TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: M-149-MSESPM-2020-2022

Optimal Network Reconfiguration and Distributed Generation Integration for Power Loss Minimization and Voltage Profile Enhancement in Radial Distribution System

by

Naresh Manandhar

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN ENERGY SYSTEMS PLANNING AND MANAGEMENT

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

SEPTEMBER, 2022

COPYRIGHT

The author has agreed that the library, Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering may make this thesis freely available for inspection. Moreover, the author has agreed that permission for extensive copying of this thesis for scholarly purpose may be granted by the professor(s) who supervised the work recorded herein or, in their absence, by the Head of the Department wherein the thesis was done. It is understood that the recognition will be given to the author of this thesis and to the Department of Mechanical Engineering and Aerospace Engineering, Pulchowk Campus, Institute of Engineering in any use of the material of this thesis. Copying or publication or the other use of this thesis for financial gain without approval of the Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering and author's written permission is prohibited. Request for permission to copy or to make any other use of the material in this thesis in whole or in part should be addressed to:

Head
Department of Mechanical and Aerospace Engineering
Pulchowk Campus, Institute of Engineering
Lalitpur, Kathmandu
Nepal

TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommend to the Institute of Engineering for acceptance, a thesis entitled "**Optimal Network Reconfiguration and Distributed Generation Integration for Power Loss Minimization and Voltage Profile Enhancement in Radial Distribution System**" submitted by Mr. Naresh Manandhar in partial fulfillment of the requirements for the degree of Master of Science in Energy Systems Planning and Management.

____

Supervisor, Dr. Shree Raj Shakya
Associate Professor, Department of Mechanical and Aerospace Engineering, Pulchowk Campus

____

Supervisor, Dr. Sudip Bhattrai
Assistant Professor, Department of Mechanical and Aerospace Engineering, Pulchowk Campus

____

External Examiner, Dr. Shailendra Kumar Jha
Associate Professor, Department of Electrical and Electronics Engineering, Kathmandu University

____

Committee Chaiperson, Dr. Surya Prasad Adhikari
Associate Professor, Head of Department,
Department of Mechanical and Aerospace Engineering, Pulchowk Campus

Date: September 20, 2022

ABSTRACT

Network Reconfiguration with Distributed Generation (DG) integration can significantly reduce power loss and improve the system voltage. This thesis explores the approach for reduction in power loss and improvement in system voltage through a combination of network reconfiguration and DG installation in radial distribution systems. Initially, the approach was verified in a typical 33 and 69 Test Bus system in MATLAB using the Backward/Forward Propagation Load Flow approach. Voltage Stability Index (VSI) technique has been applied to determine the most sensitive bus to locate for DG integration. Artificial Bee Colony (ABC) algorithm was used to determine the optimal solution. Six scenarios for different combinations of system reconfiguration and DG installation were analyzed by using NEA 63-Bus real distribution network of the Nepal Electricity Authority (NEA), Kirtipur Distribution Center. The simulated results were compared with the base case scenario and were validated with results from the previous studies for DGs injecting active power only. Among them, Scenario VI (simultaneous network reconfiguration and DG integration) gave the best result for power loss reduction and voltage profile improvement. The results obtained in this study show that, for DGs generating active power only, the percentage reduction in active or real power has been improved by 72.19%, 83.52%, and 57.69% for the IEEE 33, IEEE 69, and NEA 63-Bus system respectively. Similarly, for DGs generating both real and reactive power, the power loss has been reduced by 91.61%, 96.53%, and 90.54% for the IEEE 33, IEEE 69, and NEA 63-Bus systems respectively. Also, an improvement of voltages from 0.913 p.u , 0.908 p.u , and 0.918 p.u to 0.971 p.u, 0.981 p.u , and 0.991 for the IEEE 33, IEEE 69, and NEA 63-Bus system respectively while comparing all other scenarios to the base case have been obtained. The research work also carried out to obtain results for DGs injecting both active and reactive power, which showed even better results than that of DGs injecting active power only. All the results showed that ABC algorithm has outperformed other popular metaheuristic algorithms.

ACKNOWLEDGEMENTS

The successful completion of this thesis work would not have been possible without the supervision, direction, advice, and help of many people and I am incredibly appreciative to have received this throughout the course of my thesis study. I take this opportunity to express my gratitude and indebtedness to everyone who has supported me throughout the entire period of this thesis work.

Firstly, I would like to extend my sincere gratitude to Associate Prof. Dr. Shree Raj Shakya, and Assistant Prof. Dr. Sudip Bhattrai who served as my thesis supervisors. I am grateful for their mentorship, inspiration, invaluable support, encouragement, and friendly guidance throughout this thesis work.

I want to sincerely thank the faculty members of the Department of Mechanical and Aerospace Engineering, Pulchowk Campus. I am truly thankful to Dr. Nawaraj Bhattarai, Coordinator of MSESPM for his constant guidance and support. In addition, I would like to express my gratitude to NEA, Kirtipur Distribution Center for their cooperation in providing information and data to make this study possible.

Last but not least, I would like to thank my family members, and friends (076 MSESPM batch) for their ongoing support, who directly or indirectly made a contribution throughout the study period.

TABLE OF CONTENTS

COPYRIGHT 2

APPROVAL PAGE 3

ABSTRACT 4

ACKNOWLEDGEMENTS 5

TABLE OF CONTENTS 6

LIST OF TABLES 8

LIST OF FIGURES 9

1 CHAPTER ONE: INTRODUCTION 10

1.1 Background 10
1.2 Problem Statement 13
1.3 Objective 15
1.4 Scope of Study 15
1.5 Assumptions and Limitations 15
1.6 Outline of the thesis 16
2 CHAPTER TWO: LITERATURE REVIEW 17

2.1 Distributed Generation 20
2.1.1 Types of DG Technologies 21
2.2 Network Reconfiguration 22
2.3 Optimal Network Reconfiguration and Distributed Generation Placement 22
2.4 VSI in Radial Distribution System 23
2.5 Load Flow Analysis in RDS 24
2.6 Load Flow in Radial Distribution Systems 27
2.7 Overview of Artificial Bee Colony (ABC) Algorithm 28
2.7.1 Parameters of ABC algorithm: 28
2.7.2 Phases of ABC algorithm: 29
3 CHAPTER THREE: METHODOLOGY 31

3.1 Problem Formulation 33

3.2 Radial Network Structure 34
3.2.1 Basic Algorithm for Reconfiguration Process 35
3.2.2 Power Loss Calculations 36
3.3 Shortlisting nodes for DG integration 38
3.4 Steps in ABC Optimization 39
3.5 Flowchart of Overall Methodology 42
3.6 Scenario Studies 43
4 CHAPTER FOUR: SYSTEM UNDER CONSIDERATION, TOOLS AND SOFTWARE 45
4.1 System under Consideration 45
4.1.1 IEEE 33 Test Bus System 45
4.1.2 IEEE 69 Test Bus System 46
4.1.3 NEA 63-Bus RDS 47
4.2 Software tool 48
5 CHAPTER FIVE: RESULTS AND DISCUSSION 50
5.1 Results for IEEE 33 Test Bus System 54
5.2 Results for IEEE 69 Test Bus System 58
5.3 Results for NEA 63-Bus RDS 62
6 CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS 65
6.1 Conclusions 65
6.2 Recommendations 66
REFERENCES 67
APPENDIX A: Branch and Load Data of 33 Bus System 71
APPENDIX B: Branch and Load Data of 69 Bus System 73
APPENDIX C: Branch and Load Data of NEA-63 Bus System 77
APPENDIX D: Comparison Results of IEEE 33 Test Bus System 80
APPENDIX E: Comparison Results of IEEE 69 Test Bus System 83
APPENDIX F: Comparison Results of NEA-63 Bus RDS 85

LIST OF TABLES

Table 3.1 Parent node-child node path generation for Figure 3.2 35
Table 5.1 Summary Results of IEEE 33 Test Bus System.. 56
Table 5.2 Summary Results of IEEE 69 Test Bus System.. 60
Table 5.3 Summary Results of NEA-63 Bus RDS.. 63

LIST OF FIGURES

Figure 1.1 Power System Network... 11
Figure 2.1 Branch of Radial Distribution System 25
Figure 3.1 Methodology Flow Diagram... 31
Figure 3.2 Sample Distribution Feeder 35
Figure 3.3 Sample Radial Distribution System 36
Figure 3.4 Flowchart of Backward-Forward Propagation Load Flow Analysis 37
Figure 3.5 Working Rule for ABC Algorithm 41
Figure 3.6 Flowchart of Overall Methodology 42
Figure 4.1 IEEE 33 Test Bus System... 45
Figure 4.2 IEEE 69 Test Bus System... 46
Figure 4.3 QGIS Plot of 11 kV Kirtipur Feeder... 47
Figure 4.4 NEA 63-Bus RDS 48
Figure 5.1 Result for Base Case 50
Figure 5.2 Result for Simultaneous Network Reconfiguration and DG Integration................ 51
Figure 5.3 Bus Voltage and Branch Current for the system 52
Figure 5.4 Voltage Magnitude Comparison at Different Buses 53
Figure 5.5 Power Loss Comparison for IEEE 33 Bus System 56
Figure 5.6 Percentage Loss Reduction Comparison for IEEE 33 Bus System 57
Figure 5.7 Bus Voltage Comparison for IEEE 33 Test Bus System.. 57
Figure 5.8 Power Loss Comparison for IEEE 69 Test Bus System 60
Figure 5.9 Percentage Loss Reduction Comparison for IEEE 69 Test Bus System 61
Figure 5.10 Bus Voltage Comparison for IEEE 69 Test Bus System...................................... 61
Figure 5.11 Power Loss Comparison for NEA-63 Bus RDS 63
Figure 5.12 Percentage Loss Reduction Comparison for NEA-63 Bus RDS 64
Figure 5.13 Bus Voltage Comparison for NEA-63 Bus RDS 64

1 CHAPTER ONE: INTRODUCTION

1.1 Background

A network of electrical components associated with the generation, transmission, and distribution of electric power makes up an electric power system. Among them, the distribution system consists of interconnected radial circuits deployed to supply electrical power to end users. In order to reduce power loss, the power from generating stations is initially stepped up to make power flow in the transmission system, and it is then stepped down to the utilization voltage in the distribution system. The main feeder and laterals make up a Radial Distribution System (RDS) which serves as the conduit between the transmission line and the end users. The distribution system usually operates radially, passive in nature, and power flow is unidirectional.

Due to the continuous growth of load, utilities are experiencing acute power system issues. As the electric power systems are expanded, the losses in the distribution network increase resulting poor voltage profile to end users. As compared to the transmission system, the distribution system mostly operates at poor voltage, and also the system power loss is highly associated with distribution system power loss. High current characteristics and flow of reactive power in RDS result in higher power losses and lower power factor, which increase energy costs and reduce power quality at the consumer site. To overcome the problems in RDS, different optimization techniques including network reconfiguration, DG integration, capacitor placement, and sizing can be incorporated.

The loss minimization techniques using network reconfiguration and DG installation are efficient and give an optimum solution to implement in the distribution network (Kalambe and Agnihotri 2014). Network reconfiguration involves changing its topology or structure by opening a branch or sectionalizing switch which is normally or typically closed and closing a tie switch which is typically opened. Merlin and Back (1975) were the first to apply the theory of using sectionalizing and tie switches to reconfigure radial distribution systems for line loss minimization using branch and bound-type optimization techniques. In doing so, the radiality of the network should be maintained. In general, network reconfiguration is done to fulfill the objective of minimizing the power loss or enhancing the voltage profile, or both.

Distribution systems are very dynamic and have a different types of loads including residential, commercial, industrial, water supply, and irrigation which vary throughout the day, week, and season of the year. A diagrammatic overview of Power System Network is represented in the following Figure 1.1 (Warwick M, Hoffman M 2016).

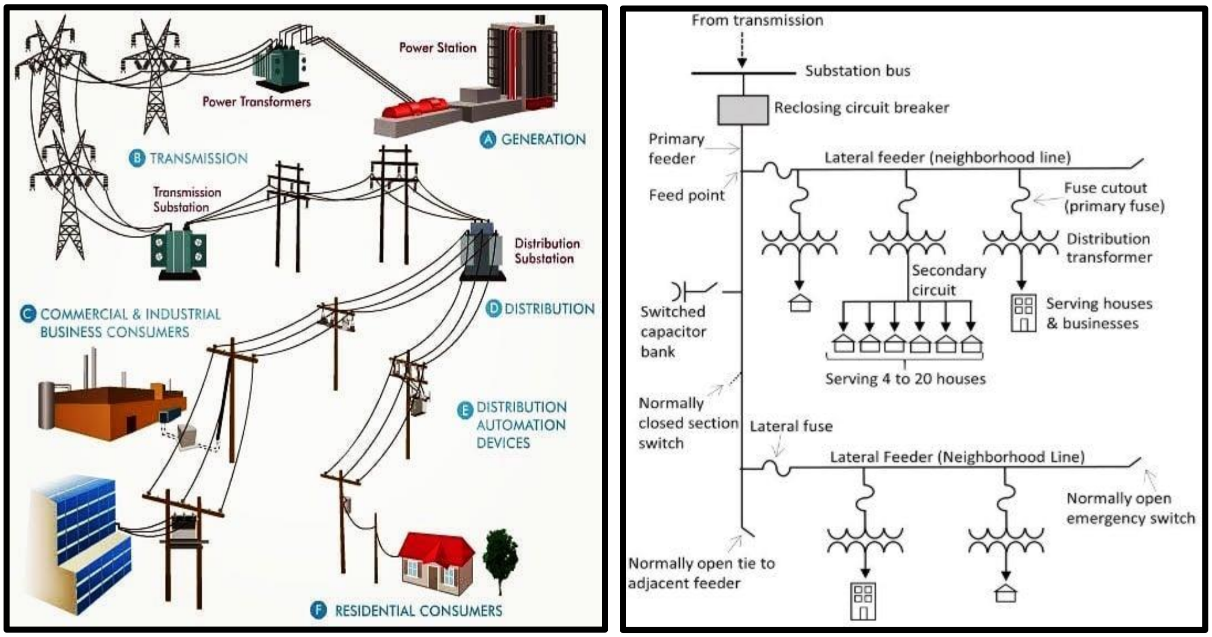


Figure 1.1 Power System Network

The minimum power loss in the distribution system will not be possible for a constant network configuration. Thus, reconfiguration must be carried out on regularly (i.e., online and in real-time) as demand changes, further increasing the computational load. By varying sectionalizing and tie switches, the distribution networks can be manipulated within the boundary of constraints. (Alam *et al.,* 2011:(Nguyen and Truong 2015). For network reconfiguration, the sectionalizing switch which is normally closed, and the tie switch which is normally opened are used. These switches increase the consistency of the distribution network without interrupting the majority of the power supply during a fault condition. It is an emerging concept that has been used to reduce power loss and increase the continuity of supply in the distribution network.

Generally, distribution networks are meshly structured but radially operated through effective protective coordination schemes to reduce the level of fault (Swarnkar *et al.* 2011a). Most of the distribution networks are heavily loaded at the load centers and violate the constraints of voltage limit requirements (Juma 2018), which ultimately reduce the quality of power supply and reliability of the system.

The losses in the power system network consist of both technical and non-technical. Most losses occur during peak load demand to meet the power required by utility customers. Research and studies have been carried out to improve the smooth integration of DG units without adverse technical difficulties.

There are basically three methods to reduce system losses in the distribution system:

i. Reduce equivalent line resistance
ii. Compensating capacitors placement
iii. Network reconfiguration or restructuring

The first strategy is to lower the conductors' resistance. The conductor's power loss is given by I^2R where I is the current through the conductor and R is the resistance of conductor. As value of R is decreased, the power loss is proportionally decreased. By replacing with small conductor's size having greater area of cross section, the power loss reduction can be obtained. The equivalent line resistance reduction can also be achieved by adding more conductors that operate in parallel. Even though these approaches could result in a significant reduction in loss, they are less cost effective and are seldom employed unless specific need is required.

The second strategy to reduce the system losses involve installing compensating capacitors at particular load buses. The power system's reactive power flow result in the system losses. If the voltage limitations are not exceeded, the best size and placement of capacitor can be chosen based on the greater loss reduction in power.

System reconfiguration is the third technique for reducing power losses in distribution networks. Both the planning and control tool can be employed when reconfiguring the distribution system. In order to achieve the lowest I^2R, feeders can be reconfigured to move loads from densely loaded feeders to relatively lighter loaded feeders. Such transfers help in minimizing losses and changing the amount of loads on the network resulting better voltage profile and lower power losses.

In this thesis work, the third technique of network reconfiguration along with distributed generation is employed.

Due to the unmanaged load growth in different distribution centers of Nepal Electricity Authority (NEA), the losses and voltage drops in various Distribution Centers have been left unchecked. To address these growing concerns of unplanned energy growth in the distribution system along with the lack of major up-gradation, network reconfiguration of such system presents a unique solution. Rather than upgrading and overhauling the entire infrastructure in place to feed the energy demand, this method reconfigures only the feeders and their connections to better optimize the load flow and decrease the overall losses while also maintaining a better voltage profile in the bus systems (Pandey *et al.* 2021).

1.2 Problem Statement

When compared to a transmission system, a radial distribution system has large power losses due to high current and low voltage characteristics. Also, high reactive power flow in radial distribution networks results in a low power factor. According to studies, almost 10 to 13 percent of the total power produced is lost as I^2R losses in the distribution system raising the energy costs and lowering the voltage quality at the site of the consumer (Ng *et al.* 2000). The voltage drops at the far-end buses increase due to expansion of the radial distribution network.

It is a fact that transformer capacity and distribution lines are becoming overloaded because of a rapid increase in demand. With the increase in load current drawn from the source, the distribution losses also increase. The performance of distribution system will suffer as a result of distribution losses. In order to minimize the distribution losses, network reconfiguration is the best option.

The Nepalese power system loss is declining, but it is still higher than the standard level. It is the general scenario of the Nepalese power system. As per A Year Book Fiscal Year 2078/79 published by NEA, Distribution and Consumer Services Directorate, Cumulative loss of Distribution system is 10.86%. NEA is trying to minimize such system losses by using various methods. One method to reduce technical distribution system loss is the implementation of network reconfiguration in a distribution system. Therefore, a thorough examination of network reconfiguration at the ground level is necessary.

The detailed study of the related papers and dissertations indicate that network reconfiguration has an effect on distribution loss. Some of the research focuses only on the network reconfiguration of IEEE networks and distribution networks of centralized areas but the research is yet to be done on network reconfiguration considering long feeder networks in the distribution system. Therefore, the network reconfiguration must be done considering DG and time-varying load.

Network Reconfiguration alters the present connection of branches between the buses and proposes a new configuration of connection that gives the shortest route between the supply and the load, resulting in minimum power loss. Additionally, effective DG allocation makes it possible to supply active and reactive power to the consumer site of the loads. In this way, all the demand power doesn’t have to travel from the grid to the load, resulting in minimum power loss. This thesis work shall give optimum distribution system reconfiguration along with proper placement, sizing, and operating power factor of DGs if there are new ones to come. Even if there are existing DGs, the outcome of this thesis will propose the best way to reconfigure the network to reduce power loss and enhance the voltage profile.

1.3 Objective

Main Objective

To determine optimal integration of Distributed Generation and Network Reconfiguration for reducing power loss and enhancing voltage profile in radial distribution system using Artificial Bee Colony (ABC) algorithm in MATLAB program.

Specific Objective

- To determine and locate open branch switches during network reconfiguration
- To determine optimal allocation (sizing, placement, and power factor) of DGs in a radial distribution system
- To determine bus voltage through power flow mechanism and analyze power loss for different scenarios of DG installation and network reconfiguration
- To apply the developed methodology to a real distribution network

1.4 Scope of Study

With the completion of the thesis, a developed program in MATLAB software can be used as inputs to any number of nodes/buses of a real distribution network. Any sort of distribution network can be reconfigured along with DG integration will help to analyze the power loss and voltage profile of the system.

Additionally, it is possible to analyze whether adding distributed generation will improve the voltage profile and reduce the power loss. Or, whether network reconfiguration is needed or not can be analyzed when distributed generations are added.

1.5 Assumptions and Limitations

The study has been carried out with certain assumptions and limitations. Some of them are given below:

i. The line length of the real distribution network has been taken without considering Sag.
ii. Five tie lines between two different nodes of real distribution network have been assumed based on short path distance and load capacity of nodes.
iii. Least cost financial analysis for different scenarios of reconfiguration and DG allocation can be carried out for further studies.

1.6 Outline of the thesis

The outline of this thesis work is categorized into six chapters which are presented below:

CHAPTER ONE deals with a brief introduction to distribution network reconfiguration, and distributed generations. It emphasizes the optimum use of existing infrastructures for power loss reduction and enhancement in system voltage.

CHAPTER TWO gives the literature reviews on similar subjects conducted in the past by various authors. It overviews problems of power loss and voltage drop issues on RDS, optimal network reconfiguration, and DGs incorporation to minimize and enhancement of voltage profile using different algorithms on available software.

CHAPTER THREE presents the methodology used for different cases of network reconfiguration and optimal DGs placement using ABC algorithm in the MATLAB program

CHAPTER FOUR includes software and tools used for test systems under consideration. It presents the bus and branch data of systems considered along with a single-line diagram.

CHAPTER FIVE presents results and a discussion of different scenarios considered in this thesis. The obtained results of test systems have been compared with reference papers.

CHAPTER SIX concludes and highlights the contribution of the thesis under different cases. It shows that the objectives of this thesis are fulfilled.

Finally, this thesis ends with a list of reference papers used for this thesis work.

2 CHAPTER TWO: LITERATURE REVIEW

One of the most crucial components of the electric power system network is the distribution system which acts as an intermediary between high voltage transmission and the utilization voltage at the consumer site. The distribution network consists of a number of radial, meshed, or loop feeders along with a number of switches. Each feeder must function in radial mode for any distribution network type, whether it be radial, parallel, or loop structure, ultimately feeding every load in the system. This is accomplished by properly managing the state of those switches situated at various locations.

DG units are normally integrated to the distribution system. In comparison to centralized power generation, DG has a number of benefits, such as, lower power losses, a better voltage profile, increased system stability, lower pollutant emissions, and less congestion in the transmission and distribution systems. Many power generating companies are financing in renewable sources of energy including wind, photovoltaic cells, micro turbines, etc. to fulfill the power demand and make a profit since the power system has been deregulated (Moravej et al. 2018).

Rao et al. (2013) used Harmonic Search Algorithm (HSA) to simultaneously reconfigure the network, and DGs location and sizing to reduce the power loss. Mohamed Imran *et al.* (2014) proposed an integration technique to reconfigure network and DG integration in a radial distribution network with an objective of reduction in power loss and voltage stability improvement using the Fireworks Algorithm (FWA). The positive impact of a combination of network reconfiguration, DG integration, and capacitor coordination on power loss reduction and voltage profile improvement has been studied (Muhtazaruddin *et al.* 2017). The optimal sizing and location of the DGs in an IEEE 33-bus radial distribution network with and without reconfiguration using Particle Swarm Optimization (PSO) algorithm has been implemented (Haider *et al.* 2021). Swarnkar *et al.* (2011b) applied a newly developed Ant Colony optimization for power loss minimization.

Myint and Naing (2015) used MATLAB tool for network reconfiguration through PSO algorithm and was applied to obtain the optimal switching operation. Tolba *et al.* (2017) introduced two stages for optimal placement and sizing of DG units to reduce power loss and maintain the stability of voltage. Loss Sensitivity Factors (LSFs) were applied for DG placement and hybrid PSOGSA was employed for optimal sizing and siting for DG so that benefits with high performance can be obtained collectively. To minimize grid loss through reconfiguration, Wang and Zhang (2017) used Gravitational Search Algorithm (GSA) and elite strategy and adaptive position (ES-APGSA). Kamble *et al.* (2019) used Discrete-improved binary particle swarm optimization (D-IBPSO) algorithm to reduce active power loss and voltage profile improvement through reconfiguration of the distribution system. The algorithm was applied in three different test bus systems for various loading conditions.

Mansur and Urinboy (2021) proposed the Henry Gas Solubility Optimization algorithm to determine the best configuration for the radial distribution system to minimize losses. Abubakar *et al.* (2019) used Improved GA to optimally locate the sectionalizing and tie switches along with implementing MATLAB for the reconfiguration model. With the help of a column amd constraint-based generation algorithm, Lee *et al.* (2015) reconfigured distribution networks with unpredictable loads for 16, 33, 70, and 94-bus systems. Haider *et al.* (2021) used PSO algorithm to identify the ideal location and sizing of the DGs with and without reconfiguration of IEEE-33 bus radial network, using MATLAB software. Sultana *et al.* (2016) conducted research relating to optimal placement of DG taking into account reduced power loss, improved voltage profile, and increased voltage stability. A technique described by Viswanadha Raju and Bijwe (2008) involved meshing the network initially, ranking the switches according to how much current they could carry, opening the switch at the top, and repeatedly calculating power flow until the system became radial.

]Mixed Particle Swarm Optimization (MPSO), which joins Binary Particle Swarm Optimization (BPSO) and the traditional PSO methods, employed by Essallah and Khedher (2020). During reconfiguring the network and DG placement, three alternative load scenarios were evaluated in order to determine the best switch status, DG placement, and DG size. Muhtazaruddin *et al.* (2017) presented the impact of network reconfiguration, capacitor, and DG placement on reducing power loss and improving voltage profiles using ABC algorithm.

Jnawali et al. (2021) carried out load aggregation taking advantage of a diversity of loads with the improvement of load factors of distribution feeders, decreasing in cost of energy supply despite an increase in power loss. Pancha *et al.* (2020) carried out the determination of capacity of DG unit and its location for a feeder with a poor voltage profile with higher network loss. The backward-forward power flow method and GA optimization technique were used to run the model in MATLAB.

Through system reconfiguration, Chidanandappa et al. (2016) aimed to anticipate an optimum restoration strategy through system reconfiguration for a power distribution system having multiple DGs. GA used the Rowlett wheel choice technique and elitism giving better results.

Priority consumers were taken into account in the service restoration algorithm proposed by Wei et al. (2012). The supply of power to the priority consumers was ensured by developing an index to restore the service rate taking load grade into consideration. The authors also used an enhanced genetic algorithm that codes chromosomes in accordance with various restoration scenarios. Chen *et al.* (2012) developed a quick, efficient solution for service restoration that was formulated as multi-objective constrained optimization problem.

Reconfiguring the distribution network was studied and characterized by Thakur and Jaswanti (2006). The studies carried out in the article examined the various characteristics of the distribution network which aid in the investigation of one particular sector of power distribution network. An optimal solution for a radial basis function network (RBFN) topology that calculated line losses in distribution network and optimized by a GA was put forth by (Feng and Jianming 2009). To reduce active power loss and node voltage deviation by integrating DGs, the author (Nayak 2014) proposed the Hyper-Cube Framework Ant Colony Optimization (HC-ACO) technique. Kansal *et al.* (2013) used technique to place various types of DGs in the best possible locations to reduce power loss using PSO algorithm.

After reviewing all the above literature, the majority of the researchers worked on either DG integration or network reconfiguration, particularly on Test Bus systems. But, only a few of them simultaneously worked on network reconfiguration with DG installation to reduce the power loss and improve the voltage profile of the distribution system. Even most of those studies were also done only on Test Bus systems. So, it is a prime concern to implement those studies on practical distribution networks considering different scenarios with improved algorithms and computer program software tools. So, this thesis is concerned not only with the cases of test bus systems but also with obtaining the quality of results even on real distribution networks using an improved metaheuristic algorithm, that is, Artificial Bee Colony (ABC) with MATPOWER toolbox of MATLAB software which gives more effective results in terms of time of computation and obtaining the optimal solution.

2.1 Distributed Generation

Distributed generation (DG) can either be operated in isolation or grid connection. An isolated or stand-alone unit meets most of the demand with or without additional generators or storage. On the other hand, a DG unit that is connected to the grid delivers power to a massive interconnected system that is also powered by other generators. The DG's connection point to the grid is termed as Point of Common Coupling (PCC).

DG is generating station that serves on-site customer directly or provides support to a power distribution system. Typically, wind power is excluded, as it is generally not produced for on-site power needs. When wind power is considered along with DG either isolated or grid connected, then it is termed as dispersed generations. Whereas if energy-storage technologies are considered along with DG collectively, then it is termed as distributed power. The benefits of DG units are briefly presented below:

- DG provides more reliability for supplying emergency power during disasters and other unforeseen events such as falling of tree branches, and storms which may fail the grid supply, leaving thousands of customers without power for an extended period of time.
- By implementing new technologies, it is easier to switch to another DG or renewable source.
- DG enables the use of numerous power-generating methods, reducing reliance on a single supply. The power of diversity grows with different stock of portfolios of energy.
- The onsite generation and location of DG result in the decrease of distribution line losses resulting increase in efficiency.
- Generally, the integration of DGs to networks results increase in voltage in the system. The installation of DG may enhance the supply quality in regions having difficulty in voltage support. (Bayod-Rújula 2009).
- As DG acts as an alternative energy system which may result in zero emissions. The overall energy efficiency of the plant rises and a corresponding drop in environmental thermal pollution occurs by using renewable DG like cogeneration.

- The utilization of non-conventional/renewable energy supplies is increasingly necessary due to the rapid depletion of fossil fuel stocks.
- By tracing power where it is more needed, DG unit avoids the need of upgrading transmission and distribution capacity.

2.1.1 Types of DG Technologies

Based on the capacity to inject or generate active/real and/or reactive power, DG technologies are categorized as below:

Type 1: DG generating active power only

DG units operating at power factor of unity i.e., supplying only active or real power such as Photovoltaic, fuel cells fall in the Type 1 category. In this category, reactive power is neither absorbed nor delivered by DG units.

Type 2: DG generating active and reactive power

DG units which operate at lagging power factor fall in Type 2 category such as a synchronous machine for geothermal, small hydro.

Type 3: DG generating reactive power only

When synchronous compensators are present, DG units are categorized as Type 3.

Type 4: DG generating active power but consuming reactive power

DG units operating at leading power factors such as induction generators operating wind turbines fall in the Type 4 category. Such DG units have the capacity to draw reactive power from the system while injecting active power into it.

With the improvement of technology, more and more DG units have been deployed in distribution systems, and this has led to more analysis of the technical, economic, and environmental impacts on the distribution network. Location, type, and size are the critical factors influencing the techno-economic impacts of the power system.

2.2 Network Reconfiguration

Due to the increase in distribution losses and decrease in voltage magnitude, the distribution network's performance degrades. As the distribution network is the last stage of the power system which accounts for the majority of power loss leading to network instability. Power loss reduction in the distribution network has received a lot of attention to researchers. Among various techniques used for power loss minimization, the study on network reconfiguration is becoming popular. Reconfiguration is to change the topology/structure of a network. Changing the network configurations can be done manually or automatically through switching modes.

In doing reconfiguration, the following constraints must be considered:

i. All the demands shall be met during reconfiguration.
ii. The radiality of the network must be retained.
iii. Capacities of feeder, transformer and other electrical equipment should be in limit.

One of the practical approaches to lowering distribution network loss is network reconfiguration, in which the flow of power is altered by closing tie switch or opening sectionalizing switch on the feeders. The radiality of the network is conserved by appropriately changing the status of the switches. Each subsequent operation selects the switching option that will minimize the losses. The best switching option to be implemented is chosen in each successive operation that minimizes losses the most, while abiding by the constraints, such as voltage deviation limits, power conservation limits, and line capacity limits. The loss minimization in a power system will lead to the stability of voltage.

2.3 Optimal Network Reconfiguration and Distributed Generation Placement

Sectionalizing switches and tie switches are frequently employed in radial distribution systems for isolating faults, recovery of power supply, and network reconfiguration. The analysis of radial network itself is a difficult task. Network reconfiguration is an extremely complex problem because of a huge number of potential network designs and the multi-modal feature of the problem.

Viswanadha Raju and Bijwe (2008) proposed a method in which the meshed network was formed and the switch with top most ranked was opened through load flow calculation. The branch exchange was performed for the loop being identified and a configuration having minimum power loss was obtained.

Though DG integration has many benefits in a radial distribution network. However, excess DG penetration will lead to an increase in system loss along with degrading the voltage profile. To maintain reliability under operational standards, optimal placement, and sizing of DG are necessary.

In (Mohamed Imran *et al.* 2014), network reconfiguration with DG placement using Fireworks Algorithm (FWA) under various scenarios has been carried out. In (Rakesh *et al.* 2017), Power Loss Index (PLI) based on optimal DG placement using GA for minimizing the power loss, enhancing the voltage profile, and Voltage Stability Index (VSI) to locate DG has been carried out.

2.4 VSI in Radial Distribution System

With increasing complexity and heavily loaded power system network, voltage collapse and stability become an issue of network stability. Voltage instability is the problem unable to conserve acceptable voltages at all nodes when the system is exposed even to a small disturbance during the normal operating condition. So, the problem associated with voltage stability is one of the keen interests in research sectors. It is a prime concern to develop a fast and accurate index to monitor the system condition. For this, a proper analysis of the VSI is necessary.

As per (Murthy *et al.*, 2014:(Maharjan and Kamalasadan 2015), VSI is a new steady state voltage stability index for locating the bus, which identifies the buses that are most susceptible to voltage collapse. The placement of DG on a distribution network has the main effect on system voltage stability. Voltage collapse phenomena occur within the node having high loads and poor voltage profile. The unexpected load growth will lead to unexpected voltage collapse. To have proper voltage stability, the DGs should be integrated with optimal capacity to improve the system performance including system loss minimization along with system stability.

2.5 Load Flow Analysis in RDS

Steady state analysis can be used to analyze the circumstances that power systems generally operate in. Load flow studies are performed to know the power system's steady state operating condition. In power systems, powers are known quantities rather than currents. Thus, non-linear load flow equations are used which are resolved iteratively during load flow analysis. Load flow studies are carried out to plan, operate, schedule economically, and exchange power between different utilities.

Load flow calculation is an essential numerical (often nonlinear) analysis needed when making power systems studies. The practical application of proposed methods for the improvement of the system network including power loss minimization, reliability increment, and voltage profile enhancement typically require many power flow analysis algorithms runs. The power flow methodologies applied to distribution systems will have to adapt to the nature of the distribution network, in strict terms, they will be demanded to include single-phase and three-phase unbalanced system analysis, as well as the influence of distributed generation interconnection. In distribution network reconfiguration, the purposes are to reduce power losses and enhance system voltage profile, consequently, power flow analysis becomes an essential procedure to be performed to obtain steady state electrical characteristics of the distribution system as a consequence of reconfiguration. Newton-Raphson, and Gauss-Seidel methods are often applied for analysis of power flow in the transmission systems. These methods often use the representation of a single-phase for a three-phase system in order to assume a balanced system. But, distribution systems have characteristics of radial topology and unbalanced loads which fail the assumptions that are made for the analysis of transmission networks. Thereupon, a power flow method considering three-phase unbalanced networks must be considered for its application in distribution systems. The forward/backward power flow methods are popularly used to perform load flow analysis in distribution system by assuming unbalanced phase systems, however, it is only applicable to radial systems. Contrarily, Newton-based methods are frequently capable of handling any type of topology or structure including radial, meshed, and weakly meshed and may take the effect of distributed generation. The representation of the Jacobian matrix, which is generated on the basis of network structure, is the main contributor to the modified Newton method in the distribution networks.

MATPOWER toolbox was used in this thesis work to compute power flows for various configurations of open/closed switches. The injection of various DGs of various capacities at various locations can easily be incorporated into power flow studies in MATPOWER. On the basis of a radial network, reconfiguration in distribution system is implemented to reduce the power loss.

A load flow method must possess five essential characteristics.

i. High processing speed
ii. Minimal computer storage
iii. Reliable solution
iv. Versatility
v. Easiness

Let us consider Figure 2.1 below, which shows a branch of a radial distribution system.

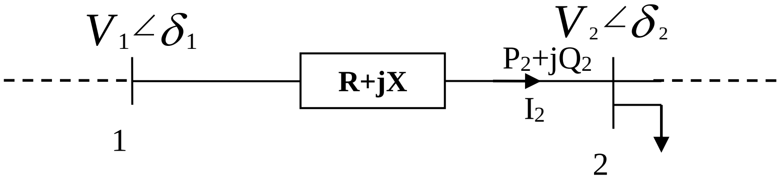


Figure 2.1 Branch of Radial Distribution System

where,

1 = Sending End of a branch or Sending end node

2 = Receiving End of a branch or receiving end node

1 2 = Branch Number

I_2 = Branch current flowing from node 1 to node 2

V_1= Voltage at node 1

V_2 = Voltage at node 2

$\mathrm{P}_2 + \mathrm{jQ}_2$ = Through Power at node 2

$\mathrm{R} + \mathrm{jX}$ = Branch Impedance

Then;

$$P_2 + jQ_2 = V_2 I_2^* \tag{1}$$

$$I_2 = \frac{P_2 - jQ_2}{V_2^*} \tag{2}$$

$$Also\ I_2 = \frac{\lfloor V_1 \rfloor \angle \delta_1 - \lfloor V_2 \rfloor \angle \delta_2}{R + jX} \tag{3}$$

From equations (2) and (3),

$\frac{P_2 - jQ_2}{\lfloor V_2 \rfloor \angle -\delta_2} = \frac{\lfloor V_1 \rfloor \angle \delta_1 - \lfloor V_2 \rfloor \angle \delta_2}{R + jX}$

$P_2R + Q_2X + j(P_2X - Q_2R) = \lfloor V_1 \rfloor \lfloor V_2 \rfloor \angle \delta_1 - \delta_2 - \lfloor V_2 \rfloor^2$

$(\lfloor V_2 \rfloor^2 + P_2R + Q_2X) + j(P_2X - Q_2R) = \lfloor V_1 \rfloor \lfloor V_2 \rfloor \angle \delta_1 - \delta_2$

Separating magnitude and phase

$$\delta_2 = \delta_1 - \tan^{-1}\left(\frac{P_2X - Q_2R}{\lfloor V_2 \rfloor^2 + P_2R + Q_2X}\right) \tag{4}$$

And

$(\lfloor V_2 \rfloor^2 + P_2R + Q_2X)^2 + (P_2X - Q_2R)^2 = (\lfloor V_1 \rfloor \lfloor V_2 \rfloor)^2$

$\lfloor V_2 \rfloor^4 + 2\lfloor V_2 \rfloor^2 (P_2R + Q_2X - 0.5\lfloor V_1 \rfloor^2) + (P_2^2 + Q_2^2)(R^2 + X^2) = 0$

$$\lfloor V_2 \rfloor^2 = \frac{-2(P_2R + Q_2X - 0.5\lfloor V_1 \rfloor^2) \pm \sqrt{\left(2(P_2R + Q_2X - 0.5\lfloor V_1 \rfloor^2)\right)^2 - 4(P_2^2 + Q_2^2)(R^2 + X^2)}}{2}$$

$$\lfloor V_2 \rfloor = \sqrt{[\{(P_2R + Q_2X - 0.5\lfloor V_1 \rfloor^2)^2 - (P_2^2 + Q_2^2)(R^2 + X^2)\}^{0.5} - (P_2R + Q_2X - 0.5\lfloor V_1 \rfloor^2} \tag{5}$$

The voltage angle and magnitude at the receiving node are given, respectively, by equations (4) and (5) above.

In generalized form, the above equations for magnitude of voltage and phase angle at receiving end node can be written as:

$$V(m2) = \sqrt{|B(j) - A(j)|} \tag{6}$$

where,

$A(j) = P(m2) * R(j) + Q(m2)X(j) - 0.5[V(m1)]^2$

$B(j) = \{A(j) - [R^2(j) + X^2(j)] * [P^2(m2) + Q^2(m2)]\}^{\frac{1}{2}}$

And

$$\delta(m2) = \delta(m1) - \tan^{-1}[\frac{P(m2) * X(j) - Q(m2) * R(j)}{P(m2) * R(j) + Q(m2) * X(j) + V^2(m2)} \tag{7}$$

In the above equations,

J: denotes branch number

m1 and m2: denote respective sending and receiving end nodes

2.6 Load Flow in Radial Distribution Systems

Conventional load flow methods are inapplicable to distribution systems for the following reasons:

- Distribution Systems are unbalanced and in certain sections carry only single or two phases. Three-phase representation is required.
- Lines and cables in distribution systems have higher R/X ratio. Hence, decoupling assumptions are invalid.

To solve the load flow problem, backward-forward power flow propagation is used. All the methods used for a radial system work in a backward-forward fashion. Except the source node, the voltages at each node is assumed during backward-forward propagation. To calculate the current in the upstream branch during backward sweep, all the currents in downstream branch and load currents are added. The obtained branch currents during backward propagation can be used to update node voltages during forward propagation. Backward-forward power sweep continues until convergence of nodes voltage within pre-defined tolerance occur. In this thesis, a method was applied that derived the magnitude of voltage and phase angle explicitly in terms of active and reactive power from a node or bus and branch resistance and reactance. In other words, the methods do not use any trigonometric functions, instead, the approaches evaluate only a straightforward algebraic expression of voltage magnitude. Hence, the methods used are computationally very efficient which require small computer memory.

2.7 Overview of Artificial Bee Colony (ABC) Algorithm

ABC algorithm is motivated by the searching behavior of honey bee swarms to seek a quality food source and was first proposed by (Akay and Karaboga 2012). The honey bee swarm possesses a variety of qualities including the ability of bees to exchange information, can remember their surroundings, retain and distribute information, and make decisions based on it. ABC uses the efficient food-finding analogy of bees to determine the optimal solution to an optimization problem. It is a population-based metaheuristic optimization in which there exists a population of food positions and the artificial bees change the positions of food over a period of time.

2.7.1 Parameters of ABC algorithm:

i. **Number of Population:**

   It determines the number of solution sets that are generated to obtain optimal objective function in each iteration. The dimension of problem should be considered while determining the number of populations. Higher the population will increase the complexity to solve the problem.

ii. **Parameter Limit:**

   It gives a number of specified chance that a solution to be better before it to be discarded. In this thesis work, *limit* has been changed from 2 to 4 so as to obtain optimal solution. Generally, while taking *limit* = 2, the convergence of solution was faster but that unable to meet global optima. On increasing its value, the global optima was found along with increasing the number of iterations.

iii. **Upper and Lower Bound:**

The number of branches were taken as the upper bound in radial configuration while the lower bound was set as 1. The upper bound and lower bounds for the size of the DGs were respectively set as 60% and 10% of the system's total active power load. For locating DGs, the respective upper was set as the number of nodes and the lower bound was set as 1. The upper and lower bound for operating power factor of DGs was set as 1 and 0.7 respectively.

2.7.2 Phases of ABC algorithm:

The three phases of ABC algorithm based on the movement of the bees are briefly described below:

i. **Employed Bee Phase**

Employed bees search for a food source that is superior to the one than that is related with it. They do this by calculating fitness, which creates a new solution utilizing a partner solution. The next stage is greedy selection, which entails adopting a new solution if it is superior to the existing one.

In this phase,

- Employed bees equal to the number of food sources
- All solutions get an opportunity to obtain a new solution
- A new solution is generated by selecting a random partner
- The existing solution and the partner should not be identical
- By changing a random variable, a newly generated solution is obtained

ii. **Onlooker Bee Phase**

In this stage, a food source is selected based on the probability of nectar amount. Then a fitness is calculated which again generates a new solution utilizing a partner solution and performs a greedy selection just as in the employed bee phase.

Every bee is related with a particular food source to generate a new solution in the employed bee phase, however in the onlooker bee phase, a probability of nectar amount is used instead of every food source to obtain a new solution.

In this phase,

- Probability values of all solutions are determined before the onlooker phase
- A solution having higher fitness value will have a better probability
- Fitter solution may undergo onlooker bee phase for more than once

iii. Scout Bee Phase

During this phase, the depleted food source is given up. A specific solution is discarded during optimization, and a new solution will be generated.

In this phase,

- The candidates to be eliminated are those solutions whose trial is more than the limit
- A randomly new solution is used to replace any solution with a trial count that exceeds the limit
- Trial counter of a newly included solution is reset to zero.

In one iteration, the scout phase

- Occurs only when the trial counter of at least one solution is greater than the limit'
- Perform just one solution with an overlimit trial counter
- Due to the limit, it is possible to exclude the best solution from the population
- Prior to beginning the scout phase, the best solution is memorized

3 CHAPTER THREE: METHODOLOGY

The methodology for network reconfiguration approach and optimal DG sizing, placement, and operational power factor to minimize active power loss and enhance voltage profile considering different cases have been performed using ABC algorithm under given constraints.

This chapter deals with the methodology followed to carry out the overall thesis work which is shown as a flow diagram in Figure 3.1.

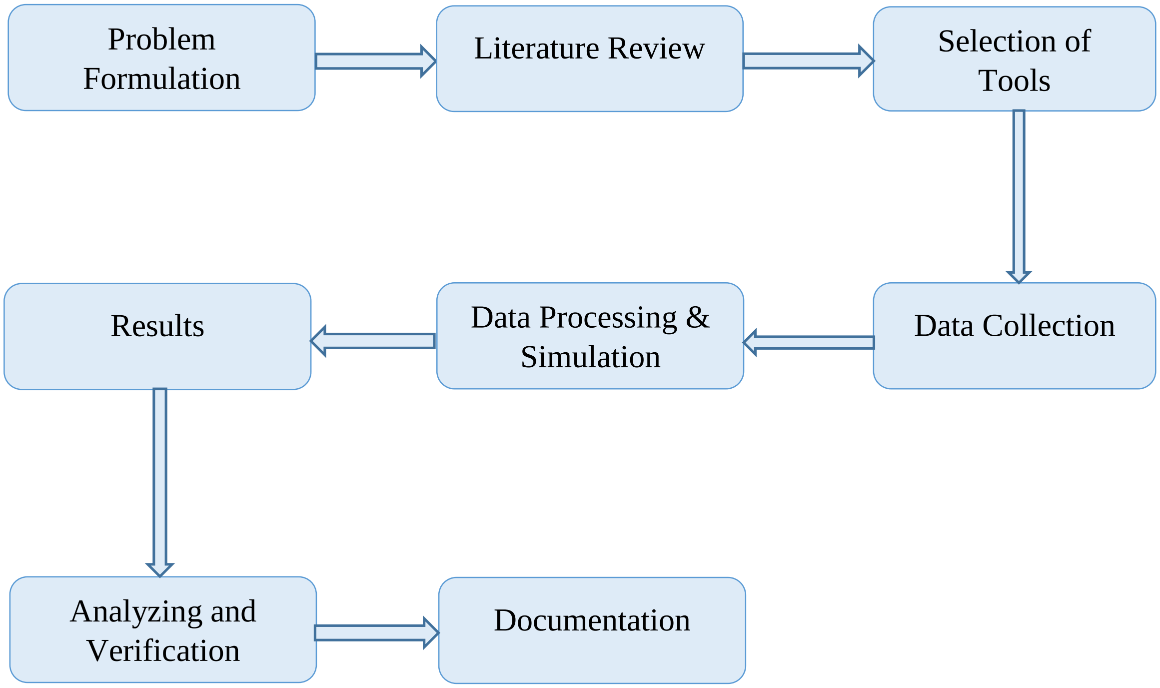


Figure 3.1 Methodology Flow Diagram

Initially, the problem in a radial distribution system relating to poor voltage profile and power loss was identified. The various types of research carried out to optimize similar problems were studied in literature reviews. The literature concerned with optimal network reconfiguration and DG placement using various tools, software, and algorithm were studied. The literature on DG optimization showed how the system's voltage stability is increased and the power loss is decreased by using the right positioning and spacing. Also the literature showed the application of network reconfiguration for increasing the system's performance. Among the used tools and algorithms, one of the tools (MATLAB) and algorithm (ABC) was chosen, which showed better results in terms of optimization and computational time. Data collection of radial distribution network consisting of branch resistance (R), branch reactance (X), active power (P), and reactive power (Q) was done and initially, simulation in MATLAB computer program was performed for test bus systems. Initially, the obtained results of the systems were tested, analyzed, verified and compared with the reference paper. The methodology was developed in the MATLAB program using ABC algorithm for analyzing any radial distribution network. Finally, the documentation of the thesis work has been performed with conclusions based on research outcomes.

To effectively perform ABC algorithm to any scale of distribution networks, firstly, it has been applied on standard test bus systems. The typical test bus systems consist of 33 and 69 bus RDS. The used methodology has been planned to apply to one of the real distribution networks of Nepal Electricity Authority, Kirtpur Distribution Center. This network consists of 63 nodes with 62 sectionalizing switches or branches. The line data has been collected from the respective distribution center. The line length of the real distribution network excludes the sag of the conductor as line length was extracted by plotting the feeder network on QGIS. Different sizes of transformers were located and plotted on QGIS and the load power factor has been taken from the substation where the 11 kV feeder originated.

3.1 Problem Formulation

Objective Function:

The objective function (F) of the problem is given by (Mohamed Imran *et al.* 2014):

$$F = \min.\left(\left(\frac{P_{TL}^{NR}+P_{TL}^{DG}}{P_{TL}}\right)+\max.\left(\frac{V_1\text{-}V_m}{V_1}\right)\right) \tag{8}$$

P_{TL}^{NR} = total system power loss with network reconfiguration, P_{TL}^{DG} = total system power loss with DG integration, P_{TL} = total system power loss (base case), V_1 = magnitude of voltage at node 1, V_m = magnitude of voltage at node *m*, where *m* = 1, 2, …,*n* be the nodes. The minimum and maximum voltage at any node should be within the range of 0.95 p.u and 1.05 p.u.

Constraints:

The following constraints are being subjected to the objective function (F) :

Power Conservation Limits:

$$P_{subs}=\sum_{m=2}^{n}P_{Lm}+\sum_{m=1}^{nbr}P_L(m,m+1)-\sum_{m=1}^{ncd}P_{DG,m} \tag{9}$$

where,

P_{subs}= power delivered by substation, P_{Lm}= active or real power load at node *m*, $P_L(m,m+1)$= active power loss in the branch joining nodes *m* and *m+1*, $P_{DG,m}$= active power delivered by DG at node *m*, *n* = number of total nodes, *nbr* = number of total branches, *ncd* = number of candidate nodes for DG integration

Voltage deviation limits:

$$|V_1\text{-}V_m| \le \Delta V_{max} \tag{10}$$

where ΔV_{max} = maximum voltage deviation = ± 5%

Branch Current limits:

$$J_m \leq J_{m,max.} \tag{11}$$

where,

J_m = current flowing in the branch section between nodes m and $m+1$, $J_{m,max.}$ = maximum current flowing capacity of branch section between nodes m and $m+1$

Distributed Generation Capacity Limits:

$$P_{DG}^{min} \leq P_{DG,m} \leq P_{DG}^{max} \tag{12}$$

where, P_{DG}^{min} and P_{DG}^{max} be minimum and maximum active power generation limit of DG given by

$$P_{DG}^{min} = 10\% * \sum_{m=2}^{n} P_{Lm} \ and \ P_{DG}^{max} = 60\% * \sum_{m=2}^{n} P_{Lm} \tag{13}$$

where P_{Lm} = active power load at node m

3.2 Radial Network Structure

Radial topology has to be checked for all the trial solutions using the ABC algorithm followed by load flow analysis. Each section of RDS is radially connected such that it has one parent node and potentially many children nodes as presented in (Thukaram *et al.* 1999). The optimally ordered nodes generate paths that ensure the radial network structure and prevent the formation of mesh loops. So, the load flow is performed after generating the appropriate parent node and child node path at each phase of network reconfiguration. In this system of path generation, there is no repetition in receiving end node. There may be more than one receiving end node for different sending end nodes. If we represent 1, 2, 3,… be the nodes or buses then a pair 1-2 represents a line or branch between nodes 1 and 2. In a radial system, if we refer 1-2 as the line section between sending end node 1 and receiving end node 2, then node 1 is called a parent of a child node 2. Sibling nodes are those that have the same parents as their children. By generating an appropriate parent-child network path during load flow, the radiality of the network is secured. Figure 3.2 shows a sample distribution feeder and Table 3.1 shows the parent node-child node path generation for that feeder.

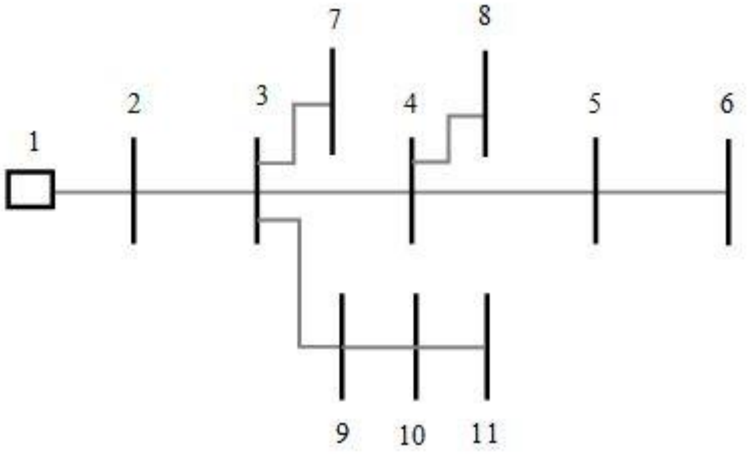


Figure 3.2 Sample Distribution Feeder

Table 3.1 Parent node-child node path generation for Figure 3.2

Parent node	1	2	3	3	3	4	4	5	9	10
Child node	2	3	4	7	9	5	8	6	10	11

3.2.1 Basic Algorithm for Reconfiguration Process

The following is the basic algorithm for the reconfiguration process (Shirmohammadi and Hong 1989):

Begin

Step 1: Read Node, Branch, and Switch Data

Step 2: Close all tie switches to form a mesh network

Step 3: Run the power flow for the resulting network after converting loads to nodal current injections

Step 4: Determine the network's optimal power flow

Step 5: Open the lowest current carrying switch

Step 6: Close the latter opened switch. Open the next lowest current carrying switch

Step 7: Is there any constraint violation?

Step 8: If yes, repeat step 6.

Step 9: If no, then is it a radial network?

Step 10: If yes, print the results.

Step 11: If no, proceed to step 3 and step 4 and repeat the steps.

End

3.2.2 Power Loss Calculations

Basically in RDS, the load flow is performed by major two techniques which are backward forward sweep and ladder theory approach. The backward/forward propagation power flow technique is typically preferred due to its efficient computation and quick convergence rate (Chang *et al.* 2007). The recursive equations are used to calculate power flow in the distribution network which are derived from the sample radial distribution system as presented in Figure 3.3.

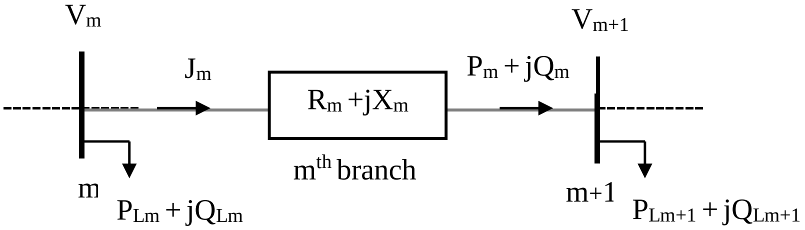


Figure 3.3 Sample Radial Distribution System

In Figure 3.3, V_m and V_{m+1} be the voltage at nodes *m* and *m+1* respectively.

The equivalent current I_m at node *m* is given by

$$I_m = \left(\frac{P_{Lm} + jQ_{Lm}}{V_m}\right)^* \tag{14}$$

The current J_m in the branch segment joining nodes *m* and *m+1* is obtained by Kirchhoff's current law through backward propagation power flow analysis which is given by

$$J_m = I_{m+1} + I_{m+2} \tag{15}$$

Once the branch current is calculated, the voltage at the bus *m+1* is obtained by Kirchhoff's voltage law through forward propagation power flow analysis which is given by

$$V_{m+1}=V_m-J_m*(R_m+jX_m) \tag{16}$$

Figure 3.4 presents the flowchart of the Backward-Forward Propagation load flow approach:

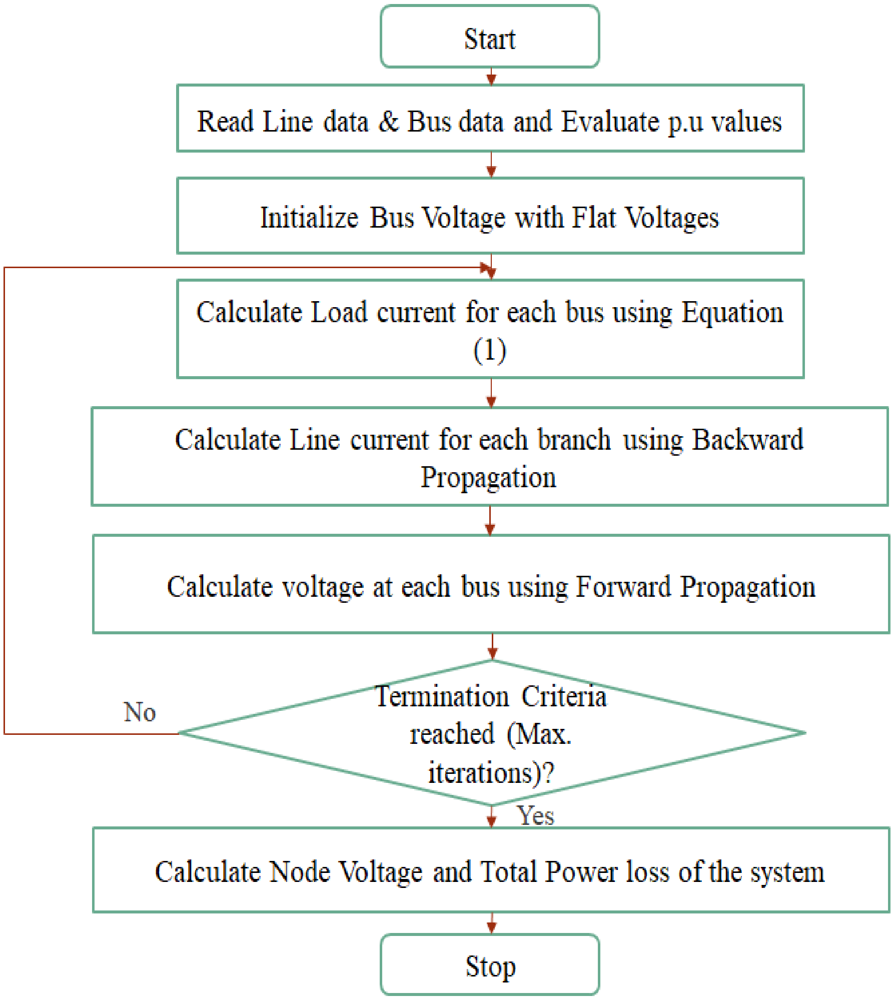


Figure 3.4 Flowchart of Backward-Forward Propagation Load Flow Analysis

The power loss calculation in the branch segment joining nodes *m* and *m+1* is given by

$$P_L(m,m+1)=R_m*\left(\frac{P_m^2+Q_m^2}{|V_m|^2}\right) \tag{17}$$

The entire power loss of a radial distribution network is the sum of all branch segments losses as given by

$$P_{TL} = \sum_{m=1}^{nbr} P_L(m,m+1) \tag{18}$$

3.3 Shortlisting nodes for DG integration

The rapid voltage drop due to heavy load in the distribution system causes voltage stability problems. Even for a small increase in load, the voltage at some buses falls rapidly. In some cases, if it is unable to control the fall in voltage then it may ultimately lead to voltage collapse. The computation of the Voltage Stability Index (VSI) was chosen as a method to shortlist candidate nodes for the integration of DGs (Chakravorty and Das 2001). In this research, for integrating *n* number of DGs, *p* number of nodes ($p>n$) with minimum VSI values were selected as candidate nodes.

The following equation can be used to compute VSI as represented in the paper (Mohamed Imran *et al.* 2014).

$$\begin{aligned} VSI_{m+1} = |V_m|^4 - 4\left(P_{m+1,eff}X_m - Q_{m+1,eff}R_m\right)^2 \\ - 4\left(P_{m+1,eff}R_m - Q_{m+1,eff}X_k\right)|V_m|^2 \end{aligned} \tag{19}$$

where,
VSI_{m+1} be the voltage stability index at node $m+1$, $R_m + jX_m$ be the impedance of the line segment and $P_{m+1,eff} + jQ_{m+1,eff}$ be the active and reactive loads connected between nodes *m* and $m+1$.

For stable operation of RDS,

$$VSI_{m+1} \geq 0 \tag{20}$$

where R_m+jX_m is the impedance of a branch connecting between nodes *m* and $m+1$. Also, a load of $P_{Lm+1} + jQ_{Lm+1}$ has been connected at node $m+1$.

The stability level of RDS can be measured by using VSI so that one can take necessary action if the index shows a low degree of stability.

After carrying out load flow study, the branch currents along with subsequent node voltages are known. On substituting all the values on Equation (18), VSI at each node can be calculated. Higher the value of VSI results in more stability of the node voltage. Whereas, if the node has minimum VSI then it is more susceptible to fall in voltage resulting collapse in the voltage. The order in which the nodes should be taken into consideration for DG installation is determined by values of VSI. Using ABC algorithm, the ideal DG size at the sensitive nodes is identified.

3.4 Steps in ABC Optimization

The basic steps in finding the optimum solution in ABC algorithm are:

Step 1: Generating random sites as an initial food source

Step 2: Dispatching Employed bees to the sites generated in step 1

Step 3: Calculating probabilities for each food source for probabilistic selection

Step 4: Using information brought by Employed bees to select sites for food sources by Onlooker bees

Step 5: Abandoning food sources using parameter ‘Limit’ and producing Scout bees

Initially, ABC produces N solution sets also called food sources for a randomly generated population within the boundaries. The ith food source within the range of jth dimension is given by the following equations as presented in (Akay and Karaboga 2012).

$$X_i^j = X_{min}^j + rand(0,1)(X_{max}^j - X_{min}^j) \tag{21}$$

$$X = \begin{bmatrix} X_1^1 & X_1^2 & X_1^3 \dots & X_1^D \\ X_2^1 & X_2^2 & X_2^3 \dots & X_2^D \\ & & . & \\ & & . & \\ X_N^1 & X_N^2 & X_N^3 \dots & X_N^D \end{bmatrix} \tag{22}$$

where X represents the starting solution vector generated for radial distribution system optimization, X_i^j corresponds to elements of X for ith row and jth column, D represents the optimizing variables or parameters, X_{max}^j and X_{min}^j give the maximum and minimum values of jth variable, and rand (0, 1) be the random number between 0 and 1. The Objective function f_i is evaluated for every food source or solution set and stored in a variable with i number of rows. Then, the fitness value $fitness_i$ is calculated for each food source as follows:

$$fitness_i = \begin{cases} \dfrac{1}{1+f_i} & if\ f_i \geq 0 \quad . \\ (1+|f_i|) & if\ f_i < 0 \quad . \end{cases} \tag{23}$$

Secondly, Employed bees (having a number equal to the food sources N) are directed to better food source sites in the neighborhood, using

$$X_i^{j^*} = X_i^j + \text{ø}_{ij}\,(X_i^j - X_k^j) \tag{24}$$

where $X_i^{j^*}$ represents a new food source in the region of X_i^j, j is a random dimension with range [1, D] and k € [1,2,3,…, N] chosen randomly other than food source i, and ø_{ij} is a random number within the range [-1,1]. If $X_i^{j^*}$ has higher fitness than X_i^j, the Employee bee forgets the previous one and remembers the new one.

The third step is to calculate probability values (P_i) for each food source based on a probabilistic selection to send the Onlooker bees in search of better food sources. The probabilistic selection might be one of Roulette Wheel, Stochastic Universal Sampling, Ranking Based, or other similar schemes. The basic ABC algorithm employs Roulette Wheel selection which is evaluated as follows:

$$P_i = \frac{fitness_i}{\sum_{i-1}^{N} fitness_i} \tag{25}$$

In the fourth step, the Onlooker bees choose food source sites using the instruction circulated by the Employer bees. The value P_i is calculated for each food source and is compared with a random number generated within the range [0, 1]. If P_i> random number, then the algorithm for the Employed bees given by the equation (23), generates a new food source. If the new solution has higher fitness, then the algorithm forgets the previous one and remembers the new one. If the previous solution is fitter than the new one, then the trial counter is increased by one, otherwise, it is reset to 0.

The last phase or step is to abandon the solution depending on how many times each food source undergoes trial count and employ Scout bees in search of an entirely new food source far away from the existing one. If the count of trials for each food source is larger than a pre-assigned value limit, then previous food source is replaced by new one, as per equation (21). In the fundamental ABC algorithm, the number of Scout bees is supposed to be one in each cycle. However, that number can be increased as per the problem taken into consideration.

When there are three DG units at locations, the percentage loss reduction ratio has been found to be maximum (Rao et al. 2013). The best optimization was found while placing three DG units in a real distribution feeder (Pancha et al. 2020). So, the maximum number of DGs integration in this thesis work is limited to three for all the systems under consideration.

The initialization parameters for ABC algorithm used to simulate networks are; number of DGs =3, VSI count limit = 15, population size = 20, number of iterations = 500, and parameter limit =3.

All the above procedures are repeated until a pre-determined number of iterations, in an attempt to find the best solution on the basis of fitness reached.

A major difference between many of the other algorithms and ABC is the use of the term fitness. In most of the algorithms, the value of the objective function corresponded directly to the term fitness, whereas in ABC, the fitness is directly corresponded to the objective function value while in ABC, the fitness is associated to the objective function.

The working rule for ABC algorithm is shown in Figure 3.5.

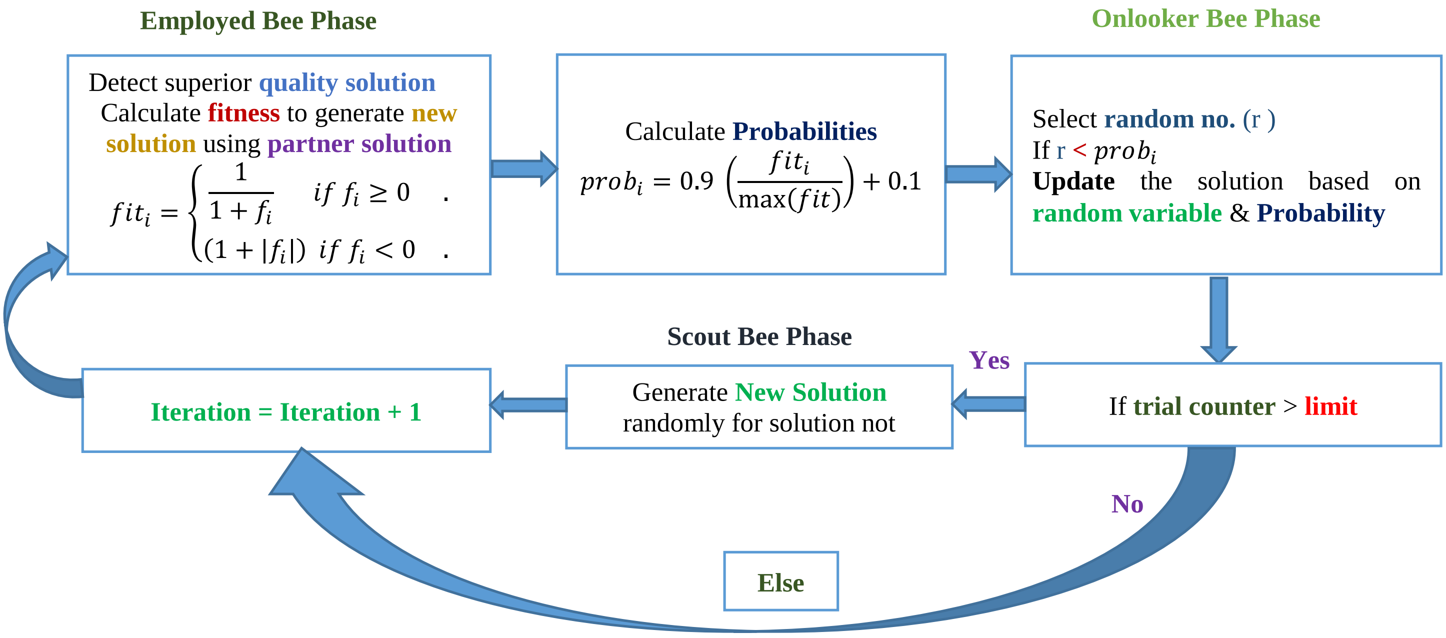


Figure 3.5 Working Rule for ABC Algorithm

3.5 Flowchart of Overall Methodology

The flowchart of overall methodology is shown in Figure 3.6 below with respective scenario representation:

Scenario Representation:

1 = Network Reconfiguration (NR) only

2= DG Integration only

3 = NR followed by DG Integration

4 = DG Integration followed by NR only

5 = Simultaneous NR & DG Integration

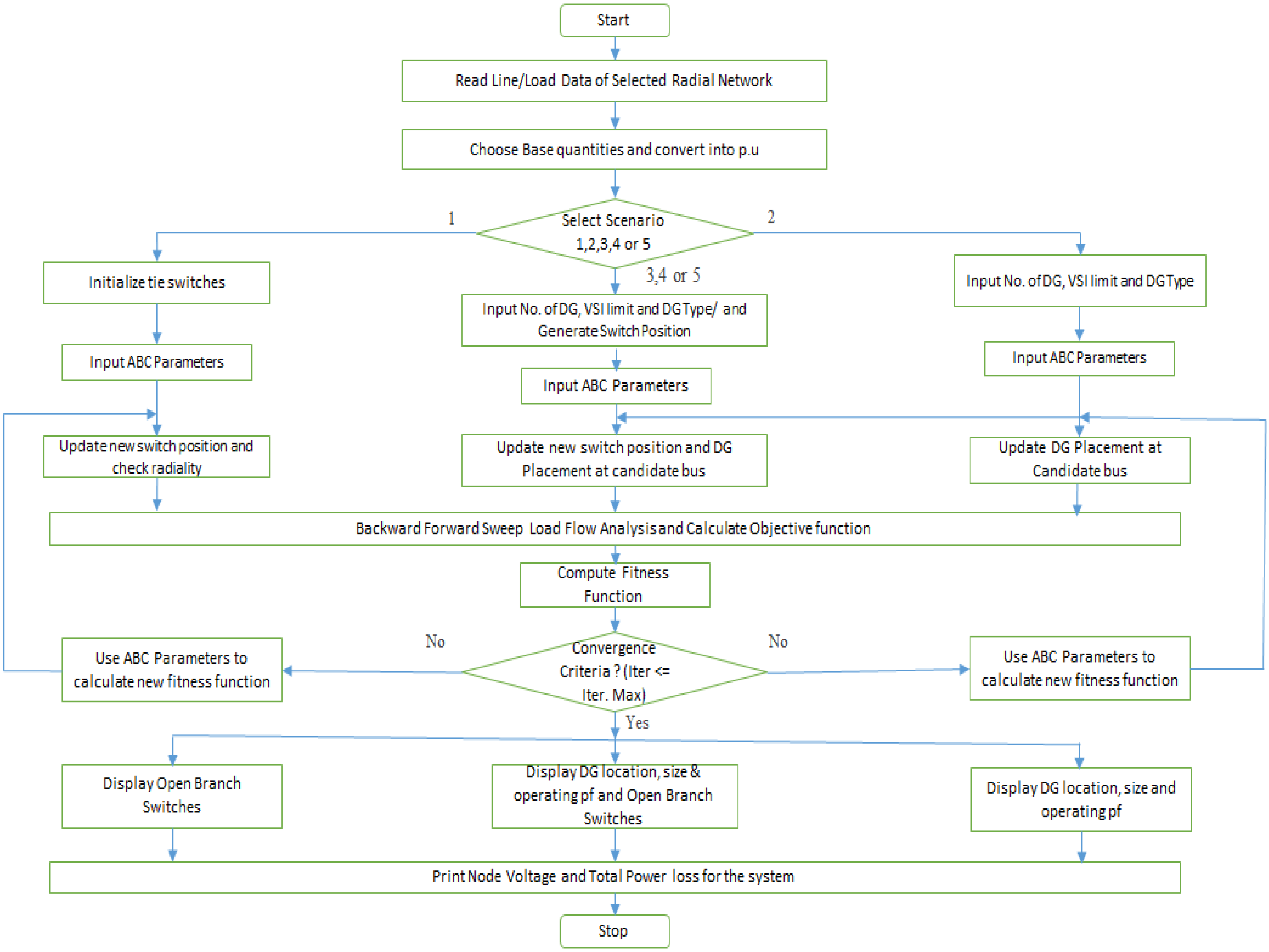


Figure 3.6 Flowchart of Overall Methodology

3.6 Scenario Studies

For modeling of a power distribution system, the MATPOWER toolbox of MATLAB was used to check power flow simulations of typical IEEE 33 and 69 bus systems and then applied on 11 kV feeder on a real distribution network.

Firstly, the *nb* number of a branch or line data was arranged in the *nb* number of rows. Further, the *ns* number of tie-switch or tie-line data was arranged in the next *ns* number of rows. Line data consist of line resistance and line reactance. Similarly, the *nnode* number of node data was arranged and was used to perform power flow analysis in the MATLAB program. Node data consists of node number, real and reactive power load. The total number of node data is one unit higher than that of branch data which is represented as $nnode = nb+1$.

The randomly generated solution vector for tie-switch, DG size, location, and operating power factor can be represented as below:

$$X = \begin{bmatrix} \overbrace{S_1^1\, S_1^2 .. S_1^5}^{Tie-Switch}\ \overbrace{D_1^1\, D_1^2\, D_1^3}^{DG\ Size}\ \overbrace{D_1^4\, D_1^5\, D_1^6}^{DG\ Location}\ \overbrace{D_1^7\, D_1^8\, D_1^9}^{DG\ pf} \\ S_2^1\ S_2^2 .. S_2^5\ D_2^1\ D_2^2\ D_2^3\ D_2^4\ D_2^5\ D_2^6\ D_2^7\ D_2^8\ D_2^9 \\ . \\ . \\ S_N^1\ S_N^2 .. S_N^5\ D_N^1\ D_N^2\ D_N^3\ D_N^4\ D_N^5\ D_N^6\ D_N^7\ D_N^8\ D_N^9 \end{bmatrix} \tag{26}$$

where S^1, S^2 .. S^5 (S^1, S^2, S^3, S^4, and S^5) are open tie-switches, and D^1, D^2, and D^3 are sizes of DG units at candidate nodes located at D^4, D^5, and D^6 respectively and D^7, D^8, and D^9 be the DG operating power factors.

Studies for six different scenarios were carried out to analyze the effective procedure to conduct network reconfiguration and DGs integration using ABC algorithm.

i. **Scenario I (Base Case)**

   The base case does not require any optimization.

ii. **Scenario II (Only Network Reconfiguration)**

   In this scenario, the variables equal the number of tie-switches. The optimal solution would be the set of open branch switches resulting minimum value of the objective function.

iii. Scenario III (Only DG Integration)

In this case, the variables is three times the number of DGs. If *n* be the number of DGs integrated at candidate nodes then the number of variables corresponding to DG size, placement, and DG power factor for the optimal solution would be *3n.*

iv. Scenario IV (Network Reconfiguration followed by DG Integration)

Initially, network reconfiguration has to be done. For *ns* number of open switches, the number of variables would be *ns*. Then, on adding *n* number of DGs in the system, *3n* be the number of variables corresponding to DG size, placement, and DG power factor for the optimal solution. It is also termed as reconfiguration then DG integration.

v. Scenario V (DG Integration followed by Network Reconfiguration)

In this scenario, initially, the problem relating to DG integration has to be carried out and subsequently network reconfiguration has to be done. The number of variables for *n* number of DGs would be *3n* corresponding to DG size, location, and power factor. Then, the value for optimal DGs would be used to perform network reconfiguration. Here, the number of variables corresponding to the tie-switches would be *ns*. It is also termed as DG integration then reconfiguration.

vi. Scenario VI (Simultaneous Network Reconfiguration with DG Integration)

Here, if the number of variables for network reconfiguration and DGs integration is *ns* and *n* respectively, then *(ns+3n)* would be the total number of variables for the network while considering the *ns* number of tie-switches, *n* for DG size, *n* for DG location and *n* for DG operating power factor. The optimal solution would be that for which the combination of *(ns+3n)* variables give the minimum objective function value.

4 CHAPTER FOUR: SYSTEM UNDER CONSIDERATION, TOOLS AND SOFTWARE

4.1 System under Consideration

For study and analysis, two test systems were considered. To examine the validation of used methodology, the obtained results were compared with the reference paper. To evaluate the efficacy of the used algorithm, the methodology was applied to a real distribution network of Nepal Electricity Authority, Kirtipur Distribution Center. For this, a radial distribution network on an 11 kV Kirtipur Feeder was taken into consideration.

4.1.1 IEEE 33 Test Bus System

This test bus consists of one primary feeder and four lateral feeders. There are 33 buses or nodes and 32 sectionalizing switches (1 to 32) while considering a branch between two nodes that are normally closed. It consists of five sets of extra branches (33-34-35-36-37) between some buses, also called tie-lines, which are initially opened. The active and reactive load power of the system is 3715 kW and 2300 kvar respectively. The base voltage and base power of the systems were taken as 12.66 kV (1 p.u) and 10 MVA respectively. The branch and load data of this system are shown in APPENDIX A. A Single Line Diagram (SLD) of the IEEE 33 test bus system forming loops (L_{p1} to L_{p5}) is shown in Figure 4.1.

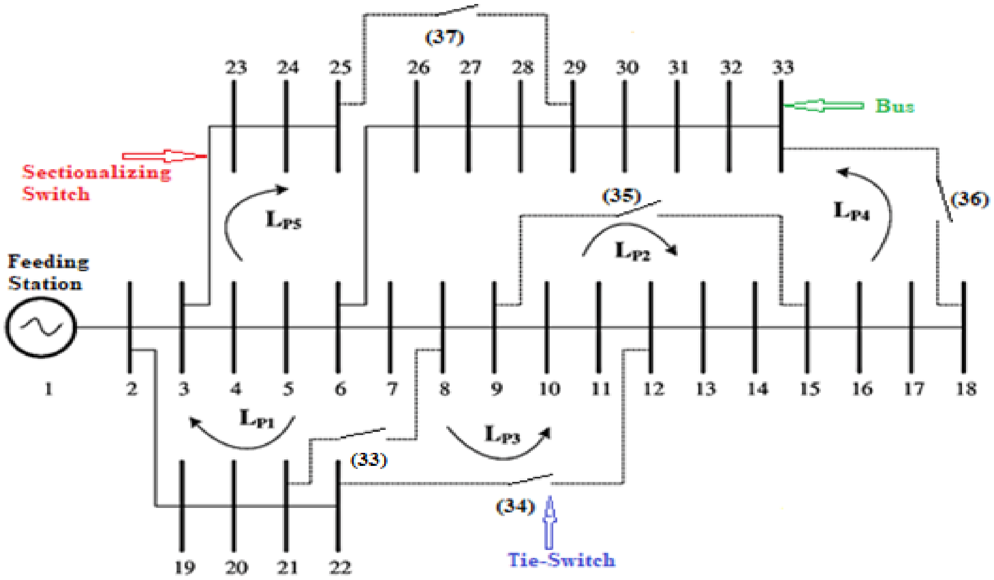


Figure 4.1 IEEE 33 Test Bus System

4.1.2 IEEE 69 Test Bus System

This test bus consists of one main feeder and seven lateral feeders. There are 69 buses or nodes and 68 sectionalizing switches (1 to 68) while considering a branch between two nodes that are normally closed. It also consists of five sets of extra branches (69-70-71-72-73) between some buses 11-43, 13-21, 15-46, 50-49, and 27-65, also called tie-lines, which are initially opened. The branch and load data of this system are shown in APPENDIX B. An SLD of the IEEE 69 test bus system forming loops (L_{p1} to L_{p5}) is shown in Figure 4.2.

Both 33 and 69 test bus systems were simulated for six different scenarios to determine the optimal solutions.

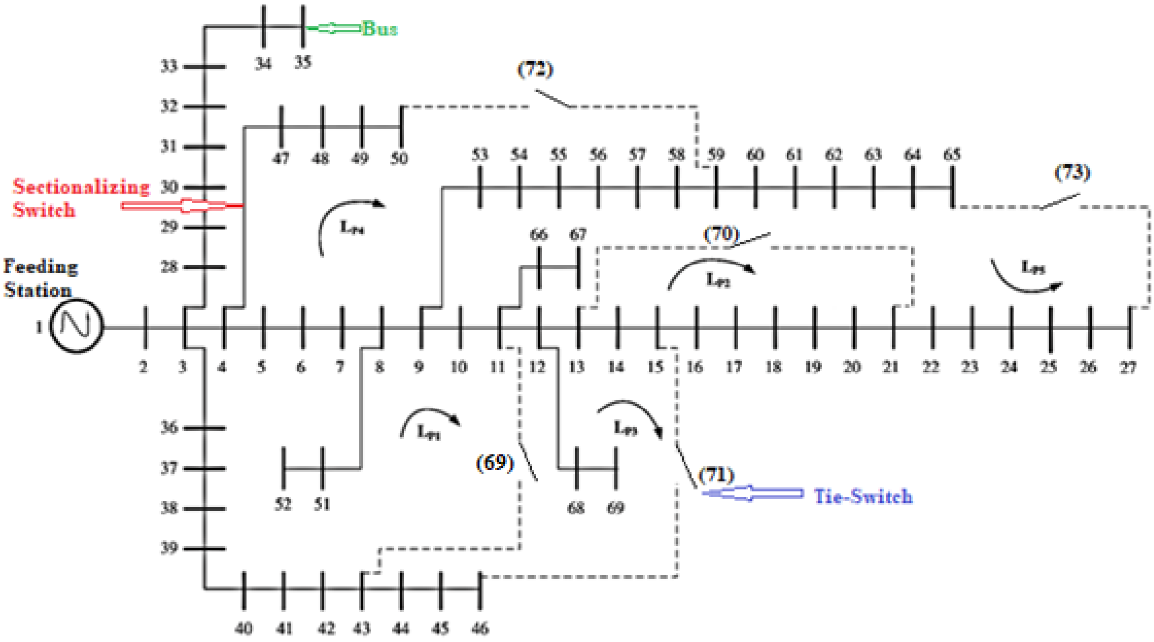


Figure 4.2 IEEE 69 Test Bus System

4.1.3 NEA 63-Bus RDS

To check the efficacy of the technique, the methodology has been applied to an 11 kV real distribution network. For this, one of the radial distribution feeders of NEA, Kirtipur Distribution Center has been chosen for analysis. The feeder under consideration (Kirtipur Feeder) originated from the Teku Substation bus situated in Teku, Kathmandu. The data required for the study were taken from the respective distribution center from which the line diagram has been plotted in QGIS. The QGIS plot from the available data is shown in Figure 4.3. The entered attributes in QGIS have been exported into MS Excel. An SLD has been created by assigning bus numbers and branch numbers. The substation is considered a reference bus and is represented by the number 1. The feeder consists of 63 nodes with 62 branches. Five set of tie-lines (63-64-65-66-67) have been assumed between nodes 9-30, 18-39, 51-60, 28-33, and 6-14 for reconfiguration purposes which have been represented by dotted lines. These normally open tie line switches are selected on the basis of short length (path) between the nodes, and also on the basis of load capacity of nodes or buses. A less impedance value will be achieved with the cable having shorter length. The data of the NEA-63 bus RDS are shown in APPENDIX C. The overall SLD of a real distribution system with tie lines is shown in Figure 4.4

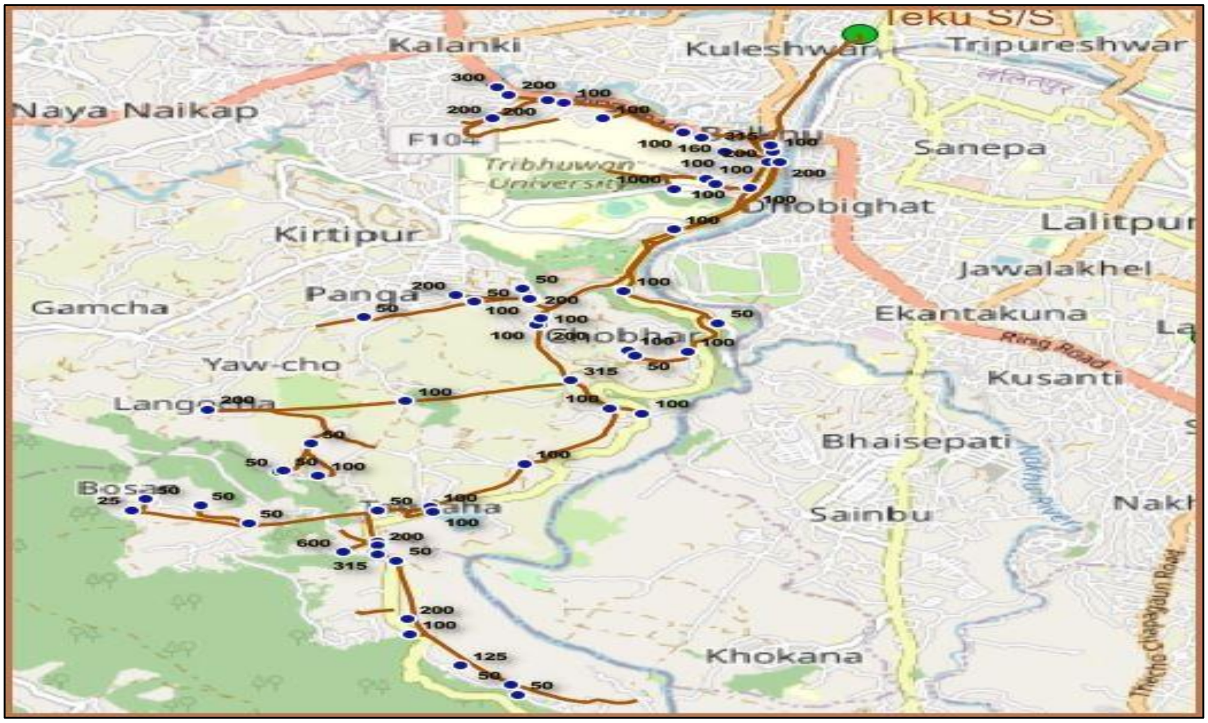


Figure 4.3 QGIS Plot of 11 kV Kirtipur Feeder

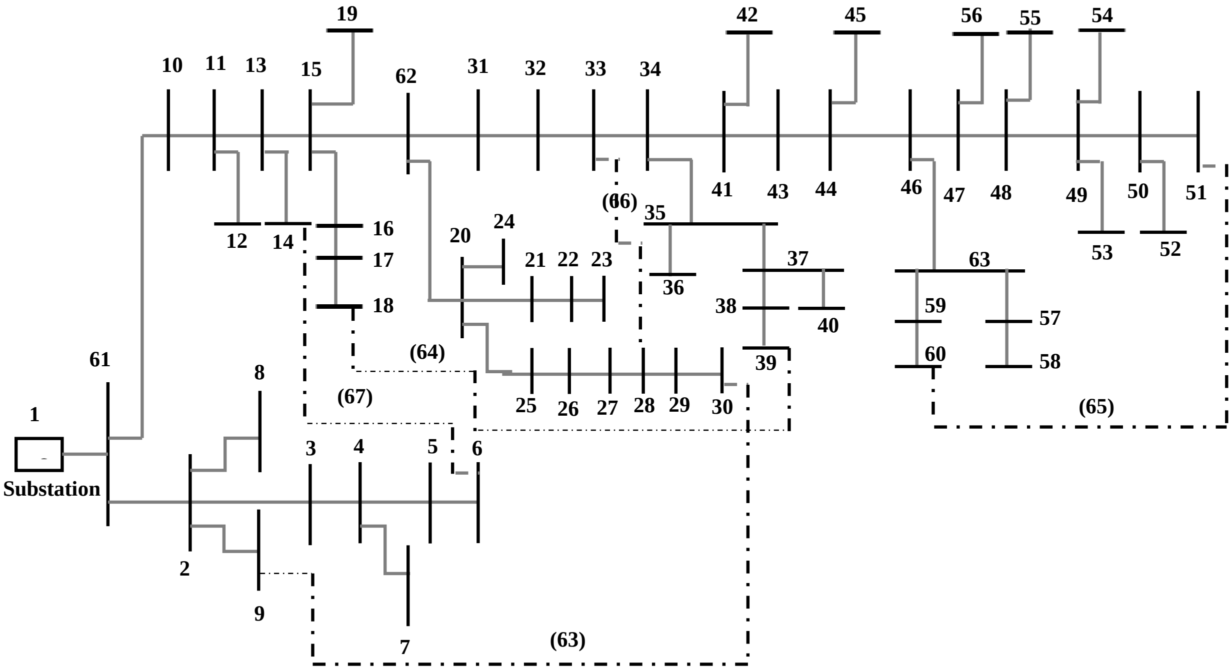


Figure 4.4 NEA 63-Bus RDS

4.2 Software tool

With the advancement of technology in computer architecture along with modern software and programming tools, it has become easier to model and analysis of power systems. By using various software tools, we can easily develop the necessary algorithm to simulate to obtain the results. MATLAB, ETAP, DIgSILENT, Power World Simulator are some of the available software tools used to simulate the power system.

In this thesis, a powerful and highly interactive MATLAB programming software has been used. MATLAB is a simulation software known as "Matrix Laboratory", designed for large numbers of engineering analyses developed by MathWorks. It is an interactive system whose Basic Data elements are an array that does not require dimensioning. It is well adapted to numerical experiments. It allows matrix manipulations, algorithm execution, functions and data plotting, and communication with other programming languages.

To compute numerous load flow in a single iteration, a time-efficient tool is required. For this, the MATPOWER toolbox of MATLAB M-files is used to solve load flow problems. Due to its simplicity of use, it is designed as a simulation tool. The objective of MATPOWER is to provide the best performance by enabling simple code which is easy to understand. MATPOWER was initially created by Ray D. Zimmerman, Carlos E. MurilloS´anchez, and Deqiang Gan at Cornell University.

In this thesis work, MATLAB R2018a and QGIS 3.22.8 software have been used. The code for ABC algorithm was done in a MATLAB scripting language and data of the real distribution network were plotted in QGIS. The testing and debugging were carried out on a PC having Windows 10, 1.8 GHz processor, 4 GB RAM, and a 64-bit operating system.

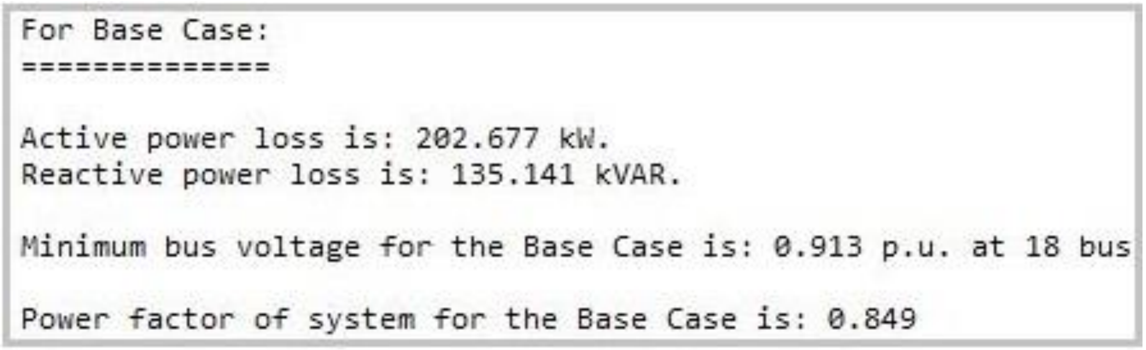
5 CHAPTER FIVE: RESULTS AND DISCUSSION

To perform network reconfiguration and optimal DGs placement, MATLAB computer programming has been developed using ABC algorithm. In carrying out network reconfiguration and DGs placement, most of the literature only considers DGs generating active power only. But, in this thesis, as per the application, two different types of DGs have been considered for analysis. They are:

i. DGs generating or injecting real or active power only
ii. DGs generating or injecting active and reactive power both

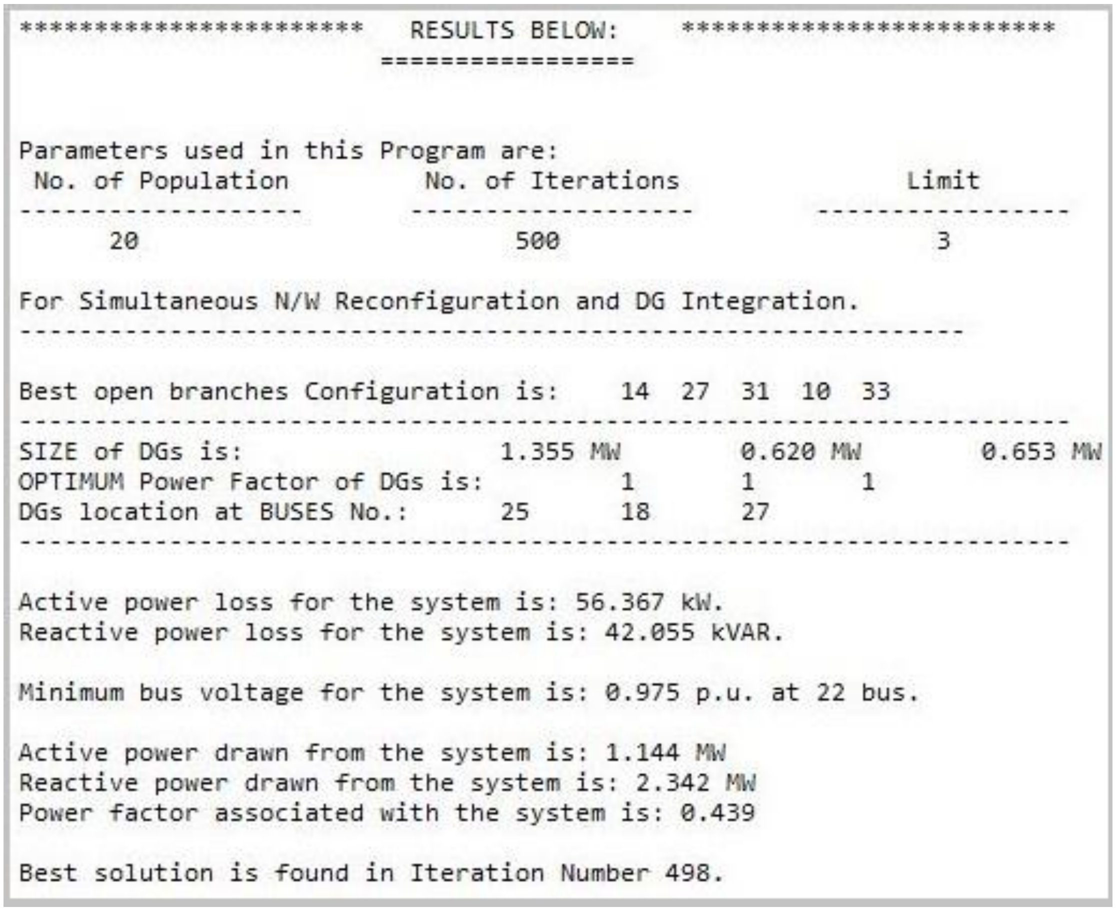
To illustrate and assess the applicability of the used methodology, ABC algorithm on MATLAB computer program was initially applied on two test bus systems which further can be implemented on any real distribution network.

The format of results obtained using ABC algorithm on the MATLAB computer program has been shown in the following figures:



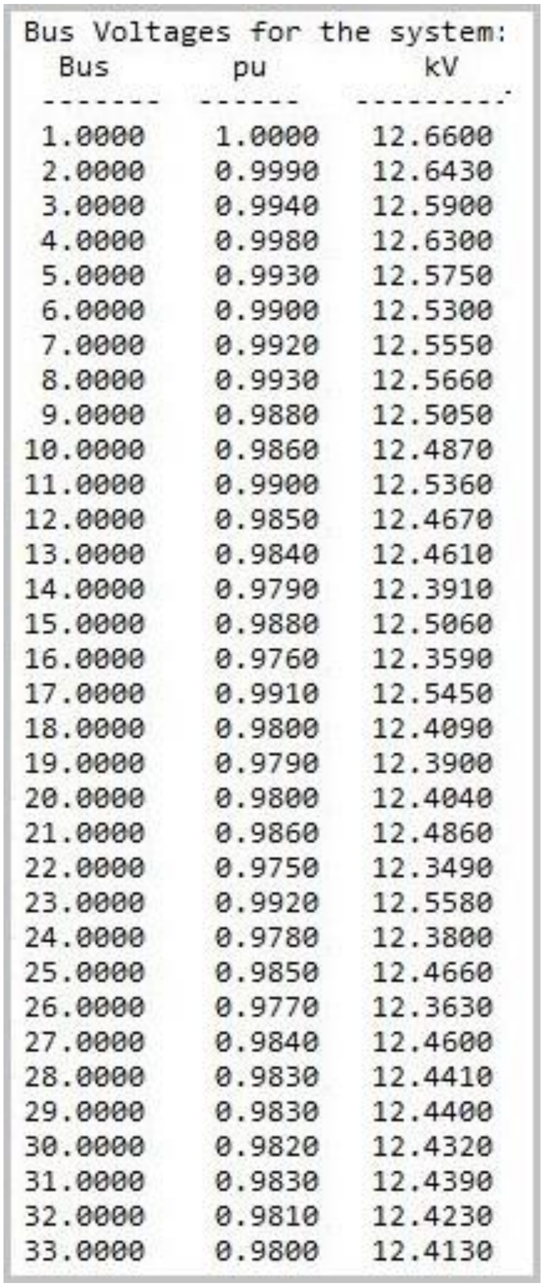
```
For Base Case:
==============

Active power loss is: 202.677 kW.
Reactive power loss is: 135.141 kVAR.

Minimum bus voltage for the Base Case is: 0.913 p.u. at 18 bus

Power factor of system for the Base Case is: 0.849
```

Figure 5.1 Result for Base Case

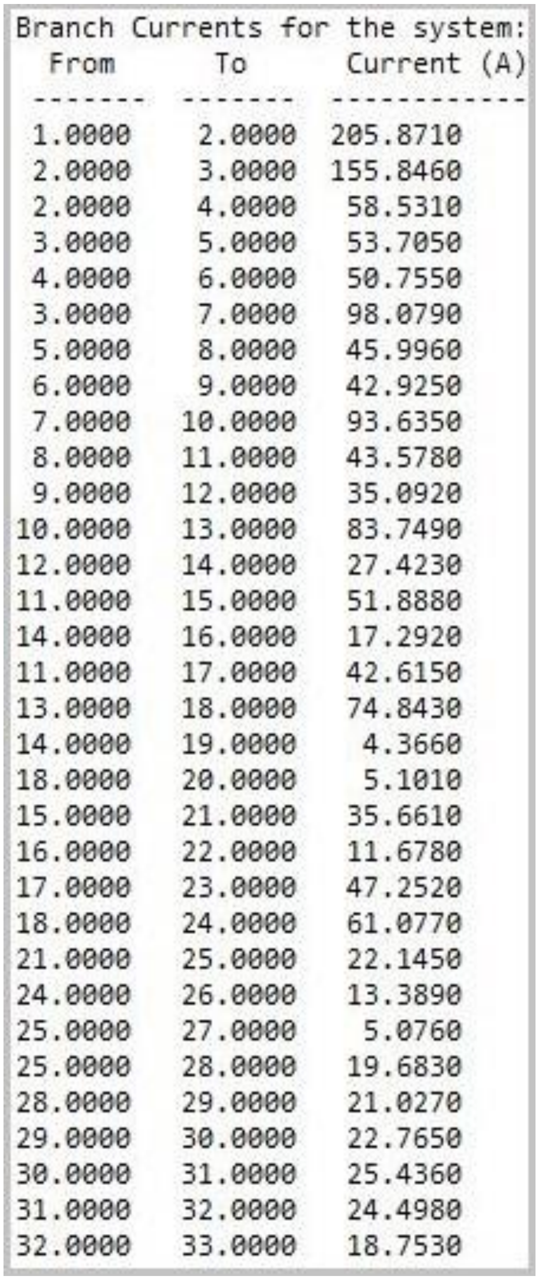


```
***********************    RESULTS BELOW:    *************************
                        =================


Parameters used in this Program are:
 No. of Population        No. of Iterations              Limit
-------------------      -------------------      -----------------
      20                       500                          3

For Simultaneous N/W Reconfiguration and DG Integration.
---------------------------------------------------------------

Best open branches Configuration is:    14  27  31  10  33
----------------------------------------------------------------------
SIZE of DGs is:                  1.355 MW        0.620 MW        0.653 MW
OPTIMUM Power Factor of DGs is:         1       1       1
DGs location at BUSES No.:       25      18      27
----------------------------------------------------------------------

Active power loss for the system is: 56.367 kW.
Reactive power loss for the system is: 42.055 kVAR.

Minimum bus voltage for the system is: 0.975 p.u. at 22 bus.

Active power drawn from the system is: 1.144 MW
Reactive power drawn from the system is: 2.342 MW
Power factor associated with the system is: 0.439

Best solution is found in Iteration Number 498.
```

Figure 5.2 Result for Simultaneous Network Reconfiguration and DG Integration



```
Bus Voltages for the system:
  Bus        pu         kV
 -------   ------   ---------
  1.0000    1.0000   12.6600
  2.0000    0.9990   12.6430
  3.0000    0.9940   12.5900
  4.0000    0.9980   12.6300
  5.0000    0.9930   12.5750
  6.0000    0.9900   12.5300
  7.0000    0.9920   12.5550
  8.0000    0.9930   12.5660
  9.0000    0.9880   12.5050
 10.0000    0.9860   12.4870
 11.0000    0.9900   12.5360
 12.0000    0.9850   12.4670
 13.0000    0.9840   12.4610
 14.0000    0.9790   12.3910
 15.0000    0.9880   12.5060
 16.0000    0.9760   12.3590
 17.0000    0.9910   12.5450
 18.0000    0.9800   12.4090
 19.0000    0.9790   12.3900
 20.0000    0.9800   12.4040
 21.0000    0.9860   12.4860
 22.0000    0.9750   12.3490
 23.0000    0.9920   12.5580
 24.0000    0.9780   12.3800
 25.0000    0.9850   12.4660
 26.0000    0.9770   12.3630
 27.0000    0.9840   12.4600
 28.0000    0.9830   12.4410
 29.0000    0.9830   12.4400
 30.0000    0.9820   12.4320
 31.0000    0.9830   12.4390
 32.0000    0.9810   12.4230
 33.0000    0.9800   12.4130
```



```
Branch Currents for the system:
  From       To      Current (A)
 -------   -------   ------------
  1.0000    2.0000   205.8710
  2.0000    3.0000   155.8460
  2.0000    4.0000    58.5310
  3.0000    5.0000    53.7050
  4.0000    6.0000    50.7550
  3.0000    7.0000    98.0790
  5.0000    8.0000    45.9960
  6.0000    9.0000    42.9250
  7.0000   10.0000    93.6350
  8.0000   11.0000    43.5780
  9.0000   12.0000    35.0920
 10.0000   13.0000    83.7490
 12.0000   14.0000    27.4230
 11.0000   15.0000    51.8880
 14.0000   16.0000    17.2920
 11.0000   17.0000    42.6150
 13.0000   18.0000    74.8430
 14.0000   19.0000     4.3660
 18.0000   20.0000     5.1010
 15.0000   21.0000    35.6610
 16.0000   22.0000    11.6780
 17.0000   23.0000    47.2520
 18.0000   24.0000    61.0770
 21.0000   25.0000    22.1450
 24.0000   26.0000    13.3890
 25.0000   27.0000     5.0760
 25.0000   28.0000    19.6830
 28.0000   29.0000    21.0270
 29.0000   30.0000    22.7650
 30.0000   31.0000    25.4360
 31.0000   32.0000    24.4980
 32.0000   33.0000    18.7530
```

Figure 5.3 Bus Voltage and Branch Current for the system

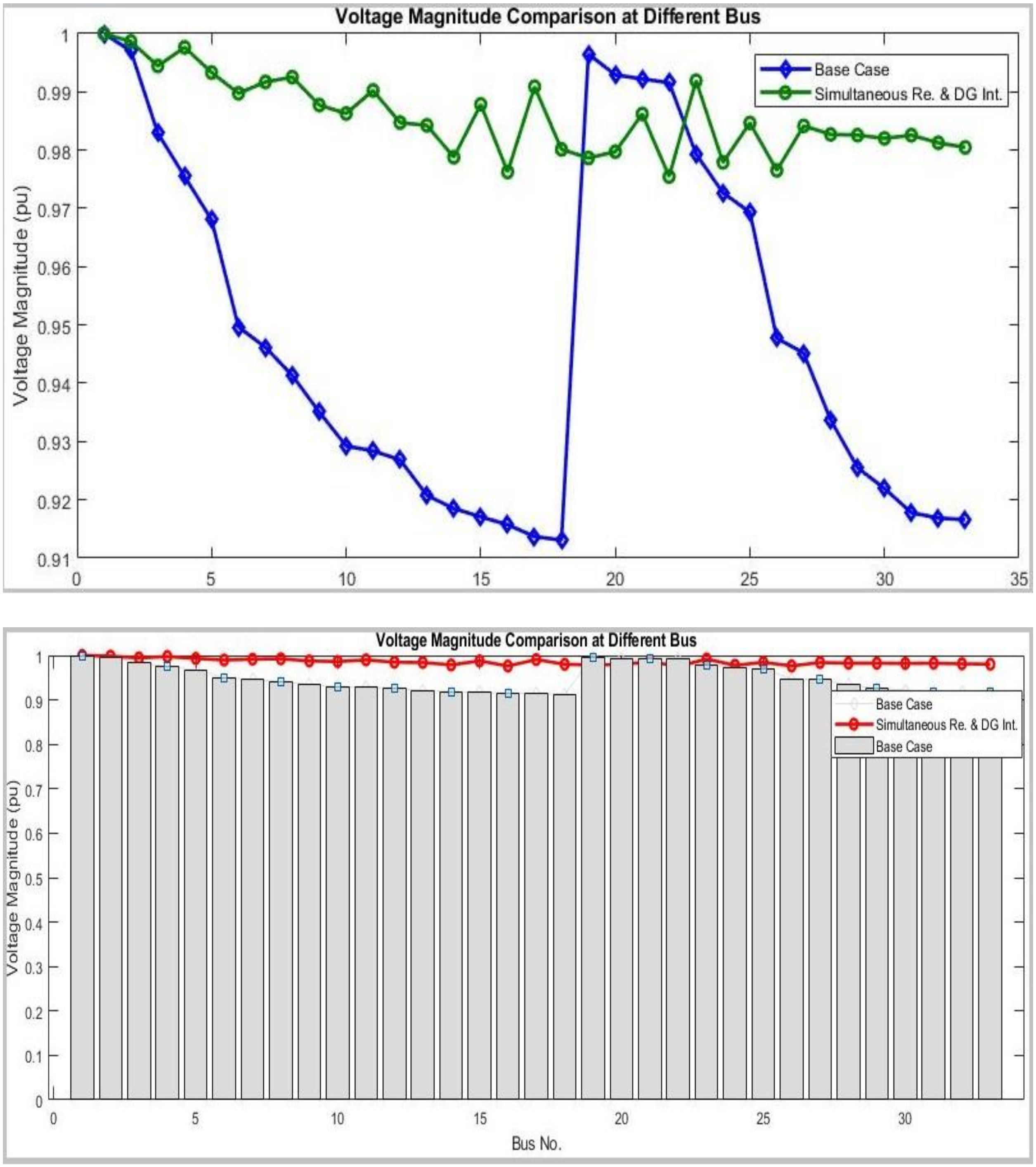


Figure 5.4 Voltage Magnitude Comparison at Different Buses

The following sections show the results and discussion for different scenarios on the proposed methodology.

5.1 Results for IEEE 33 Test Bus System

Different scenarios of the test bus system consisting of Network reconfiguration (NR), Types of DGs placement, Simultaneous network reconfiguration and DGs placement have been observed. The obtained results were compared with the reference paper, as given in APPENDIX D, considering three DGs for the cases which are discussed below.

Scenario I (Base Case):

On computing active power loss for this scenario, the result obtained was the same as that in the reference paper (Mohamed Imran *et al.* 2014). Both the scenarios have the same active power loss of 202.67 kW with minimum bus voltage (0.913 p.u at bus no. 18), which showed that the network parameters considered in both scenarios were the same.

Scenario II (Only Network Reconfiguration):

On considering only network reconfiguration, the results obtained for open switches (7-14-9-32-28), active power loss (139.978 kW), and minimum bus voltage (0.941 pu) obtained in reference paper at the bus no. 32 whereas almost the same results were obtained at bus no. 31 using ABC algorithm. The percentage of power loss as compared to the base case has been reduced by 30.93%.

Scenario III (Only DG Integration):

For this scenario, the results obtained using ABC algorithm in MATLAB environment were found to be better than that given in the reference paper (Mohamed Imran *et al.* 2014) which has been presented in summary results as shown in Table 5.1. The total active power loss (82.724 kW) using ABC algorithm was found to be better than that obtained by using FWA algorithm. However, the bus voltage (0.95 at bus no. 33) was slightly lower than that obtained in the reference paper (0.968 at bus no. 30). The result comparison was done based on DGs generating active power only.

Scenario IV (Network Reconfiguration followed by DG Integration):

The results obtained for both power loss (61.077 kW using ABC as compared to 83.91 kW using FWA algorithm) and minimum bus voltage (0.97 at bus no. 22 using ABC as compared to 0.9612 at bus no. 30) were also found to be better than that given in the reference paper (Mohamed Imran *et al.* 2014). The percentage loss reduction using ABC algorithm i.e. 69.86% has been higher than that obtained in the reference paper i.e. 58.59%. Similar to scenario III, the result comparison was done for DGs generating active power only and the results for other types of DGs have been shown in APPENDIX D.

Scenario V (DG Integration followed by Network Reconfiguration):

The respective active power loss and minimum bus voltage obtained for this scenario were 63.929 kW and 0.970 p.u on bus no. 20 against 68.28 kW and 0.9712 pu (bus no. 29) in the reference paper. Also, the percentage loss reduction of 68.46% (using ABC) as compared to 66.31% (using FWA in the reference paper) was a better one.

Scenario VI (Simultaneous Network Reconfiguration and DG Integration):

In this scenario, the real power loss obtained was 56.367 kW which has been better than the 67.11 kW obtained in the reference paper. The result obtained for minimum voltage (0.9713 p.u) at bus no. 14 using FWA algorithm was the same as the one obtained at the bus no. 32 using ABC algorithm.

The summary results for all the above six scenarios have been tabulated in Table 5.1 below. It also compared the results obtained using ABC algorithm for DGs injecting active power (P) only with the reference paper (Mohamed Imran *et al.* 2014) for IEEE 33 Test Bus System.

Table 5.1 Summary Results of IEEE 33 Test Bus System

Scenario	P_{TL}(kW) (Using FWA)	P_{TL}(kW) (Using ABC)	Min. V_{bus} (Using FWA)	Min. V_{bus} (Using ABC)	% Loss Reduction (Using FWA)	% Loss Reduction (Using ABC)
Base Case	202.670	202.670	0.913	0.913	-	-
Only NR	139.980	139.978	0.941	0.941	30.93%	30.93%
Only DG Int.	88.680	82.724	0.968	0.950	56.24%	59.18%
Reconf. then DG Int.	83.910	61.077	0.961	0.970	58.60%	69.86%
DG Int. then Reconf.	68.280	63.929	0.971	0.970	66.31%	68.46%
Simult. Reconf. & DG Int.	67.110	56.367	0.971	0.971	66.89%	72.19%

The following Figure 5.5, Figure 5.6, and Figure 5.7 show the respective graphical comparison results for power loss, percentage power loss, and voltage profile for six different scenarios for IEEE 33 Bus System. The graphs show that there has been gradual improvement in power loss (kW) reduction and voltage magnitude (p.u) improvement while moving from base case (Scenario I) towards simultaneous network reconfiguration and DG allocation (Scenario VI).

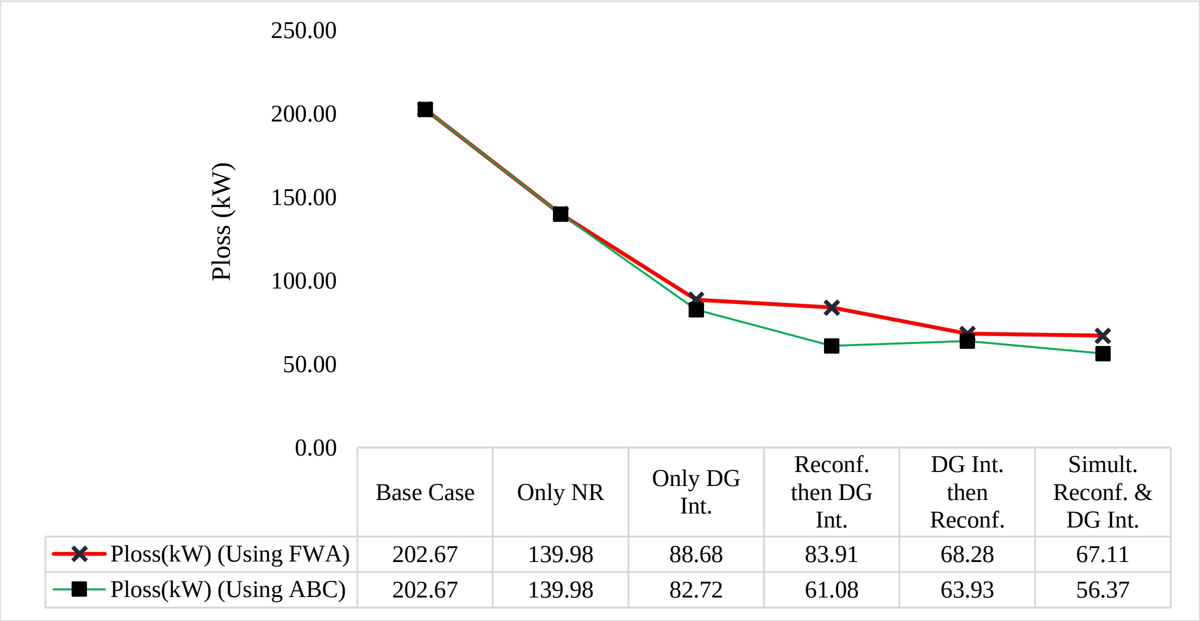
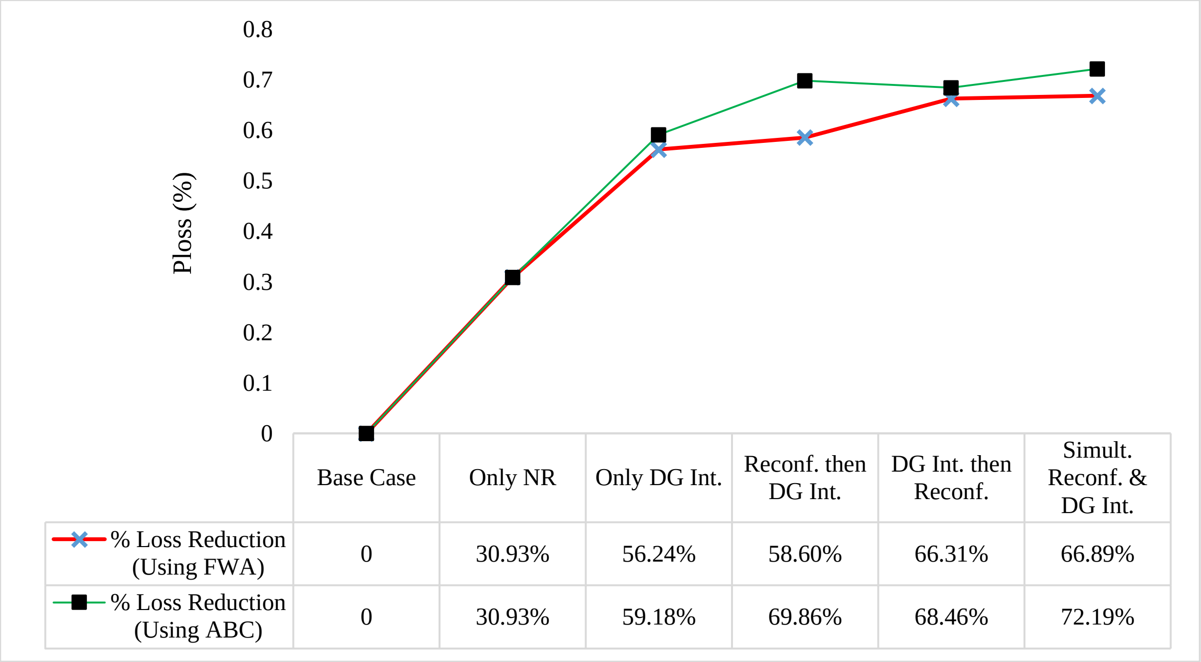
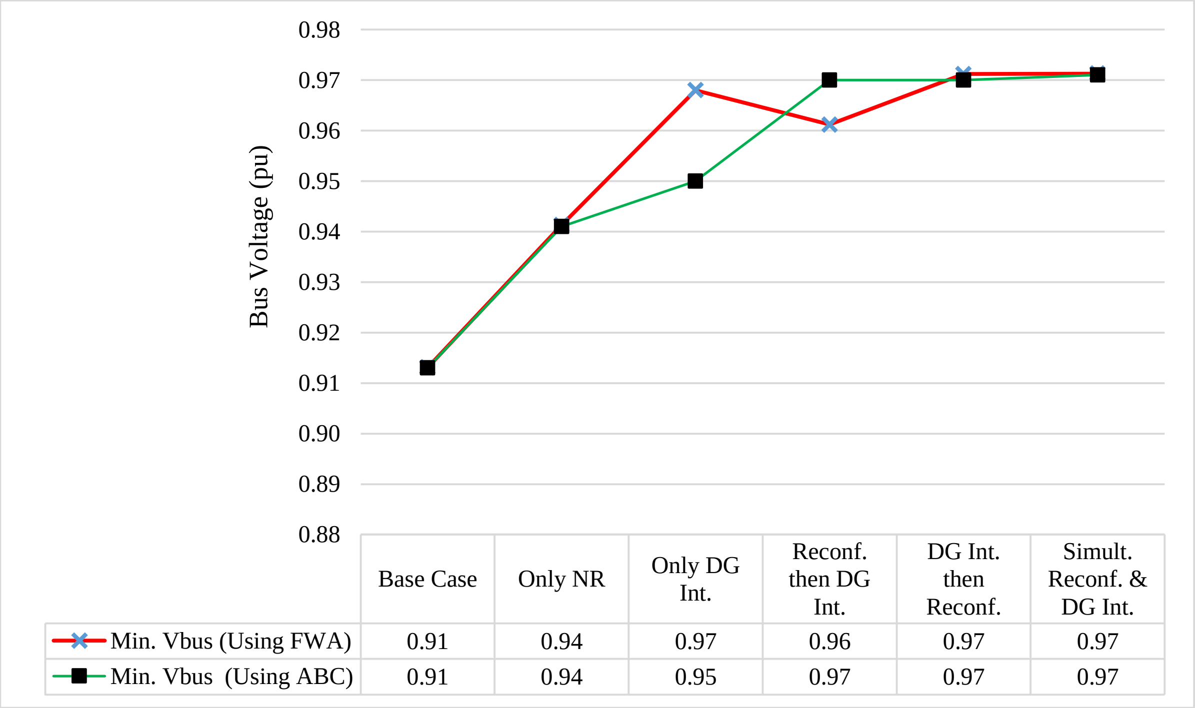


Figure 5.5 Power Loss Comparison for IEEE 33 Bus System



	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
% Loss Reduction (Using FWA)	0	30.93%	56.24%	58.60%	66.31%	66.89%
% Loss Reduction (Using ABC)	0	30.93%	59.18%	69.86%	68.46%	72.19%

Figure 5.6 Percentage Loss Reduction Comparison for IEEE 33 Bus System



	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
Min. Vbus (Using FWA)	0.91	0.94	0.97	0.96	0.97	0.97
Min. Vbus (Using ABC)	0.91	0.94	0.95	0.97	0.97	0.97

Figure 5.7 Bus Voltage Comparison for IEEE 33 Test Bus System

5.2 Results for IEEE 69 Test Bus System

This thesis work also carried out scenario results for typical 69 bus system consisting of Network reconfiguration only, Types of DGs placement only, Simultaneous network reconfiguration, and DGs placement which were also compared with the same reference paper as done for typical 33 test bus system considering three DGs. The summary of comparison results using FWA and ABC algorithm for DGs injecting active power only have been shown in Table 5.2 and detail results have been tabulated in APPENDIX E and discussed as below:

Scenario I (Base Case):

On computing active power loss for this scenario, the result obtained was almost the same as that in the reference paper (Mohamed Imran *et al.* 2014). The result obtained for active power loss was 225.001 kW using ABC algorithm which was almost the same as obtained in reference paper. The minimum bus voltage (0.909 at bus no. 65) for both the systems exactly matched, which shows that the network parameters considered in both scenarios are the same.

Scenario II (Only Network Reconfiguration):

On considering only network reconfiguration, the results obtained for open switches (69-70-14-56-61), active power loss (98.59 kW), and minimum bus voltage (0.9495 pu at bus no. 61) were obtained in the reference paper whereas almost the same results were obtained at the bus no. 61 using ABC algorithm. The percentage power loss of the system while comparing to the base case has been reduced by 56.17%.

Scenario III (Only DG Integration):

For this scenario, the results obtained using ABC algorithm in MATLAB environment were found to be better than that given in the reference paper (Mohamed Imran *et al.* 2014) which has been shown in summary results as given in Table 5.2. For 69 bus system, the results obtained for total power loss (74.891 kW), and minimum bus voltage (0.98 at bus no. 69) using ABC algorithm were found to be better than that obtained by using FWA algorithm. Also, the percentage loss reduction, 66.71%, was slightly better than that obtained using FWA algorithm (i.e. 65.39%). The result comparison was done based on DGs generating active power only. However, the results for other types of DGs were also obtained and tabulated in APPENDIX E.

Scenario IV (Network Reconfiguration followed by DG Integration):

The results obtained for both power loss (43.597 kW using ABC as compared to 43.88 kW using FWA algorithm) and minimum bus voltage (0.979 pu at bus no. 58 using ABC as compared to 0.972 pu at bus no. 61) were found to be better than that given in the reference paper (Mohamed Imran *et al.* 2014). The percentage loss reduction using ABC algorithm, which was 80.62% is slightly higher than that obtained in the reference paper which was 80.49%. Similar to scenario III, the result comparison was done for DGs generating active power only.

Scenario V (DG Integration followed by Network Reconfiguration):

The respective active power loss and minimum bus voltage achieved for this scenario were 42.92 kW and 0.98 pu at the bus no. 54 against 39.69 kW and 0.9763 pu at the bus no. 61 in the reference paper. Also, the percentage loss reduction of 80.92% (using ABC) as compared to 82.36% (using FWA in the reference paper) was the slightly lower one.

Scenario VI (Simultaneous Network Reconfiguration and DG Integration):

The results obtained for this scenario was superior to that obtained from any of the above five scenarios which have been compared with the reference paper. The percentage power loss reduction and minimum voltage for this scenario using ABC algorithm were 83.52 % and 0.981 p.u respectively which were better than that of 82.55% and 0.980 p.u. obtained in the reference paper.

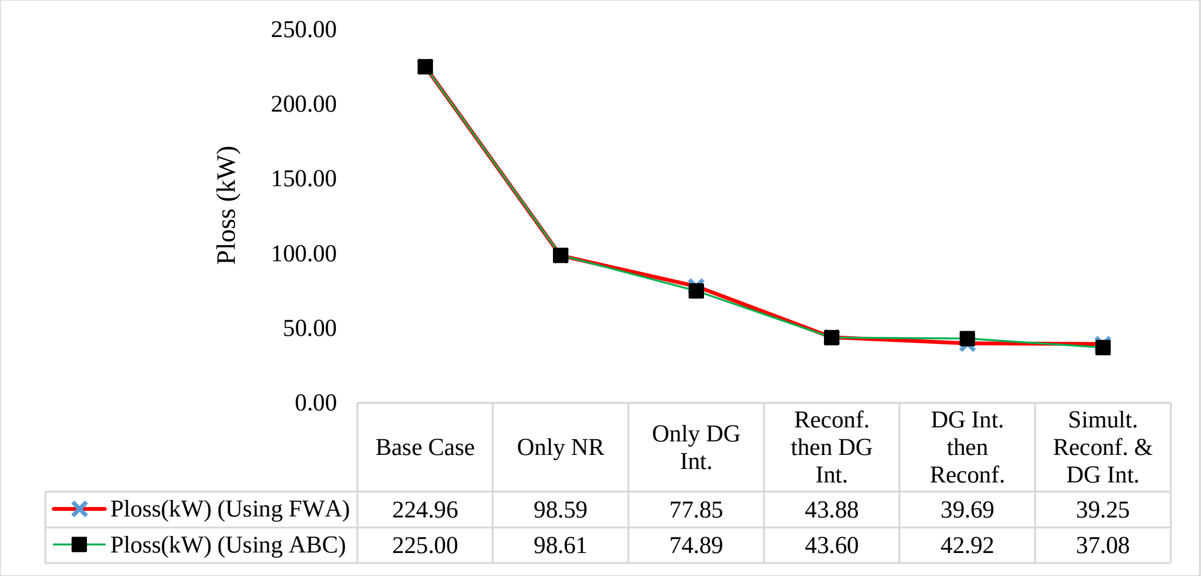
All the above results showed that the results obtained using ABC algorithm has better performance while comparing with FWA algorithm. Also, the scenario results for simultaneous network reconfiguration with DG placement has superior results than other scenarios being considered.

The summary results of the IEEE 69 Test Bus System are shown in Table 5.2.

Table 5.2 Summary Results of IEEE 69 Test Bus System

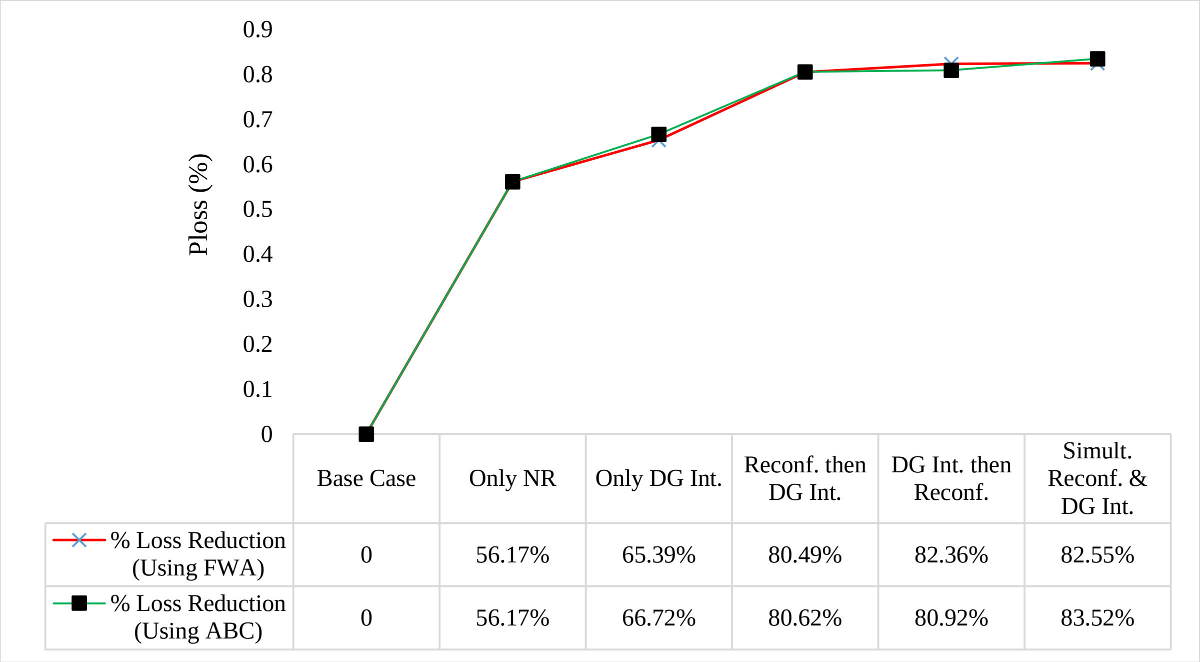
Scenario	P_{TL}(kW) (Using FWA)	P_{TL}(kW) (Using ABC)	Min. V_{bus} (Using FWA)	Min. V_{bus} (Using ABC)	% Loss Reduction (Using FWA)	% Loss Reduction (Using ABC)
Base Case	224.960	225.001	0.909	0.909	-	-
Only NR	98.590	98.610	0.950	0.950	56.17%	56.17%
Only DG Int.	77.850	74.891	0.974	0.980	65.39%	66.72%
Reconf. then DG Int.	43.880	43.597	0.972	0.979	80.49%	80.62%
DG Int. then Reconf.	39.690	42.920	0.976	0.980	82.36%	80.92%
Simult. Reconf. & DG Int.	39.250	37.080	0.980	0.981	82.55%	83.52%

The following Figure 5.8, Figure 5.9, and Figure 5.10 show the respective graphical comparison results for power loss, percentage power loss, and voltage profile for six different scenarios for IEEE 69 Bus System.The graphs show that there has been gradual improvement in power loss (kW) reduction and voltage magnitude (p.u) improvement while moving from base case (Scenario I) towards simultaneous network reconfiguration and DG allocation (Scenario VI).



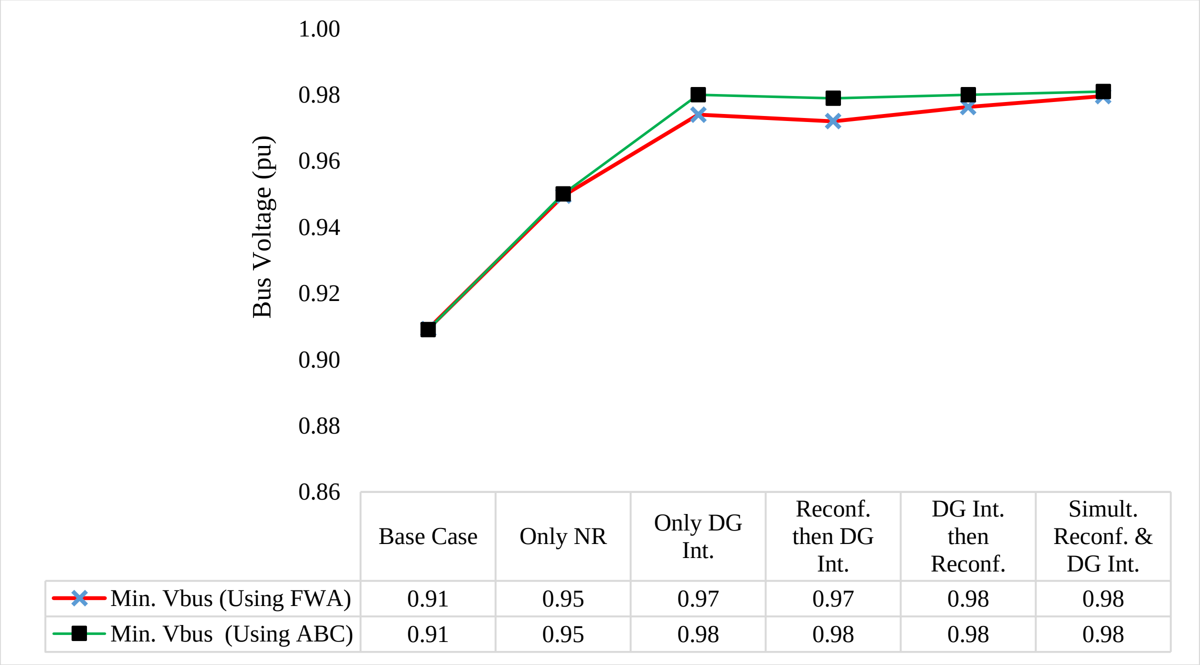
	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
Ploss(kW) (Using FWA)	224.96	98.59	77.85	43.88	39.69	39.25
Ploss(kW) (Using ABC)	225.00	98.61	74.89	43.60	42.92	37.08

Figure 5.8 Power Loss Comparison for IEEE 69 Test Bus System



	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
× % Loss Reduction (Using FWA)	0	56.17%	65.39%	80.49%	82.36%	82.55%
■ % Loss Reduction (Using ABC)	0	56.17%	66.72%	80.62%	80.92%	83.52%

Figure 5.9 Percentage Loss Reduction Comparison for IEEE 69 Test Bus System



	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
× Min. Vbus (Using FWA)	0.91	0.95	0.97	0.97	0.98	0.98
■ Min. Vbus (Using ABC)	0.91	0.95	0.98	0.98	0.98	0.98

Figure 5.10 Bus Voltage Comparison for IEEE 69 Test Bus System

While considering all the six scenarios for both 33 and 69 test bus systems, the results obtained for Scenario VI (Simultaneous network reconfiguration and DG integration) were superior to that obtained from the other five scenarios, and also the results obtained in this thesis work by using ABC algorithm has better one on comparing with the reference paper.

5.3 Results for NEA 63-Bus RDS

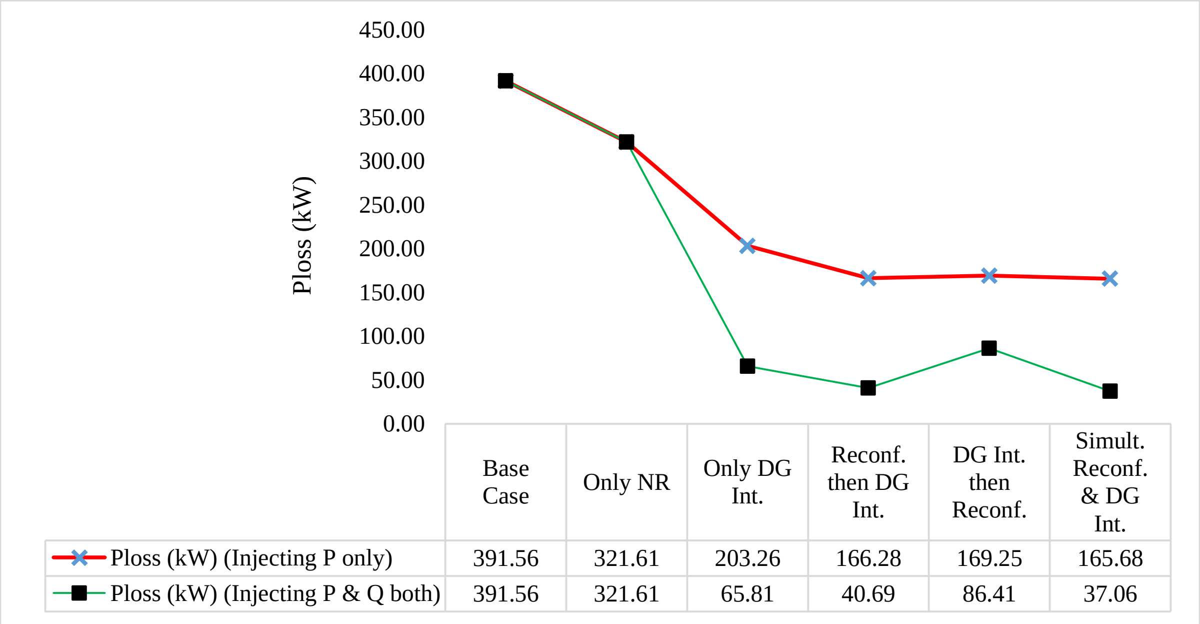
For the base case (Scenario I), the active power loss of NEA 63-Bus, Kirtipur feeder was found to be 391.564 kW as shown in Figure 5.11 and minimum voltage was not within the prescribed limit. Using ABC algorithm, for DGs generating or injecting active power (P) only, there has been a gradual improvement in power loss reduction by 17.87%, 48.09%, 57.53%, 56.78%, and 57.69% for other scenarios while compared with scenario I which has been tabulated in summary results of Table 5.3 and represented graphically in Figure 5.12. There has been a significant improvement in the minimum bus voltage too. The minimum bus voltages (p.u) obtained for six different Scenarios were 0.918 at bus no. 52, 0.93 at bus no. 58, 0.96 at the bus no. 60, 0.974 at bus no. 43, 0.981 at bus no. 60 and 0.985 at bus no. 60 respectively which has been tabulated in APPENDIX F and graphically shown in Figure 5.13. The respective reduction in power loss and minimum bus voltage for Scenario VI were 57.69% and 0.985 at bus number 60, which be the highest among other scenarios.

Similarly, for DGs injecting active and reactive power (P & Q), there has been a gradual improvement in power loss reduction by 17.87%, 83.19%, 89.61%, 77.93%, and 90.54% for other scenarios while compared with scenario I. Also, there has been a significant improvement in the minimum bus voltage too. The minimum bus voltages (p.u) obtained for six different Scenarios were 0.918 at bus no. 52, 0.93 at bus no. 58, 0.981 at bus no. 27, 0.988 at bus no. 27, 0.984 at bus no. 43 and 0.991 at bus no. 27 respectively. The respective reduction in power loss and minimum bus voltage for Scenario VI were 90.54% and 0.991 at bus number 27, which also be the highest among other scenarios. Table 5.3 shows the summary results for NEA 63-Bus RDS for two different types of DGs and overall results for the same bus have been shown in APPENDIX F.

All the above results from 33, 69, and NEA-63 bus RDS and their comparative graphical overview showed that Scenario VI having simultaneous network reconfiguration with DG placement has better performance in terms of system loss reduction and enhancing node voltage while comparing other scenarios being considered for the network. Also, the comparison results for different scenarios showed the superiority of ABC algorithm against FWA algorithm. Since, the scenario results using FWA algorithm had been compared with other metaheuristic algorithms which showed its better performance. Hence, after analyzing and discussing all the results, we can say that ABC has outperformed other popular metaheuristic algorithms.

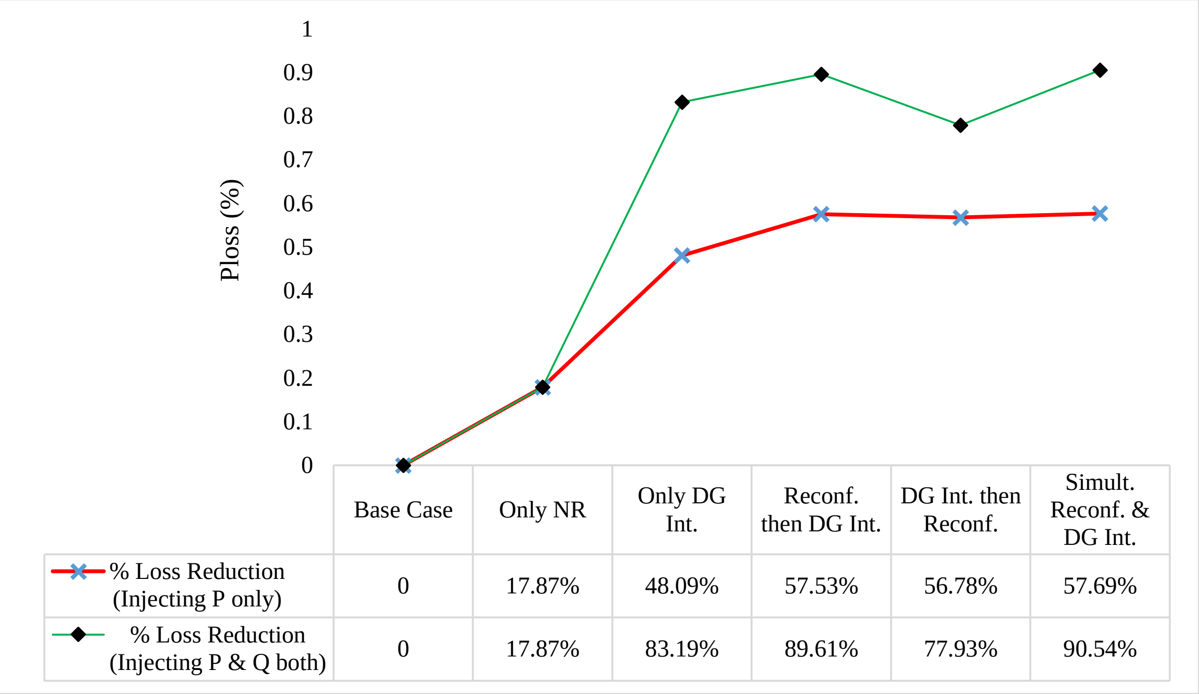
Table 5.3 Summary Results of NEA-63 Bus RDS

Scenario	P_{loss} (kW) (DG Injecting P only)	P_{loss} (kW) (DG Injecting P & Q both)	Min. V_{bus} (DG Injecting P only)	Min. V_{bus} (DG Injecting P & Q both)	% Loss Reduction (DG Injecting P only)	% Loss Reduction (DG Injecting P & Q both)
Base Case	391.564	391.564	0.918	0.918	-	-
Only NR	321.608	321.608	0.930	0.930	56.17%	56.17%
Only DG Int.	203.257	65.814	0.960	0.981	65.39%	66.72%
Reconf. then DG Int.	166.281	40.694	0.974	0.988	80.49%	80.62%
DG Int. then Reconf.	169.245	86.408	0.981	0.984	82.36%	80.92%
Simult. Reconf. & DG Int.	165.680	37.056	0.985	0.991	82.55%	83.52%



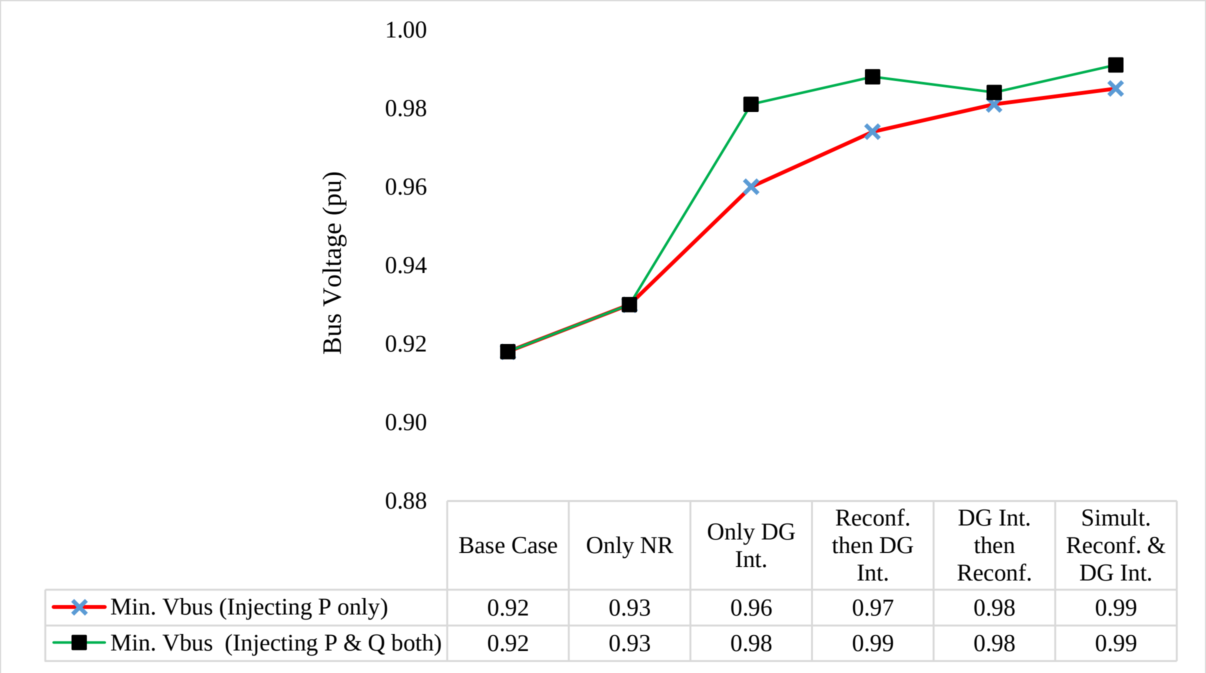
	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
Ploss (kW) (Injecting P only)	391.56	321.61	203.26	166.28	169.25	165.68
Ploss (kW) (Injecting P & Q both)	391.56	321.61	65.81	40.69	86.41	37.06

Figure 5.11 Power Loss Comparison for NEA-63 Bus RDS



	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
% Loss Reduction (Injecting P only)	0	17.87%	48.09%	57.53%	56.78%	57.69%
% Loss Reduction (Injecting P & Q both)	0	17.87%	83.19%	89.61%	77.93%	90.54%

Figure 5.12 Percentage Loss Reduction Comparison for NEA-63 Bus RDS



	Base Case	Only NR	Only DG Int.	Reconf. then DG Int.	DG Int. then Reconf.	Simult. Reconf. & DG Int.
Min. Vbus (Injecting P only)	0.92	0.93	0.96	0.97	0.98	0.99
Min. Vbus (Injecting P & Q both)	0.92	0.93	0.98	0.99	0.98	0.99

Figure 5.13 Bus Voltage Comparison for NEA-63 Bus RDS

6 CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This thesis work studied the potential of implementing simultaneous reconfiguration and Distributed Generation (DG) integration to reduce power loss and improve voltage profile in a radial distribution network using Artificial Bee Colony (ABC) algorithm in a MATLAB environment. The method that has been applied in this study maintains the radiality of the network. Voltage Stability Index (VSI) technique was carried out to locate the sensitive bus, and backward/forward propagation technique was employed to compute load flow analysis for DG integration. Six different combinations of reconfiguration and DG integration were simulated and tested on typical 33 and 69-bus test system for DGs injecting active power only and DGs injecting both active as well as reactive power.

A better result has been obtained for scenario VI (simultaneous reconfiguration and DG integration) for which percentage power loss reduction for 33 and 69-bus test systems were 72.19%, and 83.52% respectively. Also, the minimum bus voltages obtained for same scenario in both systems were 0.971, and 0.981 respectively which were the highest among other scenarios. Initially, the results were obtained for DG generating active power only.

To check the efficacy of the used technique employing ABC algorithm, the results obtained from simulations were also compared with the results produced by Fireworks Algorithm (FWA) in the reference paper (Mohamed Imran *et al.* 2014). The computational results in the thesis work showed that ABC algorithm has outperformed FWA. Later, after proving the efficacy of ABC algorithm in 33 and 69-bus test system, the developed computer program was applied to one of the real distribution feeders of Nepal Electricity Authority (NEA). Similar to a 33, and 69-bus test system, a better result has been obtained for scenario VI in which percentage power loss reduction for NEA 63-Bus system was 57.69%, and the minimum bus voltage obtained for the same scenario was 0.985 which became the highest among other scenarios. Similar outstanding results have been obtained for DG injecting both active and reactive power also. All the above results showed that scenario VI has superior performance when compared with other scenarios considered.

The following conclusions have been drawn from the research:

- The developed computer program optimizes the configuration of open branches and optimally allocates the DG units.
- With the application of the Backward-Forward Sweep algorithm and VSI technique, the best placement, size, and power factor for DG units have been determined.
- The load flow analysis in MATLAB program has been developed which determined better results for simultaneous network reconfiguration and DG integration while comparing with other scenario results.
- While comparing to the base case scenario, the respective percentage power loss reduction of 57.69% and 90.54% for DG injecting active power only (Type 1) and DG injecting active and reactive power (Type 2), have been obtained for real network of NEA-63 bus RDS. Also for the same two DG types, the improvement of minimum bus voltage from 0.918 p.u. at base case to 0.985 p.u. and 0.991 p.u. have been obtained for simultaneous network reconfiguration and DG integration (Scenario VI) which has a superior results than that with other scenario results being considered.

In summary, it is concluded that the applied technique using ABC performs better than FWA to obtain optimal network reconfiguration and DG integration to reduce power loss and improve voltage profile in a radial distribution system. Finally, the methodology used in the study can be replicated to any large radial distribution system.

6.2 Recommendations

The following recommendations have been made based on limitations and the areas of study:

i. A detail reliability assessment and financial analysis for least cost operation for different scenarios can be done for the system in the future studies.

ii. Further studies on the power loss reduction and voltage profile improvement of RDS can be performed through other techniques like optimal capacitor placement, utilization of FACTS devices, and combination of various DG types for the studied distribution network.

REFERENCES

Abubakar, A.S., Ekundayo, K.R., and Olaniyan, A.A. (2019) ‘Optimal reconfiguration of radial distribution networks using improved genetic algorithm’, *Nigerian Journal of Technological Development*, 16(1), available: https://doi.org/10.4314/njtd.v16i1.2.

Akay, B. and Karaboga, D. (2012) ‘A modified Artificial Bee Colony algorithm for real-parameter optimization’, *Information Sciences*, 192, available: https://doi.org/10.1016/j.ins.2010.07.015.

Alam, A., Farman, M., and Khatod, D. (2011) ‘Reconfiguration of Radial Distribution Network with Distributed Generation’.

Bayod-Rújula, A.A. (2009) ‘Future development of the electricity systems with distributed generation’, *Energy*, 34(3), available: https://doi.org/10.1016/j.energy.2008.12.008.

Chakravorty, M. and Das, D. (2001) ‘Voltage stability analysis of radial distribution networks’, *International Journal of Electrical Power & Energy Systems*, 23(2), 129–135, available: https://doi.org/https://doi.org/10.1016/S0142-0615(00)00040-5.

Chang, G.W., Chu, S.Y., and Wang, H.L. (2007) ‘An improved backward/forward sweep load flow algorithm for radial distribution systems’, *IEEE Transactions on Power Systems*, 22(2), available: https://doi.org/10.1109/TPWRS.2007.894848.

Chen, X., Chen, D., Liu, J., Liao, Y., Yu, K., and Hu, H. (2012) ‘Fast service restoration of distribution system with distributed generations’, *2012 IEEE Power and Energy Society General Meeting*, 1–6.

Chidanandappa, R., Ananthapadmanabha, T., and Ranjith, H.C. (2016) ‘Genetic Algorithm based service restoration in distribution systems with multiple DGs for time varying loads’, *2016 Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE)*, 1–7.

Essallah, S. and Khedher, A. (2020) ‘Optimization of distribution system operation by network reconfiguration and DG integration using MPSO algorithm’, *Renewable Energy Focus*, available: https://doi.org/10.1016/j.ref.2020.04.002.

Feng, N. and Jianming, Y. (2009) ‘Line losses calculation in distribution network based on RBF neural network optimized by Hierarchical GA’, in *1st International Conference on Sustainable Power Generation and Supply, SUPERGEN ’09*, available: https://doi.org/10.1109/SUPERGEN.2009.5348236.

Haider, W., Ul Hassan, S.J., Mehdi, A., Hussain, A., Adjayeng, G.O.M., and Kim, C.H. (2021) ‘Voltage profile enhancement and loss minimization using optimal placement and sizing of distributed generation in reconfigured network’, *Machines*, 9(1), available: https://doi.org/10.3390/machines9010020.

Jnawali, R.P., Thapa, K.B., and Karki, N.R. (2021) ‘Load Factor Improvement of Distribution Feeders by Feeder Reconfiguration Using Modified BPSO Considering Losses’, in *2021 International Conference on Sustainable Energy and Future Electric Transportation, SeFet 2021*, available: https://doi.org/10.1109/SeFet48154.2021.9375637.

Juma, S.A. (2018) ‘OPTIMAL RADIAL DISTRIBUTION NETWORK RECONFIGURATION USING MODIFIED SHARK SMELL OPTIMIZATION’.

Kalambe, S. and Agnihotri, G. (2014) ‘Loss minimization techniques used in distribution network: Bibliographical survey’, *Renewable and Sustainable Energy Reviews*, available: https://doi.org/10.1016/j.rser.2013.08.075.

Kamble, S.G., Vadirajacharya, K., and Patil, U. V. (2019) ‘Distribution system reconfiguration for loss minimization and voltage profile enhancement by using discrete – improved binary particle swarm optimization algorithm’, *International Journal of Recent Technology and Engineering*, 8(2 Special Issue 11), available: https://doi.org/10.35940/ijrte.B1148.0982S1119.

Kansal, S., Kumar, V., and Tyagi, B. (2013) ‘Optimal placement of different type of DG sources in distribution networks’, *International Journal of Electrical Power and Energy Systems*, 53(1), available: https://doi.org/10.1016/j.ijepes.2013.05.040.

Lee, C., Liu, C., Mehrotra, S., and Bie, Z. (2015) ‘Robust distribution network reconfiguration’, *IEEE Transactions on Smart Grid*, 6(2), available: https://doi.org/10.1109/TSG.2014.2375160.

Maharjan, R. and Kamalasadan, S. (2015) ‘Voltage stability index for online voltage stability assessment’, in *2015 North American Power Symposium, NAPS 2015*, available: https://doi.org/10.1109/NAPS.2015.7335245.

Mansur, H. and Urinboy, J. (2021) *Reconfiguration Of Radial Distribution System To Minimize Active Power Loss*, International Journal of Engineering and Information Systems (IJEAIS), available: https://ssrn.com/abstract=3826556.

Merlin, A. and Back, H. (1975) ‘Search for a minimal-loss operating spanning tree configuration in an urban power distribution system’, *Fifth Power Systems Computation Conference*.

Mohamed Imran, A., Kowsalya, M., and Kothari, D.P. (2014) ‘A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks’, *International Journal of Electrical Power and Energy Systems*, 63, available: https://doi.org/10.1016/j.ijepes.2014.06.011.

Moravej, Z., Ardejani, P.E., and Imani, A. (2018) ‘Optimum placement and sizing of DG units based on improving voltage stability using multi-objective evolutionary algorithm’, *Journal of Renewable and Sustainable Energy*, 10(5), available: https://doi.org/10.1063/1.5018885.

Muhtazaruddin, M.N. Bin, Bani, N.A., Aris, S.A.M., Jalil, S.Z.A., Kaidi, H.M., Fatah, A.Y.A., Jamian, J.J., Muhammad-Sukki, F., and Abu-Bakar, S.H. (2017) ‘Distribution power loss minimization via distributed generation, capacitor and network reconfiguration’, *Indonesian*

Journal of Electrical Engineering and Computer Science, 5(3), 488–495, available: https://doi.org/10.11591/ijeecs.v5.i3.pp488-495.

Murthy, G.V.K., Sivanagaraju, S., Satyanarayana, S., and Rao, B.H. (2014) 'Voltage stability analysis of radial distribution networks with distributed generation', *International Journal on Electrical Engineering and Informatics*, 6(1), available: https://doi.org/10.15676/ijeei.2014.6.1.13.

Myint, S.M. and Naing, S.W. (2015) 'Network Reconfiguration for Loss Reduction and Voltage Stability Improvement of 74-bus Radial Distribution System Using Particle Swarm Optimization Algorithm', *International Journal of Electrical, Electronics and Data Communication*, 3(6).

Nayak, M.R. (2014) 'Optimal feeder reconfiguration of distribution system with distributed generation units using HC-ACO', *International Journal on Electrical Engineering and Informatics*, 6(1), available: https://doi.org/10.15676/ijeei.2014.6.1.8.

Ng, H.N., Salama, M.M.A., and Chikhani, A.Y. (2000) 'Classification of capacitor allocation techniques', *IEEE Transactions on Power Delivery*, 15(1), available: https://doi.org/10.1109/61.847278.

Nguyen, T.T. and Truong, A.V. (2015) 'Distribution network reconfiguration for power loss minimization and voltage profile improvement using cuckoo search algorithm', *International Journal of Electrical Power and Energy Systems*, 68, available: https://doi.org/10.1016/j.ijepes.2014.12.075.

Pancha, B., Shrestha, R., and Jha, A.K. (2020) 'Optimal Integration of Distributed Generation in Distribution System: A Case Study of Sallaghari Feeder from Thimi Switching Station, Bhaktapur, Nepal', *Journal of the Institute of Engineering*, 15(1), available: https://doi.org/10.3126/jie.v15i1.27741.

Pandey, G.P., Shrestha, A., Mali, B., Singh, A., and Jha, A.K. (2021) 'Performance Enhancement of Radial Distribution System via Network Reconfiguration: A Case Study of Urban City in Nepal', *Journal of Renewable Energy, Electrical, and Computer Engineering*, 1(1), available: https://doi.org/10.29103/jreece.v1i1.3455.

Rakesh, R., Venkatapapana, P., and Keerthi, S. (2017) 'A hybrid algorithm for optimal allocation of DG in radial distribution system', in *TENSYMP 2017 - IEEE International Symposium on Technologies for Smart Cities*, available: https://doi.org/10.1109/TENCONSpring.2017.8070009.

Rao, R.S., Ravindra, K., Satish, K., and Narasimham, S.V.L. (2013) 'Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation', *IEEE Transactions on Power Systems*, 28(1), available: https://doi.org/10.1109/TPWRS.2012.2197227.

Shirmohammadi, D. and Hong, H.W. (1989) 'Reconfiguration of electric distribution networks for resistive line losses reduction', *IEEE Transactions on Power Delivery*, 4(2), available:

https://doi.org/10.1109/61.25637.

Sultana, U., Khairuddin, A.B., Aman, M.M., Mokhtar, A.S., and Zareen, N. (2016) ‘A review of optimum DG placement based on minimization of power losses and voltage stability enhancement of distribution system’, *Renewable and Sustainable Energy Reviews*, available: https://doi.org/10.1016/j.rser.2016.05.056.

Swarnkar, A., Gupta, N., and Niazi, K. (2011a) ‘A novel codification for meta-heuristic techniques used in distribution network reconfiguration’, *Lancet*, 81, 1619–1626, available: https://doi.org/10.1016/j.epsr.2011.03.020.

Swarnkar, A., Gupta, N., and Niazi, K.R. (2011b) ‘Adapted ant colony optimization for efficient reconfiguration of balanced and unbalanced distribution systems for loss minimization’, *Swarm and Evolutionary Computation*, 1(3), available: https://doi.org/10.1016/j.swevo.2011.05.004.

Thakur, T. and Jaswanti (2006) ‘Study and characterization of power distribution network reconfiguration’, in *2006 IEEE PES Transmission and Distribution Conference and Exposition: Latin America, TDC’06*, available: https://doi.org/10.1109/TDCLA.2006.311517.

Thukaram, D., Wijekoon Banda, H.M., and Jerome, J. (1999) ‘Robust three phase power flow algorithm for radial distribution systems’, *Electric Power Systems Research*, 50(3), available: https://doi.org/10.1016/S0378-7796(98)00150-3.

Tolba, M.A., Tulsky, V.N., and Diab, A.A.Z. (2017) ‘Optimal sitting and sizing of renewable distributed generations in distribution networks using a hybrid PSOGSA optimization algorithm’, in *Conference Proceedings - 2017 17th IEEE International Conference on Environment and Electrical Engineering and 2017 1st IEEE Industrial and Commercial Power Systems Europe, EEEIC / I and CPS Europe 2017*, available: https://doi.org/10.1109/EEEIC.2017.7977441.

Viswanadha Raju, G.K. and Bijwe, P.R. (2008) ‘Efficient reconfiguration of balanced and unbalanced distribution systems for loss minimisation’, *IET Generation, Transmission and Distribution*, 2(1), 7–12, available: https://doi.org/10.1049/iet-gtd:20070216.

Wang, Y. and Zhang, B. (2017) ‘Distribution Network Reconfiguration based on Improved Gravitational Search Algorithm’, in *IOP Conference Series: Earth and Environmental Science*, available: https://doi.org/10.1088/1755-1315/73/1/012022.

Wei, W., Sun, M., Ren, R., and Wang, Y. (2012) ‘Service restoration of distribution system with priority customers and distributed generation’, *IEEE PES Innovative Smart Grid Technologies*, 1–6.

APPENDIX A: Branch and Load Data of 33 Bus System

Branch No.	**Sending Bus or Node**	**Receiving Bus or Node**	**Resistance (Ohm)**	**Reactance (Ohm)**	**Load at Receiving Bus or Node**	
					P (kW)	**Q (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	0.1298	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	2	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	3	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200

Branch No.	Sending Bus or Node	Receiving Bus or Node	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
					P (kW)	Q (kVAR)
24	24	25	0.896	0.7011	420	200
25	6	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
33	21	8	2.0000	2.0000	-	-
34	9	15	2.0000	2.0000	-	-
35	12	22	2.0000	2.0000	-	-
36	18	33	0.5000	0.5000	-	-
37	25	29	0.5000	0.5000	-	-

Note: * denotes a tie-line

(Source: Case33bw, 2018a MATPOWER Toolbox)

APPENDIX B: Branch and Load Data of 69 Bus System

Branch No.	Sending Bus or Node	Receiving Bus or Node	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
					P (kW)	Q (kVAR)
1	1	2	0.0005	0.0012	0	0
2	2	3	0.0005	0.0012	0	0
3	3	4	0.0015	0.0036	0	0
4	4	5	0.0251	0.0294	0	0
5	5	6	0.366	0.1864	2.6	2.2
6	6	7	0.3811	0.1941	40.4	30
7	7	8	0.0922	0.047	75	54
8	8	9	0.0493	0.0251	30	22
9	9	10	0.819	0.2707	28	19
10	10	11	0.1872	0.0619	145	104
11	11	12	0.7114	0.2351	145	104
12	12	13	1.03	0.34	8	5
13	13	14	1.044	0.345	8	5.5
14	14	15	1.058	0.3496	0	0
15	15	16	0.1966	0.065	45.5	30
16	16	17	0.3744	0.1238	60	35
17	17	18	0.0047	0.0016	60	35
18	18	19	0.3276	0.1083	0	0
19	19	20	0.2106	0.069	1	0.6
20	20	21	0.3416	0.1129	114	81
21	21	22	0.014	0.0046	5	3.5
22	22	23	0.1591	0.0526	0	0

Branch No.	Sending Bus or Node	Receiving Bus or Node	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
					P (kW)	Q (kVAR)
23	23	24	0.3463	0.1145	28	20
24	24	25	0.7488	0.2475	0	0
25	25	26	0.3089	0.1021	14	10
26	26	27	0.1732	0.0572	14	10
27	3	28	0.0044	0.0108	26	18.6
28	28	29	0.064	0.1565	26	18.6
29	29	30	0.3978	0.1315	0	0
30	30	31	0.0702	0.0232	0	0
31	31	32	0.351	0.116	0	0
32	32	33	0.839	0.2816	14	10
33	33	34	1.708	0.5646	9.5	14
34	34	35	1.474	0.4873	6	4
35	3	36	0.0044	0.0108	26	18.55
36	36	37	0.064	0.1565	26	18.55
37	37	38	0.1053	0.123	0	0
38	38	39	0.0304	0.0355	24	17
39	39	40	0.0018	0.0021	24	17
40	40	41	0.7283	0.8509	1.2	1
41	41	42	0.31	0.3623	0	0
42	42	43	0.041	0.0478	6	4.3
43	43	44	0.0092	0.0116	0	0
44	44	45	0.1089	0.1373	39.22	26.3
45	45	46	0.0009	0.0012	39.22	26.3
46	4	47	0.0034	0.0084	0	0

Branch No.	Sending Bus or Node	Receiving Bus or Node	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
					P (kW)	Q (kVAR)
47	47	48	0.0851	0.2083	79	56.4
48	48	49	0.2898	0.7091	384.7	274.5
49	49	50	0.0822	0.2011	384.7	274.5
50	8	51	0.0928	0.0473	40.5	28.3
51	51	52	0.3319	0.1114	3.6	2.7
52	52	53	0.174	0.0886	4.35	3.5
53	53	54	0.203	0.1034	26.4	19
54	54	55	0.2842	0.1447	24	17.2
55	55	56	0.2813	0.1433	0	0
56	56	57	1.59	0.5337	0	0
57	57	58	0.7837	0.263	0	0
58	58	59	0.3042	0.1006	100	72
59	59	60	0.3861	0.1172	0	0
60	60	61	0.5075	0.2585	1244	888
61	61	62	0.0974	0.0496	32	23
62	62	63	0.145	0.0738	0	0
63	63	64	0.7105	0.3619	227	162
64	64	65	1.041	0.5302	59	42
65	11	66	0.2012	0.0611	18	13
66	66	67	0.0047	0.0014	18	13
67	12	68	0.7394	0.2444	28	20
68	68	69	0.0047	0.0016	28	20
69*	11	43	0.5	0.5	-	-
70*	13	21	0.5	0.5	-	-

Branch No.	Sending Bus or Node	Receiving Bus or Node	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
					P (kW)	Q (kVAR)
71*	15	46	1	1	-	-
72*	50	59	2	2	-	-
73*	27	65	1	1	-	-

Note: * denotes a tie-line

(Source: Case69, 2018a MATPOWER Toolbox)

APPENDIX C: Branch and Load Data of NEA-63 Bus System

Branch No.	Sending Bus or Node	Receiving Bus or Node	Length (km)	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
						P (kW)	Q (kVAR)
1	1	61	0.13	0.051	0.013	0.221	0.2250
2	2	3	0.69	0.214	0.065	0.070	0.0714
3	2	8	0.31	0.327	0.031	0.070	0.0714
4	2	9	0.1	0.039	0.010	0.112	0.1143
5	3	4	0.16	0.062	0.016	0.140	0.1428
6	4	5	0.26	0.040	0.023	0.140	0.1428
7	4	7	0.34	0.359	0.034	0.140	0.1428
8	5	6	0.18	0.070	0.018	0.210	0.2142
9	10	11	0.12	0.047	0.012	0.070	0.0714
10	11	12	0.25	0.078	0.023	0.070	0.0714
11	11	13	0.19	0.148	0.019	0.140	0.1428
12	13	14	0.11	0.043	0.011	0.140	0.1428
13	13	15	0.32	0.099	0.030	0.070	0.0714
14	15	16	0.28	0.087	0.026	0.070	0.0714
15	15	19	0.44	0.343	0.044	0.070	0.0714
16	15	62	0.82	0.639	0.083	0.070	0.0714
17	16	17	0.09	0.070	0.009	0.070	0.0714
18	17	18	0.28	0.218	0.028	0.700	0.7141
19	20	21	0.39	0.000	0.000	0.035	0.0357
20	20	24	0.24	0.093	0.023	0.035	0.0357
21	20	25	0.98	0.304	0.092	0.140	0.1428
22	21	22	0.31	0.121	0.030	0.035	0.0357

Branch No.	Sending Bus or Node	Receiving Bus or Node	Length (km)	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
						P (kW)	Q (kVAR)
23	22	23	0.13	0.040	0.012	0.070	0.0714
24	25	26	0.01	0.008	0.001	0.070	0.0714
25	26	27	0.29	0.226	0.029	0.035	0.0357
26	27	28	0.6	0.186	0.056	0.035	0.0357
27	28	29	0.13	0.101	0.013	0.035	0.0357
28	29	30	0.32	0.249	0.032	0.140	0.1428
29	31	32	0.09	0.070	0.009	0.140	0.1428
30	32	33	0.01	0.008	0.001	0.070	0.0714
31	33	34	0.66	0.697	0.067	0.221	0.2250
32	34	35	0.97	0.301	0.091	0.070	0.0714
33	34	41	0.35	0.109	0.033	0.070	0.0714
34	35	36	0.95	0.295	0.089	0.140	0.1428
35	35	37	0.57	0.177	0.054	0.035	0.0357
36	37	38	0.5	0.390	0.051	0.035	0.0357
37	37	40	0.38	0.118	0.036	0.070	0.0714
38	38	39	0.04	0.031	0.004	0.035	0.0357
39	41	42	0.18	0.056	0.017	0.070	0.0714
40	41	43	1.52	0.471	0.143	0.070	0.0714
41	43	44	0.89	0.276	0.084	0.070	0.0714
42	44	45	0.22	0.171	0.022	0.070	0.0714
43	44	46	0.38	0.059	0.034	0.035	0.0357
44	46	47	0.34	0.265	0.034	0.070	0.0714
45	46	63	0.87	0.919	0.088	0.035	0.0357
46	47	48	0.1	0.078	0.010	0.140	0.1428

Branch No.	Sending Bus or Node	Receiving Bus or Node	Length (km)	Resistance (Ohm)	Reactance (Ohm)	Load at Receiving Bus or Node	
						P (kW)	Q (kVAR)
47	47	56	0.16	0.169	0.016	0.420	0.4285
48	48	49	0.13	0.101	0.013	0.035	0.0357
49	48	55	0.1	0.106	0.010	0.221	0.2250
50	49	50	2.2	2.323	0.222	0.035	0.0357
51	49	53	1.71	1.806	0.173	0.070	0.0714
52	49	54	0.89	0.940	0.090	0.140	0.1428
53	50	51	0.12	0.019	0.011	0.035	0.0357
54	50	52	1.81	1.911	0.183	0.088	0.0893
55	57	58	0.38	0.401	0.038	0.035	0.0357
56	59	60	0.72	0.760	0.073	0.018	0.0179
57	61	2	0.61	0.644	0.062	0.018	0.0179
58	61	10	0.89	0.940	0.090	0.018	0.0179
59	62	20	0.33	0.348	0.033	0.018	0.0179
30	62	31	0.92	0.717	0.093	0.070	0.0714
61	63	59	0.68	0.718	0.069	0.035	0.0357
62	63	57	0.53	0.560	0.054	0.035	0.0357
*63	9	30	1.84	0.716	0.070	-	-
*64	18	39	1.29	0.502	0.049	-	-
*65	51	60	2.79	1.085	0.106	-	-
*66	28	33	0.98	0.381	0.037	-	-
*67	6	14	1.65	0.642	0.063	-	-

Note: * denotes a tie-line

APPENDIX D: Comparison Results of IEEE 33 Test Bus System

Scenario	**Description**	**Using FWA** (Mohamed Imran *et al.* 2014)	**Using ABC**	**Using ABC, DGs injecting active & reactive power (P & Q)**
Scenario I (Base Case)	Open Branches	33-34-35-36-37	33-34-35-36-37	33-34-35-36-37
	P_{TL} (kW)	202.67	202.677	202.677
	Bus V_{min} (pu)	0.9131 (18)	0.913 (18)	0.913 (18)
Scenario II (Only Network Reconfiguration)	Open Branches	7-14-9-32-28	9-7-14-28-32	9-7-14-28-32
	P_{TL} (kW)	139.98	139.978	139.978
	Bus V_{min} (pu)	0.9413 (32)	0.941 (31)	0.941 (31)
	% Loss reduction	30.93	30.93	30.93
Scenario III (DG Integration only)	Open Branches	33-34-35-36-37	33-34-35-36-37	33-34-35-36-37
	DG Location	14-18-32	25-26-31	25-26-30
	Size of DG (MW)	(0.5897)-(0.1895)-(1.0146)	(0.816)-(1.606)-(0.683)	(0.855)-(1.610)-(1.156)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(0.902)-(0.821)-(0.800)
	P_{TL} (kW)	88.68	82.724	26.607
	Bus V_{min} (pu)	0.968 (30)	0.950 (33)	0.966 (33)
	% Loss reduction	56.24	59.18	86.87
Scenario IV (Network Reconfiguration	Open Branches	7-14-9-32-28	9-7-14-28-32	28-34-32-11-33
	DG Location	32-33-18	29-24-9	26-15-30

Scenario	**Description**	**Using FWA** (Mohamed Imran *et al.* 2014)	**Using ABC**	**Using ABC, DGs injecting active & reactive power (P & Q)**
followed by DG Integration)	Size of DG (MW)	(0.5996)-(0.3141)-(0.1591)	(1.003)-(0.927)-(0.63)	(1.368)-(0.786)-(1.315)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(0.800)-(0.842)-(0.853)
	P_{TL} (kW)	83.91	61.077	18.445
	Bus V_{min} (pu)	0.9612 (30)	0.970 (22)	0.987 (29)
	% Loss reduction	58.59	69.86	90.89
Scenario V (DG Integration followed by Network Reconfiguration)	Open Branches	7-34-9-32-28	33-30-28-11-14	31-30-11-28-14
	DG Location	14-18-32	25-26-31	31-26-25
	Size of DG (MW)	(0.5897)-(0.1895)-(1.0146)	(0.844)-(1.789)-(0.624)	(0.662)-(1.637)-(0.795)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(1)-(1)-(1)
	P_{TL} (kW)	68.28	63.929	61.87
	Bus V_{min} (pu)	0.9712 (29)	0.970 (20)	0.977 (22)
	% Loss reduction	66.31	68.46	69.47
Scenario VI (Simultaneous Network Reconfiguration and DG Integration)	Open Branches	7-14-11-32-28	14-27-31-10-33	13-36-9-37-6
	DG Location	32-29-18	25-18-27	24-15-30
	Size of DG (MW)	(0.5367)-(0.6158)-(0.5315)	(1.355)-(0.620)-(0.653)	(1.131)-(0.953)-(1.314)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(0.872)-(0.901)-(0.800)
	P_{TL} (kW)	67.11	56.367	17.015

Scenario	**Description**	**Using FWA** (Mohamed Imran *et al.* 2014)	**Using ABC**	**Using ABC, DGs injecting active & reactive power (P & Q)**
	Bus V_{min} (pu)	0.9713 (14)	0.971 (32)	0.983 (18)
	% Loss reduction	66.89	72.19	91.61

APPENDIX E: Comparison Results of IEEE 69 Test Bus System

Scenario	**Description**	**Using FWA** (Mohamed Imran *et al.* 2014)	**Using ABC**	**Using ABC, DGs injecting active & reactive power (P & Q)**
Scenario I (Base Case)	Open Branches	69-70-71-72-73	69-70-71-72-73	69-70-71-72-73
	P_{TL} (kW)	224.96	225.001	225.001
	Bus V_{min} (pu)	0.9092 (65)	0.9092 (65)	0.9092 (65)
Scenario II (Only Network Reconfiguration)	Open Branches	69-70-14-56-61	69-56-14-61-70	69-13-12-26-58
	P_{TL} (kW)	98.59	98.61	120.694
	Bus V_{min} (pu)	0.9495 (61)	0.950 (61)	0.935 (57)
	% Loss reduction	56.17	56.17	46.35
Scenario III (DG Integration only)	Open Branches	69-70-71-72-73	69-70-71-72-73	69-70-71-72-73
	DG Location	65-61-27	68-62-54	62-66-68
	Size of DG (MW)	(0.4085)-(1.1986)-(0.2258)	(0.613)-(1.666)-(0.486)	(2.035)-(0.644)-(0.505)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(0.813)-(0.833)-(0.842)
	P_{TL} (kW)	77.85	74.891	11.087
	Bus V_{min} (pu)	0.974 (62)	0.98 (69)	0.989 (69)
	% Loss reduction	65.39	66.72	95.07
Scenario IV (Network Reconfiguration followed by DG Integration)	Open Branches	69-70-14-56-61	12-55-22-10-70	22-10-13-57-12
	DG Location	61-62-64	59-43-61	16-61.4
	Size of DG (MW)	(1.0014)-(0.2145)-(0.1425)	(0.38)-(0.814)-(1.667)	(0.621)-(2.041)-(0.428)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(0.845)-(0.800)-(0.924)

Scenario	**Description**	**Using FWA** (Mohamed Imran *et al.* 2014)	**Using ABC**	**Using ABC, DGs injecting active & reactive power (P & Q)**
	P_{TL} (kW)	43.88	43.597	7.632
	Bus V_{min} (pu)	0.972 (61)	0.979 (58)	0.99 (62)
	% Loss reduction	80.49	80.62	96.61
Scenario V (DG Integration followed by Network Reconfiguration)	Open Branches	69-70-12-58.61	20-10-64-55-13	14-18-21-10-58
	DG Location	65-61-27	50-62-67	62-54-68
	Size of DG (MW)	(0.4085)-(1.1986)-(0.2258)	(0.719)-(1.710)-(0.937)	(1.677)-(0.49)-(0.647)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(1)-(1)-(1)
	P_{TL} (kW)	39.69	42.92	45.339
	Bus V_{min} (pu)	0.9763 (61)	0.98 (54)	0.974 (62)
	% Loss reduction	82.36	80.92	79.84
Scenario VI (Simultaneous Network Reconfiguration and DG Integration)	Open Branches	69-70-13-55-63	69-62-13-70-53	12-9-67-6-20
	DG Location	61-62-65	65-61-66	61-43-53
	Size of DG (MW)	(1.1272)-(0.2750)-(0.4159)	(0.491)-(1.588)-(0.458)	(2.138)-(1.235)-(0.38)
	DG operating pf	(1)-(1)-(1)	(1)-(1)-(1)	(0.814)-(0.800)-(0.800)
	P_{TL} (kW)	39.25	37.08	7.814
	Bus V_{min} (pu)	0.9796 (61)	0.981 (50)	0.991 (69)
	% Loss reduction	82.55	83.52	96.53

APPENDIX F: Comparison Results of NEA-63 Bus RDS

Scenario	**Description**	**Using ABC, DGs injecting active power (P) only**	**Using ABC, DGs injecting active & reactive power (P & Q) both**
Scenario I (Base Case)	Open Branches	64-65-66-67-68	64-65-66-67-68
	P_{TL} (kW)	391.564	391.564
	Bus V_{min} (pu)	0.918 (52)	0.918 (52)
Scenario II (Only Network Reconfiguration)	Open Branches	34-27-13-49-24	34-27-13-49-24
	P_{TL} (kW)	321.608	321.608
	Bus V_{min} (pu)	0.93 (58)	0.93 (58)
	% Loss reduction	17.87	17.87
Scenario III (DG Integration only)	Open Branches	64-65-66-67-68	64-65-66-67-68
	DG Location	43-48-36	47-59-55
	Size of DG (MW)	(0.917)-(1.450)-(0.749)	(2.038)-(0.665)-(0.755)
	DG operating pf	(1)-(1)-(1)	(0.8)-(0.8)-(0.8)
	P_{TL} (kW)	203.257	65.814
	Bus V_{min} (pu)	0.96 (60)	0.981 (27)
	% Loss reduction	48.09	83.19
Scenario IV (Network Reconfiguration followed by DG Integration)	Open Branches	34-27-13-49-24	49-24-13-27-34
	DG Location	6/16/1946	47-5-16
	Size of DG (MW)	(1.400)-(1.848)-(2.330)	(2.871)-(1.221)-(2.489)
	DG operating pf	(1)-(1)-(1)	(0.815)-(0.825)-(0.952)
	P_{TL} (kW)	166.281	40.694
	Bus V_{min} (pu)	0.974 (43)	0.988 (27)

Scenario	**Description**	**Using ABC, DGs injecting active power (P) only**	**Using ABC, DGs injecting active & reactive power (P & Q) both**
	% Loss reduction	57.53	89.61
Scenario V (DG Integration followed by Network Reconfiguration)	Open Branches	50-63-13-34-24	24-64-27-34-49
	DG Location	43-48-36	59-47-55
	Size of DG (MW)	(0.754)-(1.561)-(0.770)	(0.595)-(1.089)-(0.936)
	DG operating pf	(1)-(1)-(1)	(0.91)-(0.93)-(0.92)
	P_{TL} (kW)	169.245	86.408
	Bus V_{min} (pu)	0.981 (60)	0.984 (43)
	% Loss reduction	56.78	77.93
Scenario VI (Simultaneous Network Reconfiguration and DG Integration)	Open Branches	34-27-13-50-24	56-33-28-13-49
	DG Location	32-47-37	48-26-37
	Size of DG (MW)	(1.036)-(1.937)-(0.793)	(0.464)-(1.007)-(0.816)
	DG operating pf	(1)-(1)-(1)	(0.89)-(0.95)-(0.97)
	P_{TL} (kW)	165.68	37.056 (27)
	Bus V_{min} (pu)	0.985 (60)	0.991 (27)
	% Loss reduction	57.69	90.54

Optimal Network Reconfiguration and Distributed Generation Integration for Power Loss Minimization and Voltage Profile Enhancement in Radial Distribution System

ORIGINALITY REPORT

15%
SIMILARITY INDEX

PRIMARY SOURCES

1	section.iaesonline.com Internet	79 words — < 1%
2	elibrary.tucl.edu.np Internet	63 words — < 1%
3	www.mdpi.com Internet	59 words — < 1%
4	www.tandfonline.com Internet	55 words — < 1%
5	A. Mohamed Imran, M. Kowsalya, D.P. Kothari. "A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks", International Journal of Electrical Power & Energy Systems, 2014 Crossref	47 words — < 1%
6	www.diplomarbeiten24.de Internet	46 words — < 1%
7	ir.jkuat.ac.ke Internet	45 words — < 1%