ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

NETWORK RECONFIGURATION IN DISTRIBUTION SYSTEM WITH CONSIDERATION OF DISTRIBUTED GENERATION

(CASE STUDY: ADDIS WEST DISTRIBUTION)

A THESIS SUBMITTED TO ADDIS ABABA INSTITUTE OF TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ELECTRICAL AND COMPUTER ENGINEERING (POWER ENGINEERING)

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DEDICATED TO

My beloved family and friends

Declaration

I, the undersigned, declare that this M.Sc. thesis is my original work, has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis are duly acknowledged.

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This thesis has been submitted for examination with my approval as a university advisor.

Advisor's Name: **Dr. Getachew Bekele** **Signature:** ______________

Abstract

In this thesis, a technique has been established for solving best distribution network reconfiguration with better placement of Distributed Generation (DG) to reduce power loss and to improve the voltage profile in the Addis west distribution system.

In the proposed method, a radial distribution power flow of the Addis West (ADW) is simulated for the developed radial distribution network power flow using Newton-Raphson (NR) method. Then an extensive network reconfiguration is performed on the developed radial distribution network using the Particle Swarm Optimization (PSO) algorithm. A MATLAB code is developed to determine the best reconfiguration and compare it with the original configuration in terms of voltage profile and total real power loss. Furthermore, a DG inserted version of the original configuration has been compared with the original configuration for its voltage profile as well as the total real power loss. DG size and location are determined using loss sensitivity factors with the forward-backward algorithm to calculate total power loss of the network and to identify the node loss sensitivity factors.

During simulation of the network reconfiguration, switches 34, 41, 52, 66 and 81 are found to be open while the rest of the switches are closed. Moreover, the suitable site and size of DG are found at bus numbers 45 and 57 with suitable size of 1.903 MW and 2.713 MW respectively. The real power loss in the network after reconfiguration with DG is reduced by 60.733% (i.e. 1146 kW to 450 kW). The minimum bus voltage is increased from 0.8491 p.u to 0.965 p.u. The total cost of the determined DG size was carried out by considering the steam-turbine DG type. Consequently, the total cost of the 4.616 MW DG installation is found to be $3,092,720 with its payback period of 9.3 years. Hence, the results show that the combination of network reconfiguration with the DG installation method in the distribution system is more effective in power loss reducing and improving the voltage profile of the system.

Keywords: *Distributed Generation, network reconfiguration, real power loss, voltage profile, PSO & Forward-Backward.*

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List of Acronyms

AADMP	Addis Ababa Distribution Master Plan
ADW	Addis west substation
AIS	Air Insulated Switchgear
DFR	Distribution feeder reconfiguration
DG	Distributed Generation
DSR	Distribution system reconfiguration
EA	Evolutionary Algorithm
EEA	Ethiopian Electricity Agency
EEP	Ethiopian Electric Power
EEU	Ethiopia Electric Utility
ESS	Energy supply Service
GA	Genetic Algorithm
G_{best}	Global best
GIS	Gas Insulated Switchgear
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineering
KV	Kilo Volt
KVA	Kilo Volt Ampere
KVAr	Reactive power
LSF	Loss Sensitivity Factor
LV	Low Voltage
MV	Medium Voltage
MVA	Mega Volt Ampere
MVAR	Reactive Power in Mega watts
MW	Real power in Mega Watts
P.U	Per Unit
P_{best}	Personal best
P_{DG}	Distributed Generation Real Power

P_{DG}	Real Power of DG
P_i	Active power injections i^{th} node
P_k	Active power at k^{th} bus
P_L	Total real power loss
P_L	Total real power loss
P_{LK}	Real Power of load at k^{th} bus
P_{loss}	Power loss
PQ	Load Bus
PSO	Particles Swarm Optimization
$P_{T,Loss}$	Total active power loss
P_V	Voltage Controlled Bus
Q_i	Reactive power load of i^{th} node
Q_k	Reactive power at k^{th} bus
Q_L	Total reactive power loss
Q_{LK}	Reactive Power of load at k^{th} bus
RES	Renewable Energy Source
R_k	Reactance at k^{th} bus
SW/St	Switching Station
V_i	V_i Voltage at i^{th} bus
V_k	Voltage at k^{th} bus
V_n	Receiving end voltage
V_o	Sending end voltage
VSI	Voltage Sensitivity Index
X	Reactance of the branch
X_k	Inductance at kth bus
Y	Admittance of the branch
Y_k	Admittance at kth bus
Z	Impedance of the branch

CHAPTER 1: Introduction

1.1 Overview

The electric power system is the key to industrial progress, which is important to the continual development in the standard of living of the people in the world. Normally, the power system network comprises electrical components that used to supply, transmit and distribute electric power. An example of an electric power system is the network that supplies a town and industry with the power – for large regions, this power system can be broadly separated into the generators that supply the power, the transmission line that carries the power from the generating centers to the load centers and the distribution system that supply the power to nearby households and industries.

Electricity distribution is the final phase in the delivery of electricity to end-users. The majority of the distribution system feeders are designed radially. Radial distribution feeders are delivered through a single voltage source (distribution substation). The main feeders branch into lateral and sub laterals, which finally connect to the customer service switches. The distribution system feeders consist of tie (normally-open) and sectionalizing (normally-closed) switches. These switches are used to enhance the distribution network consistency and to make sure continuous service for the majority of the load in the case of system faults. When a fault happens in the distribution system, the tie and sectionalizing switches can be coordinated so that the fault is separated and loads can be changed from one feeder to another, which minimizes the number of customers affected by the outage fault and reduce the restoration time. The operation of the tie and sectionalizing switches in the distribution system is referred to as network reconfiguration. It is one of the methods that has been applied for reducing losses in the distribution system. In 1975, Merlin and Back first proposed the theory of utilizing existing ties and sectionalizing switches to reconfigure the distribution system for minimizing line losses during a specific load condition [1].

The growing demand in the power system has posed a challenging task to power system engineers in maintaining a reliable and safe system cheaply. In the heavily loaded network, the load current drawn from the source would rise. This may lead to an increase in voltage drop and system losses. The performance of distribution system becomes inefficient due to the reduction in voltage magnitude and increase in distribution losses. Therefore, the operating cost will also increase. In this regard, changing environment of power systems design and operation have necessitated the need to consider active distribution network by incorporating Distributed Generations (DGs) sources [2]. The integration of DGs in distribution system would lead to improving the voltage profile, reliability improvement such as service restoration and uninterruptible power supply and increase energy efficiency. The distribution feeder reconfiguration (DFR) is one of the mainly significant control schemes in the distribution networks, which can be affected by the interconnection of DGs. Generally, the DFR is defined as varying the topological structure of distribution feeders by changing the open/closed status of sectionalization and tie switches so that the power losses is minimized, and the constraints are met [3].

Network reconfiguration changes the topological structure of the distribution system via changing the open/closed status of switches resulting in altering loads from the heavily loaded to the lightly loaded feeders while, at one time maintains the radial structure of distribution feeders. The difficulty of network reconfiguration is in general to place the optimal switching configuration, which results in minimum losses in the distribution system. Network reconfiguration is a challenging mission since there could be many probable combinations of sectionalizing switches and tie switches. Moreover, there are multiples of constraints, which must not be violated while finding the best (optimal) or near optimal solution to that problem.

However, due to the dynamic character of loads, total system load is more than its generation capacity that makes relieving of load on the feeders not possible and for this reason voltage profile of the system will not be recovered to the required level. In order to meet up required level of load demand, DG units are incorporated in the distribution network to improve the voltage profile, to give reliable and uninterrupted power supply and also to accomplish economic benefits such as minimum power loss, energy efficiency and load leveling. Yet, network reconfiguration and DG placement in distribution networks are considered as independent [4]. Studies have shown that inappropriate selection of the location and size of DG may lead to greater system losses without DG.

A lot of researchers studied network reconfiguration and DG placement problem using a variety of methods in the past decade. One of the recent and powerful soft computing techniques being developed is Particle Swarm Optimization (PSO) that is initially proposed by Dr. Eberhart and Dr. Kennedy in 1995 [5].

There are very few researchers who considered DFR with DG as mentioned in [6],[7]. This thesis proposes a network reconfiguration method for distribution network connected with the presence of DGs using the PSO algorithm. The proposed method is able to produce an optimum configuration in network distribution and at the same time yield the optimal size of DG and decrease power loss.

1.2 Background of the Study Area

The Addis west GIS substation is located in Addis Ababa around Kolfe Keranio Sub-City Woreda10 and it mainly has two voltage levels 132kV and 15kV. It contains three 132kv incoming lines, two 50MVA, 132/15kV transformer bays and twelve 15kV outgoing lines. The substation supplies residential, commercial and industrial customers.

There are 12 outgoing feeders in the substation namely, ADW-1, ADW-2, ADW-3, ADW-4, ADW-5, Reserve, LINE-07, LINE-08, LINE-09, LINE-10, LINE-11 and LINE-12 shown in figure below and see appendix-II.

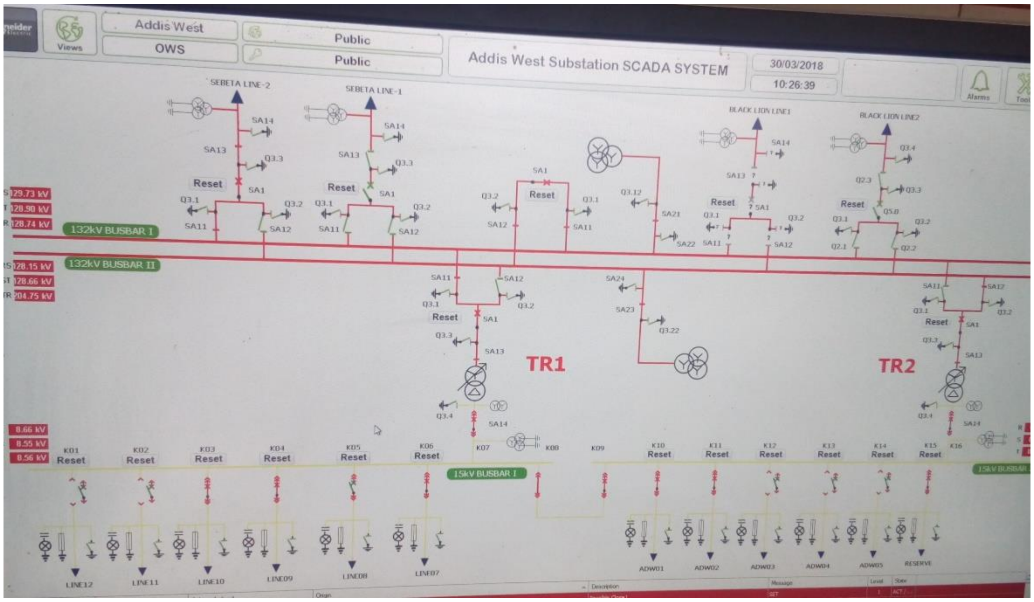


Figure 1-1: Addis West Substation SCADA system Feeder lines

1.2.1 Motivation of Distribution systems Reconfiguration (DSR)

As the demand for energy is increasing rapidly and the rise in the environmental concerns, the power utility has to struggle to find the best solutions to overcome the problem related to the increasing power losses in distribution feeder.

Electrical distribution systems link high voltage transmission systems and the end-consumers. They are often designed in a slightly meshed manner, but normally operated in a radial configuration because of a number of reasons such as the reduction of costs, straightforward coordination of protection systems, reduced occurrence of faults, better control power flows and voltage profile. Because of such reasons, maintaining the radial topology of the network systems is very critical. The reasons further explain the need for optimizations of distribution network systems to obtain the best radial topology [8].

For the system to work on a stable basis, it is desirable to increase its efficiency and reduce its operating costs. One way to achieve this is by minimizing losses [9]. Some techniques used to reduce system losses are increasing the voltage level, cable replacement, installation of condensers and/or distribution system reconfiguration (DSR). Among these techniques, the reconfiguration is the most attractive for the electricity distribution utility because it allows the use of resources that already exist in the system. Consequently, DSR can be implemented by changing the status of the switches that connect/disconnect the branches of the system, in order to obtain a radial topology [10],[11]. Reconfiguration can be done for numerous reasons, as in normal or emergency operation conditions.

1.2.2 Problems of the Distribution Network in Addis Ababa

- **Lack of Capacity:**

Capacity of transformer and distribution line is becoming overloaded because of rapid demand increases.

- **Poor Reliability and Quality of Supply:**

There are so many aged equipment and some devices are excessing standard lifespan. Maintenance is not properly done for many facilities. Frequent power outage can cause.

1.2.3 Distribution Loss

Distribution loss in Addis Ababa is assumed to be 20% to 22.7%. This value is quite high compared to international level of 12% to 13% [12].

On the other hand, EEU has a plan to improve distribution loss described in Table 1-1 through AADMP project.

Table 1-1: Improvement Objective of Distribution Loss [12].

Year	Technical Loss (%)	Non-Technical Loss (%)	Total (%)
2017	12.9	3.0	15.9
2034	8.0	1.0	9.0

1.3 Problem Statement

Usually, utility demand needs to consider the demands of power and those demands are from domestic and industrial factories which will give bigger impact to them in terms of economic factors. The reason is that in heavy loads, when the load current drawn from source increases, system losses will also increase which are also known as distribution losses. Distribution losses will lead to an inefficient performance of the distribution system.

Therefore, network reconfiguration in distribution systems is best for reducing distribution losses by finding the best (optimal) configuration of switches. Meanwhile, DGs are normally used in distribution systems to reduce the power disruption in the power system network. The total power loss of reconfiguration and the installation of DGs in the distribution network can be reduced and voltage profile of the basis of the system can be improved. Simultaneous optimization of reconfiguration and DG power allocation tasks can provide a more satisfying solution than separate optimization of each task. Most of the previous works in distribution system normally focused on a single optimization which may not be adequate for total improvement of the distribution network. For that reason, the use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer.

1.4 Objectives

1.4.1 General Objective

The main objective of this thesis is to reconfigure network in distribution system with consideration of optimal placement of distributed generation.

1.4.2 Specific Objective

- Load flow analysis of the distribution system.
- To implement a network reconfiguration method for distribution network without and with DGs connected.
- To size the distributed generators for reduction of total power loss and voltage profile improvement
- To identify the candidate nodes for the placement of distributed generators based on power loss and voltage profile problems.
- To produce best reconfiguration and DGs sizing together in the distribution network.

1.5 Scope of the Project

Scope of work focused is as follows:

- The investigation covers on the impact of network reconfiguration and DGs sizing on the real power losses and voltage profile in a radial distribution network.
- The modeling covers the model of a single-line diagram radial distribution system includes the radial structure and DGs size in improving the real power losses and voltage profile of the distribution network.

1.6 Constraints

Every configuration is a reasonable solution to the network reconfiguration problem. If all of the switches were put in the open state and all bus voltages set to zero, the real power losses in the system would also be zero, but a distribution system operated in this state would obviously cause the utility company to lose customers. So it is necessary to specify which states are feasible and which ones are not. As was mentioned earlier, this involves four types of constraints [13].

1. Topological constraints
2. Electrical constraints
3. Operational constraints
4. Load constraints

1.6.1 Topological Constraints

The topology or layout of the system is constrained to be the radial configuration which is typical in power distribution networks. This means that no loops are allowed in the network.

The network configuration is also constrained to be a connected topology such that each bus is connected via at least one path to the substation. The combination of these two requirements classifies the feasible topology as a spanning tree.

1.6.2 Electrical Constraints

Since a distribution system can be quite large, involving thousands of buses, the formulation of these constraints can be rather involved. This topic is treated in much more detail in three-phase power flow equations. This obviously must be disallowed. Each line, transformer, and switch in the system has a certain thermal limitation which restricts the maximum allowable current through that component. In general, these physical limitations can be accounted for by constraining line currents, the line flows, and bus voltages lie within appropriate bounds.

1.6.3 Operational Constraints

It is possible that the network configuration which theoretically minimizes the real power losses in the system might require one or several of the components in the system to be operated at a level beyond its physical limitations. Each line, transformer and switch in the system has a certain thermal limitation which restricts the maximum allowable current through that component. In general, these physical limitations can be accounted for by constraining line currents, the line flows, and bus voltages lie within appropriate bounds.

1.6.4 Load Constraints

The power company's customers have certain requirements for the electrical power they receive. The power company must be able to maintain a certain voltage level at each bus in the system while supplying the power demanded by each customer. This inequality constraint, which requires the voltage magnitude of each phase *p* at each bus *i* to lie in the appropriate range,

$$|V_{\min}| \le |V_i| \le |V_{\max}|$$

1.7 Thesis Outline

This thesis has been divided into five chapters and five appendices. Chapter 1 introduces thesis background in general, background of the case study, an explanation of the thesis objective, scope of work, motivation to do this thesis, thesis outline.

Chapter 2 describes theoretical background and literature review of electric distribution system. This Chapter also includes an explanation of what are network reconfiguration, Distributed Generation (DG) and recent ongoing effort for network reconfiguration and DG planning method. Network reconfiguration for distribution network connected with DGs

Chapter 3 Distribution system data collection and analysis of the case study area.

Chapter 4 includes the tabulated results of power loss reduction and voltage profile with their related diagrams and corresponding discussion.

Chapter 5 presents conclusions resulting from this study and recommendations for future works.

CHAPTER 2: Theoretical Background and Literature Review

2.1 Distribution System Reconfiguration

Due to its explicit benefits (mentioned earlier), there has been a growing number of literature on the DSR problems over the past years, and it still remains an actual working topic. Generally, the goal of network reconfiguration is not only to reduce power losses, but also to improve the voltage profile, network reliability and economic operations. Therefore, DSR aims to find the best topology of the system, taking into account power losses, energy demand, operational performance and other relevant determining factors.

Based on the solution techniques applied to solve DSR problems, the literature on DSR can be broadly classified into two categories: 1) mathematical techniques; 2) heuristic and metaheuristic techniques [14].

2.1.1 Mathematical Solution Techniques in DSR

In the literature, a number of techniques have been widely employed to solve DSR problems, such mixed-integer linear programming (MILP) [15], analytic hierarchic process (AHP) [16]. Nikolaos G. & Paterakis [17] proposed a MILP DSR optimization model, which is formulated as a multi-objective mathematical programming (MMP) problem. The objective function constitutes the minimization of the active power losses and the minimization of commonly used reliability indices, which are explicitly treated within the MILP formulation. In [18], Chen *et al.* presents the assessment of distribution network total supply capability (TSC) value modelled as an optimization problem. Gupta *et al.* [19] suggest a new MILP model which combines power and reliability objectives into a single objective function. A real time configuration based on load rate analysis is proposed by Pfitscher *et al.* [20].

The mathematical techniques have been less commonly used mainly due to computational limitations. However, this model has been changing with increased processing capability of computing machines in addition to the new processing styles that have been developed recently such as cloud computing. Heuristics and metaheuristics techniques have been employed in recent years. Several of these techniques are combined in order to achieve the best characteristic of each technique.

2.1.2 Heuristic and Metaheuristic Solution Techniques in DSR

The computational complexity of the DSR problem (mainly due to its combinatorial, non-convex and nonlinear nature) has led to the extensive use of heuristic and metaheuristic techniques in the literature by researchers. Some of these methods which have been widely used to solve the aforementioned problem include Genetic Algorithm (GA) [21], Particle Swarm Optimization (PSO) [22]. For automated reconfiguration with the aim of determining the optimal network configuration that leads to the minimum power losses and/or the maximum system reliability, it has been used a GA for solving a DSR problem with the purpose of minimizing real power losses while satisfying several system operating constraints [23],[24].

In [25],[26] the DSR optimization is formulated as a single objective problem, incorporating only the active power losses minimization. To find the best or near-best configuration, each candidate configuration is analyzed in two steps. First, the candidate topology is assessing whether or not it is a valid radial configuration. Second, if the first condition is fulfilled, a power flow module is run from which steady state variables are determined. The meshed heuristic algorithm has been developed by Mena and García [26]to solve the reconfiguration problem with an objective function of network losses minimization. Abul'Wafa [27] propose a heuristic approach, embedded in a load flow algorithm that gives precise branch currents, node voltages and system power losses. Sahoo and Prasad [28] consider voltage stability as the objective function, and the resulting DSR problem is solved using a fuzzy GA. Minimize losses via reconfiguration, which is solved using a generic GA. The GA technique is based on the creation of an initial population of feasible individuals. A fuzzy mutated GA is proposed by Siano P. and Wallace [29] for reconfiguration of distribution systems with a new chromosome representation of the network and a fuzzy mutation control.

Radial network has some advantages than other network because it has lower short circuit currents and simpler switching and protecting equipment's [10].

2.2 Overview of Distributed Generation

As mentioned in the previous section, DSR can be characterized as changing the positions of various switches that connect/disconnect the branches of the system in order to obtain a radial topology which improves overall system performance and efficiency.

The subsequent topology, yet, depends on many input parameters and needs to be updated on a daily, monthly, or periodic basis to adjust to the changes in the system operating condition. With increased penetration of variable renewable Distributed Generation (DG), one is more likely to experience constantly changing system conditions. As a result, the need for network reconfiguration increases because this enhances the flexibility of the system, which is useful to handle with operational variations.

Distributed generation is an alternative, ways to solve the ever increasing environmental concerns and demand of energy [30]. DG means integrating small generators in a distribution system in order to meet the required level of load demand, thereby improving the voltage profile, increasing lifespan of system equipment, provide reliable and economic benefit such as minimum power losses and energy efficiency. It is important as it makes use of renewable energy as well as non-renewable energy. Significant impact of installing distributed generations on voltages, load demand, power loss and system reliability make it as the key issue for distribution system planning in a power system environment [31]. DG placement is very important for the efficiency of the system.

The purpose of distributed generation (DG) placement in distribution system is to connect distributed generating units, generally based on non-conventional energy sources, at end consumers. According to the International Energy Agency (IEA), there are five key factors that have significantly increased interest in distributed generations: 1) development in DG technologies, 2) constraints on construction of new transmission lines, 3) increased customer demand for highly reliable electricity, 4) electricity market liberalization and 5) concerns about climate change.

Distributed generation (DG) implies the placement of small generation units (from 1kW to 1MW) connected to the distribution network and close to the end-consumers [32]. In addition, unlike conventional electrical networks that have unidirectional power flow, the introduction of DG leads to a bidirectional power flow.

Technical, economic and environmental advantages, as well as the disadvantages of DG integrations are presented [33],[32].

DG is classified in renewable energy sources (RES) and non-renewable energy sources. RES-based DGs are classified as photovoltaic (PV), wind, hydro, geothermal, tidal and biofuel. Some of the advantages of integrating DGs [34],[35] are listed here below. Distributed networks have been designed to handle the unidirectional power flow. The introduction of DGs can have a positive or negative impact on the distribution network systems [33],[32]. The main negative impacts include:

- Integration of DGs can result in overvoltage issues. This is not a problem when DG is connected to a system with low voltage issues. However, for weakly loaded systems, DG integration may result in high voltage problems interfering with standard voltage regulation practices. RES based DGs can especially degrade the voltage profile due to their irregular nature.
- The impact on protection co-ordination given that the power grids are designed to operate for unidirectional power flow.
- The impact on harmonics as a result of integrating RES based DGs, which often require power electronic interfaces, major sources of harmonics injected into the system.
- The impact on reactive power management can be an issue with DG units which are incapable of providing reactive power. Hence, if DG units are not properly located

and sized, they can have negative effects on the system. When connected to the network, various DG technologies can lead to high levels of reliability and security issues [33],[32].

Despite the steady growth of DG systems in recent years, there are still certain barriers (technical, economic, regulatory) that restrict progress towards a new model of electric networks [32].

2.2.1 Importance of DG

The main motive behind applying DGs in the power distribution are energy efficient or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of sectional generating plant, ease of finding locations for smaller generators, shorter construction time and lower capital costs for smaller plants, and proximity of the generation plant to heavy loads, which can reduce the transmission costs. The DG when connected to network can provide a number of benefits. Some of the benefits are power loss reduction, energy undelivered cost reduction, preventing or delaying network expansion [36],[37]. Other benefits are peak load operating cost reduction, improved voltage profile and improved load factors [38]. In addition to providing benefits, DG can also have negative impacts on the network. These impacts include frequency deviation, voltage deviation and harmonics on network [39]. The increase of power losses is another effect that may occur [36, 40]. Thus, careful considerations need to be taken when sizing and locating DGs in distribution systems.

2.3 DG Location and Sizing Issues

The following few paragraphs present review of models, methods and future research on optimal DG placement in electrical distribution systems. Typically, the DG allocation is a complex optimization problem that deals with the optimal planning of DGs in existing distribution networks while respecting a number of technical, economic and environmental constraints. Such an optimal work should lead to the optimal location and size as well as the installation timing of DGs. The DG planning, optimization problem is usually difficult to solve using traditional mathematical methods because it is a nonlinear, non-convex and combinatorial problem [41].

If the size of DG is further increased, the losses start to increase and it is likely that it may overshoot the losses of the base case. Also notice that the location of DG plays an important role in minimizing the losses. It is not advisable to construct sufficiently high DG in the network. The size at most should be such that it is consumable within the distribution substation boundary. Any attempt to install high capacity DG with the purpose of exporting power beyond the substation (reverse flow of power through distribution substation), will lead to very high losses [42]. The reason for higher losses and high capacity of DG can be explained by the fact that the distribution system was initially designed such that power flows from the sending end (source substation) to the load and conductor sizes are gradually decreased from the substation to consumer point. Thus, without reinforcement of the system, the use of high capacity DG will lead to excessive power flow through small sized conductors and hence results in higher losses.

However, existing technique such as loss sensitivity method finds the location issue before and sizing issues. This methodology requires load flow to be carried out only twice, once for the base case and once at the end with DG included, to obtain the final solution [43].

A multi-objective algorithm using GA for sitting and sizing of DG in distribution system presented [44]. Proposed an analytical method to determine optimal location to place a DG in distribution system for power loss minimization. A methodology for multiple DG placements in primary distribution systems presented [45].

2.4 Simultaneous Network Reconfiguration & DG Placement

A number of approaches and methods have been proposed in the literature for simultaneously restructuring of distribution network, and placement and sizing of DGs. The majority of the previous work aim to reduce active power losses and improve the voltage profile [46]. The solution methods applied for solving the problems can be broadly classified as 1) mathematical, 2) heuristic and meta-heuristic 3) hybrid types [14].

In the heuristic and meta-heuristic solution techniques category, a uniform voltage distribution based constructive reconfiguration algorithm (UVDA) [47], GA [48], artificial immune system (AIS) [36], harmony search algorithm (HSA) [40], ant colony algorithm (ACA) [7]. Bayat [47] propose a new heuristic method base on UVDA for simultaneously optimizing reconfiguration with DG siting and sizing with the aim of minimizing losses. Implements an algorithm which predicts the optimum reconfiguration plan for power distribution system with multiple PV generators. A genetic algorithm is used to solve the resulting problem and forward, backward load flow method is implemented to consider time varying load conditions [49]. Jangir *et al.* [50] propose a methodology for determining optimal placement and sizing of DG units to minimize the cost of annual energy losses, and also to enhance node voltage profiles of the system. The optimal DG allocation problem is solved using MPSO algorithm whose control parameters is varied with iteration in order to improve its performance. S. Sirisumrannukul [46b] presents a methodology for DSR considering different types of DGs with an overall objective of minimizing real power losses. Rao *et al.* [4] proposes a new methodology to solve the network reconfiguration problem in the presence of distributed generation (DG) with an objective of minimizing real power losses and improving voltage profile in distribution systems. A metaheuristic HSA is used to simultaneously reconfigure and identify the optimal locations for installing DG units in a distributed network system. Sensitivity analysis is used to identify the optimal locations of DG units. Different scenarios of DG placement and network reconfiguration are considered to study the performance of the proposed method. The proposed method finds the optimal network reconfiguration and optimal size of DG simultaneously. Esmaeilian and Fadaeinedjad [43] present a novel hybrid method of metaheuristic and heuristic algorithms to solve distribution network reconfiguration in the presence of DGs, especially considering solar PV type DGs. The solution method, according to the authors, is capable of boosting robustness and reducing the computational time. Maciel *et al.* [13] report a broad comparison of different meta-heuristics solution techniques applied on multi objective problems.

Applying reconfiguration with DG installation in the PSO method, the amount of power loss is improved. But the same application done on the GA method has given lower improvement. Thus, the proposed PSO method in this paper has improved greater power loss as compared to GA method. In addition, the reading of power loss from PSO method after reconfiguration with DG is less than a GA method. From the perspective of power losses, PSO impacted positively in the analyzed distribution network. Comparing the CPU time, PSO method elapsed faster than GA method [51].

The PSO shows a great difference after reconfiguration with DG. Since the PSO gives the fastest solution compared to others and its performance is better than traditional methods, it can be concluded that PSO is a superior method in reconfiguration with DG process [52].

The results of the proposed algorithm are compared with a GA method for the analysis and simulation of the results, the overall perspectives between the two methods show that the PSO result betters than GA in this application. PSO has shown great improvement in term of processing time, number of iterations to reach the optimal value of power losses and the optimum value of DG sizing. From the simulation results indicated that the optimal on/off patterns of the tie line can be identified which give the minimum power loss while keeping bus voltage magnitudes within the acceptable limits. Based on these reasons, it is strongly expected that PSO is capable of solving large-scale problems arose in network reconfiguration as compared to the existing methods [52].

2.5 Mathematical Model

Based on the literature review PSO shows a great difference after reconfiguration with DG. Since the PSO gives the fastest solution compared to others and its performance is better than traditional methods, it can be concluded that PSO is a superior method in reconfiguration with DG process.

Network reconfiguration problem in a distribution system is to find a better configuration of radial network that gives minimum power loss while the imposed operating constraints are satisfied, which are voltage profile of the system, current capacity of the feeder, and radial structure of the distribution system. The penetration of DG may impact the operation of a distribution network in both beneficial and detrimental ways. Some of the positive impacts of DG are: voltage support, power loss reduction, support of additional services and improved reliability. In distribution network the number of such switching options is very large.

The problem of determining the status of the network switches, therefore, when formulated as a non-linear optimization techniques. The forward and backward power flow techniques have been suggested to solve the reconfiguration problem. In this thesis presents a PSO for reconfiguration of unstable radial distribution systems for loss minimization. The main contribution of this work is to present an approach to finding the best solution of feeder reconfiguration in unstable loading distribution systems with the objective of power loss reduction. A simple method is developed for determining the open/closed status of sectionalizing and tie switches to achieve minimum loss reduction.

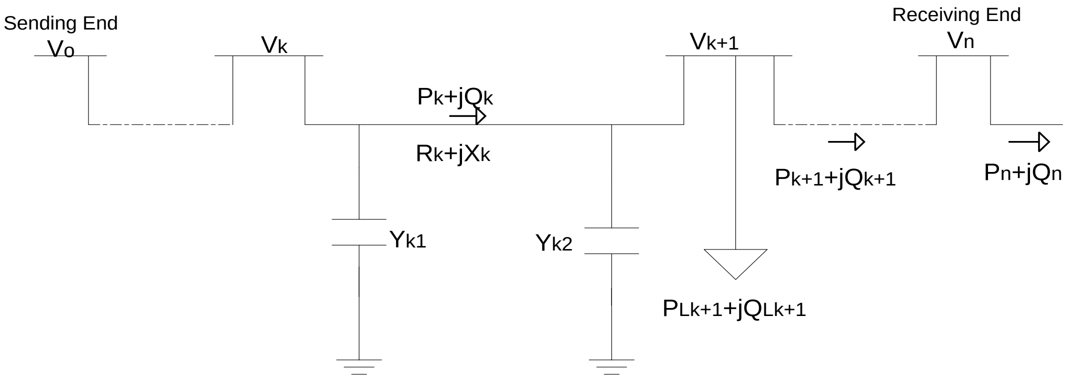


Figure 2-1: Single line diagram of a main feeder [53].

2.6 Problem Formulation

2.6.1 Power Flow Equations

Power flows in a distribution system are computed by the following set of simplified recursive equations (13) derived from the single-line diagram shown in Figure 2-1 [53].

$$P_{K+1} = P_K - P_{loss,K} - P_{LK+1} = P_K - \frac{R_K}{|V_K|^2}\left\{P_K^{\ 2} + \left(Q_K + Y_K |V_K|^2\right)^2\right\} - P_{LK+1} \tag{2.1}$$

$$Q_{K+1}=Q_K-Q_{loss,K}-Q_{LK+1}=Q_K-\frac{X_K}{|V_K|^2}\left\{P_K^{\,2}+\left(Q_K+Y_{K1}|V_K|^2\right)^2\right\}-Y_{K1}\,|V_K\,|^2-Y_{K2}\,|V_{K+1}|^2-Q_{LK+1} \qquad (2.2)$$

$$|V_{K+1}\,|^2=|V_K\,|^2+\frac{R_K^{\;2}+X_K^{\;2}}{|V_K\,|^2}\left(P_K^{\;2}+Q_K^{\;2}\right)-2(R_KP_K+X_KQ_K) \qquad (2.3)$$

$$=V_K^{\;2}+\frac{R_K^{\;2}+X_K^{\;2}}{|V_K\,|^2}\left(P_K^{\;2}+\left(Q_K+Y_K|V_K\,|^2\right)^2\right)-2(R_KP_K+X_K(Q_K+Y_K\,|V_K\,|^2))$$

The power loss in the line section connecting buses k and k+1 may be computed as

$$P_{Loss}\left(k,k+1\right)=R_k\,\frac{(P_k^{\;2}+Q_k^{\;2})}{|V_k\,|^2} \qquad (2.4)$$

The total loss of the feeder, $P_{T,\,LOSS}$, may then be determined by the feeder, which is given as,

$$P_{T,Loss}=\sum_{k=1}^{n}P_{Loss}(k,k+1) \qquad (2.5)$$

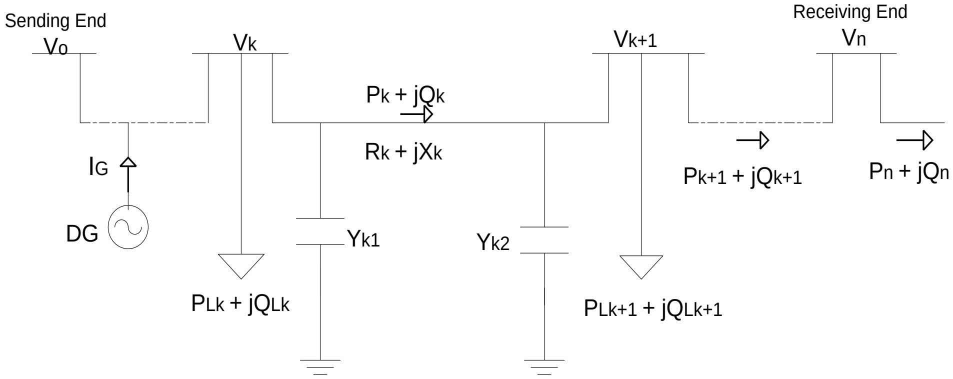


Figure 2-2: Distribution System with DG installation at an arbitrary location [53].

2.6.2 Power Loss using Network Reconfiguration

The network reconfiguration problem in a distribution system is to find a better configuration of radial network that gives minimum power loss while the imposed operating constraints are satisfied, which are voltage profile of the system, current capacity of the feeder and radial structure of the distribution system. The power loss of a line section connecting buses between k and k+1 after reconfiguration of the network can be computed as [53].

$$P^{'}_{Loss}\left(k,k+1\right)=R_k\,\frac{(P_k^{'2}+Q_k^{'2})}{|V_k^{'}|^2} \tag{2.6}$$

The total power loss of the feeder $P'_{T,Loss}$ can be determined by summing up the losses of all line sections of the network, which is written as,

$$P^{'}_{T,Loss}=\sum_{k=1}^{n}P^{'}_{Loss}(k+1) \tag{2.7}$$

Net power loss reduction, ΔP^{R}_{Loss} in the system is the difference of power loss before and after reconfiguration, that is equation (2.5) - equation (2.7) and is given by,

$$\Delta P^{R}_{Loss}=\sum_{k=1}^{n}P_{T,Loss}(k,k+1)-\sum_{k+1}^{n}P^{'}_{T,Loss}(k,k+1) \tag{2.8}$$

2.6.3 Power Loss Reduction using DG Installation

Installation of distribution generation units in optimal locations of a distribution system results in several benefits. These include reduction of line losses, improvement of voltage profile, peak demand shaving, relieving the overloading of distribution lines, reduced environmental impacts, increased overall energy efficiency, and deferred investments to upgrade existing generation, transmission, and distribution systems. The power loss when a DG is installed at an arbitrary location in the network as shown in Figure 2-2, is given by,

$$P_{DG,Loss}=\frac{R_K}{V_k^2}(P_K^2+Q_k^2)+\frac{R_k}{V_k^2}(P_G^2+Q_G^2-2P_kP_G-2Q_kQ_G)\left(\frac{G}{L}\right) \tag{2.9}$$

Net power loss reduction, ΔP_{Loss}^{DG}, in the system is the difference of power loss before and after installation of DG unit, that is equation (2.9) – equation (2.14) and is given by

$$\Delta P_{Loss}^{DG} = \frac{R_k}{V_k^2}\left(P_G^2 + Q_G^2 - 2P_k P_G - 2Q_k Q_G\right)\left(\frac{G}{L}\right) \tag{2.10}$$

The positive sign of ΔP_{Loss}^{DG} indicates that the system loss reduces with the installation of DG. In contrast, the negative sign of ΔP_{Loss}^{DG} implies that DG causes the higher system losses [53].

2.6.4 Objective Function of the Problem

The objective function of the problem is formulated to maximize the power loss reduction in distributed system, which is given by [53].

$$\text{Maximize } f = \max\left(\Delta P_{Loss}^{R} + \Delta P_{Loss}^{DG}\right) \tag{2.11}$$

$$\text{Subjected to } \left.\begin{cases} V_{\min} \le |V_k| \le V_{\max} \\ \left|I_{k,k+1}\right| \le \left|I_{k,k+1,\max}\right| \\ \sum_{k=1}^{n} P_{Gk} \le \sum_{k=1}^{n}\left(P_k + P_{Loss,k}\right) \end{cases}\right\} \tag{2.12}$$

$$\left.\begin{array}{l} \det(A) = 1 \text{ or } -1 \text{ (radial system)} \\ \det(A) = 0 \text{ (not radial)} \end{array}\right\} \tag{2.13}$$

2.6.5 Sensitivity Analysis for DG Installation

Sensitivity analysis is used to compute sensitivity factors of candidate bus locations to install DG units in the system. Estimation of these candidate buses helps in reduction of the search space for the optimization procedure. Consider a line section consisting an impedance of $R_k + jX_k$ and a load of $P_{Lk,eff} + jQ_{Lk,eff}$ connected between k-1 and k buses as given below [54].

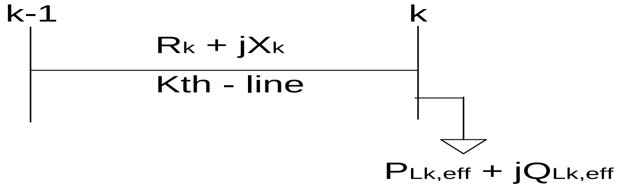


Figure 2-3: Line section of distribution system [54].

Active power loss in the kth -line between k and k-1 buses is given by

$$P_{lineloss} = \frac{(P_{Lk,eff}^2 + Q_{Lk,eff}^2)R_k}{V_k^2} \tag{2.14}$$

Now, the loss sensitivity factor (LSF) can be obtained by the equation

$$\frac{\partial P_{lineloss}}{\partial P_{Lk,eff}} = \frac{2 * P_{Lk,eff} * R_k}{V_k^2} \tag{2.15}$$

Using equation (2.15) LSFs is computed from load flows and values are arranged in descending order for all buses of the given system. It is worth to note that LSFs decide the sequence in which buses are to be considered for DG unit installation. The size of the DG unit of candidate bus is calculated using PSO.

As stated above, the main objective of this thesis is to find its actual size of distributed generation while minimizing the power losses in the distribution system. The voltage constraints also took into consideration as to validate that the minimum and maximum voltage will not be exceeded.

Both techniques are combined with each other to get a minimum active power loss in the distribution system. Therefore, minimum power losses can be calculated based on the formulation as follows.

$$P_{Loss} = \sum_{t=1}^{N_{line}} |I_t|^2 k_t R_t \tag{2.16}$$

Where,

t : line number

I_t : current of line *t*

R_t : Resistance of line *t*

N_{line} : total line

k_t : variable represents the topology status of line t (1=close, 0 = open)

The general power system constraints that applied in the analysis are:

a) Generator operation constraint:

$$P_k^{\min} \le P_{dg,k} \le P_k^{\max} \qquad (2.17)$$

The value of active power generation ($P_{dg,k}$) at DG_k (k = 1, 2..total DG) should be within $P_k^{\min}$ and $P_k^{\max}$ which represents the lower and upper bound of DG output, and for analysis involving DG units, the DG sizing are within this limit and must not be exceeded.

b) Power injection constraint

$$\sum_{k=1}^{N_{dg}} P_{dg,k} < P_{load} + P_{losses} \qquad (2.18)$$

Where,

N_{dg} : total number of DG

In the effort of avoiding power injection from DG unit for its main grid (substation), the DG output can’t be more than the total load and the total power losses as formulated below.

c) Power balance constraint:

$$\sum_{k=1}^{N_{dg}} P_{dg,k} + P_{substation} = P_{load} + P_{losses} \tag{2.19}$$

The sum amount of power of DG unit ($P_{dg,\mathrm{k}}$) and substation ($P_{substation}$) must be equal to the total sum of power load (P_{load}) and power losses (P_{losses}).

d) Voltage bus constraint:

$$V_{\min} \le V_{bus} \le V_{\max} \tag{2.20}$$

The amount of voltage for each bus should be operated as in equation (2.20) within the range of 1.05 and 0.95 ($\pm$ 5%).

e) Radial configuration constraints:

The network configuration must be in radial form to avoid excessive current flow in the system. Several constraints need to take into account to ensure the radial network is maintained. Few rules have been adopted for the selection of switches. Closed switches that do not belong to the loop, connected to the sources and contributed to a meshed network.

2.7 Optimal Placement & Size of DG in Distribution Networks

2.7.1 Loss Sensitivity Factor

The loss sensitivity factor is used for the placement of DG is explained as, the real power loss in the system is given by the equation (2.21).This formula is popularly referred as “Exact Loss” formula [55].

$$P_L = \sum_{\substack{i=1 \\ j=1}}^{N} [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j + P_i Q_j)] \tag{2.21}$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{v_{ij}} \cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{x_{ij}}{v_{ij}} \sin(\delta_i - \delta_j)$$

$z_{ij} = r_{ij} + jx_{ij}$ are the **ij**$_{\text{th}}$ element of **[Z$_{\text{bus}}$]** matrix, $P_i = P_{Gi} - P_{Di}$ & $Q_i = Q_{Gi} - Q_{Di}$

P_{Gi} & Q_{Gi} are power injection of generators to the bus P_{Di} & Q_{Di} are the loads P_i & Q_i are active and reactive power of the buses.

The sensitivity factor of real power loss with respect to real power injection from the DG is given by,

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\alpha_{ii} P_i + 2\sum_{\substack{j=1 \\ j \neq i}}^{N} (\alpha_{ij} P_j - \beta_{ij} Q_j) \tag{2.22}$$

Sensitivity factor is evaluated at each bus by using the values obtained from the base case load flow. The bus having lowest loss sensitivity factor will be the best location for the placement of DG [56]. Conventional load flow studies, like Gauss seidal, Newton Raphson and fast decoupled load flow methods are not suitable for distribution load flows because of the high R/X ratio. A load flow method for distribution systems, i.e. backward sweep and forward sweep method for load flow that offers better solution was proposed [55].

2.7.2 DG Size Limits

To have a considerable impact of DG on the system and to avoid voltage rise problem, constraints are imposed on DG sizes.

Active power generated by DG is limited as

$$DG_{p_{\min}} \leq DG_{p_i} \leq DG_{p_{\max}} \tag{2.23}$$

DG at any bus is assumed to generate the active power within the limits given above. DG_{Pmin} is the minimum active power of DG and is set as the 25 % of the total active power load on the system. DG_{Pmax} is the maximum active power of DG and is set as the 80 % of the total active power load on the system.

And reactive power generated by DG is limited within the following limits

$$DG_{Q_{\min}} \le DG_{Q_i} \le DG_{Q_{\max}} \tag{2.24}$$

DG_{Qmin} is the minimum reactive power of DG and is set as the 25 % of the total reactive power load on the system. DG_{Qmax} is the maximum reactive power of DG and is set as the 80 % of the total reactive power load on the system [57].

2.7.3 Best Sizing of DG:

The total power loss against injected power is a parabolic function and at minimum losses, the rate of change of losses with respect to injected power becomes zero [58].

$$\frac{\partial P_L}{\partial P_i} = 2\alpha_{ii} P_i + 2\sum_{\substack{j=1 \\ j\neq i}}^{N} (\alpha_{ij} P_j - \beta_{ij} Q_j) = 0 \tag{2.25}$$

It follows that

$$P_i = \frac{1}{\alpha_{ii}} \left[\sum_{\substack{j=1 \\ j\neq i}}^{N} (\alpha_{ij} P_j - \beta_{ij} Q_j) \right] \tag{2.26}$$

Where $\boldsymbol{P_i}$ is the real power injection at node $\boldsymbol{i}$, which is the difference between real power generation and the real power demand at that node:

$\boldsymbol{P_i = (P_{DGi} - P_{Di})}$

Where $\boldsymbol{P_{DGi}}$ is the real power injection from ***DG*** placed at node $\boldsymbol{i}$, and $\boldsymbol{P_{Di}}$ is the load demand at node $\boldsymbol{i}$. By combining the above, we get.

$$P_{DGi} = P_{Di} - \frac{1}{\alpha_{ij}}\left[\sum_{\substack{j=1\\ j\neq i}}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right] \tag{2.27}$$

The equation (2.27) gives the best size of ***DG*** for each bus ***i***, for the loss to be minimized. Any size of ***DG*** other than $\boldsymbol{P_{DGi}}$ placed at bus ***i***, will lead to higher loss.

2.8 Best Location of DG

After finding the optimal size of DG at each bus, the next step is to find the best location of DG, which will give the lowest possible total losses. The bus having less power loss will be the optimal location for the placement of DG [59].

2.8.1 Candidate Node Selection using Loss Sensitivity Factors

The Loss Sensitivity Factors ($\frac{\partial \mathrm{Plineloss}}{\partial \mathrm{Qeff}}$) are calculated from the base case load flows and the values are arranged in descending order for all the lines of the given system. Sensitivity factor is evaluated at each bus by using the values obtained from the base case load flow. The bus having lowest loss sensitivity factor will be the best location for the placement of DG [54].

2.9 Single Phase Representation of a Balanced Three Phase System

The power system has three phases. These three phases can be either balanced or unbalanced. A balanced three phase network can easily be represented by a single phase equivalent circuit. This equivalent single phase circuit can be used to analyze the three phase system. The parameters (current, voltage, impedance, etc.) of the three phase networks can be estimated using the single phase equivalent circuit [60]. Figure 2-3 shows a simple, balanced three phase network. As the network is balanced, the neutral impedance Zn does not affect the behavior of the network. Figure 2-4 gives the single phase equivalent of a balanced three phase network of Figure 2-3 as the system is balanced, the voltage and currents in the other phases have the same magnitude but are shifted in phase by 120^0 [60].

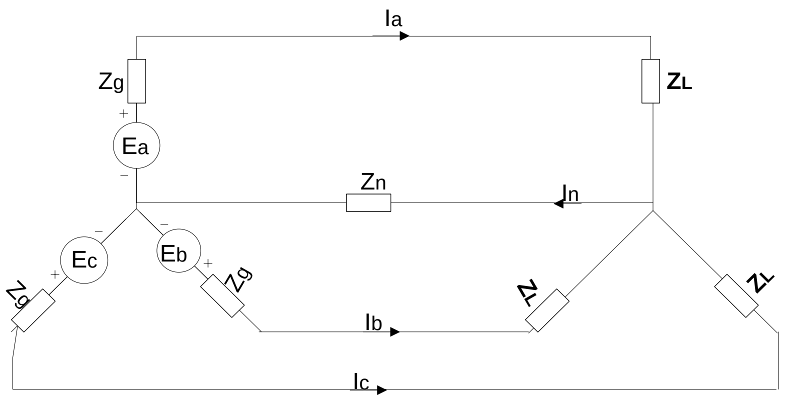


Figure 2-3: Balanced Three Phase Network [60].

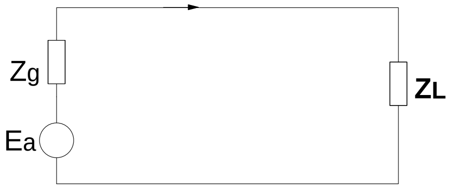


Figure 2-4: Single Phase Representation of Balanced Three Phase Network [60].

For the reference phase a;

$$E_a = (Z_g + Z_L)I_a \tag{2.28}$$

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

2.9.1 Per-Unit (pu) System

The per-unit system of analysis is based on the application of Ohm's law to a single impedance or admittance as illustrated in Figure 2-5 Using actual physical units of kilovolts (kV), kilo-amps (kA), ohms (Ω) and Siemens (S) the voltage drop across the impedance and injected current into the admittance are given by equation (2.29) and equation (2.30) respectively [61].

$$V_{Actual.KV} = Z_{Actual.\Omega} * I_{Actual.KA} \tag{2.29}$$

$$I_{Actual.KA} = Y_{Actual.\Omega} * V_{Actual.KV} \tag{2.30}$$

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

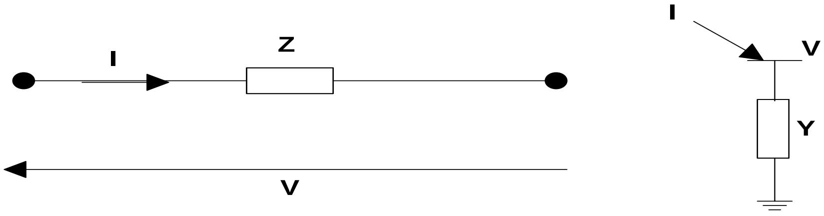


Figure 2-5: Per-Unit Analysis of a single-phase impedance & admittance Connections [61].

Firstly, Let $V_{Base,kV}$ and $I_{Base,kA}$ be the base voltage and base current, respectively. Therefore, equations (2.29) and (2.30) can be written as equations (2.31) and (2.32) or (2.33) and (2.34) respectively [61].

$$\frac{V_{Actual.KV}}{V_{Base.KV}} = \frac{Z_{Actual.\Omega}}{\frac{V_{Base.KV}}{I_{Base.KA}}} * \frac{I_{Actual.\Omega}}{I_{Base.KA}} \tag{2.31}$$

$$\frac{I_{Actual.KA}}{I_{Base.KA}} = \frac{Y_{Actual.S}}{\frac{I_{Base.KA}}{V_{Base.KV}}} * \frac{V_{Actual.kv}}{V_{Base.KV}} \tag{2.32}$$

$$V_{pu} = Z_{pu} * I_{pu} \tag{2.33}$$

$$I_{pu} = Y_{pu} * V_{pu} \tag{2.34}$$

Where,

$$V_{pu} = \frac{V_{Actual.kv}}{V_{Base.kv}} \tag{2.35}$$

$$I_{pu} = \frac{I_{Actual.KA}}{I_{Base.KA}} \tag{2.36}$$

$$Z_{pu} = \frac{Z_{Actual.\Omega}}{Z_{Base.\Omega}} \tag{2.37}$$

$$Z_{Base.\Omega} = \frac{V_{Base.KV}}{I_{Base.KA}} \tag{2.38}$$

$$Y_{pu} = \frac{Y_{Actual.S}}{Y_{Base.S}} \tag{2.39}$$

$$Y_{Base.S} = \frac{I_{Base.KA}}{V_{Base.KV}} = \frac{1}{Z_{Base.\Omega}} \tag{2.40}$$

$Z_{Base\Omega}$, and $Y_{Base,S}$ are also defined as shown in equations (2.38) and (2.40) respectively, likewise the per-unit expression for the product of the actual voltage and current is defined in equation (2.41). It should be noted that the base quantities $V_{Base,kV}$ and $I_{Base,kA}$ are defined as real numbers so that the phase angles of V_{pu} and I_{pu} remain unchanged from $V_{Actual,kV}$ and $I_{Actual,kA}$, respectively, using equation (2.42), we have [61].

$$V_{Actual.KV} * I_{Actual.KA} = V_{Base.KV} V_{pu} * I_{Base.KA} I_{pu} \tag{2.41}$$

$$V_{pu} * I_{pu} = \frac{V_{Actual.KV} * I_{Actual.KA}}{V_{Base.KV} * I_{Base.KA}} \tag{2.42}$$

$$MVA_{pu} = \frac{MVA_{Actual}}{MVA_{Base}} \tag{2.43}$$

$$MVA_{Actual} = V_{Actual.KV} * I_{Actual.KA} \tag{2.44}$$

$$MVA_{Base} = V_{Base.KV} * I_{Base.KA} \tag{2.45}$$

$$MVA_{pu} = V_{pu} * I_{pu} \tag{2.46}$$

It is noted that by defining $V_{Base,kV}$ and $I_{Base,kA}$, MVA_{Based} is also defined according to the equation (2.45). In practical power system analysis, it is more convenient to define or choose MVA_{Base} and $V_{Base,kV}$ and calculate $I_{Base,kV}$ if required. Therefore, using equations (2.35), (2.36) and (2.45), equations (2.47) and (2.48) can be obtained [61].

$$I_{pu} = \frac{I_{Actual.KA}}{MVA_{Actual} / V_{Base.KV}} \tag{2.47}$$

$$Vpu = \frac{V_{Actual.KV}}{MVA_{Actual} / I_{Base.KA}} \tag{2.48}$$

Also, using equations (2.48) and (2.45), equations (2.49) and (2.50) can be written [61].

$$Z_{Base.\Omega} = \frac{V_{Base.KV}}{I_{Base.KA}} * \frac{V_{Base.KV}}{V_{Base.KA}} = \frac{(V_{Base.KV})^2}{MVA_{Base}} \tag{2.49}$$

$$Y_{Base.S} = \frac{1}{Z_{Base.\Omega}} = \frac{MVA_{Base}}{(V_{Base.KV})^2} \tag{2.50}$$

Substituting equation (2.49) into equations (2.37) and equation (2.50) into equation (2.38), equation (2.51) can be obtained [61].

$$Z_{pu} = \frac{Z_{Actual.\Omega}}{\left((V_{Base.KV})^2 / MVA_{Base} \right)} \tag{2.51}$$

$$Y_{pu} = \frac{Y_{Actual.S}}{\left(MVA_{Base} / (V_{Base.KV})^2 \right)} \tag{2.52}$$

To convert per-unit values to per cent, the per-unit values are multiplied by 100 [61].

2.10 Newton-Raphson method

The load flow program solves for the set of unknowns that produces power balance at all busses,

$$P_i^{spec} + jQ_i^{spec} = P_i^{cal} + jQ_i^{cal} \tag{2.53}$$

Where,

$$P_i^{cal} + jQ_i^{cal} = V_i I_i^* \tag{2.54}$$

In other words, the power specified at each bus must equal the power flowing into the system. Since there are two unknowns at every bus, the size of the load flow problem is 2*N*, where *N* is the number of busses. Obviously, to solve the problem, there must be two equations for every bus. These come from KCL, which for any bus *i* have the form,

$$P_i^{spec} + jQ_i^{spec} = P_i^{cal} + jQ_i^{cal} = V_i I_i^* = V_i \left[\sum_{j=1}^{N} y_{i,j} V_j \right] \tag{2.55}$$

Separating into real and imaginary components yields two equations for the bus *i*,

$$P_i^{spec} = \sum_{j=1}^{N} |V_i| |y_{i,j}| |V_j| \cos(\delta_i - \delta_j - \theta_{i,j}) \tag{2.56}$$

$$Q_i^{spec} = \sum_{j=1}^{N} |V_i| |y_{i,j}| |V_j| \sin(\delta_i - \delta_j - \theta_{i,j}) \tag{2.57}$$

Where,

$$\mathrm{V_i} = |\mathrm{V_i}| \angle \delta_i, V_j = |V_j| \angle \delta_j, y_{i,j} = |y_{i,j}| \angle \theta_{i,j} \tag{2.58}$$

The Newton-Raphson method is a very powerful load flow solution technique that incorporates first-derivative information when computing voltage updates. Normally, only 3 to 5 iterations are required to solve the load flow problem, regardless of system size. Newton-Raphson is the most commonly used load flow solution technique. In the load flow problem, the matrix update equation is symbolically written in mixed rectangular-polar form as given in equation (2.59).

$$\begin{aligned} J1 &= \frac{\partial P}{\partial \delta} & \qquad J2 &= \frac{\partial P}{\partial |V|} \\ J3 &= \frac{\partial Q}{\partial \delta} & \qquad J4 &= \frac{\partial Q}{\partial |V|} \end{aligned} \tag{2.59}$$

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \triangle \delta \\ \triangle |V| \end{bmatrix} \tag{2.60}$$

In highly inductive power systems, P is closely related to voltage angles, and Q is closely related to voltage magnitudes. Therefore, in the above mixed rectangular-polar formulation, the terms in J_1 and J_4 tend to have larger magnitudes than those in J_2 and J_3. This feature makes the Jacobian matrix more diagonally dominant, which improves robustness when Gaussian eliminates or LU decomposing *J*. The above formulation of the Jacobian matrix is often modified to take advantage of symmetry in the partial derivatives. The modification is given in equation (2.61).

$$\begin{bmatrix} \triangle P \\ \triangle Q \end{bmatrix} = \begin{bmatrix} \frac{1}{|V|} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{1}{|V|} \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix} = \begin{bmatrix} |V| \triangle \delta \\ \triangle |V| \end{bmatrix} \tag{2.61}$$

The partial derivatives are derived from equation (2.62) and (2.63) it has the forms given in equations (2.64) - (2.67).

$$P_i^{calc} = \sum_{j=1}^{N} |V_i| |y_{i,j}| |V_j| \cos(\delta_i - \delta_j - \theta_{i,j}) \tag{2.62}$$

$$Q_i^{calc} = \sum_{j=1}^{N} |V_i| |y_{i,j}| |V_j| \sin(\delta_i - \delta_j - \theta_{i,j}) \tag{2.63}$$

For, ***J*₁**

$$\begin{aligned}\frac{\partial P_i}{\partial \delta_i} &= \sum_{j=1,\, j\neq i}^{N} |V_i||y_{i,j}||V_j|\sin(\delta_i-\delta_j-\theta_{i,j}) \\ \frac{\partial P_i}{\partial \delta_k} &= |V_i||y_{i,k}||V_k|\sin(\delta_i-\delta_k-\theta_{i,k}), k\neq i\end{aligned} \tag{2.64}$$

For, ***J*₂**

$$\begin{aligned}\frac{\partial P_i}{\partial |V_i|} &= \sum_{j=1,\, j\neq i}^{N} |y_{i,j}||V_j|\cos(\delta_i-\delta_j-\theta_{i,j}) + 2|V_i||y_{i,j}|\cos(\theta_{i,j}) \\ \frac{\partial P_i}{\partial |V_k|} &= |V_i||y_{i,k}|\cos(\delta_i-\delta_k-\theta_{i,k}), k\neq i\end{aligned} \tag{2.65}$$

For, ***J*₃**

$$\begin{aligned}\frac{\partial Q_i}{\partial \delta_i} &= \sum_{j=1,\, j\neq i}^{N} |V_i||y_{i,j}||V_j|\cos(\delta_i-\delta_j-\theta_{i,j}) \\ \frac{\partial Q_i}{\partial \delta_k} &= |V_i||y_{i,k}||V_k|\cos(\delta_i-\delta_k-\theta_{i,k}), k\neq i\end{aligned} \tag{2.66}$$

For, ***J*₄**

$$\begin{aligned}\frac{\partial Q_i}{\partial |V_i|} &= \sum_{j=1,\, j\neq i}^{N} |y_{i,j}||V_j|\sin(\delta_i-\delta_j-\theta_{i,j}) + 2|V_i||y_{i,j}|\sin(\theta_{i,j}) \\ \frac{\partial Q_i}{\partial |V_k|} &= |V_i||y_{i,k}|\sin(\delta_i-\delta_k-\theta_{i,k}), k\neq i\end{aligned} \tag{2.67}$$

Note the symmetry in the J terms. If $|V|\delta$ is used as an updating parameter rather than δ, then the expressions for J_1 are,

$$\begin{aligned}\frac{\partial P_i}{|V_i|\partial \delta_i} &= \sum_{j=1,\, j\neq i}^{N} |y_{i,j}||V_j|\sin(\delta_i-\delta_j-\theta_{i,j}) \\ \frac{\partial P_i}{|V_k|\partial \delta_k} &= |V_i||y_{i,k}|\sin(\delta_i-\delta_k-\theta_{i,k}), k\neq i\end{aligned} \tag{2.68}$$

And, for J_3

$$\begin{aligned} \frac{\partial Q_i}{|V_i|\partial\delta_i} &= \sum_{j=1,\, j\neq i}^{N} |y_{i,j}||V_j|\cos(\delta_i-\delta_j-\theta_{i,j}) \\ \frac{\partial Q_i}{|V_i|\partial\delta_k} &= |y_{i,k}||V_k|\cos(\delta_i-\delta_k-\theta_{i,k}), k\neq i \end{aligned} \qquad (2.69)$$

The solution procedure for the Newton-Raphson load flow proceeds with:

1. Initialize the bus voltages. For load busses, use $V = 1 + j0$. For generator busses (including the swing bus), $V = V_{spec} + j0$ is used.
2. Form the Jacobian matrix, and update all bus voltage magnitudes and phase angles, except for those at the swing bus, and except for the voltage magnitudes at PV busses.
3. Check the mismatch P and Q at each bus. If all are within tolerance (typical tolerance is 0.00001 pu), a solution has been found. Otherwise, return to Step 2.

2.11 Forward-Backward Sweep Technique for Power Flow Analysis

In the technique, the network is assumed to be balanced, as such; it is represented by an equivalent single line diagram. The analysis proceeds from one branch to another in a systematic way until all the branches in the feeders have been traced [62]. Firstly, the voltages at all the buses, except the slack/swing bus, are assumed to be one (1) p.u at angle zero (0). Based on these voltages and specified active and reactive power, simultaneously, the branch currents, starting from the end buses to the source, are calculated and saved (Backward Sweep). This, of course, requires a logical procedure to ensure that the branches of the system are correctly traced; therefore, the branch incidence table is usually used. Then, branch currents, are computed in order to find the active and reactive power losses in the system. The current at the source end is now calculated using the equation (2.70). The computation then proceeds from source to the end of the feeders to find the voltage drop using equation (2.72), current (I_{ij}), real and reactive power losses using equations (2.73) and (2.74) respectively (Forward Sweep). The branch incidence table is again used to facilitate proper retracting of the network branches. Once this process is completed, the total losses are calculated and compared to the values initially obtained. If the difference is outside the specified tolerance limits, the source current is re-computed using equation (2.70), in terms of the newly obtained values for losses, and the path retracting operation is repeated. The process is repeated until the difference in losses between 2 successive values of the source current is within the specified tolerance limits [62].

$$I=\left(\sum_{\substack{i=1\\i\neq s}}^{n}P_i+\sum_{\substack{j=1\\i=1\\i\neq j}}^{n}P_{loss,ij}+j\left(\sum_{\substack{i=1\\i\neq s}}^{n}Q_i+\sum_{\substack{j=1\\i=1\\i\neq j}}^{n}Q_{loss,ij}\right)\right)/V_s^* \tag{2.70}$$

$$Z_{ij}=R_{ij}+jX_{ij} \tag{2.71}$$

$$V_{Drop,ij}=V_j-V_i=I_{ij}Z_{ij} \tag{2.72}$$

$$P_{loss,ij}=I_{ij}^2R_{ij} \tag{2.73}$$

$$Q_{loss,ij}=I_{ij}^2X_{ij} \tag{2.74}$$

Where,

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

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

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

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

V_s^* : is the conjugate of the source voltage

I : is the current at the source end

Z_{ij}: is the impedance of branch ij

R_{ij} : is the resistance of branch ij

X_{ij} : is the reactance of branch ij

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

V_j and V_i : are the voltage at bus j and I respectively

I_{ij} : is the current flowing from bus I to j

2.12 Voltage Drop

The voltage drop is a quantity which defines the voltage relationship between any two points on a given network. Let the voltage of two points on a given network be V_A and V_B The voltage drop between these two points can be expressed using equation (2.75) [63].

$$V_{AB} = V_B - V_A \tag{2.75}$$

$$V_{AB} = -V_{BA} \tag{2.76}$$

In distribution network analysis, the source node voltage is usually considered as the reference/rated voltage, from which other node voltages are estimated. This estimation is carried out using iterative techniques. Therefore the voltage drop (V_{D_k}) along the path linking the source and kth node can be expressed using equation (2.77) [63].

$$V_{D_k} = V_{rated} - V_k \tag{2.77}$$

Thus: it is possible to express the VSI as a function of voltage drop as in equation (2.78) [63].

$$VSI = \sqrt{\frac{\sum_{k=1}^{n} V_{D_k}^2}{n}} \tag{2.78}$$

CHAPTER 3: Data Collection and Analysis

3.1 Data and Existing Facilities

3.1.1 General Information of Addis Ababa Distribution System

The LV design standard of the EEU of Addis Ababa capital region obtained by a survey shown below on a Table 3-1, the comparison between the current situations of LV feeders. Based on the LV design standard, the number of customers and the distance from the transformer are determined separately for the two different types of areas, one where the demand growth is expected (Growing areas) and the other where demand is saturated (Saturated areas).

From this table, it can be seen that the number of customers connected to each transformer and the maximum distance largely exceeds the number set in the standard. For example, in the case of a transformer with a capacity of 100kVA, the maximum number of customers and the maximum distance are defined as 80 and 200 m by standard, whereas the average number of customers and average maximum distance based on survey data are 118 and 948m. This means that more than half of the transformers are not as per the standard. The distance also exceeds the standard by about 4 to 5 times1, it can be assumed that a large voltage drop occurs due to the excess in the number of customers. In addition, the data survey of the project group was conducted about five years ago, so it is assumed that the number of customers has further increased.

Table 3-1: Current situation of LV feeders in the Addis Ababa capital region

Transformer capacity	Low voltage Network Design Guideline			Results of data survey project		Assumed Distance from the transformer
	Saturated areas	Growing areas	Maximum Distance from the transformer	Average number of customers	Average number of pole	
(KVA)	(No.)	(No.)	(m)	(No.)	(No.)	(m)
100	120	80	200	118	95	948
200	250	160	290	209	126	1,257
315	390	260	360	268	142	1,418

It is thought that the construction of facilities has deviated largely from the prescribed standard because of improper facility management. In case of including LV feeders to the scope of this project, it is necessary to investigate such enormous amount of facilities.

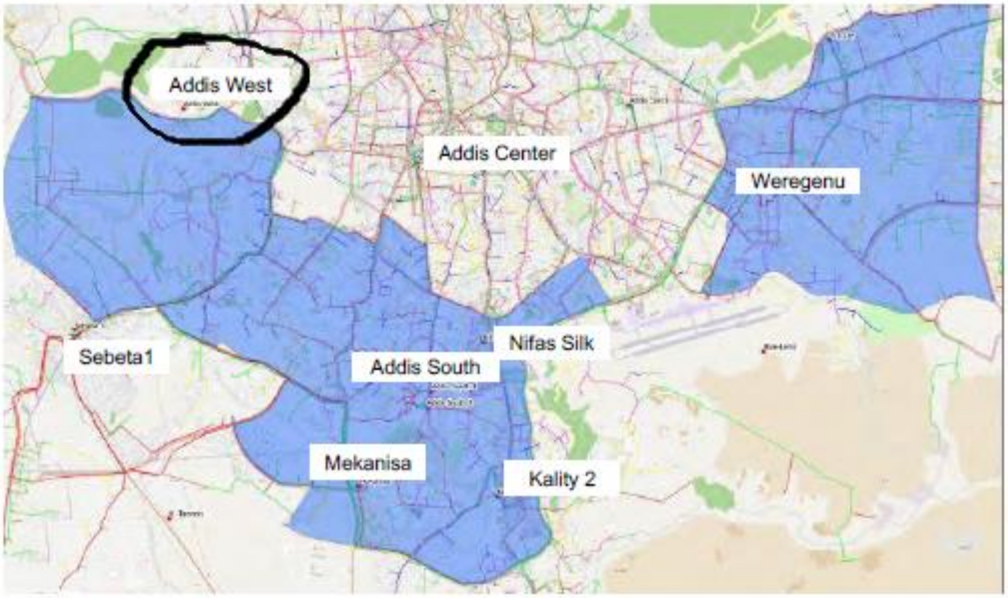


Figure 3-1: Study Area

Study area covers on the western side of Addis Ababa city starts from the substation of Addis west sub-station.

3.2 Configuration of Distribution Network

3.2.1 Configuration of Distribution Equipment

The distribution network in Addis west is implemented with 15kV or 132kV on the primary side (medium voltage) and 400V/230V on the secondary side (low voltage), and most of the facilities are formed by overhead distribution equipment. The medium voltage feeder and the low voltage feeder are supported by separate poles, the route of both feeders also has a different layout, with few overlapping parts.

Various capacity transformers are applied to the distribution transformer, but mainly those of the 200 - 315kVA class is installed. Small capacity Transformers (up to 400kVA) are installed on the poles of the MV feeder using a concrete pedestal, or installed on the H arranged poles. In the case of a large capacity transformer of 500kVA or more, they are installed on the ground.

3.2.2 Configuration of Distribution Network

The network configuration of the distribution system in Addis Ababa is configured with a large capacity backbone line called an Express way draw out from each substation, and it is connected at the end point to the other Express way draw out from the adjacent substation. At this interconnection point, a switching station (here in after called “SW/St”: ring main unit) is installed, and the interconnection switch is normally open.

3.3 Evaluation indices

In this thesis, it is required to evaluate the impact of the installation place and the installed capacity of the generator on the technical characteristics of the network such as voltage profile, network losses, and emission reduction. For the purpose of evaluation, some indices have been defined and their values were calculated and studied for different scenarios. In the following the indices will be introduced. Then selecting the network model, for different scenarios, the performance of DGs will be evaluated.

3.4 Reduction of power loss

One of the main reasons for the use of network reconfiguration and distributed generation in the network is that the place of production has gotten closer to the place of consumption resulting in reduction of power loss. As a result, there is a possibility of on-site consumption, Moreover, the power transmission substation and primary feeder buses get reduced. Depending on the selection of equipment it also economically important. The target function for locating and determining the optimal size of DG to reduce power loss used in this thesis is as follows.

$$F_1 = P_L = \sum_{i=1}^{N} P_{Loss,i} \tag{3.1}$$

Minimizing the power loss is the goal of the problem. Provisions governing the issue as follows: Balance constraint

$$\sum_{i=1}^{N} P_{DG,i} = \sum_{i=1}^{N} P_{DG,i} + P_i \tag{3.2}$$

Range of active and reactive power generated by

$$P_{DG,i}^{\min} \le P_{DG,i} \le P_{DG,i}^{\max} \tag{3.3}$$

$$Q_{DG,i}^{\min} \le Q_{DG,i} \le Q_{DG,i}^{\max} \tag{3.4}$$

Range of network losses

$$\sum_i Loss_i(with, DG) \le \sum_i Loss_i(without, DG) \tag{3.5}$$

Where;

P_L: power loss

P_i: active power at the bus i

Q_i: the reactive power at the bus i

Best location and optimal size of DG are required to improve the Voltage profile of the distribution networks with radial structures. The highest voltage drop happens at the end of the network (i.e. farthest). It should be noted that the there is a high voltage drop (voltage loss). Voltage profile in radial distribution networks in which there is no distribution generation is decreasing, which means voltage near the source is close to unity. How far away from the source, the voltage decreases, which could have negative effects for consumers. The target function for locating and determining the optimal size of DG used to improve the voltage profile in this paper is as follows:

$$F_2 = \sum_{i=1}^{N} \left| V_i - V_{i,ref} \right| \tag{3.6}$$

V_i: voltage at the bus i

$V_{i,ref}$: optimal voltage considered in PU. Voltage range at the bus i

$$\left| V_i^{\min} \right| \le \left| V_i \right| \le \left| V_i^{\max} \right| \tag{3.7}$$

3.5 Introducing the proposed power-flow in the presence of DG

Distribution networks, power-flow is one of the important issues in most tasks relating to the network such as designing, developing, etc. Due to the magnitude and shape of the load flow in radial distribution networks, it have it’s own characteristics. The radial distribution network is a network that the whole buses are fed from the same source. In other words, there is only one path for power delivery for each of the loads. A simple radial network is shown in Figure 3-2.

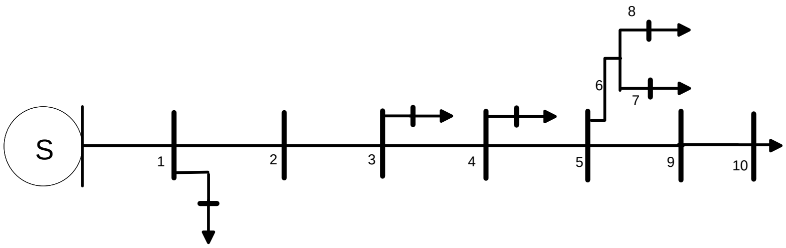


Figure 3-2: Typical radial distribution network

3.6 Forward-Backward power-flow method

In this thesis, forward-backward method is used for power-flow of radial distribution networks. This method is formulated as a set of duplicate equations from the existing power and voltage networks. In this method 1 p.u bus voltage is initially considered, and then with the help of backward equations, power and voltage at each bus to the first bus will be measured from the known the power of the loads and the impedance of the lines. Forward movement begins after the arrival of the first bus which is the main bus. Since the voltage and angle of the bus are determined on forward direction, the voltage of each bus to the final bus will be computed with the help of equation (3.11) and from the powers obtained in backward direction. This process is repeated until obtaining the convergence achieve.

$$P_{j-1} = P_j + r_j \frac{P_j^{'2} + Q_j^{'2}}{V_j^2} + P_{Lj} \tag{3.8}$$

$$Q_{j-1} = Q_j + X_j \frac{P_j^{'2} + Q_j^{'2}}{V_j^2} + Q_{Lj} \tag{3.9}$$

$$V_{j-1}^2 = V_j^2 + 2(r_j P_j^{'} + x_j Q_j^{'}) + (r_j^2 + x_j^2)\frac{P_j^{'2} + Q_j^{'2}}{V_j^2} \tag{3.10}$$

$$V_{j+1}^2 = V_j^2 - 2(r_j P_j + x_j Q_j) + (r_j^2 + x_j^2)\frac{P_j^2 + Q_j^2}{V_j^2} \tag{3.11}$$

In which,

$$P_j^{'} = P_j + P_{Lj}$$
$$Q_j^{'} = Q_j + Q_{Lj}$$

In systems with branching path, for each sub- track, the same procedure mentioned above is used, except that the primary bus voltage is not 1p.u. In fact, the voltage obtained from a backward direction in the backward direction and forward direction from the forward direction is the criterion. The forward - backward process is repeated until obtaining the convergence on the direction. Convergence condition can be considered as follows:

1. There should be voltage differences between any buses of the forward and backward directions, so that the differences become smaller than the errors defined.
2. The P_{Loss} differences of the forward and backward directions should be smaller than the defined error value.

3.7 Numerical studies and simulation results

3.7.1 Network Introduction

In order to evaluate the proposed network method, the distribution of 78-bus test was simulated. Figure 3-3 shows the linear diagrams of the network. Basic values of system were considered as 15kV and 100MVA. This network consists of 78 distribution transformers with different buses. The details of distribution conductors are shown in Table 2-2. The length of each feeder and the connected load of transformer are shown in appendix-I.

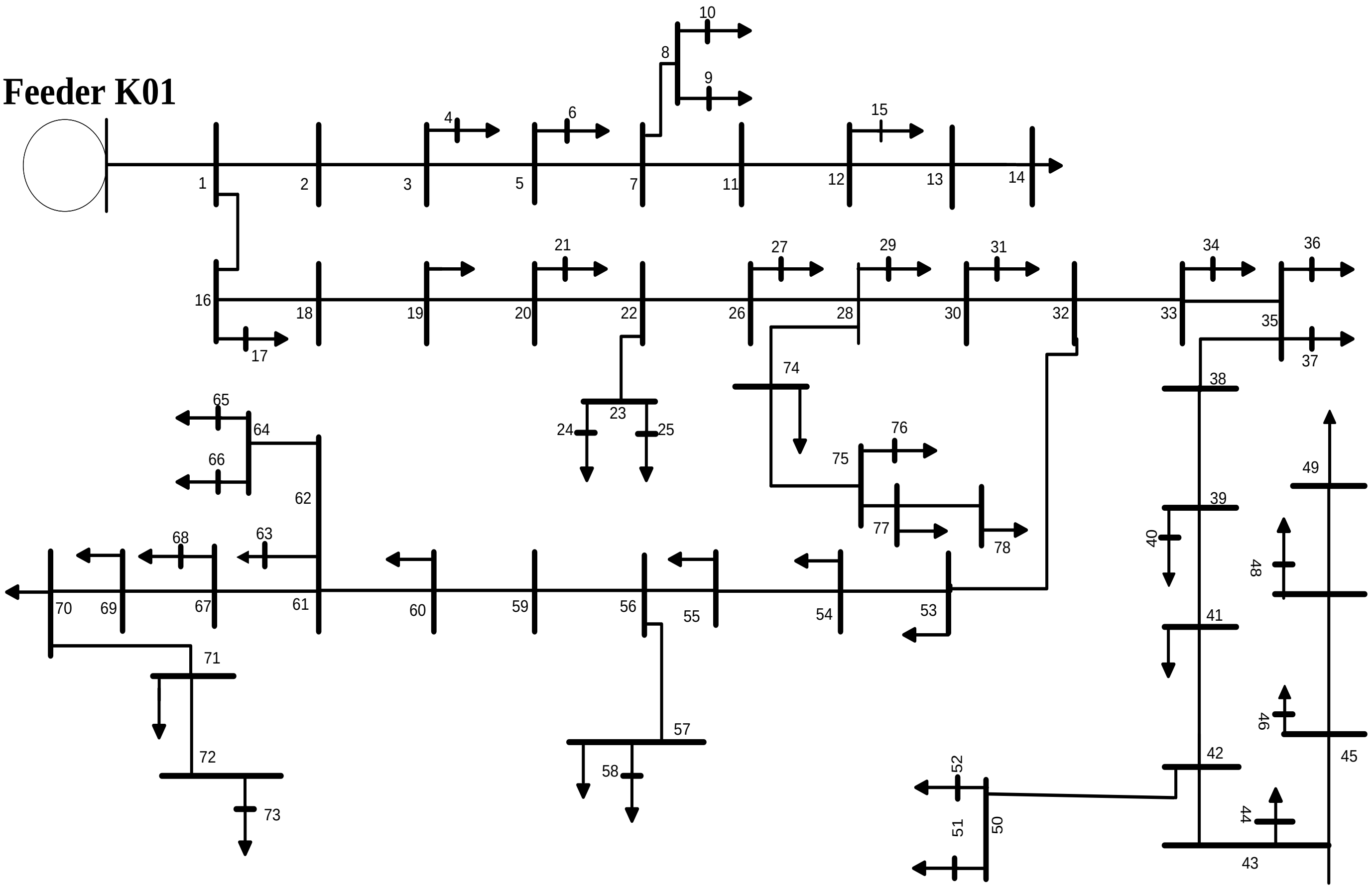


Figure 3-3: Single line diagram of the distribution system

Table 2-2: Conductor details

Type	**R[Ω/km]**	**X[Ω/km]**	**Imax [A]**	**A [mm^2]**
Hyena	0.1576	0.2277	550	126
Dog	0.2712	0.2464	440	120
Mink	0.4545	0.2664	315	70

3.8 System Modeling

The modeling of the system is based on the assumption that the three-phase system is balanced under steady state conditions. The available locations to install the suggested distributed generators are selected among the nodes with the highest loss sensitivity factor (LSF) in addition to the physical factors and right of way which are considered as important factors affecting this selection. The load flow algorithm identifies the nodes with the highest LSF. The parameters for the load flow are calculated first.

3.8.1 Impedance Calculation of Overhead Line

The inductance of a transmission line depends upon the material, dimensions, and configuration of the wires themselves and length with the spacing between them. The AC resistance of a conductor is always higher than its DC resistance due to the skin effect forcing more current flow near the outer surface of the conductor. The higher the frequency of the current, the more noticeable skin effect would be. Wire manufacturers usually supply tables of resistance per unit length at common frequencies (50Hz). Therefore, the resistance can be determined from such tables. The impedance is calculated at a frequency of 50Hz, and at a length of one kilometer. Thus, the impedances are given by,

$$Z_a = R_a + j0.06283\ln\frac{D}{GMR_a}\,\Omega/km \tag{3.12}$$

$$D = \sqrt[3]{D_{ab} * D_{bc} * D_{ac}} \tag{3.13}$$

Since the conductors that are used in distribution feeders strand conductors. For stranded conductors, the GMR is given by,

$$GMR_a = K * r$$

Where,

GMR_a: Geometric mean ratio of conductor a

K: the GMR factor

r: actual conductor radius

Z: impedance of conductor a in Ω/km

R: resistance of conductor i in Ω/km

D: distance between conductors in meter

Dab: Distance between conductors a and b in meter

D_{bc}: Distance between conductor's b and c in meter

D_{ac}: Distance between conductors a and c in meter

From appendix–I applying Equations results in the following.

1 For AAC-120 conductor type, the self-impedance for phase conductors is,

$$Z_a = R_a + j0.062832 \ln \frac{D}{GMR_a} \Omega/km$$

$$Z_a = 0.3085 + j0.06283 \ln \frac{0.72135}{9.24 * 10^{-3}} \Omega/km$$

$$= 0.2853 + j0.2738 \Omega/km$$

For the three phase three conductors the impedance of each conductor is the same (i.e. Z_a= Z_b= Z_c).

Then the positive sequence impedance of the conductors is obtained by multiplying the impedance per kilometer by its length.

2 For AAC-95 conductor type, the self-impedance for phase conductors is

$$Z_a = R_a + j0.062832 \ln \frac{D}{GMR_a} \Omega/km$$

$$Z_a = 0.3085 + j0.06283 \ln \frac{0.72135}{4.129 * 10^{-3}} \Omega/km$$

$$= 0.3085 + j0.32441 \Omega/km$$

For the three phase three conductors the impedance of each conductor is the same (i.e. $Z_a = Z_b = Z_c$). Then the positive sequence impedance of the conductors is obtained by multiplying the impedance per kilometer by its length.

3 For AAC-50 conductor type

Using the same procedure like AAC-95 the process and equations is followed to obtain the impedances of the conductor AAC-50. Thus, the positive sequence impedance

$$Z_a = R_a + j0.062832 \ln \frac{D}{GMR_a} \Omega/km$$

$$Z_a = 0.5785 + j0.06283 \ln \frac{0.72135}{2.88 * 10^{-3}} \Omega/km$$

$$= 0.5785 + j0.34702 \Omega/km$$

For the three phase three conductors the impedance of each conductor is the same (i.e. $Z_a = Z_b = Z_c$). Then the positive sequence impedance of the conductors is obtained by multiplying the impedance per kilometer by its length. Since the line is short, the shunt admittance of overhead lines is neglected.

4 For AAC-25 conductor type

Using the same procedure like AAC-50 the process and equations is followed to obtain the impedances of the conductor AAC-25. Thus, the positive sequence impedance

$$Z_a = R_a + j0.062832 \ln \frac{D}{GMR_a} \Omega/km$$

$$Z_a = 0.5785 + j0.06283 \ln \frac{0.72135}{1.881 * 10^{-3}} \Omega/km$$

$$= 1.181 + j0.37367 \Omega/km$$

The value of GMR factor with its strand number of AAC conductor & Conductor parameters of the feeder see appendix–I.

3.9 Particle Swarm Optimization (PSO)

The concept of PSO is its particles move towards each other to find P_{best} and G_{best}. The best solution achieved by that particle in the solution space is known as P_{best} while G_{best} is the value obtained by any particle in the neighborhood of that particle. Based on the flowchart in Figure 3-4, each particle tries to relocate its position by using the information;

i. The current positions.

ii. The current velocities.

iii. The distance between the current position and P_{best}.

iv. The distance between the current position and G_{best}.

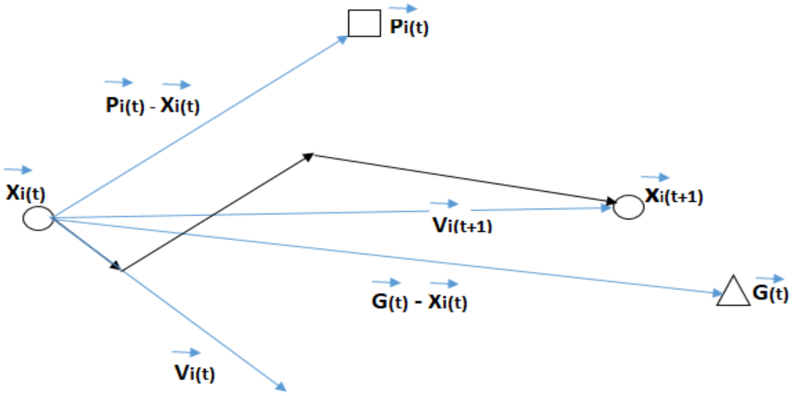


Figure 3-4: Concept of modification of searching point by PSO

The modification of the particle's position can be modeled by using equations (3.14) and (3.15).

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 (P_{best_i} - S_1^k) + C_2 r_2 (G_{best} - S_i^k) \tag{3.14}$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \tag{3.15}$$

Where,

C_1, C_2: The weighting factor,

r1, r2: The random numbers between 0 and 1

ω : The weighting function

V_1^k : The current velocity of particle i at iteration k

V_1^{k+1} : The modified velocity of particle i

S_1^k : The current position of particle i at iteration k

S_1^{k+1} : The modified position of particle i

P_{best_i} : The personal best of particle i

G_{best_i} : The global best of the group

The weighting function is set according to equation (3.16).

$$\omega(t+1) = \omega_{\max} = \frac{\omega_{\max} - \omega_{\min}}{t_{\max}} * t \tag{3.16}$$

Where,

$t_{\max}$: Maximum number of iterations

t : Current iteration number

$\omega_{\max}$: Maximum inertia weight

$\omega_{\min}$: Minimum inertia weight

3.10 The Procedure of PSO Implementation

Step 1: The input data, including network configuration, line impedance, DG location with its size and switches are to be read.

Step 2: Set up the set of parameters of PSO such as the number of particles N, weighting factors and C_1 and C_2. The initial population is determined by selecting the tie switches and DG size randomly from the set of the original population. The variable for tie switches represented by P_g. The proposed particles can be written as:

$$X_{particle} = \{S_1, S_2, ...S_\beta, P_{g1}, P_{g2}, ..., P_{g\alpha}\} \tag{3.17}$$

Where β is the number of tie line and α is the number of DG.

Step 3: Calculate the loss using distribution load flow based on backward-forward sweep.

Step 4: randomly generates an initial population (array) of particles with random positions and velocities on dimension in the solution space. Set the iteration counter k=0.

Step 5: For each particle, if the bus voltage is within the limits, calculate the total loss using distribution load flow. Otherwise, the particle is infeasible.

Step 6: Record and update the best value. The two best values are recorded in the searching process. Each particle keeps track of its coordinate in the solution space that is associated with the best solution it has reached so far. This value denoted as P_{best_t}. Another best value denoted as G_{best}, which is the overall best value obtained so far by any particle. P_{best} and G_{best} are the generation of switches, DG sizes and power loss. This step also updates P_{best} and G_{best}. At first, the fitness of each particle compare with its P_{best}. If the current solution is better than its P_{best}, then replace P_{best}t by the current solution then the fitness of all particles is compared to G_{best}. If the fitness of any article is better than G_{best}, then replace G_{best}.

Step 7: Update the velocity and position of particles. The equation (3.14) is applied to update velocity of the particles. The velocity of a particle is represented as the movement of the switches. Meanwhile, the equation (3.15) is to update the position of the particles.

Step 8: $P_{Loss} = \sum_{t=1}^{N_{line}} |I_t|^2 k_t R_t$, $V_{\min} \le V_{bus} \le V_{\max}$ and $DG_{p_{\min}} \le DG_{p_i} \le DG_{p_{\max}}$ Check the end condition, if it has reached the algorithm stop or else repeat step 3-7 until the end condition is satisfied.

The PSO algorithm is able to reach a good solution by finite steps of evolution steps performed on a finite set of possible solutions. The objective function for the optimization is the power loss reduction as shown in equation (3.18). The PSO algorithm sets in the core of this optimization problem. This routine is programmed by MATLAB software.

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij}(P_iP_j + Q_iQ_j) + B_{ij}(Q_iP_j - P_iQ_j) \tag{3.18}$$

Where,

$$A_{ij} = \frac{R_{ij}\cos(\delta_i - \delta_j)}{V_iV_j}$$

$$B_{ij} = \frac{R_{ij}\sin(\delta_i - \delta_j)}{V_iV_j}$$

3.11 Cost Analysis

The economics attributes of energy loss, P and Q power of DG considered based on: Energy Loss (E_L): The cost of energy loss on an annual basis is given by

$$E_{L_{cost}} = \$\left(Total\ real\ power\ loss\right) * \left(Ec\ * T\right) \tag{3.19}$$

Where,

Ethiopian electric billing tariff, Cost of energy is given below.

E_c = 0.03318 $/kWh

T = 8760 hours/year

CHAPTER 4: Result and Discussion

The objective of this simulation is to evaluate the reconfigured distribution network of Addis West distribution system feeder line K01 for its power loss minimization & improvement of voltage profile. It’s to check the design and test its implementation with software based analysis. The simulation is made in MATLAB (R2015a version) software using the PSO algorithm for finding shortest moving path and Forward-Backward algorithm for the rest of best solution of DG placement & size. The drawings for the lateral-design are redrawn to the existing distribution network in Microsoft Visio software for illustration.

The capacity of transformers and the number of customers connected in each transformer are not proportional. In some nodes in the feeder, transformers with a large kVA capacity supply a few numbers of customers. On the other hand, some transformers with a small kVA capacity supply a high number of customers and the node feeders are going beyond the standard length. That is, the impedance of the line increase with its length. When impedance of line increases the power loss in the distribution system also increase.

Configuration of the distribution system is radial. So, the highest voltage drop occurs at the end of the distribution networks (i.e. farthest). It should be noted that the more drop in voltage lines, the more voltage loss. Voltage profile in radial distribution networks in which there is no distribution generation is decreasing, which means voltage near the source is close to 1 p.u, and how far we get from the source, the voltage decreases. Therefore, the design shall come up with a result that moderates both power loss and voltage profile from the substation up to customer side.

4.1 Descriptions on Four Different Case Studies

From the base system, four different cases are formed and shall be analyzed for their better and efficiency of PSO in obtaining the best configuration. The lists of cases are:

Case 1: All the tie switches in the network are open and there are no DG units added into the system. This network is an original 78 bus distribution network without any modification.

Case 2: Reconfiguration technique is employed in the system in Case 1 with the objective to reduce the power losses and to improve the voltage profile in the system.

Case 3: Analyze with DG units that are placed at the best location with its size. In the system the effects of these DGs are analyzed without reconfiguration action.

Case 4: The conditions of the system are similar to the Case 2, but the best size and location of DGs obtained in the reconfiguration case 2.

4.1.1 Case 1: Original (Base case) Configuration

The system consists of one feeder with 77 normally closed lines (i.e. the connection between buses) and five tie line switches are selected. Those five normally open tie lines (dotted line) are selected based on their shortest path (length) between the buses, other than the rest of buses and also selected based on load capacity of the buses. A short run length cable can have a less impedance value. So that the branch Numbers are selected due to the above criteria and assigned as 78, 79, 80, 81 and 82; those dotted lines are initially open connection lines used for reconfiguration. The line and load data details are available in the appendix-I. The total load on the system is 7550 kW with the minimum voltage 0.8491 p.u are shown in Table 4-2 below and Figure 4-2.

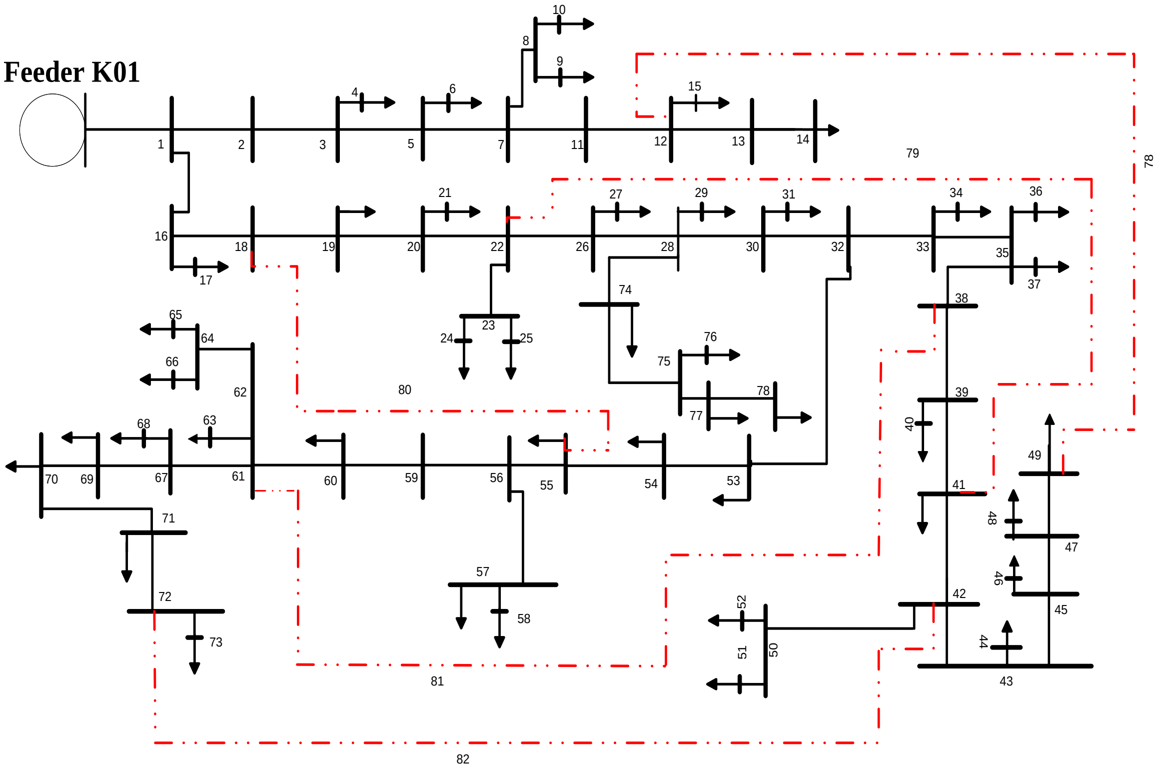


Figure 4-1: Single Line Diagram of ADW Distribution System Feeder-K01

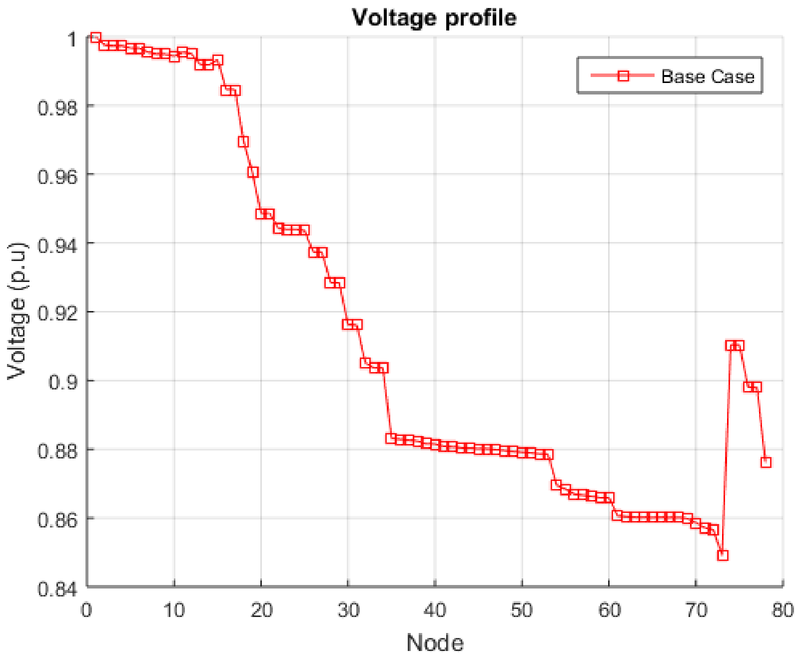


Figure 4-2: Voltage profile of the distribution System base case

4.1.2 Case 2: After Reconfiguration of the Network

With the help of the initial open tie switch branch Number 78, 79, 80, 81 and 82 used for the optional branch connection between buses; for minimization of real power loss and to improve the voltage profile of the network. Due to the impedance of the branches that forms a given distribution network, a certain percentage of the total active power injected at the source node, get wasted along the network branches. This power wasted (in the form of heat) on the branches is termed as power loss. The total power loss of a distribution network is the summation of the individual branch loss across the entire network. The total real power losses of the original configuration were found to be 1146 kW, while that of the best configuration is 712 kW. The best configuration of the ADW network can be formed by opening the best tie branches (34, 41, 52, 66 & 81) in the original configuration of the network (i.e, Figure 4-3), while closing the proposed tie branches (78, 79, 80, 82). Therefore the total real power loss is reduced by 434 kW (37.8709%) which means 9.4305% losses from the total power supply in the best configuration. Table 4-2 shows the total real power loss.

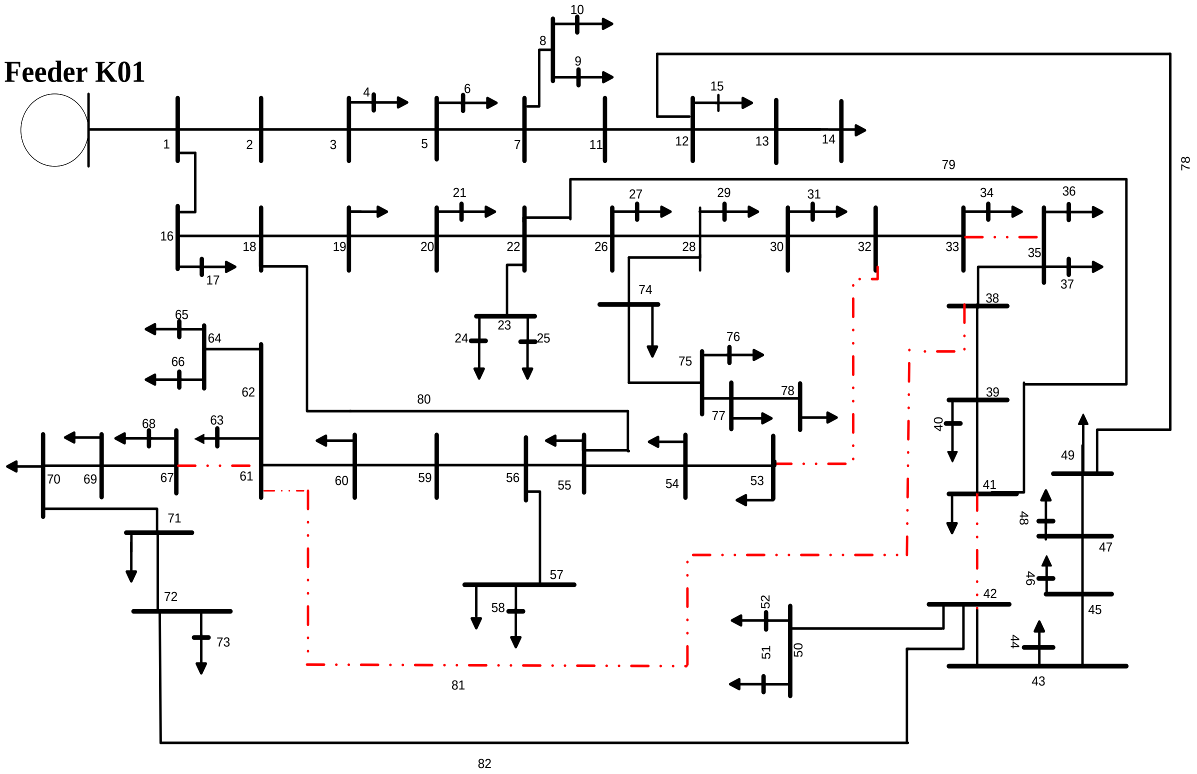


Figure 4-3: Single line diagram of ADW Distribution System Feeder-K01 after reconfiguration

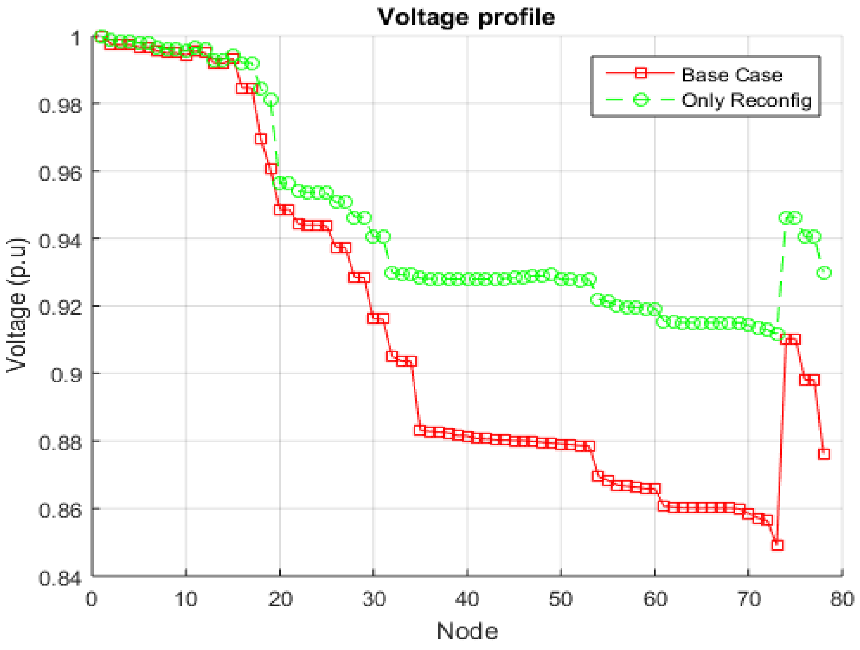


Figure 4-4: Voltage profile of the Distribution System after reconfiguration

4.1.3 Case 3: DG Inserted into the Original Network

The result shows that the power losses decrease from case 1 to case 3. Power loss in case 1 is 1146 kW and reduces to 37.8709% for case 2. In case 3 where the power loss is 600 kW reduced by 47.644 %. The difference between the power loss between case 2 and case 3 is 112 kW. From the impact of power loss, it shows that the allocation of DGs based on voltage profile can improve power losses in the system. Figure 4-5 shows the network reconfiguration switches and DG allocation at bus 33 and 72, whereas Figure 4-6 shows the voltage profile of the network after DG inserted into the original (base case).

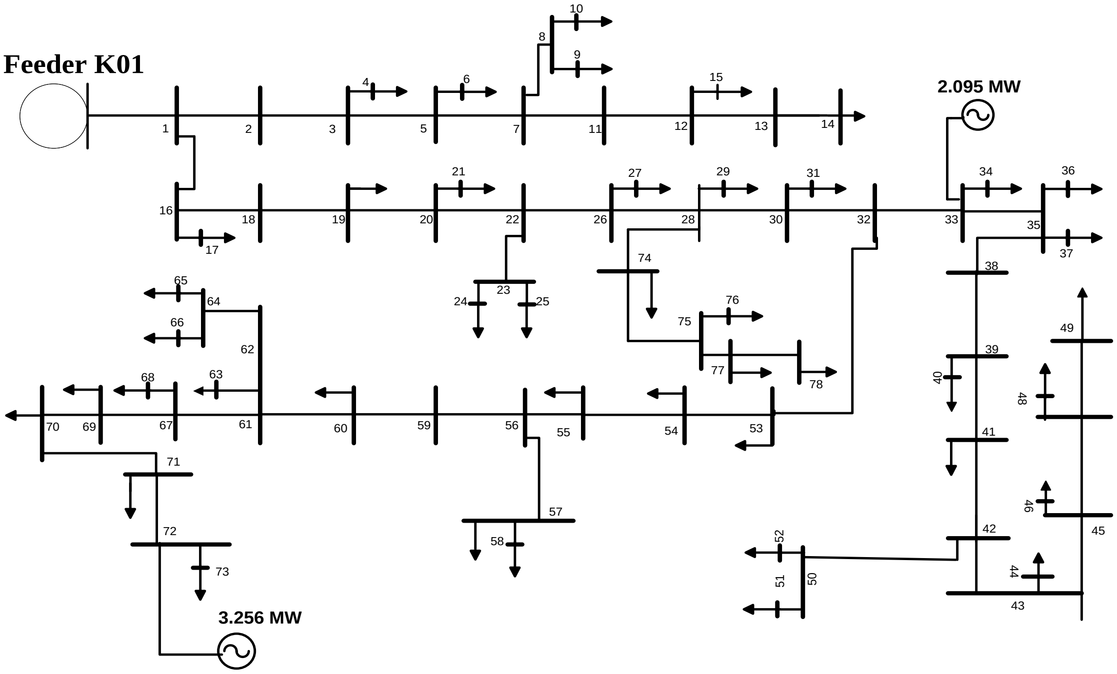
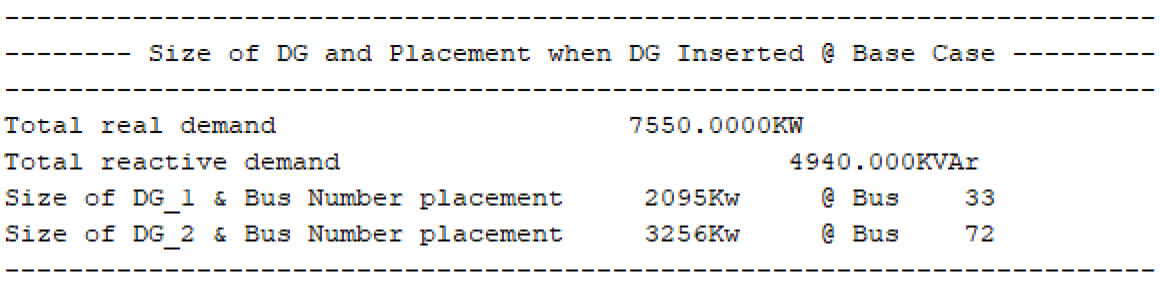


Figure 4-5: Single line diagram of ADW Distribution System Feeder-K01 only DG connected

Table 4-1: DG inserted in the base case



```
---------------------------------------------------------------------
-------- Size of DG and Placement when DG Inserted @ Base Case ---------
---------------------------------------------------------------------
Total real demand                       7550.0000KW
Total reactive demand                             4940.000KVAr
Size of DG_1 & Bus Number placement      2095Kw     @ Bus    33
Size of DG_2 & Bus Number placement      3256Kw     @ Bus    72
---------------------------------------------------------------------
```

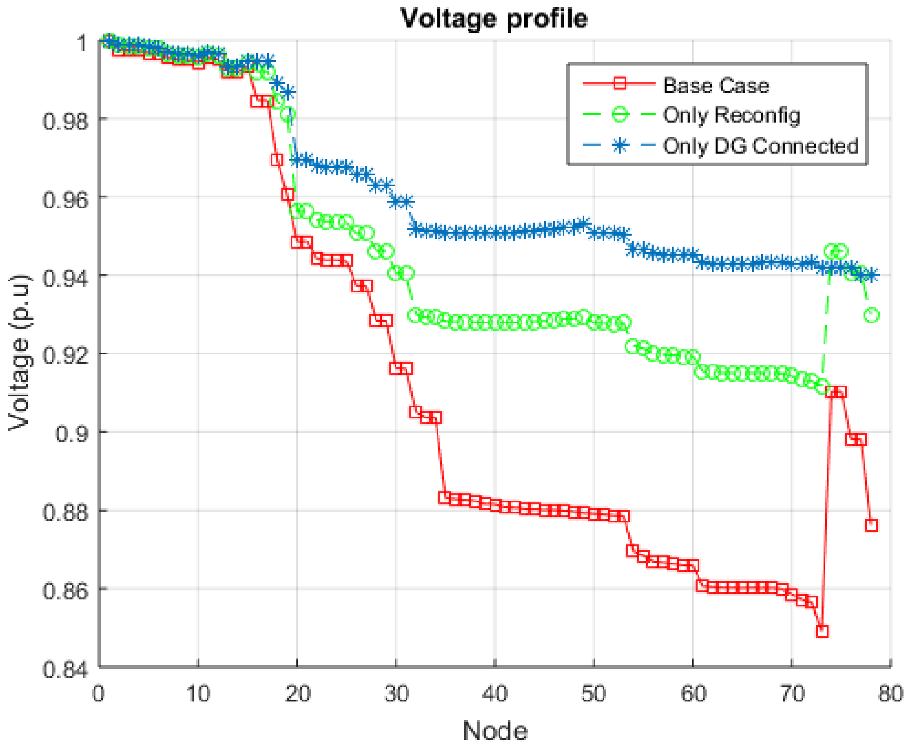


Figure 4-6: Voltage profile of the Distribution System only DG connected

4.1.4 Case 4: DG with Reconfiguration in the Distribution Network

In the case of a reconfiguration network with DG, the best size and location of DG units is obtained from the simulation after reconfiguration action takes place. The size of each DG is already set within the limitation range of equation (2.23) (i.e., 1.8875MW < $DG_{Pi} \leq$ 6.040 MW) in the program. The best power losses are based on flexible switches while the best size of DG depends on the optimal power losses. After this simulation is run randomly, then only the minimum power loss with best DG size is selected. The results obtained consists of the total power loss and two best DG sizing and location. For the result of the case study, it can be seen from the Table 4-1 and Table 4-3 show the two DGs are installed in different locations with different size.

The size of DGs is varied and run at range 1.8875 MW $\leq DG_{Pi} \leq$ 6.040 MW. The total best DGs size for case 3 and case 4 are 5.351 MW and 4.616 MW respectively.

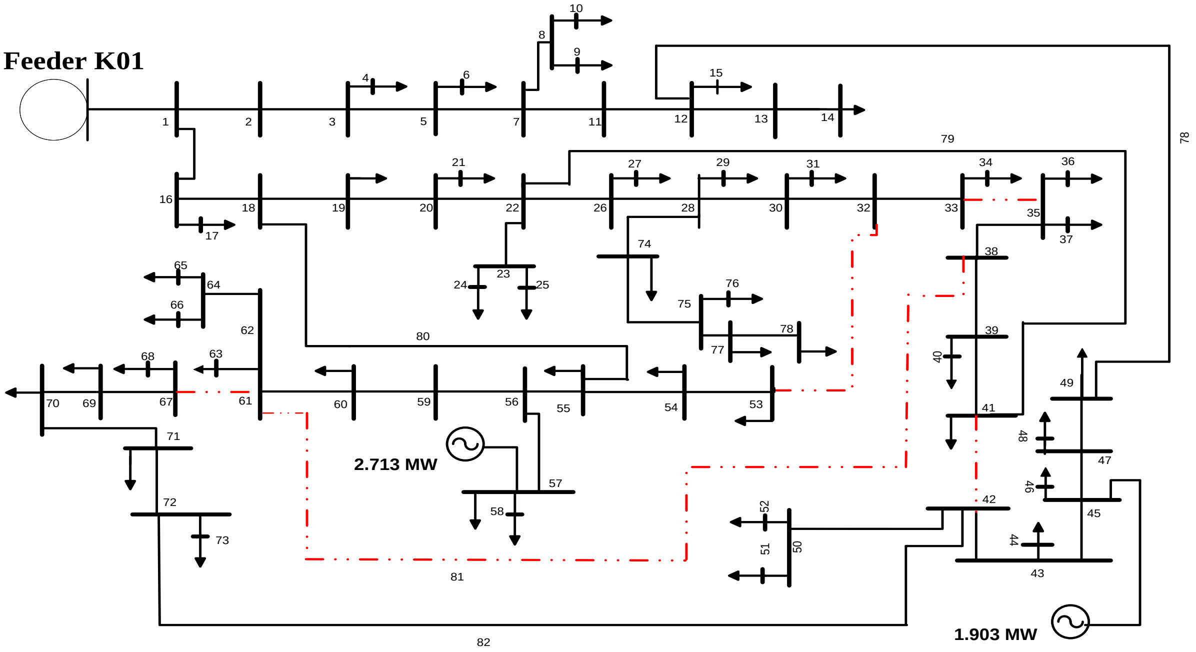


Figure 4-7: Single line diagram of ADW Distribution System Feeder-K01 reconfiguration & DG

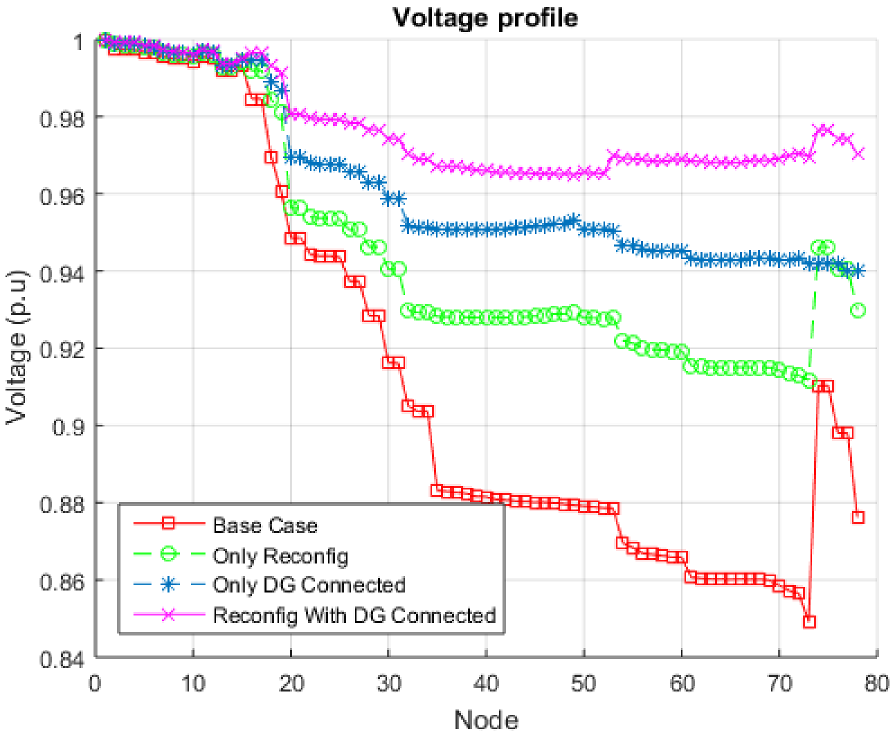
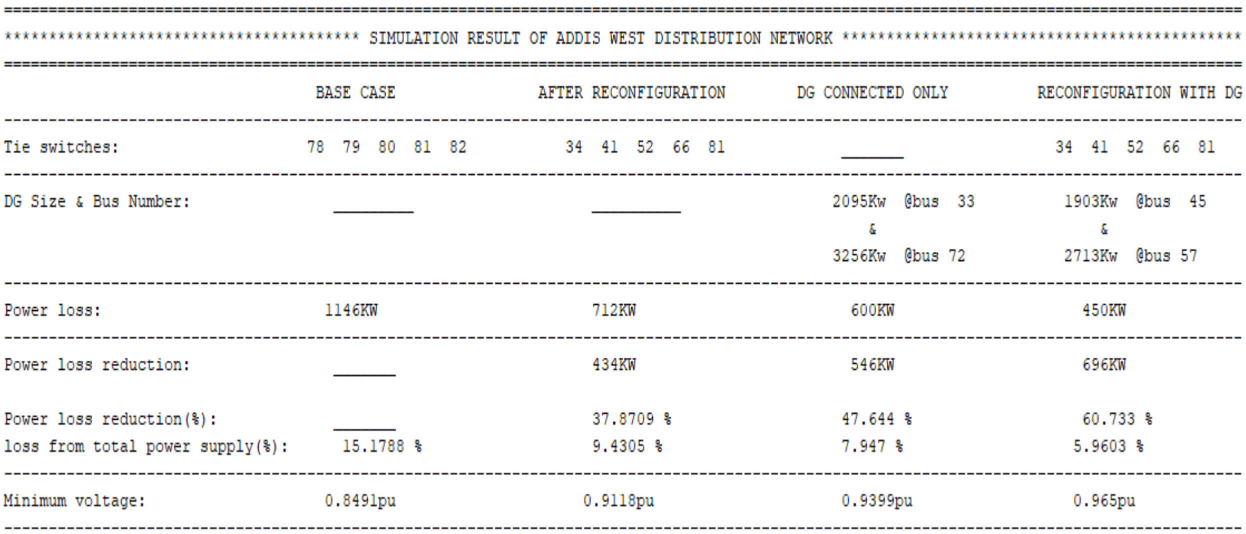


Figure 4-8: Voltage profile of the Distribution System reconfiguration with DG

The schematic diagram of the system after reconfiguration with DG installation (case 2 and case 4) is illustrated in Figure 4-3 and Figure 4-7. The DG is placed on bus number 45 and 57 as shown on the diagram. The numerical results for the four cases are summarized in Table 4-2. As mention earlier, the output of the result display five opened switches, optimal total power loss and optimal DG size as shown in Table 4-2. From the analysis of the results, the system which operates with DG technique in case 3 produced a lower power loss as compared to case 2 in which the reconfiguration technique is applied. Although the network configuration has changed the power flow direction which gives the low power loss in the system, hence, this proves that the existence of DG in the distribution system is indeed significant in ensuring a lower power loss.

However, optimal power loss can be further improved by the combination of both techniques into the distribution system. This can be seen in case 4 in which the loss has been improved further from 1146 kW to 450 kW.

Table 4-2: Summary of the results

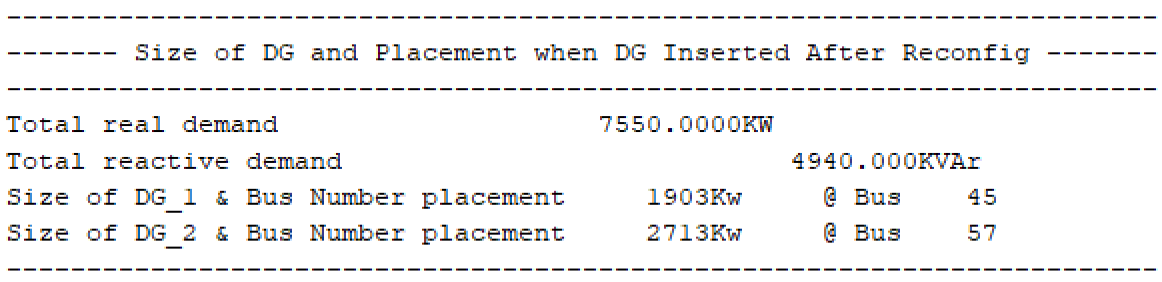


```
====================================================================================================================================
**************************************** SIMULATION RESULT OF ADDIS WEST DISTRIBUTION NETWORK *******************************************
====================================================================================================================================
                                   BASE CASE            AFTER RECONFIGURATION        DG CONNECTED ONLY          RECONFIGURATION WITH DG
------------------------------------------------------------------------------------------------------------------------------------
Tie switches:                     78  79  80  81  82         34  41  52  66  81            ______                34  41  52  66  81
------------------------------------------------------------------------------------------------------------------------------------
DG Size & Bus Number:               _________             __________               2095Kw  @bus  33          1903Kw  @bus  45
                                                                                     &                          &
                                                                                   3256Kw  @bus 72           2713Kw  @bus 57
------------------------------------------------------------------------------------------------------------------------------------
Power loss:                         1146KW                712KW                      600KW                     450KW
------------------------------------------------------------------------------------------------------------------------------------
Power loss reduction:               _______               434KW                      546KW                     696KW

Power loss reduction(%):            _______               37.8709 %                 47.644 %                  60.733 %
loss from total power supply(%):     15.1788 %            9.4305 %                  7.947 %                  5.9603 %
------------------------------------------------------------------------------------------------------------------------------------
Minimum voltage:                    0.8491pu             0.9118pu                  0.9399pu                  0.965pu
------------------------------------------------------------------------------------------------------------------------------------
```

Based on case 4, two DG are installed in different locations. Once the program is run, the sizes of DG will vary automatically between the ranges of 1.8875 < DG ≤ 6.040MW until it reaches the optimal values. The best DG size is 1.903MW and 2.713MW. In fact, the size of DG in case 3 is somewhat higher than case 4 due to the absence of reconfiguration.

Table 4-3: DG size and location after reconfiguration



```
------------------------------------------------------------------------
------- Size of DG and Placement when DG Inserted After Reconfig -------
------------------------------------------------------------------------
Total real demand                      7550.0000KW
Total reactive demand                              4940.000KVAr
Size of DG_1 & Bus Number placement     1903Kw     @ Bus    45
Size of DG_2 & Bus Number placement     2713Kw     @ Bus    57
------------------------------------------------------------------------
```

The proposed method does not only give the lowest power losses, but also improves the overall voltage profile of the network reconfiguration. Figure 4-2, Figure 4-4 and Figure 4-6 shows the voltage profile for case 1, case 2 and case 3. It shows that allocation DG based on voltage profile can improve the voltage profile for the system as in Figure 4-6. The minimum voltage profile for case 1, case 2 and case 3 are 0.8491 p.u, 0.9118 p.u and 0.9399 p.u respectively, compared to the minimum voltage profile for case 4 is 0.965 p.u shown in Figure 4-8. Voltage profile for case 4 is more stable because the values are within the standard range compared to other cases. On the other hand, allocation and sizing of DG also improve the voltage profile.

The minimum bus voltage at base case is equal to 0.8491 p.u (case 1) which is under the minimum voltage limit and then being raised to nearly 0.965 p.u (case 4) after reconfiguration and DG system is applied.

4.2 Cost Analysis of DG and Power Loss

4.2.1 Cost of Energy Loss

Based on Ethiopian electric billing tariff Cost of energy, loss of the distribution system is calculated using the equation (3.19).

$$Cost\ of\ \ Energy\ loss\ per\ year\ = \ Power\ loss * Time\left({}^{h}\!/_{year} \right) * Tariff\left({}^{Birr}\!/_{kWh} \right)$$

By considering an average electricity price of 0.6943 Birr/kWh from appendix-III, the average cost of energy loss at the base case of Addis west distribution system feeder K01 for one year are calculated as follow.

$$Cost\ of\ \ Energy\ loss\ per\ year\ =\ 1146\ kW\ *\ 8760\ {}^{hours}\!/_{year} *\ 0.0331\ {}^{\$}\!/_{kWh}$$

$$=\ 332,\ 289.576\ {}^{\$}\!/_{year}$$

4.2.2 Cost of Steam turbine DG

The cost of the Steam turbine DG system includes equipment cost, installation cost and operation and maintenance costs are given in the form of Cost/kW is equal to $670 per kW from Steam turbine datasheet (catalog). Total capacity of Distributed Generation (DG) of distribution system at case 4 (i.e. Reconfiguration with DG) is 4.616MW.

$$Cost\ of\ \ DG = \ \mathrm{DG}_{\mathrm{Total}}\ *\ Tariff\ \left({}^{\$}\!/_{kW}\right)$$

$$Cost\ of\ \ DG\ =\ 4.616MW\ *\ 670\ \left({}^{\$}\!/_{kW}\right)$$

$$= \$3,092,720$$

Therefore, total cost of distributed generation is $3,092,720.

4.2.3 Payback Period

Total revenue loss from the distribution system due to power loss in the distribution system is $332, 289.576. When divide the cost of 4.616 MW DG by the annual loss, it will be 9.3 years. This means the cost of DG can be paid from the 9.3 years of revenue loss from the distribution system.

CHAPTER 5: Conclusion and Recommendation

5.1 Conclusion

This thesis demonstrates a favorable approach to improve distribution network performance. Many researchers studied network reconfiguration; some of these researches applied network reconfiguration for either loss reduction or service restoration and some of them applied it for both. A few number of researches applied network reconfiguration on the distribution system with DGs without taking into consideration that the advantages of DGs are conditional and dependent on installation characteristics.

Network reconfiguration has been applied as two cases: 1) without DGs, 2) with best located DGs. The percentage of loss reduction and minimum voltage increment have been calculated and recorded after optimally locating DGs, after case 1 and after case 2. All the results prove that the proposed approach are not only favorable, but also effective and can be applied on balanced distribution systems.

Both network reconfiguration and DG installation of the distribution system is to minimize the real power losses and improve the voltage profile. The results show that combination network reconfiguration and DG installation method are more effective in reducing power loss and improving the voltage profile in the system. The best on/off pattern of the switches can be identified which give the minimum power loss and improve the voltage profiles. The network reconfiguration found in the simulation, switches 34, 41, 52, 66 and 81 are open and the rest are closed. This configuration is shown in Figure 4-7. The real power loss in this best network is reduced by 60.733 % (i.e. 1146 kW to 450 kW) which is the total power supply loss is reduced from 15.1788% to 5.9603%.

Not only is the total real power loss for the system reduced, the system’s overall voltage profile is improved as well. The voltage magnitude is plotted versus the bus number for the initial system configuration and for the best system configuration. The bus minimum voltage is increased from 0.8491p.u to 0.965p.u. Decreasing system losses often improves the quality of service to the customer. Hence the proper site and size of DG is found and determined by a bus number 45 and 57 with proper size of 1.903 MW and 2.13 MW respectively. The total estimated cost of the determined DG size was carried out by taking the micro turbine DG type. Consequently, the total cost of the 4.616 MW DG installation was found to be $332, 289.576 with its payback period of 9.3 years.

5.2 Recommendations for Future Works

The analysis in the PSO based model can be further extended by considering different operational situations (instead of one), ESSs and different cost drivers such as emission costs, etc. Relevant conclusions can be drawn from such comparative results. Selection of switches, Tie switch placement and types, doing with the addition of more constants what have done in this thesis such as constraint of isolation and power injection.

The configuration must be in radial to avoid excess current flow in the system. Therefore, in order to ensure the radial network is maintained, adding of multi-objective functions several constraints must be taken into account. Several standard rules have been adopted for selection of switches. Those switches that do not belong to any loop, connected to the sources and loads.

The impact on protection co-ordination provided that the power grids are designed to operate for unidirectional power flow. The impact on harmonics as a result of integrating RES based DGs, which often require power electronic interfaces, major sources of harmonics injected into the system. Generally, all the impacts of DG integration in distribution system.

Future works to be done in the area of reliability improvement by using DG. Different distributed generation options other than PV and diesel technologies can be studied for this distribution reliability improvement. DG can be used for a backup purpose or for peak shaving. So for each of these purposes, there should be a control system modeled between the DG and the existing grid. Please go through it again and further improve it.

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Appendix-I: Line and Bus data

Table: *GMR Factor (k) and Strand Relationship for AAC conductor*

Strands	GMR factor, k
1	0.7788
3	0.6778
7	0.7256
19	0.7577
37	0.7678
61	0.7722

Table: *Conductor parameters in the feeder*

Conductor Type	Nominal area (mm^2)	Actual area (mm^2)	Stranding and wire diameter (mm)	Overall diameter (mm)	Actual diameter (mm)	GMR (mm)	Resistance (Ω/km)
AAC	5	24.2	7/2.1	6.3	5.56	1.88	1.181
AAC	50	49.5	7/3.00	9	7.9377	2.88	0.5785
AAC	95	93.5	19/2.5	12.5	10.8975	4.129	0.3085
AAC	120	117	19/2.8	14	12.2	9.24	0.2853

Table: *The Line Impedance*

From	**To**	R(Ω)	X(Ω)
1	2	0.029433	0.030932
2	3	0.165418	0.173847
3	4	0.193244	0.203091
4	5	0.118464	0.1245
5	6	0.009448	0.00299
6	7	0.164122	0.172485
7	8	0.126518	0.075873
8	9	0.294216	0.309208
8	10	0.171236	0.10269
7	11	0.036793	0.022065
11	12	0.279011	0.167323
12	13	0.102568	0.06151
13	14	0.090825	0.054467
12	15	0.061437	0.036844
1	16	0.139361	0.083575
16	17	0.087527	0.05249
16	18	0.152898	0.091693
18	19	0.009025	0.005412
19	20	0.099271	0.059533
20	21	0.128965	0.040807
20	22	0.112345	0.067373
22	23	0.040264	0.024146
23	24	0.199438	0.119603
23	25	0.011223	0.00673
22	26	0.150063	0.089993
26	27	0.008793	0.005273
26	28	0.101006	0.060573
28	29	0.259747	0.15577
28	30	0.074349	0.078137
30	31	0.203857	0.214244
30	32	0.041031	0.043121
32	33	0.071942	0.075608
33	34	0.198426	0.118996
33	35	0.242623	0.145501
35	36	0.048033	0.050481
35	37	0.003394	0.003566
35	38	0.255747	0.268778
38	39	0.109741	0.065812
39	40	0.170658	0.102343
39	41	0.161402	0.096793
41	42	0.053974	0.032368
42	43	0.095221	0.057104
43	44	0.038563	0.040527

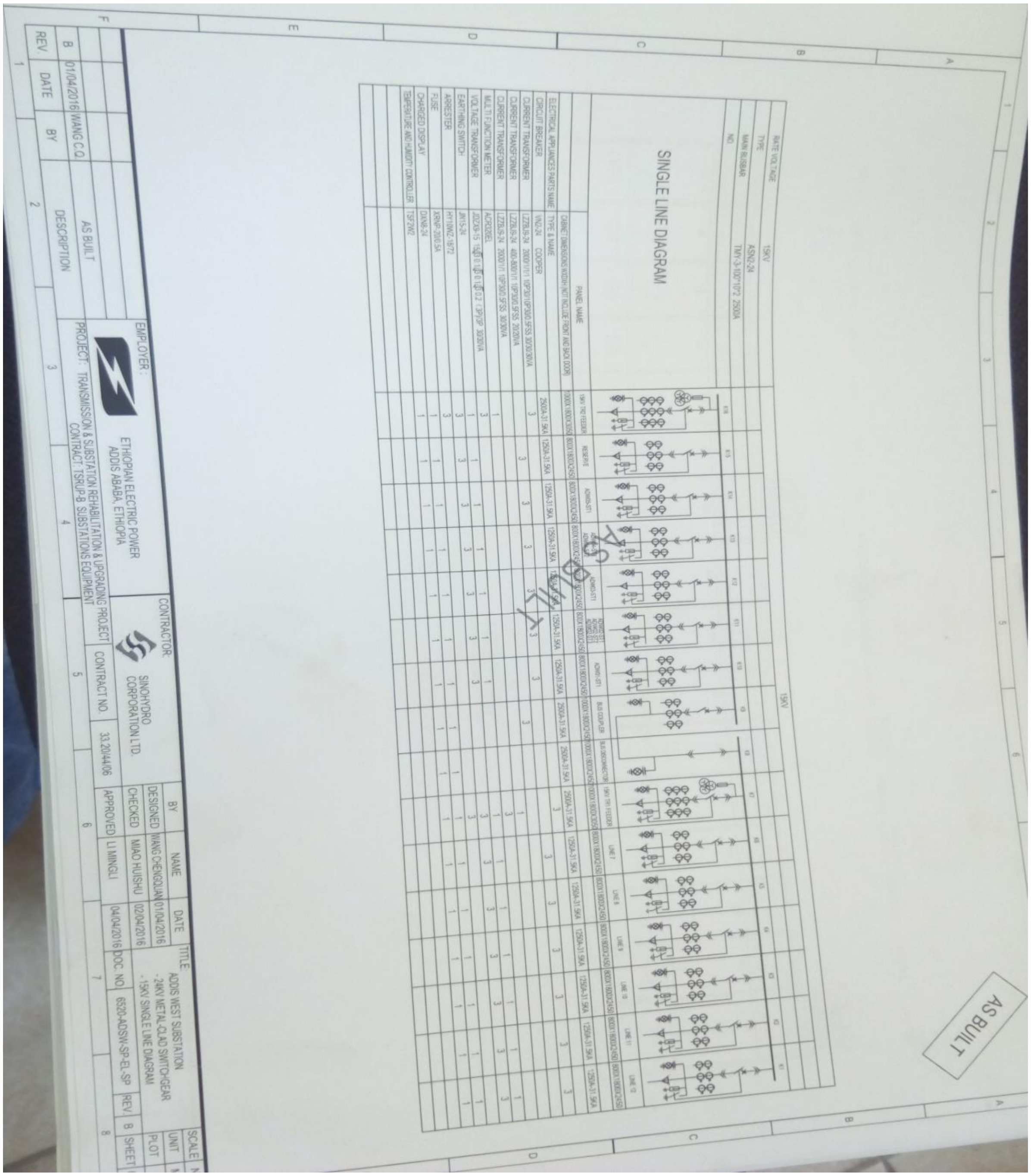
Table: *Connected loads of transformers*

Transformer No.	KW	KVAr
1	-	-
2	-	-
3	-	-
4	108.4	93.8
5	-	-
6	123.2	92.4
7	-	-
8	116.8	87.6
9	176	132
10	134	98.6
11	-	-
12	-	-
13	-	-
14	180	123
15	135.2	101.4
16	176	124
17	-	-
18	202.4	111.8
19	-	-
20	132	99
21	-	-
22	-	-
23	210	100
24	144.8	108.6
25	-	-
26	120	70
27	-	-
28	150	70
29	-	-
30	192.8	144.6
31	-	-
32	-	-
33	123.2	92.4
34	-	-
35	199.2	149
36	192.8	120.6
37	-	-
38	-	-
39	116.8	87.6
40	248.8	152.6
41	-	-
42	-	-
43	135.2	101.4

43	45	0.037255	0.022342
45	46	0.01938	0.011622
45	47	2.1036	1.261529
47	48	0.112634	0.067547
47	49	2.984366	1.789725
42	50	0.051949	0.031154
50	51	0.404487	0.242571
50	52	1.402284	0.84095
32	53	0.193244	0.203091
53	54	2.1036	1.261529
54	55	0.112634	0.067547
55	56	0.165418	0.173847
56	57	0.166875	0.052802
56	58	0.637361	0.669838
56	59	0.041099	0.013004
59	60	0.056394	0.059267
60	61	0.192756	0.115596
61	62	1.24789	0.89897
62	63	0.03693	0.02632
62	64	0.04790	0.028726
64	65	0.23321	0.16965
64	66	0.06789	0.04659
61	67	0.02123	0.016987
67	68	0.041031	0.043121
67	69	0.03348	0.02965
69	70	0.071942	0.075608
70	71	0.184542	0.11067
71	72	0.091779	0.096455
72	73	0.017529	0.010512
28	74	0.199438	0.119603
74	75	0.259747	0.15577
75	76	0.203857	0.214244
75	77	0.04930	0.03095
77	78	0.07961	0.05781

44	-	-
45	200	100
46	-	-
47	161.6	116.2
48	199.2	113
49	223.2	137.4
50	100.8	75.6
51	198.4	129
52	189.6	67.2
53	215.2	121.4
54	181.6	136.2
55	-	-
56	120	60
57	183.2	137.4
58	-	-
59	178.4	133.8
60	-	-
61	-	-
62	104.8	78.6
63	-	-
64	143.2	107.4
65	250	128
66	-	-
67	150	70
68	210	100
69	120	80
70	192.8	144
71	248.8	167.6
72	209.2	100
73	135.2	101.4
74	-	-
75	144.8	108.6
76	105.6	79.2
77	116.8	87.6

Appendix-II: Single Line Diagram of the Substation



Appendix-III: Ethiopian electric billing system

	Active Energy Rang (kWh)	Price Rate (Birr/kWh)
Residential	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	401-500	0.5880
	Above 500	0.6943
Commercial	0-50	0.6088
	Above 50	0.6943
Low Voltage Time of Day industry@ 15Kv		
Peak		0.7426
Off peak		0.5354
High Voltage Industry 132Kv		
Peak		0.4736
Off peak		0.3664

Appendix-IV: Data Measurement Using Fluke Meter

Fluke 434 series Energy meter

Appendix-V: MATLAB codes for the research work

The main Matlab program calling the sub-programs

```
clc;

close all;

clear;

% INITIALIZING SWARM PARAMETER

n=20;

dim=5;% Dimmension of searching space

x=swarm;% Creating a swarm

vnew=rand(n,dim);% Creating a randomized initial velocity

vold=vnew;

sig=zeros(n,dim);

pbest=swarm;% Creating pbest matrice

gbest=[4 3 14 23 19];% Introducing a randomized gbest

fitness=zeros(1,n);

wmax=0.9;

wmin=0.4;

r1=rand(n,dim);% Creating a randomized matrice, size (n x dim)

r2=rand(n,dim);% Creating a randomized matrice, size (n x dim)

iter=0;

maxiter=40;% Maximum iteration

tap=[11 12 13 14 43 44 45 71 74 75 79 80 0 0 0 0

    4 5 6 7 8 46 47 48 49 52 53 54 55 56 57 58

    3 9 10 35 36 37 38 39 40 41 42 69 76 77 0 0
```

```
    21 22 23 24 25 26 59 60 61 62 63 64 73 0 0 0
    15 16 17 18 19 20 70 78 81 82 0 0 0 0 0 0];
ta=tap';
caselv=loadcase(case);
% Establish the incidence matrix
doc=xlsread('branch');
nhanh=82;
nut=78;
matrix=zeros(nhanh,nut);
    nutdau=doc(:,1);
    nutcuoi=doc(:,2);
for i=1:nhanh
matrix(i,nutdau(i))=1;
matrix(i,nutcuoi(i))=1;
end
 % Initializing fitness function for pbest
 fpbest=zeros(1,n);
 for i=1:n
     fpbest(i)=50000;
 end
% Main loops
while iter<maxiter
    iter=iter+1;
    w=wmax-(wmax-wmin)*iter/maxiter;% Specilize the weight coefficient
    c1=2*rand(1);
```

```
    c2=2*rand(1);

    % Updating velocity

    for i=1:n

        for j=1:dim

            vold=vnew;

        vnew(i,j)=w*vnew(i,j)+c1*r1(i,j)*(pbest(i,j)-
x(i,j))+c2*r2(i,j)*(gbest(j)-x(i,j));

       if abs(vnew(i,j))==abs(vold(i,j))

           vnew(i,j)=rand(1,1).*vnew(i,j);

       end

        end

    end

    % Updating sigmoid function

    for i=1:n

        for k=1:dim

        sig(i,k)=length(nonzeros(ta(:,k)))/(1+exp(-vnew(i,k)));

        end

    end

    % Updating particles' coordinate

    for i=1:n

        for k=1:dim

            x(i,k)=ta(ceil(sig(i,k)),k);

        end

    end

    % Calculating fitness function for each particle

         for k=1:n
```

```
            hop=caselv ; matran=matrix;
             for i=1:dim
                 hop.branch(x(k,i),11)=0;
                 matran(x(k,i),:)=0;
             end
     % Check on constraint of radial distribution network
             for j=1:length(matrix(1,:))
                 for i=1:length(matrix(1,:))
                     if sum(matran(:,i))==1
                         row=find(matran(:,i));
                         matran(row,:)=0;
                     end
                 end
             end
             if sum(sum(matran))==0
                 result=runpf(hop);
fitness(k)=sum(result.branch(:,14)+result.branch(:,16))*1e3;
             end
         end
    % Updating pbest
          for k=1:n
            if fitness(k)<fpbest(k)
                 pbest(k,:)=x(k,:);
                 fpbest(k)=fitness(k);
            end
```

```
          end
     % Calculating value of gbest
          hop1=caselv;
          for i=1:dim
              hop1.branch(gbest(i),11)=0;
          end
          result=runpf(hop1);
          fgbest=sum(result.branch(:,14)+result.branch(:,16))*1e3;
          gbestvolt=result.bus(:,8);
          minvolt=min(gbestvolt);
    % Updating gbest
     for k=1:n
        if fpbest(k)<fgbest
           gbest=pbest(k,:);
        end
     end
end
% Calculating initial configuration
bandau=caselv;
o=[78 79 80 81 82];
[BC,Config,Dg,Config_DG,z,Y] = pvplot();
Gbest=Y;
Agbest= x;
Bgbest= z;
total_ploss=v;
```

```
for i=1:length(o)

    bandau.branch(o(i),11)=0;

end

%% Printing results

ketqua=runpf(bandau);

tonthat=sum(ketqua.branch(:,14)+ketqua.branch(:,16))*1e3;

dienap=ketqua.bus(:,8);

dienapmin=min(dienap);

gbestvolt;

a=sort(Gbest);

% ploss=(tonthat-fgbest)*100/tonthat;

ploss=(total_ploss-fgbest)*100/total_ploss;

DPloss=(total_ploss-Agbest)*100/total_ploss;

CPloss=(total_ploss-Bgbest)*100/total_ploss;

 [VBN,VBN1,NB,val17] = budi_test_case();

BC = min(z(:,1));

 Config = min(z(:,7));

 Dg = min(z(:,17));

 Config_DG = min(z(:,15));

%% Results in the form of figures

% Base case

figure('Name','Voltage Profile');

hold all;

plot(z(:,1),'-sr');

legend('Base Case')
```

```
ylabel('Voltage (p.u)')

xlabel('Node')

title('Voltage profile')

grid on;

hold off

% After Reconfiguration

figure('Name','Voltage Profile');

hold all

Basecase=plot(z(:,1),'-sr');

Reconfig=plot(z(:,7),'g--o');

legend('Base Case','Only Reconfig')

ylabel('Voltage (p.u)')

xlabel('Node')

title('Voltage profile')

grid on;

hold off;

% DG Inserted

figure('Name','voltage Profile');

hold all

Basecase=plot(z(:,1),'-sr');

Reconfig=plot(z(:,7),'g--o');

DG=plot(z(:,17),'*--');

legend('Base Case','Only Reconfig','Only DG Connected')

ylabel('Voltage (p.u)')

xlabel('Node')
```

```
title('Voltage profile')

grid on;

hold off;

% Reconfiguration with DG

figure('Name','voltage Profile');

hold on

Basecase=plot(z(:,1),'-sr');

Reconfig=plot(z(:,7),'g--o');

DG=plot(z(:,17),'*--');

Reconfig_DG=plot(z(:,15),'-Xm');

legend('Base Case','Only Reconfig','Only DG Connected','Reconfig With DG
Connected')

legend('location','southwest')

ylabel('Voltage (p.u)')

xlabel('Node')

title('Voltage profile')

grid on;

hold off;

disp('===================================================================
================================================================')

disp('************************************** SIMULATION RESULT OF ADDIS
WEST DISTRIBUTION NETWORK ***************************************')

disp('===================================================================
================================================================')

disp('                                 BASE CASE                     AFTER
RECONFIGURATION        DG CONNECTED ONLY          RECONFIGURATION WITH DG
')

disp('-------------------------------------------------------------------
----------------------------------------------------------------')
```

```
disp(['Tie switches:           ',   num2str(O)   , '         ',num2str(a),'
', '_______','                 ',num2str(a)   ])

disp('-----------------------------------------------------------------
--------------------------------------------------------------')

disp(['Power  loss:                       ',num2str(total_ploss),'  KW','
',num2str(fgbest),'  KW','                     ',num2str(Agbest),'  KW','
',num2str(Bgbest),'  KW'])

disp('-----------------------------------------------------------------
--------------------------------------------------------------')

disp(['Power   loss   reduction:                       ',   '_______','
',num2str(total_ploss-fgbest),' KW','              ',num2str(total_ploss-
Agbest),' KW','                   ',num2str(total_ploss-Bgbest),' KW'])

disp('      ')

disp(['Power    loss    reduction(%):                ',     '_______','
',num2str(ploss), '  %','                        ',num2str(DPloss),  '  %','
',num2str(CPloss), '  %'])

disp('-----------------------------------------------------------------
--------------------------------------------------------------')

disp(['Minimum  voltage:                             ',num2str(BC),'   pu','
',num2str(Config),'  pu','                         ',num2str(Dg),'  pu','
',num2str(Config_DG),' pu'])

disp('-----------------------------------------------------------------
--------------------------------------------------------------')
```