	12.66kV	11kV
2	base MVA	100MVA	10MVA
3	Real power	3.72MW	1.84MW
4	reactive power	2.3MVAr	0.82MVar

3.2.2 Determination of Base Case Network Parameters Using Backward-Forward Algorithm

3.2.2.1Formulation of Objective Functions

The main objectives of DNR and DG deployment in distribution system are minimization of real power loss, voltage deviation and load balancing among feeders while satisfying network operating constraints that include voltage profile, current capacity and radial structure of the distribution network. Network reconfiguration means changing the topological structure of a network by altering the OFF/ON states of tie and sectionalizing switches of the distribution network.

The process can be achieved by considering the possible number of radial structure for a given configuration of the distribution network with the following expression as given in equation (2.12). The possible DG location can be determined by considering the difference of the power loss before and after the installation of DG in the network as given in equation (2.10)

Therefore, the network bus that gives the highest value of PLR will be considered as the optimal DG location in the network.

The possible DG size was computed by considering equation (2.11) which means calculating the product of maximum loss saving DG current and voltage magnitude of the network bus

The objective function was mathematically formulated as multi-objective function that include reduction of power loss, voltage deviation and load balance among feeders as follows;

A. The weighting technique was used in this research work to convert multi-objective function (MOF) into a single objective function. The objective function can be represented mathematically as indicated in equation (3.1)

$$\text{Min } F = w1f1 + w2f2 + w3f3 \quad (3.1)$$

Where;

f1; represent the total real power loss in distribution network

f2; represent voltage deviation index of the network buses

f3; represent load balance enhancement of the distribution network

While w1, w2 and w3 are the weighing factors. For simplicity, the weighting factors are usually considered within the range of 0 as minimum and 1 as maximum value which can be represented mathematically as;

and; $0 < Wi < 1$ (3.2)

But the distribution utility usually gives higher weighting factor to an objective function depending upon its overall importance in the research work. In this research work the weighting functions were determined in the given pseud code of BA in page 56. The weighing factors values are w1; 0.4, w2; 0.36 and w3; 0.24 respectively, and the values were determined after possible Pareto fronts combination process situated in BA.

f_1: Power Losses: The total real power losses at all nodes cause by circulating current in the network with the DG installation in the distribution network was determined as part of the objective function formulated as follows;

$$f1a = R_{i,i+1}\frac{\left(P^{2}_{i} + Q^{2}_{i}\right)}{|V|^{2}_{i}} \quad (3.3)$$

The minimum losses were computed by considering the difference between equation (3.3) and equation (3.4) respectively

$$\text{f1b} = P'_{Loss(\text{i,})} = R'_{i,i+1}\frac{\left(P'^{2}_{i} + Q'^{2}_{i}\right)}{|V'|^{2}_{i}} \qquad (3.4)$$

Where; P_{LOSS} (i), Ri, Pi_2 and Qi_2 are the total power losses, resistance of the branch, active and reactive power before DNR and DG installation in the network and P' Loss (i), R', $P'i_2$ and $Q'i_2$ is the total power losses, resistance of the branch, active and reactive power after DNR and DG installation in the distribution network.

f_2: Voltage Deviation: The voltage deviation can be determined by normalizing the reconfigured network with DG and non-reconfigured network with the following expression as follows;

$$\text{f2 = Voltage deviation minimization, } \Delta V_{dev} \frac{\Delta V^{recong+DG}_{Total}}{\Delta V^{initial}_{Total}} \quad (3.5)$$

Where; $V^{initial}_{dev}$, Represents the initial voltage deviation before reconfiguration of the distribution network

$V^{recong+DG}_{dev}$, Represents voltage deviation after DNR and DG placement in the distribution network

ΔV_{dev}, Represents the total voltage deviation of the distribution network

f_3: Load balance: The load balance usually measures how much a particular branch can be loaded without exceeding the rated capacity of the branch in the distribution network, and load balance can be determined by minimizing the branch current of the distribution network as follows;

$$f_3 = \frac{|I|_{i,n}}{I_{c,n}} \quad (3.6)$$

For i= 1, 2, 3--------------Ni & for n= 1, 2, 3-----------NB-1

Where: Ni; The total number of branches of the distribution network

NB-1; The total number of buses of the distribution network

$|I|_{i,n}$; The branch, n electric current magnitude when the i-th branch in the loop is opened

$I_{C,i}$; The maximum capacity of the line branch of the network

L_{BI}; The load balancing index of the distribution network

B Constraints

DNR and DG deployment might upset voltage level in the distribution network due to inrush current in the network. Hence, voltage magnitude must be maintained within minimum and maximum limits at each bus as indicated below

$$|V|_i^{\min} \leq |V|_i \leq |V|_i^{\max} \qquad (3.7)$$

Where: Vi represent voltage magnitude at ith node. $V_i^{min}$and Vimax are considered as 0.95pu and 1.05pu respectively, as power system equipment is designed to operate within the allowable variation of ±5 to 10% of the rated voltage. The system must not exceed the current carrying capacity of the of its conductors as indicated below

$$\left|I\right|_{i,i+1} \leq \left|I\right|_{i,i+1,\max}^{\max} \leq 600A \qquad (3.8)$$

Where, $\left|I\right|_{i,i+1}$: The circulating current in the distribution network

$\left|I\right|_{i,i+1,\max}^{\max}$: The maximum circulation current capacity of the network

Radial distribution networks are configured in radial structure that makes R/X higher. This usually results in power loss in the network, as such the constraint is as indicated below

Det (A) = 1 or -1 (radial structure)

Det (A) = 0 (not radial)

3.2.2.2 Backward-Forward Sweep Technique

The backward- forward sweep technique was suitable for distribution network load flows analysis. The technique assumed the network to be balanced so that the distribution network could be represented in a single line diagram. In this technique, the voltage at all the buses was also assumed to be one pu at angle zero except the slack bus. Therefore, based on the above information, the voltage, the specified active power, the reactive power and the branch currents were computed and saved simultaneously, from the end buses to the source buses.

Then, the branch currents were also calculated in order to find the active and reactive power losses in the distribution network. The current at the source end was computed iteratively. The calculation starts from source to the end of the distribution network feeders to find the voltage drop, current, real and reactive power losses respectively using equation *(2.18)* and *(2.19)* respectively.

The backward-forward sweep equation for voltages, current, active and reactive power was determined for the base case scenario. Furthermore, the flow chart for the backward-forward sweep technique of the radial distribution system using the topological characteristics of the distribution network was shown in Figure. 2.11of chapter two.

3.2.3 Application of BA for Optimal Reconfiguration and DGs Deployment

Bat Algorithm (BA) is a nature inspired Meta heuristic algorithm developed by Xing-She Yang in 2010. Bat algorithm is based on echolocation that is important feature of the bat behavior. Bats are fascinating group of mammals that rely on echolocation to detect obstacles in flight, finding their way into roosts and forage for food/prey.

The principle of operation of this algorithm is as follows; Bats emit a very loud sound pulse and listen for the echo that bounces back from surrounding objects, thus the loud pulse can determine the distance between bats and also can distinguish obstacles and prey. Based on that behavior of bats; the ability to compute the distance between them and object, echolocation can be used in such a way that it can be associated with the objective function to be optimized.

For each iteration the loudness A_i and the emission pulse rate r_i were updated as given in equation *(2.26)* and *(2.27)*, where $\propto$ and γ are constants. At the first step of the algorithm the values of these two parameters were chosen randomly, generally as in equation *(2.28).*

From Table 3.2 The explanation of the BA results parameters were observed as follows; NPF is 10 which was the best combination for weighing factor selection, α (A)& γ (r) were 0.9 obtained from parametric results, Fmin & Fmax were set fequency ranges which were 0 and 2, i. was 60 as set number of iterations, N were 33 & 29 as the number of bats population and dimension size of the virtual bats. The summary of the parameters used for BA are indicated in Table 3.2

Table 3.2: BA Parameter notation, definition and value

Parameter	Notation	Value
NPF	Number of Pareto Fronts	10
α(A)	Loudness	0.9
γ(r)	Pulse Rate	0.9
Fmin	Minimum Frequency	0
Fmax	Maximum Frequency	2
Number of generation i	Iterations	60
Number of Bats N	Populations	33 & 29

3.2.3.1 BA implementation for Network Reconfiguration and DG Deployment

The following viable equations showed the steps involved in solving optimal network reconfiguration with DG deployment in the radial distribution network for the DGs sizing as well as DGs and switches optimal placement in the distribution network based on the equations were derived from equation (2.23) and (2.24)

$$\mathrm{SWLoc}\,v_i^t = v_i^{t-1} + (\mathrm{sw}\,loc_i^t - \mathrm{bestloc},)f_i \tag{3.8}$$

The equation *(3.8)* was used to determine the best positions of the optimal network switches, where SW means Switches and Loc. means Location

$$\mathrm{DGLoc}\,v_i^t = v_i^{t-1} + (\mathrm{DG}\,loc_i^t - \mathrm{bestloc},)f_i \tag{3.9}$$

The equation *(3.9)* was used to determine the best positions for optimal DGs locations, where $v_{i.}^{t-1}$ means best Location of the DGs and f_i ,means initial position of the DGs

$$\mathrm{DGSIZE}\,v_i^t = v_i^{t-1} + (\mathrm{DG}\,size_i^t - \mathrm{best}\,size_*)f_i \tag{3.10}$$

The equation *(3.10)* was used to determine the optimal DGs capacities in the network, where $v_{i.}^{t-1}$ means best Size of the DGs

$$\mathrm{SW}\,loc_i^t = \mathrm{sw}\,loc_i^{t-1} + \mathrm{loc}\,v_i^t) \tag{3.11}$$

The equation *(3.11)* was used to determine the new solution of the optimal network switches

$$\mathrm{DG}\,loc_i^t = \mathrm{DG}\,loc_i^{t-1} + \mathrm{loc}\,v_i^t) \tag{3.12}$$

The equation *(3.12)* was used to determine the new solution for optimal DGs locations

$$\mathrm{DG}\,size_i^t = \mathrm{DG}\,size_i^t + \mathrm{size}\,v_i^t) \tag{3.13}$$

The equation *(3.13)* was used to determine the new solution for optimal DGs capacities

BA flow chart for DNR and DG considering the stated objective functions

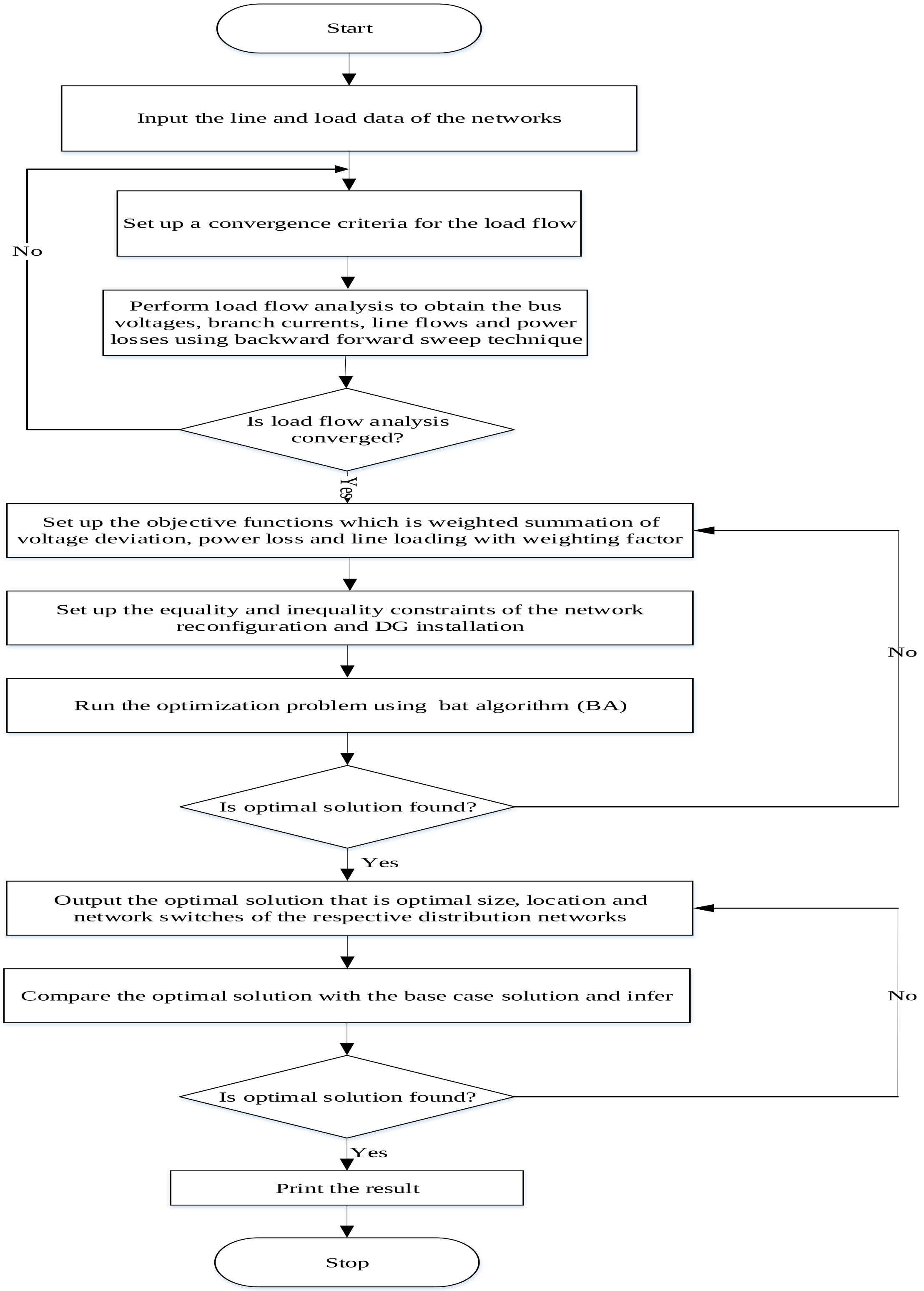


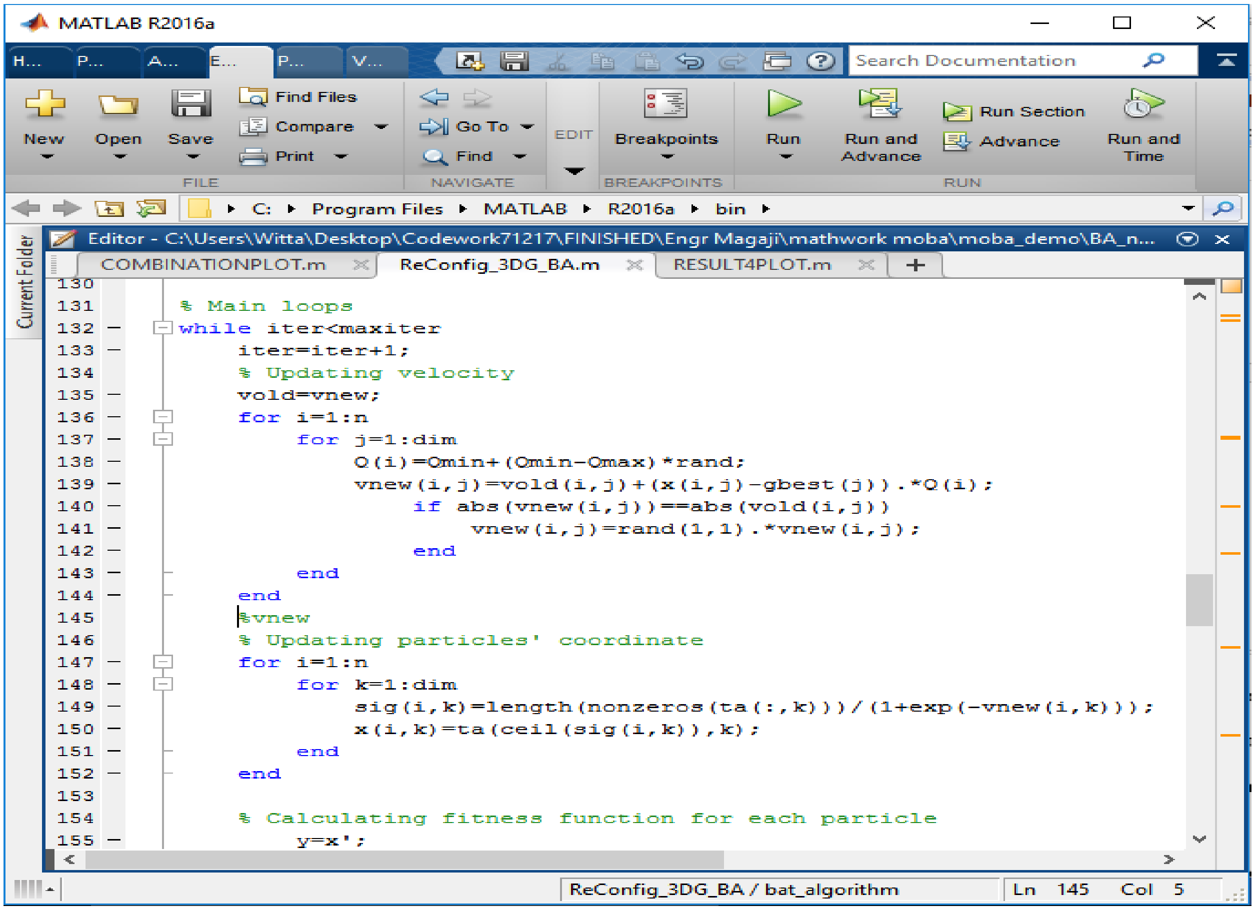
Figure: 3.1TheFlow Chart of the Research Work Algorithm

3.2.3.2 The Pseudo Codes for $w_{1,}$ $w_2$and $w_3$of the Developed Method

The following pseudo codes were developed using equation (2.23) and (2.24) for $w_{1,}$ w_2 and w_3 of DG deployment with reconfiguration

```
Objective functions $f1(x), ...,fk(x)$.
Initialize the bat population $xi$ and $vi$;
Initialize pulse rates $ri$and the loudness $Ai$;
for $j = 1$ to $N$ (points on Pareto fronts) do
    Generate K weights $wk \geq 0$ so that ***;
    Form a single objective ***
    while ($t <$ Max number of iterations) do
        Generate new solutions (DG Sizes, Locations and Reconfiguration) by adjusting Frequency fi;and updating velocities and locations/solutions
        Generate a new solution (DG Sizes, Locations and Reconfiguration) xi
        if ($rand > ri$) then
            Generate a local solution (DG Sizes, Locations and Reconfiguration) around the Selected best solution by changing onlyone item in the rule;
        end if
        if($f(xi) < f(xi*)$) then
            Accept the new solutions;
            $xi* = xi$;
            Increase ri and reduce Ai
        end if
        Rank the bats according to the best solution;
    end while
    Record $xi*$as non-dominate solution;
end for
Post-process results and visualize the best detected rules.
```

The snippet of the MATLAB program of Bat Algorithm-based method for multi-objective optimal network reconfiguration and DG deployment is shown in Figure 3.2



```
% Main loops
while iter<maxiter
    iter=iter+1;
    % Updating velocity
    vold=vnew;
    for i=1:n
        for j=1:dim
            Q(i)=Qmin+(Qmin-Qmax)*rand;
            vnew(i,j)=vold(i,j)+(x(i,j)-gbest(j)).*Q(i);
                if abs(vnew(i,j))==abs(vold(i,j))
                    vnew(i,j)=rand(1,1).*vnew(i,j);
                end
        end
    end
    %vnew
    % Updating particles' coordinate
    for i=1:n
        for k=1:dim
            sig(i,k)=length(nonzeros(ta(:,k)))/(1+exp(-vnew(i,k)));
            x(i,k)=ta(ceil(sig(i,k)),k);
        end
    end

    % Calculating fitness function for each particle
        y=x';
```

Figure: 3.2 MATLAB Snapshot of BAT Algorithm for Reconfiguration and DG Deployment

3.2.3.3 Summary of the Research work Algorithms Processes

The summary of the BA algorithms are indicated in the Figure 3.4 flow chart

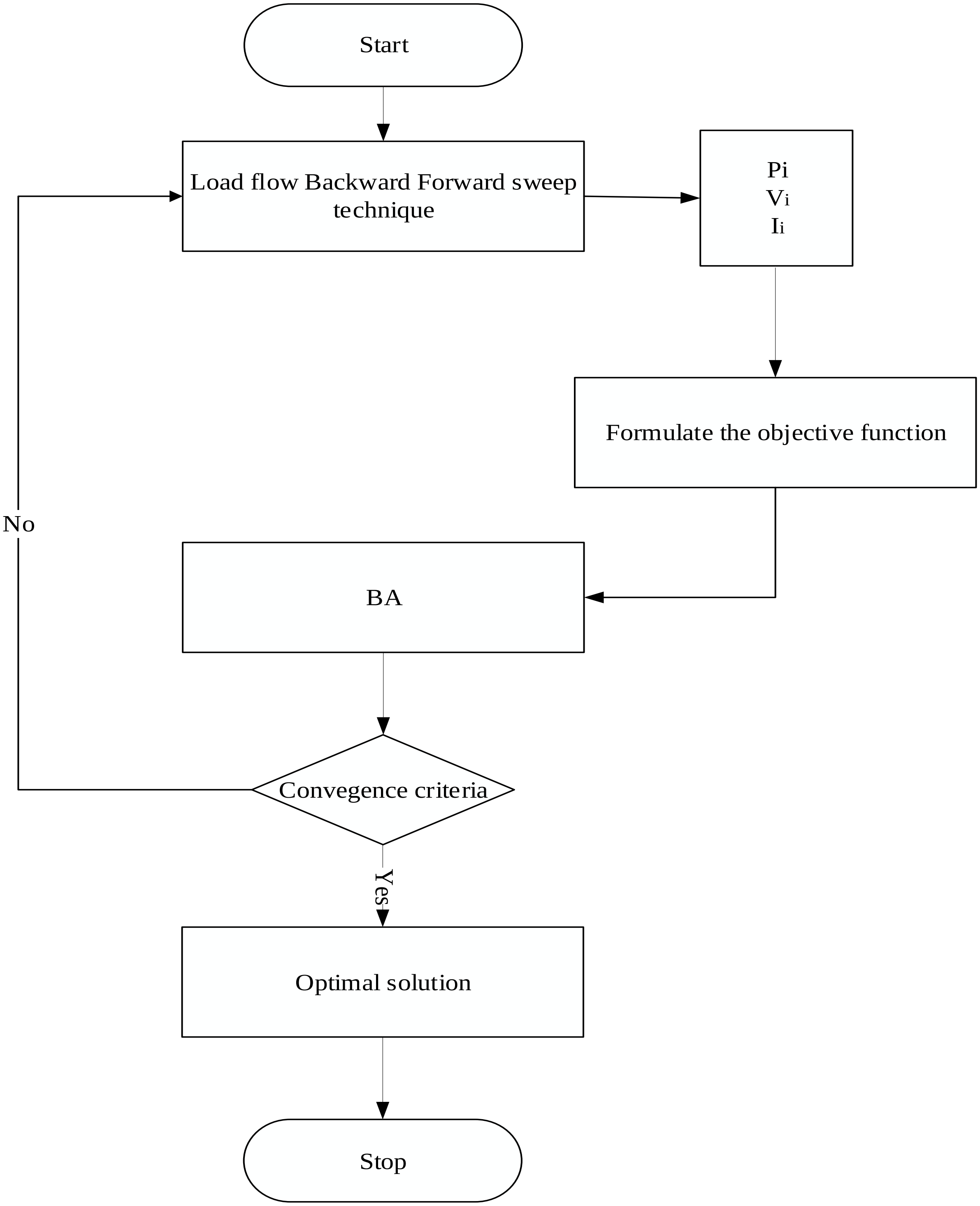


Figure: 3.3The Summary of the Developed Method Algorithms Flow Charts

3.2.4 Validation of the Developed Method

The Parameters used for comparison on IEEE-33 bus distribution network with the work of Syahputra at el., 2015 were active power loss, power loss reduction, reactive power loss, voltage profile, DGs locations, DGs capacities as well as network operational switches.

3.2.5Implementation of the Developed Method on Sabo Feeder in Zaria Distribution Network

The Bat Algorithm-based method for multi-objective optimal network reconfiguration and DG deployment was implemented on a simulated feeder of Sabon-Gari at Zaria distribution network with the view to optimize the synchronous DG placement as well as network reconfiguration where the significant metric parameters improvements were observed.

3.2.6 Placement and Sizing of DG in the Radial Network

The power flows in the radial network were calculated by the following number of simplified recursive equations derived from Figure: 2.5

The power loss in the line section connecting buses, i and i+1 could be calculated as in equation*(2.8)* .The total power loss of the network, $P_{T,\ Loss}$ could be determined by summing up the losses of all line sections of the network as given in equation *(2.9)*

The DG location could be determined by considering the difference of the power loss before and after the installation of DG in the network as given in equation *(2.10).*

Therefore, the network bus that gives the highest value of PLR has been considered as the optimal DG location in the network. The DG size could be computed by considering the product of maximum loss saving DG current and voltage magnitude of the network bus as indicated in equation *(2.11)*

CHAPTER FOUR

RESULTS ANALYSIS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results obtained as well as the discussions of the obtained results. The results obtained include the base case (without network reconfiguration and DG placement), then case with network reconfiguration only then also the case with DG placement only and finally the case with simultaneous DG placement and network reconfiguration as the presented research work. Then the developed method implementation on a standard IEEE-33 bus and 29-bus of Sabo feeder networks were evaluated respectively. The comparison between the developed methods with the work of Syahputra*et al.,* (2015) was also presented in this chapter**.**

4.2 The IEEE 33-Bus Radial Distribution Test System

The test was carried out on the IEEE 33-Bus network based on the base case (without network reconfiguration and DG placement) and evaluating the network parameters on base case scenario using FBS technique discussed in subsection (2.2.6.3), the IEEE 33-bus test system detail was discussed in chapter two and the single line diagram was shown in Figure 2.9.The line and bus data are given in appendix A

4.2.1 Case I: Base Case

For the base case, power flow analysis was carried out without DG and reconfiguration on the network. The power flow analyses were performed using power flow analysis based on BFS technique by considering equations (2.18), (2.19)and (2.21) on a Mat Lab R2013b environment where the steady state of the network was determined. The results of power analysis (P loss, Q loss and voltage magnitude) of the developed method were presented in Table 4.1.

From Table 4.1, it is observed that base case total active power loss of the distribution network is 208.4592kW, the base total reactive power loss is 111.6726kVar, the minimum base voltage is 0.91075p.u at bus 18. The OFF-switches before reconfiguration were 33,34,35,36 and 37 respectively while the ON-switches for 33-bus system before reconfiguration were 1-32 switches at the base case. From the base case result, it shows that 18-bus was the critical bus. The bus that has higher voltage drop is the bus that is far away from sub-station.

The result of the analysis (power loss, voltage magnitude, OFF-switches and ON-switches) of the 33-bus network was presented in tabular form in Table 4.1

Table 4.1: IEEE-33 Bus Base Case Power Flows Results

SERIAL NUMBER	PREREC.&DG BUS VOLT (pu)	PLOSS PRE REC.& DG (kW)	QLOSS PRE REC.& DG (kW)
1	1.0000	12.2025	6.3130
2	0.9970	51.6024	26.2827
3	0.9829	19.7843	9.9462
4	0.9755	18.5835	9.4649
5	0.9681	38.0041	3.2482
6	0.9561	1.9178	6.3395
7	0.9526	11.6983	8.4425
8	0.9390	4.2022	3.0190
9	0.9328	3.5657	2.5371
10	0.9270	0.5566	0.1840
11	0.9261	0.8857	0.2929
12	0.9246	2.6802	2.1087
13	0.9185	0.7330	0.9648
14	0.9162	0.3588	0.3194
15	0.9148	0.2829	0.2066
16	0.9134	0.2530	0.3377
17	0.9114	0.0534	0.0419
18	0.9108	0.1610	0.1536
19	0.9965	0.8323	0.7500
20	0.9929	0.1008	0.1177
21	0.9922	0.0436	0.0577
22	0.9916	3.1820	2.1742
23	0.9794	5.1442	4.0621
24	0.9727	1.2876	1.0075
25	0.9694	2.5642	1.3061
26	0.9542	3.2819	1.6710
27	0.9516	11.1407	9.8225
28	0.9403	7.7222	6.7274
29	0.9321	3.8403	1.9561
30	0.9286	1.5709	1.5525
31	0.9245	0.2101	0.2449
32	0.9236	0.0130	0.0202
33	0.9233	0	0
		0	0
		0	0
		0	0
		0	0

4.2.2 Case II: Network Reconfiguration Only

In this case, the forward-backward sweep technique using equations *(2.13)* and *(2.19)* in sub-section (2.2.6.3) was employed to obtain the base case result. The BA was run using sub-section (3.2.3.1) for network reconfiguration to obtain optimal switches to reduce power loss and relieve loading condition of the network. The result of the active power loss obtained before and after reconfiguration is as shown in Figure 4.9, from the Figure, it is observed that, the active power loss before and after reconfiguration was 208.4592kW and 140.5803kW respectively, which represents the active power loss reduction of 32.5622%.The reactive power loss before and after reconfiguration was 111.6726kVar and 93.0210kVar respectively, which represents the reactive power loss reduction of 16.7020%. Similarly, from Figure 4.2 it shows that, the magnitude of voltage before reconfiguration was 0.91075p.u after reconfiguration was 0.94234p.u respectively. It could also be observed from Figure 4.2 that, bus 18 has higher voltage profile improvement due to network reconfiguration.

The OFF-switches before reconfiguration were 33, 34, 35, 36 and 37 while after reconfiguration they were optimally found to be 7, 11, 14, 32 and 37 respectively.

The plot of the active power loss before and after reconfiguration is shown in Figure: 4.1

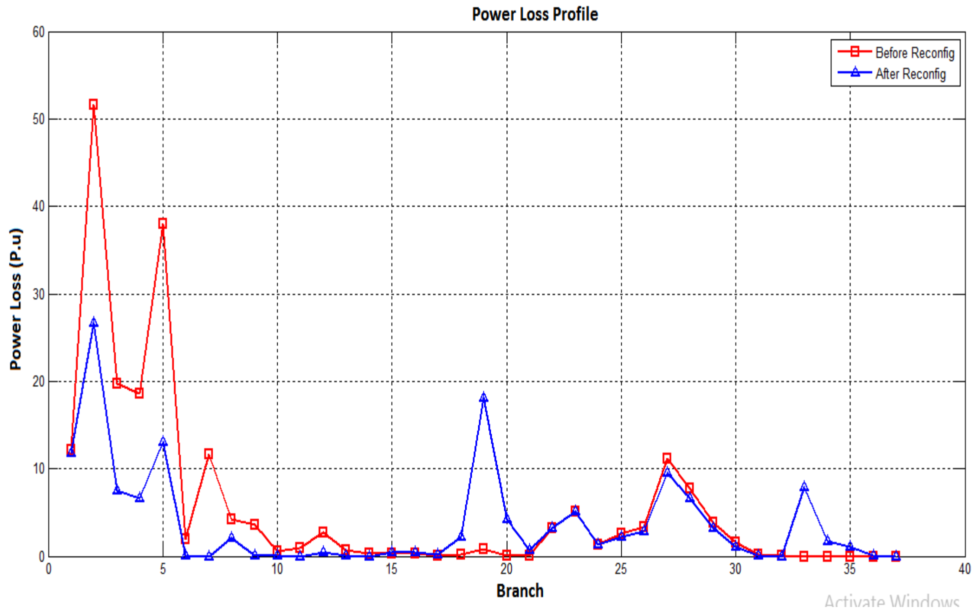


Figure: 4.1 Active Power Loss Before and After Reconfiguration of 33-Bus System

The voltage profile plot of 33-bus system before and after reconfiguration is shown in Figure 4.2

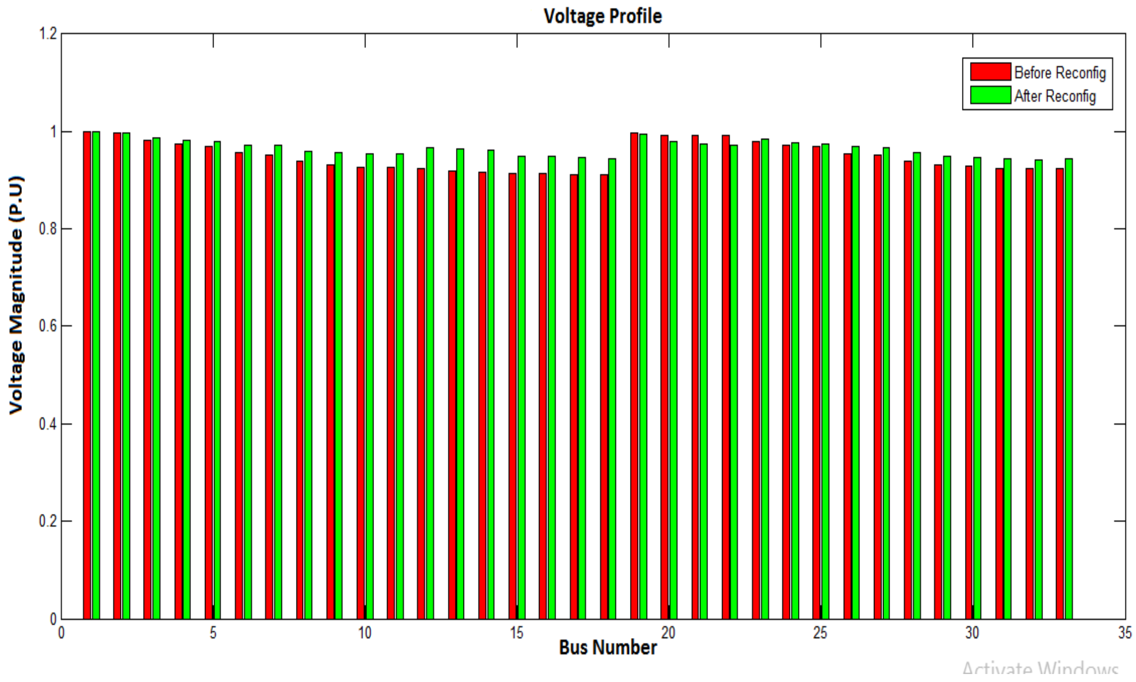


Figure:4.2 Voltage Profile Plot of 33-Bus System Before and After Reconfiguration

4.2.3Case III: DG Placement Only

In this case, the forward-backward sweep technique using equations *(2.13)* and *(2.19)* in sub-section (2.2.6.3) was employed to obtain the base case result. The BA was run using sub-section (3.2.3.1) for DG placement and sizing to reduce power loss and improve voltage profile of the network. Three synchronous DGs were installed to improve the network performance, the DGs sizes and locations were957kW, 870kW, 822kW as well as 593kVar, 539kVar, 509kVar at buses 29, 31 and 12 respectively. The result of active power loss obtained before and after reconfiguration is shown in Figure 4.3. From the Figure it is observed that, the active power loss before and after DG placement and sizing was 208.4592kW and 39.5823kW respectively, which represents the power loss reduction of 81.012%. The reactive power loss before and after DG location and sizing was 111.6726kVar and29.7789kVarrespectively, which represents the reactive power loss reduction of 73.3337%.Similarly, it is observed that from Figure 4.4, the magnitude of voltage before DG deployment was 0.91075p.u after DG deployment was 0.98305p.u respectively. It could also be observed from Figure 4.4 that, buses 6, 7, 8, 9, 10, 11, 12 to 18 show highest voltage profile improvement due to DG installation in the distribution network

The plot of the active power loss before DG location and sizing after DG is shown in Figure: 4.3

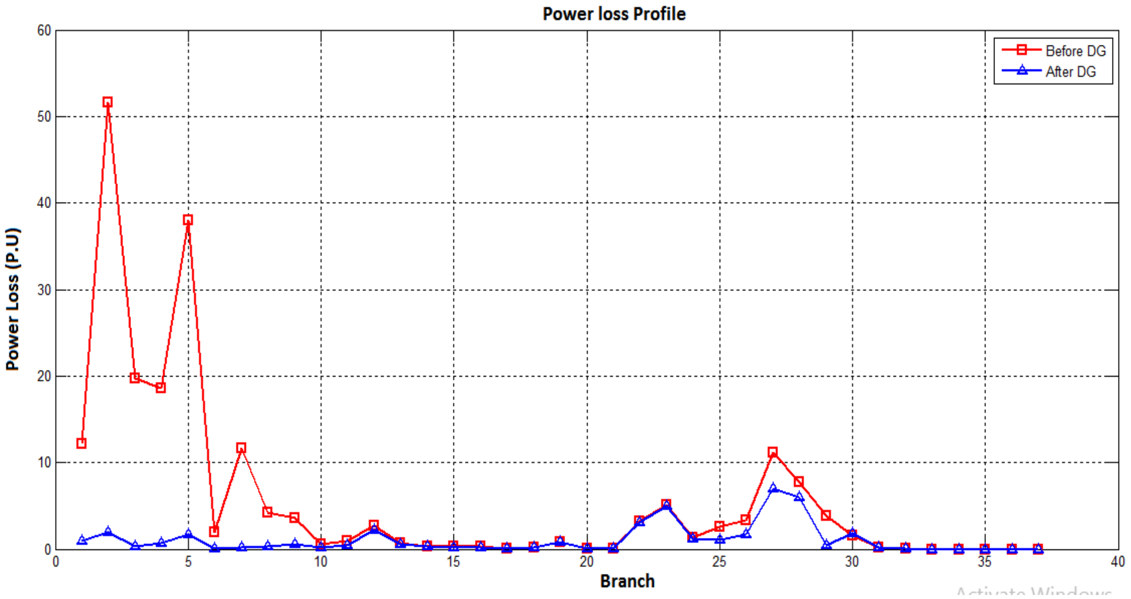


Figure: 4.3 Active Power Loss Before and After DG of 33-Bus System

The voltage profile plot of 33-bus system before and after DG is shown in Figure 4.4

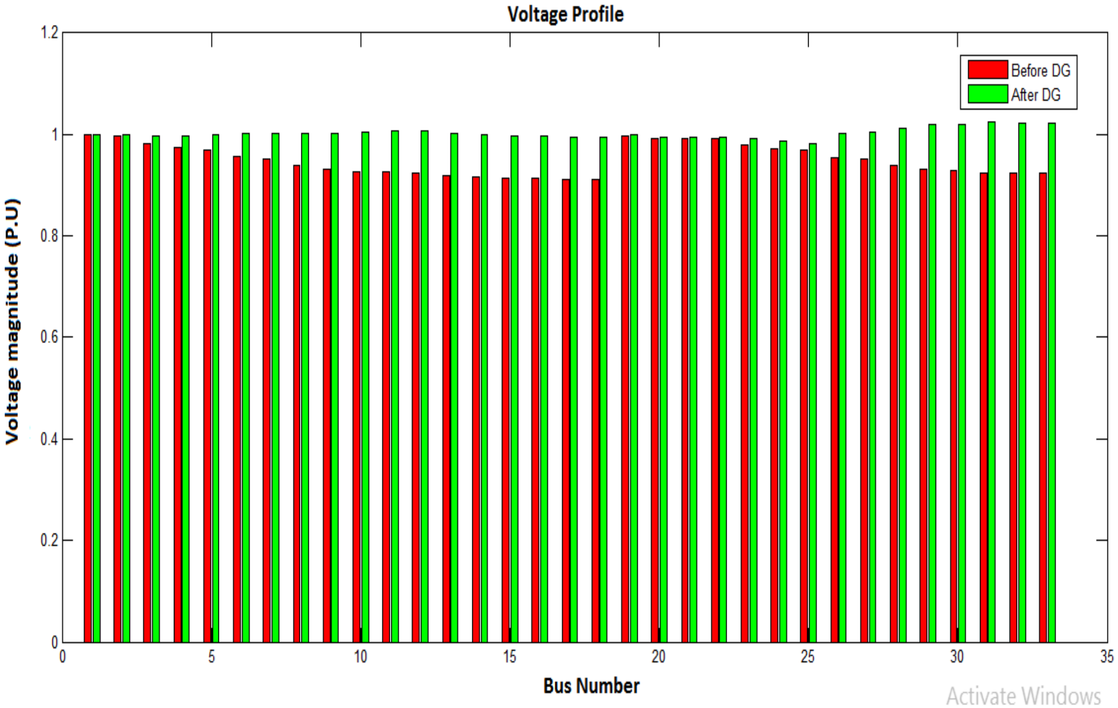


Figure:4.4 Voltage Profile Plot Before and After of DG for 33-Bus System

4.2.4 Case IV: Simultaneous DG and Reconfiguration

Once again for 33-bus system, the forward-backward sweep using equations *(2.13)* and *(2.19)* in sub-section (2.2.6.3) was employed to obtain the base case result. The BA was run using sub-section (3.2.3.1) for simultaneous DG placement, sizing and reconfiguration to reduce power loss and enhance load balancing of the network., after simultaneous DG placement with reconfiguration of the network, the DGs sizes and locations were957kW, 870kW, 822kW as well as 593kVar, 539kVar, 509kVar at buses 29, 31 and 12 respectively. The optimal OFF-switches were 7, 8, 14, 16 and 25 respectively. The result of the active power loss obtained before and after reconfiguration is as shown in Figure 4.5. It is observed that from the Figure, the active power loss before and after DG with reconfiguration was 208.4592kW and 15.2353kW respectively, which represents the power loss reduction of 92.6915%. The reactive power loss before and after DG with reconfiguration was 111.6726kVar and12.0593kVar respectively which represents the reactive power loss reduction of 89.2012%. Similarly, it is observed that from 4.6, the magnitude of voltage before DG with reconfiguration was 0.91075p.u after DG with reconfiguration was 0.99179p.urespectively.It could also be observed from Figure 4.6 that, buses 9, 10, 11, 12 to 18 show highest voltage profile improvement due to DG installation with reconfiguration in the distribution network

The plot of the active power loss before DG with reconfiguration and after DG with reconfiguration is shown in Figure: 4.5

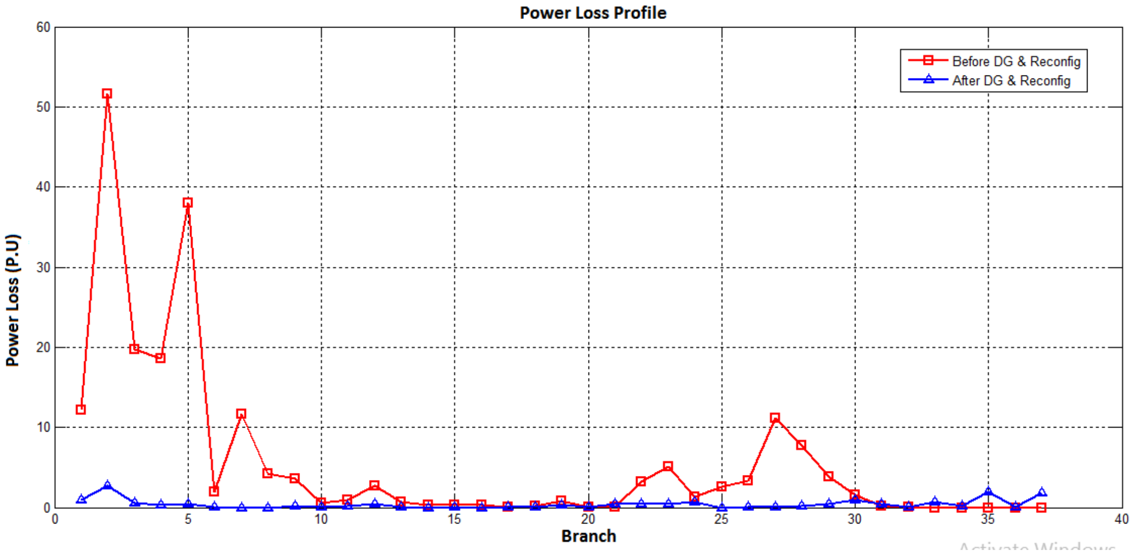


Figure: 4.5 Active Power Loss Before and After DG with Reconfiguration of 33-Bus System

The voltage profile plot of 33-bus system before and after DG with reconfiguration is shown in Figure 4.6

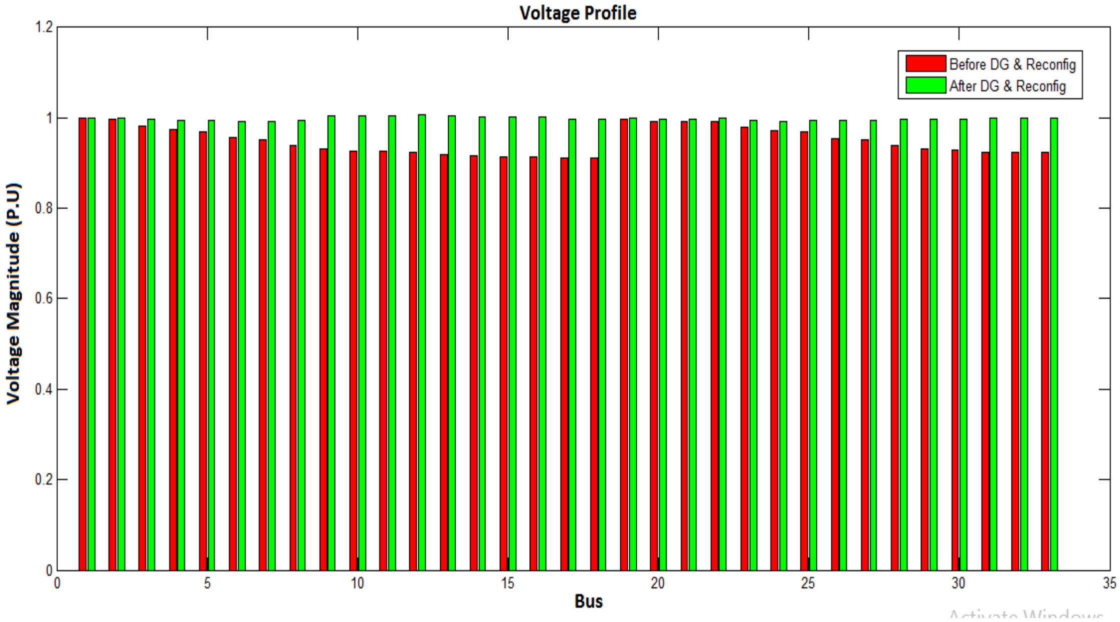


Figure:4.6 Voltage Profile Plot of DG with Reconfigurationfor 33-Bus System

4.2.5 Case V: Combination of Four Case Scenarios

Finally, in this case four different conditions were considered which include, the base case result only, reconfiguration result only, DG result only and simultaneous DG with reconfiguration results were combined together, it is observed that from Figure 4.7, the result of simultaneous DG with reconfiguration was better as the active power loss was 15.2353kW which represents the active power loss reduction of 92.6915% compared with the other results. The reactive power loss was 12.0593kVar which represent the reactive power loss reduction of 89.2012% compared with the other results. It is also observed that from Figure 4.8, the voltage profile has been enhanced from 0.91075*p.u* to 0.99179*p.u* after DG deployment with reconfiguration. This shows that the simultaneous DG deployment with reconfiguration method has better improvement.

The plot of the combined active power loss of four scenarios is shown in Figure: 4.7

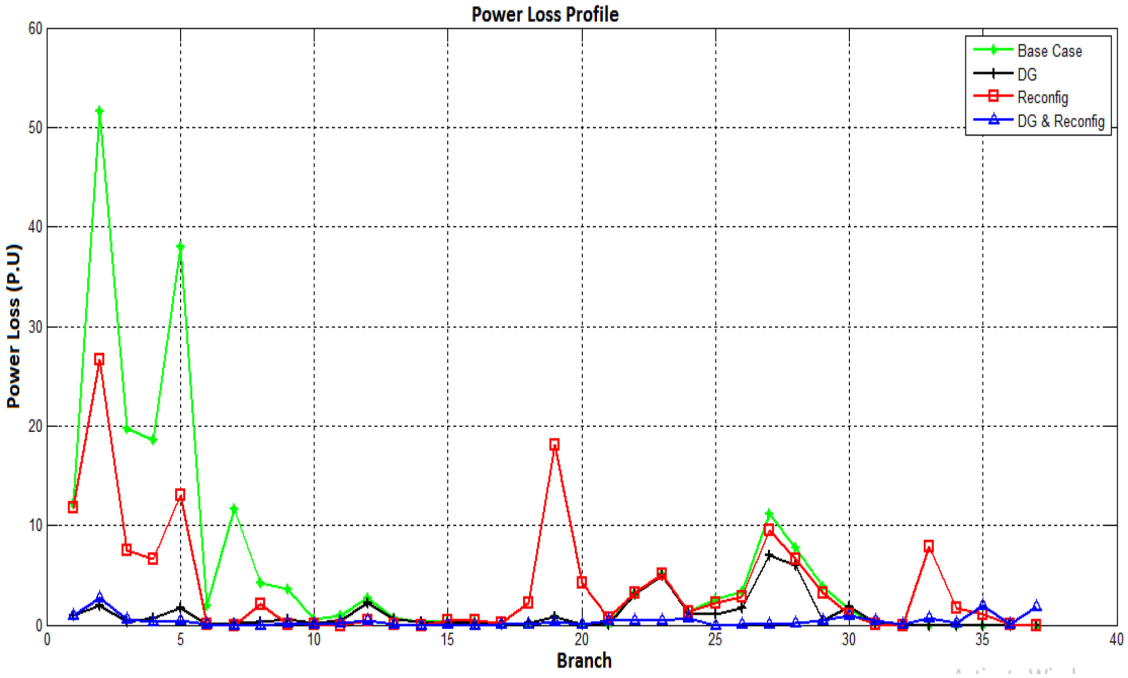


Figure: 4.7 Active Power Loss of Four Scenarios of 33-Bus System

The voltage profile plot for four scenario of 33-bus system is shown in Figure 4.8

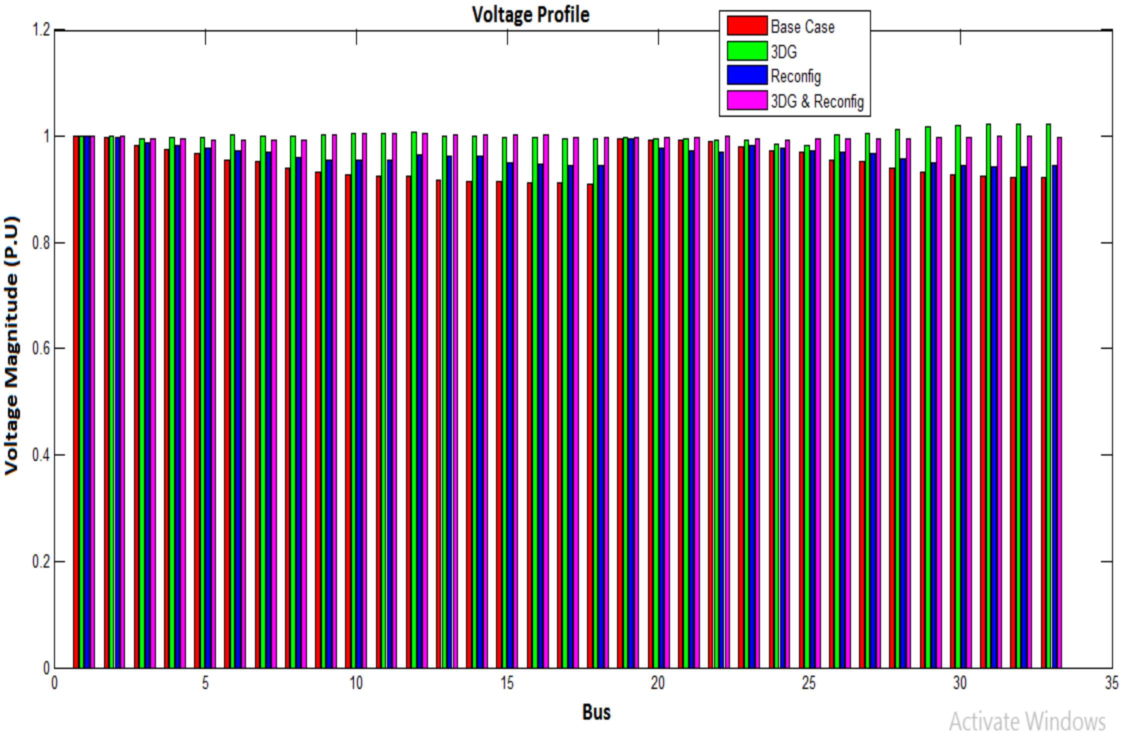


Figure:4.8 Voltage Profile Plot of Four Scenarios for 33-Bus System

4.3 29-Bus Sabo Radial Distribution Feeder

The 29-Bus Sabo feeder is discussed in chapter two and chapter three, the line and bus parameters are given in appendix B.

4.3.1 Case I: Base Case

For the base case of 29-bus, power flow analysis was carried out without DG and reconfiguration on the network. The power flow analyses were performed using power flow analysis based on forward-backward sweep technique by considering equations (2.18), (2.19)and (2.21) on a MATLAB R2013b environment where the steady state of the network was determined. The results of power analysis (P loss, Q loss and voltage magnitude) of the developed method were presented in Table 4.2.

From Table 4.2, it is observed that, the base case total active power loss of the distribution network is 4.7864kW, the base total reactive power loss is 3.5675kW, and from Table 4.2, it is shown that the minimum base voltage is 0.95695p.u at bus 22 respectively. The OFF-switches before reconfiguration were 29, 30 and 31 respectively while the ON-switches for 29-bus system before reconfiguration were 1-28 switches at the base case. From the base case result, it shows that 22-bus was the critical bus. The bus has higher voltage drop as the bus is far away from the sub-station.

The result of the analysis (power loss, voltage magnitude, OFF-switches and ON-switches) of the 29-bus network was presented in tabular form in Table 4.2

Table 4.2: 29-BusBase Case Power Flows Results

SERIAL NUMBER	PRE REC.& DG BUS VOLT(PU)	PLOSS PRE REC.& DG(kW)	QLOSS PRE REC.& DG (KW)
1	1.0000	0.3946	0.2946
2	0.9980	0.4313	0.3219
3	0.9956	0.4044	0.3019
4	0.9933	0.6285	0.4691
5	0.9897	0.3814	0.2847
6	0.9874	0.2498	0.1863
7	0.9853	0.2576	0.1924
8	0.9830	0.2025	0.1510
9	0.9811	0.2580	0.1925
10	0.9785	0.0915	0.0682
11	0.9775	0.3060	0.2284
12	0.9740	0.3076	0.2295
13	0.9704	0.2829	0.2111
14	0.9668	0.1908	0.1424
15	0.9642	0.0493	0.0368
16	0.9635	0.0964	0.1019
17	0.9615	0.1240	0.0544
18	0.9595	0.0409	0.0305
19	0.9585	0.0325	0.0243
20	0.9573	0.0013	0.0009
21	0.9571	0.0010	0.0008
22	0.9569	0.0017	0.0013
23	0.9978	0.0017	0.0013
24	0.9873	0.0262	0.0195
25	0.9867	0.0171	0.0128
26	0.9859	0.0046	0.0034
27	0.9857	0.0022	0.0016
28	0.9855	0.0005	0.0004
29	0.9854	0	0
		0	0
		0	0
		0	0

4.3.2 Case II: Network Reconfiguration Only

In this case, the forward-backward sweep technique using equations *(2.13)* and *(2.19)* in sub-section (2.2.6.3) was employed to obtain the base case result. The BA was run using sub-section (3.2.3.1) for network reconfiguration to obtain optimal switches to reduce power loss and relieve loading condition of the network. The result of the active power loss obtained before and after reconfiguration is shown in Figure 4.9. From the Figure it is observed that, the active power loss before and after reconfiguration was 4.7864kW and 2.0558kW respectively, which represents the active power loss reduction of 57.0492%. The reactive power loss before and after reconfiguration was 3.5675kVar and 1.4247kVar respectively, which represents the reactive power loss reduction of 60.0241%. Similarly it is observed that from Figure 4.10, the magnitude of voltage before reconfiguration was 0.95695p.u after reconfiguration was 0.98217p.u respectively. It could also be observed from Figure 4.10 that, buses 13, 12, 14 to 21 have highest voltage profile due to network reconfiguration.

The OFF-switches before reconfiguration were 29, 30 and 31 while after reconfiguration they were optimally found to be 7, 19 and 26 respectively.

The plot of the active power loss before and after reconfiguration is shown in Figure: 4.9

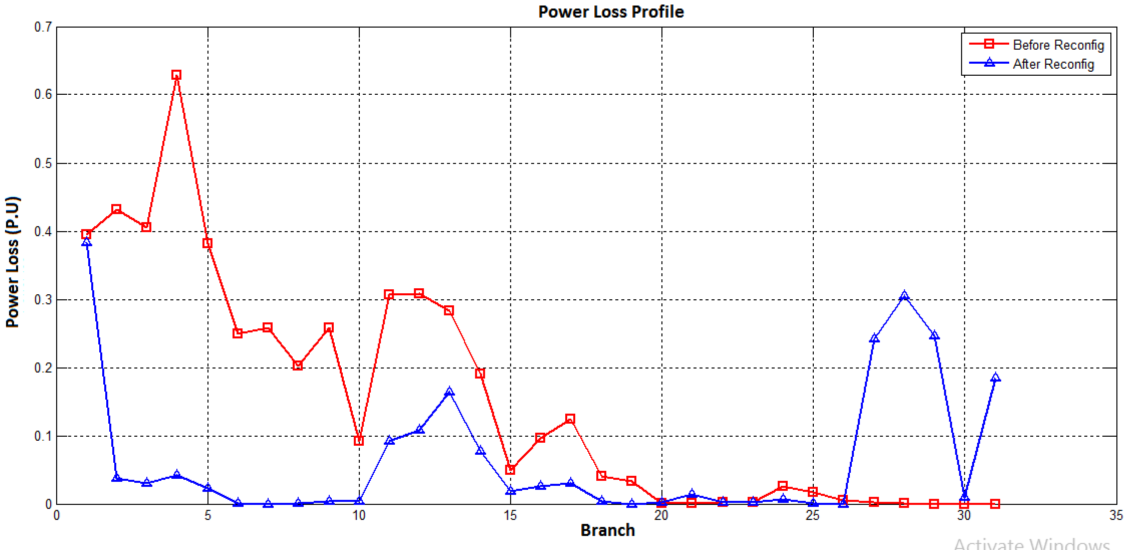


Figure 4.9: The Active Power Loss Plot of 29-Bus System Before and After Reconfiguration

The voltage profile plot of 29-bus system before and after reconfiguration is shown in Figure 4.10

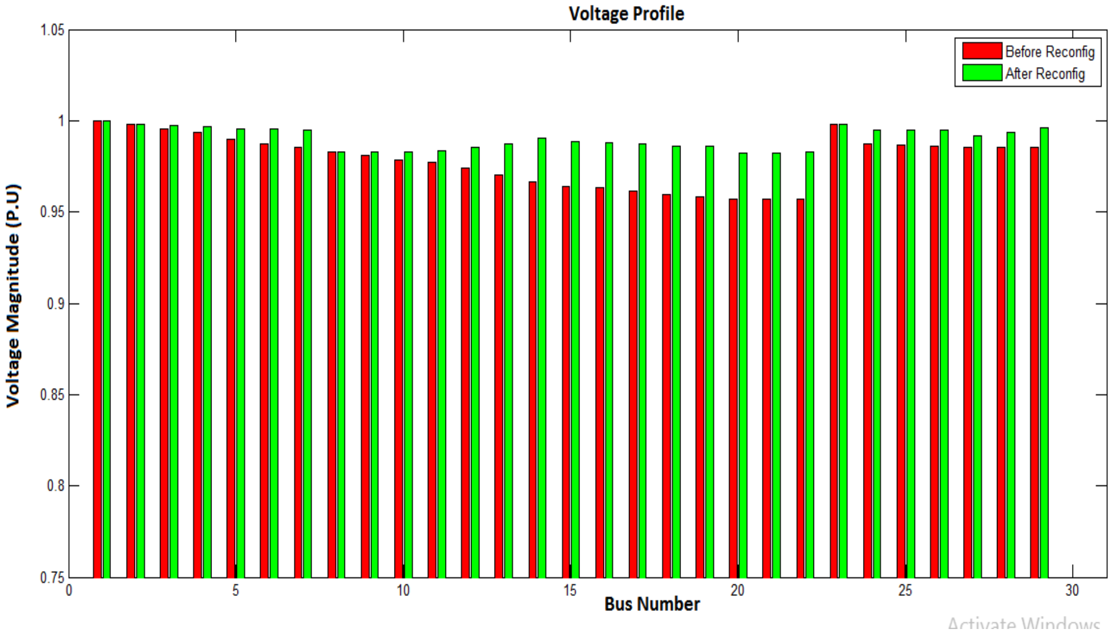


Figure:4.10 Voltage Profile Plot of 29-Bus System Before and After Reconfiguration

4.3.3 Case III: DG Placement Only

In this case, the forward-backward sweep technique using equations *(2.13)* and *(2.19)* in sub-section (2.2.6.3) was employed to obtain the power flow results. The BA was run using sub-section (3.2.3.1) for DG placement and sizing to reduce power loss and improve voltage profile of the network. Three synchronous DGs were installed to improve the network performance, DGs sizes and locations were95kW, 83kW, 54kW as well as 59kVar, 52kVar, 34kVar at buses 17, 3 and 12 respectively. The result of the active power loss obtained before and after reconfiguration is shown in Figure 4.11.It can be seen that from the Figure, the active power loss before and after DG placement and sizing was 4.7864kW and 0.65703kW respectively, which represents the power loss reduction of 86.2729%. The reactive power loss before and after DG location and sizing was 3.5675kWand 0.4687kVar which represents the reactive power loss reduction of86.8487%. Similarly, it is observed that from Figure 4.12, the magnitude of voltage before DG placement and sizing was 0.95695p.u after DG placement and sizing was 0.99743p.u respectively. It could also be observed from Figure 4.12 that, buses 7, 8, 9, 10, 11, 12, 13 15, 16 to 22 have highest voltage profile due to network reconfiguration.

The plot of the active power loss before DG location and sizing and after DG placement and sizing is shown in Figure: 4.11 while the voltage profile plot was shown in Figure 4.12

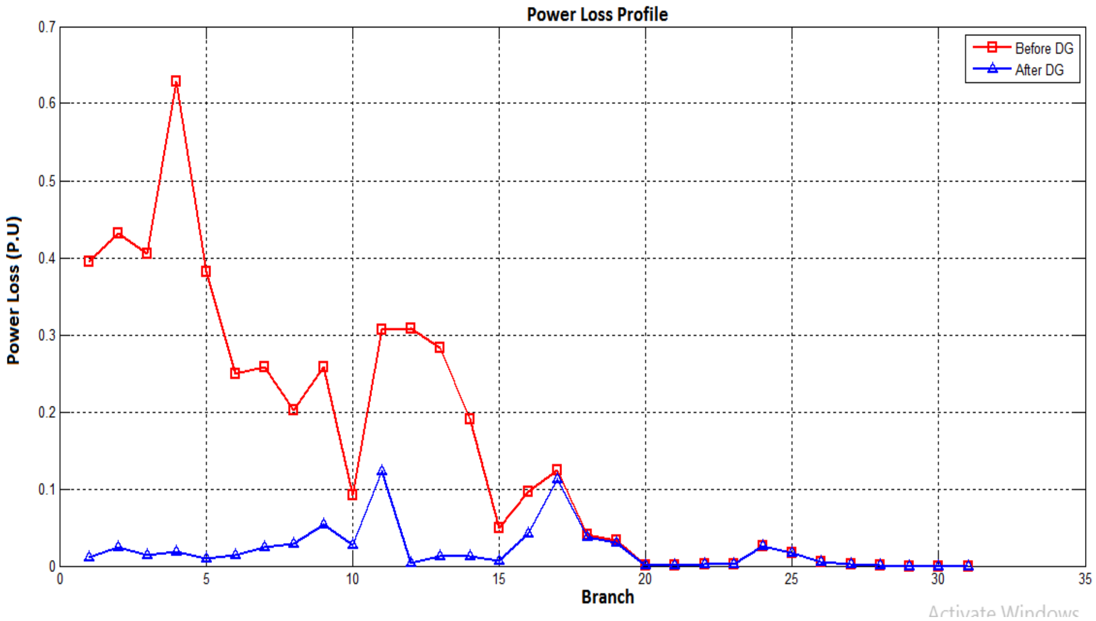


Figure: 4.11The Plot of the Active Power Loss Before and After DG Placement and Sizing

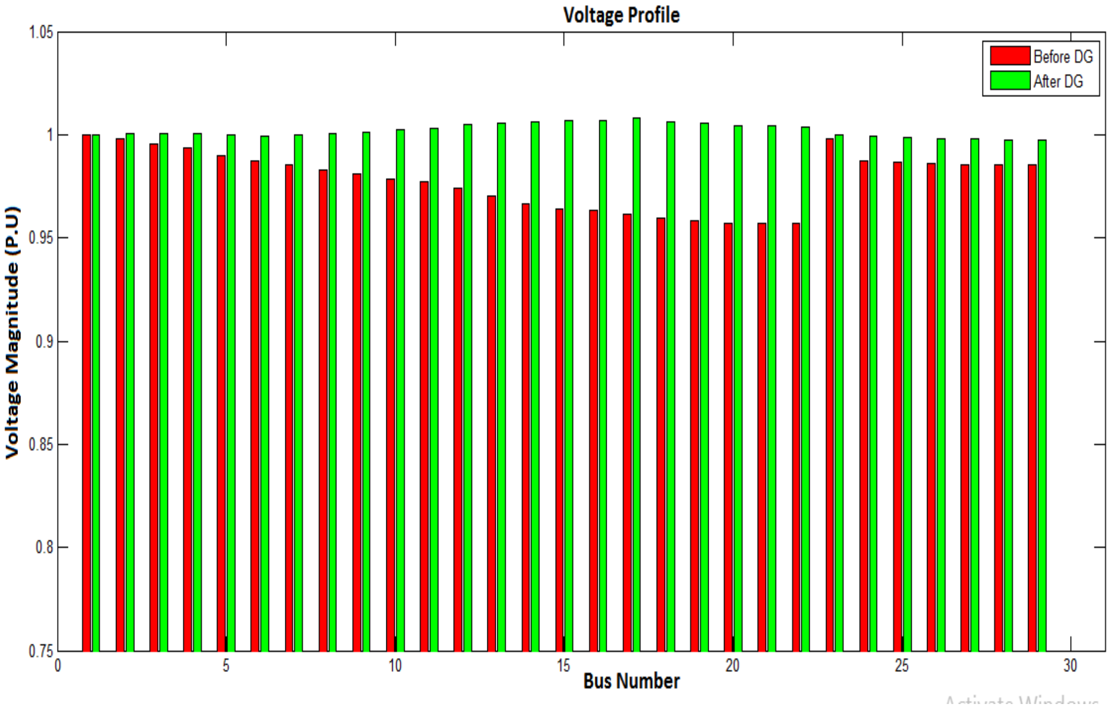


Figure: 4.12 The Voltage Profile Plot of 29-Bus System Before and After DG Placement

4.3.4 Case IV: Simultaneous DG Placement with Reconfiguration

Once again for 29-bus system, the forward-backward sweep technique using equations *(2.13)* and *(2.19)* in sub-section (2.2.6.3) was employed to obtain the power flow results. The BA was run using sub-section (3.2.3.1) for simultaneous DG placement, sizing and reconfiguration to reduce power loss and enhance load balancing of the network. It is observed that after simultaneous DG with reconfiguration of the network, the DGs sizes and locations were95kW, 83kW, 54kW as well as 59kVar, 52kVar, 34kVar at buses 17, 3 and 12 respectively. The optimal OFF-switches were 7, 17 and 26 respectively. The result of the active power loss obtained before and after reconfiguration is as shown in Figure 4.13.It is shown that from the Figure, the active power loss before and after DG with reconfiguration was 4.7864kW and 0.53735kW respectively, which represent the power loss reduction of 88.7734%. The reactive power loss before and after DG with reconfiguration was 3.5675kWand 0.4210kVarrespectively, which represents the reactive power loss reduction of 88.1871%. Similarly, it is observed from Figure 4.14that, the magnitude of voltage before DG with reconfiguration was 0.95695p.u after DG with reconfiguration was 0.99796p.u respectively. It could also be observed from Figure 4.14 that, buses 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 15, 16 to 22 have highest voltage profile due to DG with reconfiguration.

The plot of the active power loss before DG with reconfiguration and after DG with reconfiguration is shown in Figure: 4.13

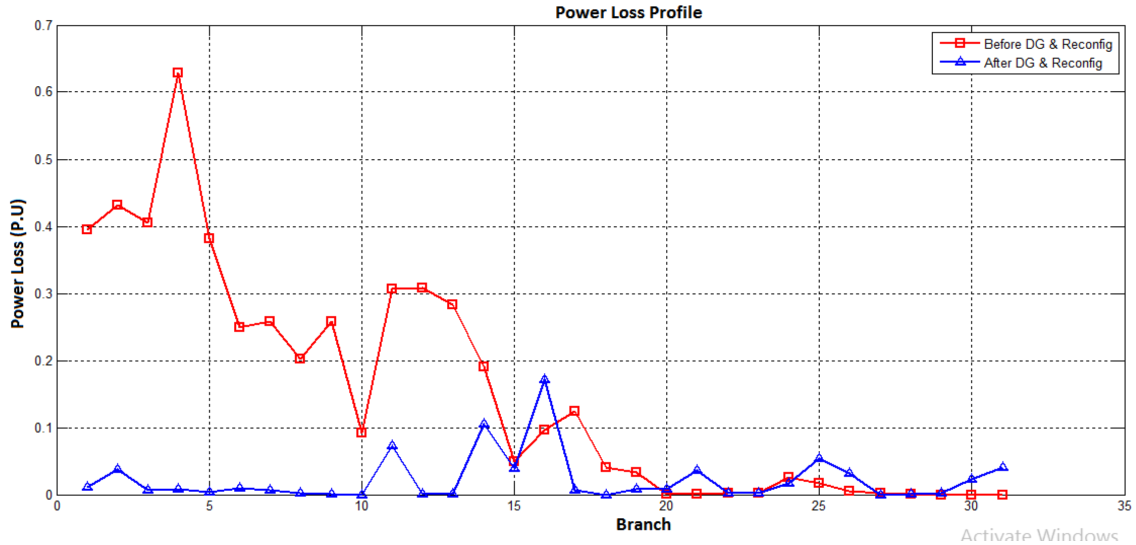


Figure: 4.13The Active Power Loss Before and After DG with Reconfiguration

The voltage profile plot of 29-bus system before and after DG with reconfiguration is show in Figure 4.14

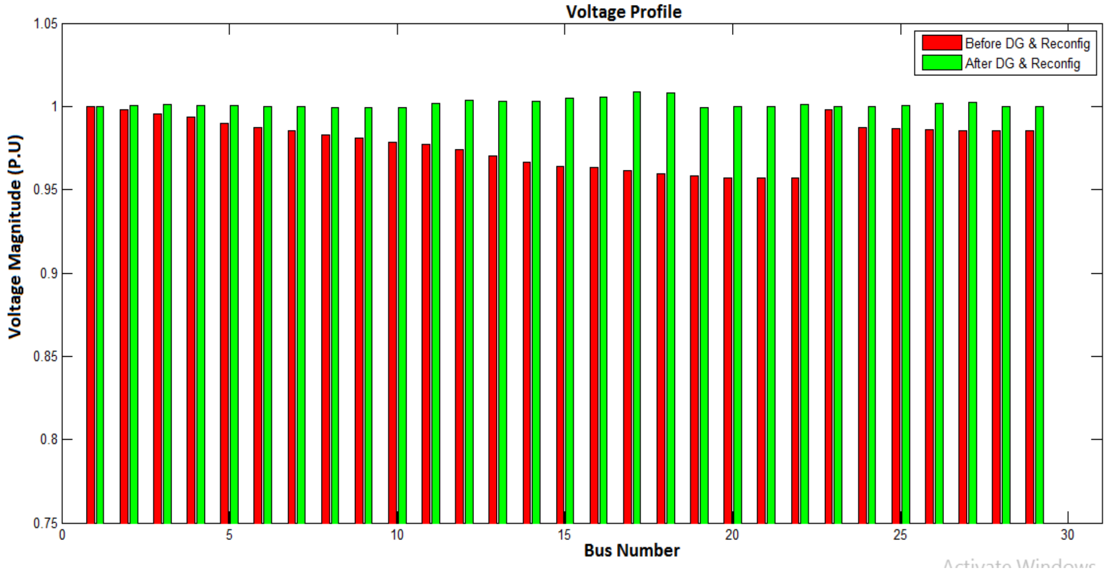


Figure: 4.14The Voltage Profile Plot of 29-Bus System Before and After DG with Reconfiguration

4.3.5 Case V: Combination of Four Case Scenarios

Finally, in this case four conditions were considered such as; the base case result only, reconfiguration result only, DG result only and simultaneous DG and reconfiguration results were combined together. From Figure 4.15, it is observed that the result of simultaneous DG with reconfiguration was better as the active power loss was 0.53735kW, which represents the active power loss reduction of 88.7734% compared with the other results. The reactive power loss was 0.4210kVar which represent the reactive power loss reduction of 88.1871% compared with the other results. Likewise from Figure 4.16 shows that the voltage profile has been enhanced from 0.95695p.u to 0.99796p.u. This shows that the developed method is better than the other three case scenarios.

The plot of the combined active power loss of four scenarios is shown in Figure: 4.7

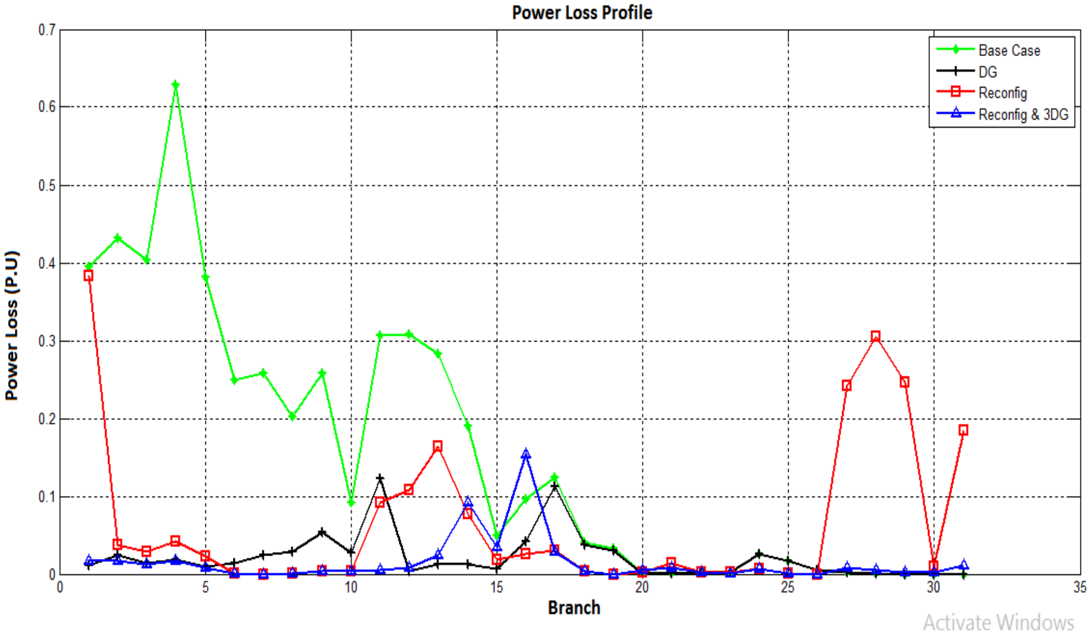


Figure: 4.15 Active Power Loss of four Scenarios of 29-Bus System

The voltage profile plot for four scenario of 29-bus system is shown in Figure 4.16

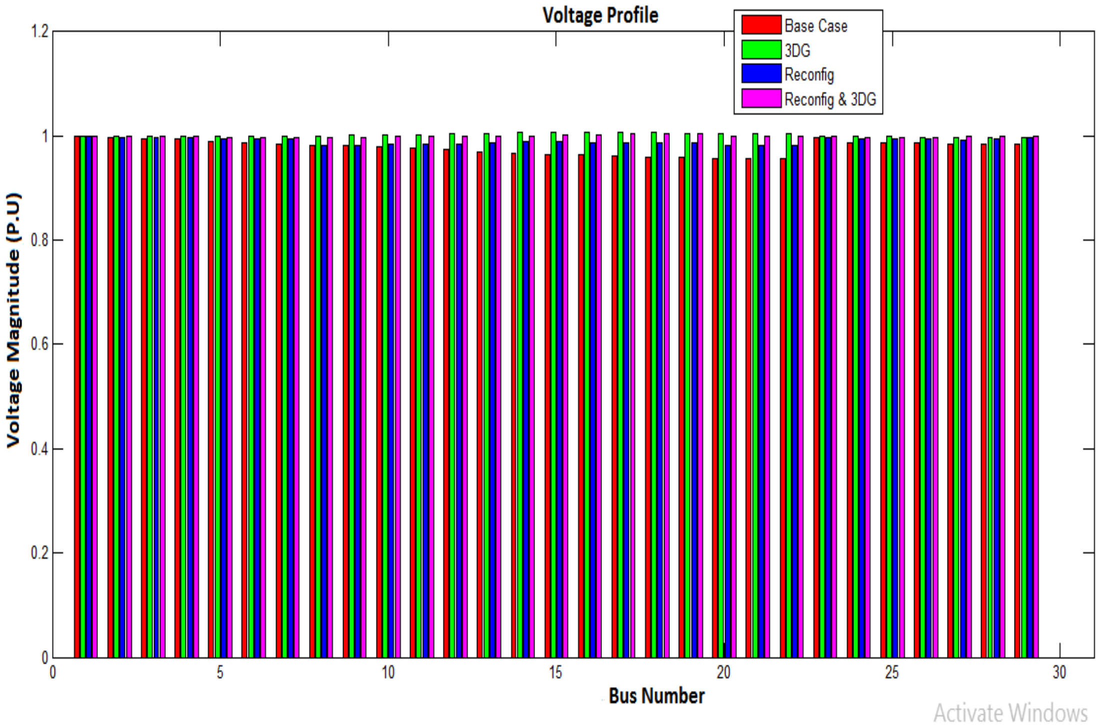


Figure: 4.16The Voltage Profile Plot for Four Scenario of 29-Bus System

4.4 Validation of the Developed Method

In order to validate the developed method, the work of Syahputra*et al.*, (2015) was used and the comparison of the developed method and that of Syahputra is as shown in Figure 4.17. From the Figure the performance metric used for the comparison were active power loss, active power loss reduction, reactive power loss, reactive power loss reduction, voltage profile, DG location, DG size, and switches. The comparison was done on IEEE 33-Bus system.

In the developed method, the optimal locations of the three DGs obtained were on bus 29, 31 and 12 respectively. The DGs sizes were 957kW, 870kW, 822kW with corresponding reactive power components of 593kVar, 539kVar, 509kVar respectively.The active and reactive power loss of the network were found to be 15.2353kW and 12.0593kVAr respectively as compared to the base case of 208.4592kW and 111.6726kVAr respectively. This showed a percentage loss reduction of 92.69% and 53.56% for active and reactive power loss respectively. Figure 4.18 shows that the voltage profile of the developed method recorded significant improvement of 0.9918pu compared to 0.9840pu obtained by Syahputra*et al* (2015). For Syahputra*et al* (2015), the optimal locations at which the DGs were installed werebus16 and 35 in the network and the sizes of the installed DGs were 1.92MW, 1.75MW, 1.68MW as well as 930kVAr, 0kVar 810kVar for active and reactive power respectively. The power loss obtained by the Syahputra*et al.*, (2015) was 27.63kW for active power as compared to the base of 202.68kW which showed a percentage loss reduction of 86.37% for active power.

For power loss reduction, the comparison between the developed method and Syahputra*et al* (2015) showed that, the developed method recorded a percentage loss reduction of 92.69% for active power while Syahputra recorded a percentage loss reduction for active power of 86.37%.

Therefore, the developed method showed an improvement to performance metric over the work of Syahputra*et al*., (2015).

Figure 4.17 below showed the power loss plot of the developed method and Syahputra*et al* (2015)

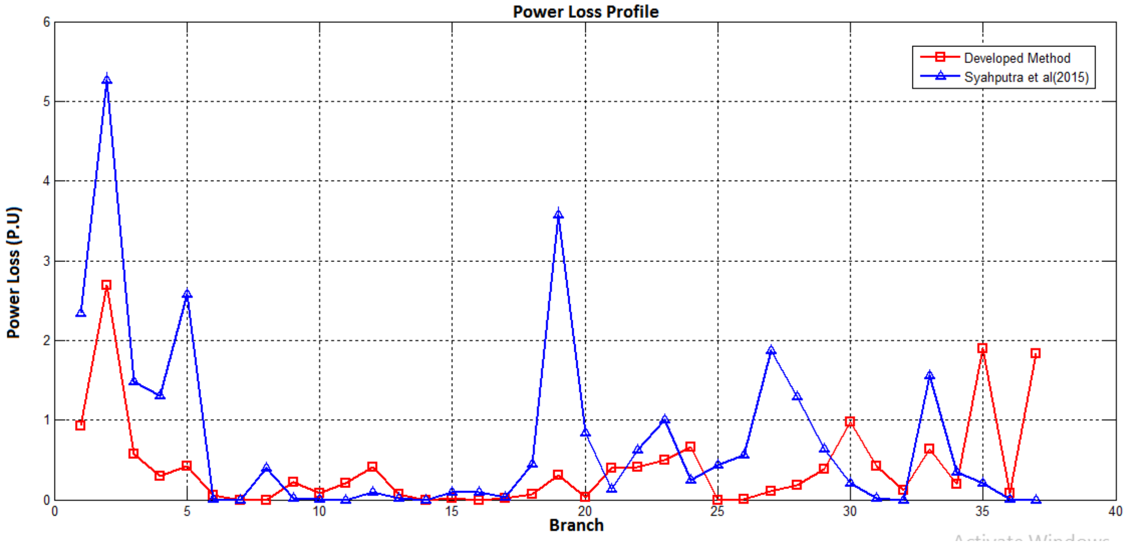


Figure: 4.17The Power Loss Plot of the Developed Method and Syahputra*et al* (2015)

Figure 4.18 shows the voltage profile of the developed method and Syahputra*et al* (2015).

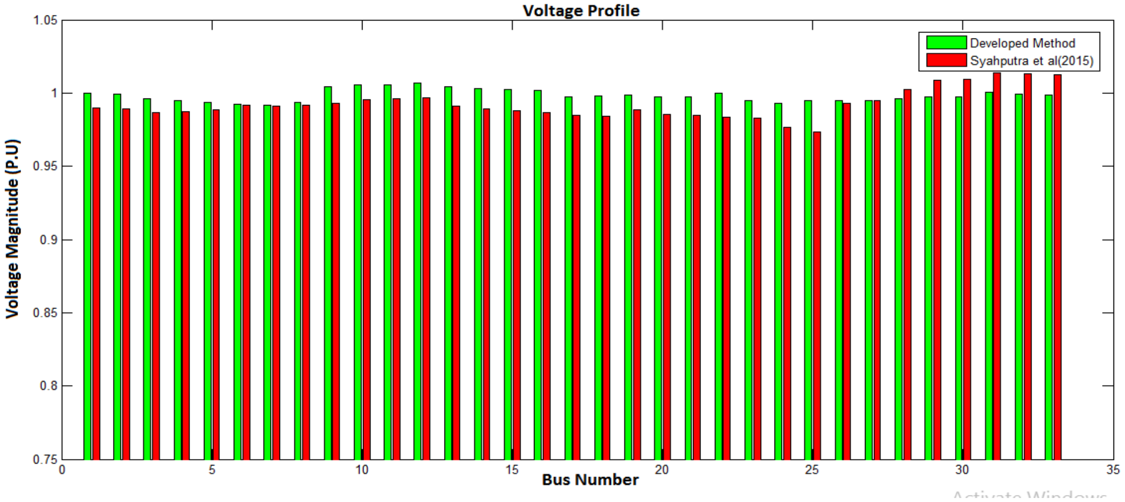


Figure: 4.18The Voltage Profile of the Developed Method and Syahputra*et al* (2015).

Table 4.3: Summary Results of Syahputra *et al* (2015) and the Developed Method

Descriptions	Syahputra *et al*(2015)	Developed method
Optimal DG location	18, 22 & 33	29, 31 & 12
Optimal DG active power	1.92MW, 1.75MW & I.68MW	957 kW, 870 kW& 822 kW
Optimal DG reactive power	930kVAr, 0kVar &810kVar	593kVar, 539kVar & 509kVar
ON switches	8, 19, 27, 34 & 37	7, 8, 14, 16 & 25
Active power loss	27.6300kW	15.2353kW
Reactive power loss	Not Considered	10.014 kVAr
%loss reductionofactive power	86.37%	92.69%
Minimum Voltage	0.9840	0.9918

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The developed method is intended to improve distribution network performance of radial distribution network through optimal network reconfiguration and DGs placement; synchronous distributed generators with the objectives function of power loss reduction, voltage deviation minimization and load balancing using BA with the consideration of Sabo-feeder of Zaria distribution network.

The power flow analysis was carried-out based on forward-back sweep technique for base casescenario. Two test systems were used in implementing the work; the standard IEEE 33-bus and a real life 29-bus Sabo-feeder. The developed method was validated by comparing it with thework presented by Syahputra*et al.*, (2015) and was implemented on the standard IEEE 33-bus test system.

The developed method was applied on standard IEEE-33 bus system, the base case total active and reactive power losses were determined to be 208.46kW and 111.67kW respectively. Then, the developed BA technique was also applied on the IEEE-33 to determine the optimal DG sizes and the location as well as the optimal reconfiguration of the network,the sizes and locations of DGs were 957kW, 870kW, 822kW as well as593kVar, 539kVar, 509kVar at buses 29, 31 and 12 respectively. The total active and reactive power loss obtained after the DG placement as well as network reconfiguration were 15.2353 kW and 12.0593 kVAr respectively.Thus , the developed method recorded a loss reduction of 92.6915% and 53.56% for both active and reactive power respectively over the base case, the voltage profile value was 0.91075*p.u*for base case and

0.9918*p.u*when the developed method was considered on IEEE 33-bus system. Then when compared with the work of Syahputra*et al*., the developed method recorded 6.32% active power loss reduction and 1.04% voltage profile improvement. The developed method was also applied on a simulated feeder of Sabo-Gari at Zaria distribution network with the view to implement the synchronous DG placement as well as network reconfiguration. The results indicated that total active and reactive power losses were reduced by 88.77% and 88.18% respectively, while the voltage profile has been improved to 4.1% of the base case. It is evident that the developed method has a better result over the work of Syahputra*et al*., (2015).

5.2 Significance Contribution

The proposed research work was able to reduced active power loss, voltage deviation and balanced the load among feeders in the network as follows;

1. Application of Multi-Objective Bat Algorithm based method for simultaneous optimal network reconfiguration with DG placement

2. The developed method achieved an improvement in power loss reduction of 92.69% for active power and voltage improvement of 8.20%over the work of Syahputra*et al* (2015) for the 33-Bus distribution network.

3. The developed method achieved a better performance metric over the base case for practical power network of 29-Bus Sabo-feeder.

5.3 Limitation of the Work

1. Only steady state analysis of the research network was considered.

2. Most of the practical networks have no sufficient data

5.4 Recommendations

The future research work should consider the following aspects for further work

1. The research work should be extended to consider islanding operation mode of the DGs with reconfiguration
2. The possibility of hybridization of two or more Meta-heuristic algorithms should be explored to solve network reconfiguration problem with DG placement
3. Other types of DGs could be evaluated to determine the type of DG that can best suit the particular network due to the nature of load on the network.

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APPENDIX A1

Line and Bus Data for Standard IEEE 33-bus Distribution Network

Branch Number (ik)	Sending Bus (i)	Receiving Bus (k)	$R_{ik}\,(\Omega)$	$X_{ik}\,(\Omega)$	$P_{Dk}\,(kW)$	$Q_{Dk}\,(kVAr)$
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	18	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	22	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200

25	25	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40

APPENDIX B

Line and Bus Data for Zaria Distribution Network (Sabon-Gari)

Branch Number (ik)	Sending Bus (i)	Receiving Bus (k)	$R_{ik}\ (\Omega)$	$X_{ik}\ (\Omega)$	$P_{Dk}\ (kW)$	$Q_{Dk}\ (kVAr)$
1	1	2	0.0671	0.0501	0	0
2	2	3	0.0840	0.0627	6.21	3.56
3	3	4	0.0840	0.0627	2.84	1.53
4	4	5	0.1344	0.1003	2.84	1.53
5	5	6	0.0840	0.0627	6.21	3.56
6	6	7	0.1176	0.0877	6.21	3.56
7	7	8	0.1343	0.1003	6.21	3.56
8	8	9	0.1176	0.0877	6.21	3.56
9	9	10	0.1679	0.1253	6.21	3.56
10	10	11	0.06718	0.0501	5.58	2.96
11	11	12	0.2519	0.188	2.84	1.53
12	12	13	0.2687	0.2005	8.62	5.12
13	13	14	0.3023	0.2256	2.84	1.53
14	14	15	0.2183	0.1629	5.58	5.12
15	15	16	0.06718	0.05012	12.31	10.11
16	16	17	0.20154	0.2130	2.84	1.53
17	17	18	0.2855	0.1253	12.31	10.11
18	18	19	0.16795	0.1253	12.31	10.11
19	19	20	0.3023	0.2256	15.20	10.11
20	20	21	0.06718	0.0501	5.48	3.56
21	21	22	0.21834	0.16291	5.48	3.56
22	22	23	0.06718	0.0501	12.31	10.11
23	23	24	0.06718	0.0501	12.31	10.11

24	24	25	0.1344	0.1003	12.31	10.11
25	25	26	0.21834	0.16291	5.48	3.56
26	26	27	0.1008	0.0751	5.58	5.12
27	3	28	0.1176	0.0877	5.58	5.12
28	28	29	0.1344	0.1003	4.68	3.56

APPENDIX C

BA CODES FOR THE DEVELOPED METHOD

```
% ========================================================== %
% Files of the Matlab programs included in the book:         %
% Xin-She Yang, Nature-Inspired Metaheuristic Algorithms,     %
% Second Edition, Luniver Press, (2010).   www.luniver.com    %
% ========================================================== %

% -------------------------------------------------------- %
% Bat-inspired algorithm for continuous optimization (demo)   %
% Programmed by Xin-She Yang @Cambridge University 2010       %
% For details, please see the following papers:
% 1) Xin-She Yang, Bat algorithm for multi-objective optimization,
% Int. J. Bio-Inspired Computation, Vol.3, No.5, 267-274 (2011).
% 2) Xin-She Yang, Xingshi He, Bat Algorithm: Literature Review
% and Applications, Int. J. Bio-Inspired Computation,
% Vol. 5, No. 4, pp. 141-149 (2013).
% -------------------------------------------------------- %
```

M-File: Matlab code for sizing and placement of distributed generation

```
function [DG3]=moba_DG3(~)
%%%%    Moving Forward   %%%%
ifnargin==1,
NPareto=10;  % Number of points on the Pareto front
end
global w;
l_res=3;
DG1=zeros(1,l_res);
for k=1:0.5:NPareto,
   w=k/NPareto;
global w;
global dg2;
dg2=moba_DG2;
size(dg2);
l_res=3;
for k=1
   [best,fmin,N_iter,II]=bat_algorithm;
   bestdg3s=best;
   bestdg3l=II;
   bestdg3f=fmin;
   dg3=[bestdg3s bestdg3l bestdg3f];
DG3(k,:)=dg3;
end
```

```
[a,idx]=min(DG3(:,l_res));
   DG3=DG3(idx,:);
DG_Set=[dg2; DG3];
   DG3=DG_Set;
% The main part of the Bat Algorithm                    %

function [best,fmin,N_iter,II]=bat_algorithm(para)
% Default parameters
nb=33;
ifnargin<1,  para=[nb 0.9 0.9];  end
n=para(1);      % Population size, typically 10 to 25
A=para(2);      % Loudness  (constant or decreasing)
r=para(3);      % Pulse rate (constant or decreasing)
% This frequency range determines the scalings
Qmin=0;         % Frequency minimum
Qmax=0.1;       % Frequency maximum
% Iteration parameters
N_iter=60;       % Total number of function evaluations
% Dimension of the search variables
d=1;
% Initial arrays
Q=zeros(n,1);   % Frequency
v=zeros(n,d);   % Velocities
% Initialize the population/solutions
set1=zeros(n,1);
fori=2:n,
pf=0.85;
dg_u_lim=0.2000;
dg_l_lim=0.0000;
  a=(+1)*tan(acos(pf));
set1(i)=rand(1,d)/10;
if set1(i)>dg_u_lim
set1(i)=dg_u_lim;
end
set2(i)=set1(i).*a;
set3(i)=set1(i)+(set2(i)*1i);
Sol(i,:)=set3(i);
Fitness(i)=Fun((Sol(i,:)),i);
Fitness(1)=10;
end
Sol;
% Find the current best
[fmin,I]=min(Fitness);
best=Sol(I,:);
II=I;
% Start the iterations -- Bat Algorithm
```

```
fori_ter=1:N_iter,
      % Loop over all bats/solutions
fori=2:n,
Q(i)=Qmin+(Qmax-Qmin)*rand;
        v(i,:)=(v(i,:)+(Sol(i,:)-best)*Q(i));
S(i,:)=Sol(i,:)+v(i,:);
        % Pulse rate
if rand>r
S(i,:)=best+0.01*randn(1,d);
end
        %%%%%  constraints on DG Size  %%%%%
r_dgs=real(S(i,:));
ifr_dgs>dg_u_lim
r_dgs=dg_u_lim;
i_dgs=r_dgs.*a;
S(i,:)=r_dgs-(i_dgs*1i);
end
ifr_dgs<dg_l_lim
r_dgs=dg_l_lim;
i_dgs=r_dgs.*a;
S(i,:)=r_dgs-(i_dgs*1i);
end
    % Evaluate new solutions
Fnew=Fun(S(i,:),i);
    % If the solution improves or not too loudness
if (Fnew<=Fitness(i)) && (rand<A) ,
Sol(i,:)=S(i,:);
Fitness(i)=Fnew;
end
        % Update the current best
ifFnew<=fmin,
best=S(i,:);
fmin=Fnew;
            II=i;
end
end
%        Sol;
end
% Put your objective functions here
function z=Fun(u,i)
global w;
[obj1,obj2,obj3]=Funobj(u,i);
z=obj1*(w)+obj2*((1-w)*0.36)+obj3*((1-w)*0.24);

% Three objectives
function [obj1,obj2,obj3]=Funobj(u,i)
```

```
global dg2;
n=33;

%%%%  Considering DG1  %%%%
dg1s=dg2(1,1);
    dg1s=dg1s*1e7;
dg1l=abs(dg2(1,2));
dg1f=dg2(1,3);

    %%%%  Considering DG2  %%%%
    dg2s=dg2(2,1);
        dg2s=dg2s*1e7;
    dg2l=abs(dg2(2,2));
    dg2f=dg2(2,3);

load_power=load_33;
ldg1=load_power(dg1l);
    ldg1=ldg1-dg1s;
load_power(dg1l)=ldg1;
ldg2=load_power(dg2l);
    ldg2=ldg2-dg2s;
load_power(dg2l)=ldg2;
lload_power=load_power;

%%% Base Case %%%
V_base=12.66e3;
S_base=10e6;
line=line_33;
load_power=load_33;
load_power=(conj(load_power));
[result] = PFLOW(V_base, S_base, line, load_power );
v=ones(n,1);
v(2:end)=Vi;
v_bc_ave=(sum(v)/n);

%%% Running Power flow for each u  %%%
u;
u=u*1e7;
V_base=12.66e3;
S_base=10e6;
line=line_33;
load_power=lload_power;
load_power(i)=load_power(i)-u;
load_power=(conj(load_power));
[result] = PFLOW(V_base, S_base, line, load_power );
v=ones(n,1);
```

```
v(2:end)=Vi;
v_dg1_ave=(sum(v)/n);

obj1=result(end,9)+(result(end,10)*1i);
obj2=(v_nom-result(:,12))/(v_nom-result(end,11));
obj3=sqrt(result(end,9)/sum(real(line)))/(sum(load(:,11))/n);
```

M-File: Matlab code for Reconfiguration and Distributed generation

```
function []=ReConfig_3DG_BA()
clear all;
clc;
ifnargin==1,
NPareto=10;  % Number of points on the Pareto front
end
global w;
l_res=3;
DG1=zeros(1,l_res);
for k=1:0.5:NPareto,
   w=k/NPareto;
global w;
globalnb;

for k=1
nb=29;                    % should be accompanied by a change in case: info, line 60 or so
bat_algorithm;

end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The main part of the Bat Algorithm
function []=bat_algorithm(para)
tic
globalnb;
%%%   DGs %%%
dgs=moba_DG3(nb)
    dg1s=dgs(1,1);
    dg1s=dg1s*1e1;
    rdg1s=real(dg1s);
    idg1s=imag(dg1s);
        dg1l=abs(dgs(1,2));
    dg2s=dgs(2,1);
    dg2s=dg2s*1e1;
    rdg2s=real(dg2s);
    idg2s=imag(dg2s);
        dg2l=abs(dgs(2,2));
    dg3s=dgs(3,1);
```

```
 dg3s=dg3s*1e1;
     rdg3s=real(dg3s);
     idg3s=imag(dg3s);
         dg3l=abs(dgs(3,2));

info=loadcase(casenb);
info.bus(dg1l,3)=info.bus(dg1l,3)-rdg1s;
info.bus(dg1l,4)=info.bus(dg1l,4)-idg1s;
info.bus(dg2l,3)=info.bus(dg2l,3)-rdg2s;
info.bus(dg2l,4)=info.bus(dg2l,4)-idg2s;

info.bus(dg3l,3)=info.bus(dg3l,3)-rdg3s;
info.bus(dg3l,4)=info.bus(dg3l,4)-idg3s;

% info.bus;
% Default parameters
ifnargin<1,  para=[20 0.9 0.9];  end
n=para(1);                          % Population size, typically 20 to 40
A=para(2);                           % Loudness  (constant or decreasing)
r=para(3);                          % Pulse rate (constant or decreasing)

% This frequency range determines the scalings
Qmin=0;                             % Frequency minimum
Qmax=2;                              % Frequency maximum

%%% Bus29
v_nom=1;
dim=3;                             % Dimmension of searching space
x=load('swarm29.m');
pbest=load('swarm29.m');                  % Creating pbestmatrice
gbest=[7 19 26];                       % Introducing a randomized gbest
tap=[   8   9   10  11  21  31  29  0   0
       2   3   4   5   6   11  18  19  20
12  19  14  16  0   0   0   0   0];
nhanh=31;
nut=29;
o=[29 30 31];

vnew=rand(n,dim);   % Velocities
vold=vnew;
sig=zeros(n,dim);
fitness=zeros(1,n);

% Initial arrays
Q=zeros(n,1);   % Frequency
```

```
iter=0;
maxiter=60;% Maximum iteration

ta=tap';
% Establish the incidence matrix
data=info;
doc=data.branch;

matrix=zeros(nhanh,nut);
nutdau=doc(:,1);
nutcuoi=doc(:,2);
fori=1:nhanh
matrix(i,nutdau(i))=1;
matrix(i,nutcuoi(i))=1;
end

% Calculating fitness function for pbest
fpbest=zeros(1,n);
fori=1:n
fpbest(i)=50000;
end

% Main loops
whileiter<maxiter
iter=iter+1;
   % Updating velocity
vold=vnew;
fori=1:n
for j=1:dim
Q(i)=Qmin+(Qmin-Qmax)*rand;
vnew(i,j)=vold(i,j)+(x(i,j)-gbest(j)).*Q(i);
if abs(vnew(i,j))==abs(vold(i,j))
vnew(i,j)=rand(1,1).*vnew(i,j);
end
end
end
   % Updating particles' coordinate
fori=1:n
for k=1:dim
         sig(i,k)=length(nonzeros(ta(:,k)))/(1+exp(-vnew(i,k)));
x(i,k)=ta(ceil(sig(i,k)),k);
end
end
   % Calculating fitness function for each particle
      y=x';
for k=1:n
```

```
hop=info;
matran=matrix;

fori=1:dim
hop.branch(y(i,k),11)=0;
matran(x(k,i),:)=0;
end
                % Check on constraint of radial distribution network
for j=1:length(matrix(1,:))
fori=1:length(matrix(1,:))
if sum(matran(:,i))==1
row=find(matran(:,i));
matran(row,:)=0;
end
end
end
if sum(sum(matran))==0
result=PFLOW(hop);
                     obj1=result(end,9)+(result(end,10)*1i);
                     obj2=(v_nom-result(:,12))/(v_nom-result(end,11));
                     obj3=sqrt(result(end,9)/sum(real(line)))/(sum(load(:,11))/n);
fitness(k)=sum(z=obj1*(w)+obj2*((1-w)*0.6)+obj3*((1-w)*0.4);)*1e3;
end
end
   % Updatingpbest
for k=1:n
if fitness(k)<fpbest(k)
pbest(k,:)=x(k,:);
fpbest(k)=fitness(k);
end
end
   % Calculating fitness function for gbest
        u=gbest';

hop=info;
fori=1:length(u)
hop.branch(u(i),11)=0;
end
result=PFLOW(hop);
fgbest=sum(result.branch(:,14)+result.branch(:,16))*1e3;
gbestvolt=result.bus(:,8);
minvolt=min(gbestvolt);
   % Updatinggbest
for k=1:n
iffpbest(k)<fgbest
gbest=pbest(k,:);
```

```
end
end
end
% Calculating initial configuration
bandau=info;
fori=1:length(o)
bandau.branch(o(i),11)=0;
end
ketqua=PFLOW(bandau);
tonthat=sum(ketqua.branch(:,14)+ketqua.branch(:,16))*1e3;
dienap=ketqua.bus(:,8);
dienapmin=min(dienap);
gbestvolt;
a=sort(gbest);
ploss=(tonthat-fgbest)*100/tonthat;
plot(dienap,'-sr')
hold on
plot(gbestvolt,'-^b')
ylabel('Voltage (p.u)')
xlabel('Node')
title('Voltage profile')
legend('Before Reconfig','After Reconfig')
hold off
disp('      ')
disp('      ')
disp('      ')
```