SALP SWARM ALGORITHM BASED OPTIMAL NETWORK RECONFIGURATION WITH DISTRIBUTED GENERATION FOR POWER LOSS MINIMIZATION AND VOLTAGE PROFILE IMPROVEMENT (CASE STUDY: YIRGALEM SUBSTATION)

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IN

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BY

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HAWASSA UNIVERSITY

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HAWASSA (ETHIOPIA)

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A thesis submitted to Hawassa University, institute of technology, school of graduate studies, for the partial fulfillment of the requirement for the degree of Master of Science in power system and energy engineering.

Advisor: Mr. Tewodros Tesfaye

Co-advisor: Mr. Mesfin J.

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SCHOOL OF RESEARCH AND POSTGRADUATE STUDIES

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ADVISOR'S APPROVAL SHEET

This is to certify that the thesis entitled "SALP SWARM ALGORITHM BASED OPTIMAL NETWORK RECONFIGURATION WITH DISTRIBUTED GENERATION FOR POWER LOSS MINIMIZATION AND VOLTAGE PROFILE IMPROVEMENT (CASE STUDY: YIRGALEM SUBSTATION)" submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Engineering with specialization in Power system and Energy Engineering, The Graduate Program of the Department of Electrical and Computer Engineering, and has been carried out by Fikadu Alemayehu ID No- GPPoSyR/012/12 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We the under signed Board of examiners of the final open defense by Fikadu Alemayehu have read and evaluated his thesis entitled "SALP SWARM ALGORITHM BASED OPTIMAL NETWORK RECONFIGURATION WITH DISTRIBUTED GENERATION FOR POWER LOSS MINIMIZATION AND VOLTAGE PROFILE IMPROVEMENT (CASE STUDY :YIRGALEM DISTRIBUTION)" and examined the candidate. This is therefore, to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree.

Mr. Tewodros Tesfaye	________	________
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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the school of graduate studies (SGS) through the department Graduate Committee (DGC) of Electrical and Computer Engine

Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for fulfillment of a degree or otherwise in this or any other university, and all sources and materials used for the thesis have been acknowledged. All Advisor's comments are duly incorporated.

Fikadu Alemayehu	________	________
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This thesis has been submitted for examination with my approval as a university advisor

Mr. Tewodros Tesfaye	________	_________
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Abstract

In a distribution system, power loss and voltage deviation are the main concern for the customers and utility. The distribution system has a lower voltage level and higher amount of flowing current than the transmission system, so that, the percentage real power loss in the distribution system is higher. Therefore, this thesis work presents optimal network reconfiguration with the distributed generation of yirgalem radial distribution network to minimize the power loss, operation cost, and enhance the voltage profile of the distribution system using the Salp Swarm Algorithm (SSA). The resource feasibility of solar and wind power in yirgalem city was analyzed and the outcomes showed that solar power generation is more desirable. For this reason, the solar-type Distributed Generation (DG) is used. The proposed SSA algorithm was compared with Particle Swarm Optimization (PSO) and Whale Optimization Algorithm (WOA) in three various scenarios (only optimal network reconfiguration, only optimal DG size and site, and simultaneous optimal network reconfiguration and DG allocation) for the abosto feeder. After analysis of the three scenarios in MATLAB-R2016a, it can be concluded that the simultaneous network reconfiguration with DG shows a dominant result over only network reconfiguration and only DG allocation. The simulation result of base case backward forward sweep load flow analysis revealed that the abosto feeder has a base case power loss of 401.3KW. The feeder minimum voltage profile at the base case is 0.87pu. After simultaneous optimal network reconfiguration and DG size and site with SSA, the optimal tie switch open is 11, 25, 16, 42, 14 and the optimal location of the solar-type DG is at bus 23 and its size is found to be 895.3KW. Consequently, power loss of the selected abosto feeder is reduced to 101.5KW from the base case. The power loss reduction of the abosto feeder is 74.7% with respect to the base case loss. The voltage profile after optimal network reconfiguration with DG is improved by 11.4%. As per the economic evaluations, the proposed method is cost-effective. Depending on the findings of this thesis, it is concluded that optimal network reconfiguration with DG reduces power loss, operating cost and enhance the voltage profile of the distribution system.

Keywords: Distributed Generation, Network reconfiguration, Optimal, Power loss reduction, Salp swarm Algorithm.

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List of Abbreviation, Acronym and Symbols

AC	Alternative Current
BCBV	Branch Current to Bus Voltage
BIBC	Bus Injected to Branch Current
DC	Direct Current
DLF	Distribution load flow
DG	Distributed Generation
D	Dimension of problem
DER	Distributed Energy resource
DNR	Distribution network reconfiguration
DOD	Depth of discharge
EPRI	Electric power Research Institute
EEP	Ethiopian Electric power
EEA	Ethiopian Electric Agency
ETB	Ethiopian Birr
EEPCO	Ethiopian Electric power corporation
GWO	Grey Wolf Optimization
HAS	Harmony Search Algorithm
Hr	Hour
IEEE	Institute of Electrical and Electronics Engineers
IEA	International Energy Agency
I	current
KVL	Kirchhoff's Voltage Law
KCL	Kirchhoff's current law
KWh	Kilo what hour
KV	Kilo volt
L	Inductor
LCL	Inductor Capacitor Inductor
MVA	Mega Volt Ampere
MPPT	Maximum power point tracking

MW	Mega watt
MATLAB	Matrix Laboratory
MVAr	Mega Volt Ampere reactive
NASA	National Aeronautics and Space Administration
N	Population size
OF	Objective Function
PL	Power loss
PWM	Pulse Width Modulation
PDS	Power distribution system
P	Active power
PSO	Particle swarm optimization
PCC	Point of common coupling
P.U	Per unit
PLL	Phase locked loop
PV	Photovoltaic
Q	Reactive power
RDS	Radial distribution system
R/X	Resistance to Reactance
SW	Switch
SFLA	Shuffled Frogs Leaping Algorithm
SSA	Salp swarm Algorithm
SPSO	Selective Particle Swarm Optimization
USD	US dollar
VDI	Voltage Deviation Index
VSI	Voltage source inverter

CHAPTER ONE

1. INTRODUCTION

An Electric power system comprises a generating system, a transmission system, and a distribution system. Generating station convert fuel energy into electricity, transmission system connects the generating stations and distribution substations and distribution system distribute power to consumers. In view of network structure, transmission and distribution systems are different. Generally, a transmission system will have a loop structure and a distribution system tends to have a radial structure [1].

Ethiopian Electric Power was started in 1956 as the Ethiopian Electric Light and Power Authority (EELPA), which comprises all Ethiopian activity around electricity in a solitary organization. The main administrator guiding five departments, these are Operations, Engineering, Planning, Finance and Administration, and Services. In 1996, Ethiopian Electric Light and Power Authority (EELPA) has split into the Ethiopian Electric Authority (EEA), carry-out overall regulating work, and a company, Ethiopian Electric Power Corporation (EEPCO) building activities from power generation to household delivery. In 2013, Ethiopian Electric Power Corporation (EEPCO) was split into two companies, Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). Ethiopian Electric Power (EEP) is responsible for generation, transmission, and system operation while Ethiopian Electric Utility (EEU) is responsible for power distribution to the end user. Generally, the above corporation consists of 500kV (where it is under construction), 400kV, 230kV, 132kV primary transmission systems and 66kV, 45kV as sub transmission system and 33kV and 15kV as distribution system according to [2].

1.1 Background of Research

Electrical power is transferred by high voltage transmission lines from generation station at long distance to the distribution substation. When the power reach the distribution system, the high value voltage is decreased (say 66kV, 33kV or 15kV) by using step down transformer. The power at the distribution system further stepped down (say 0.4kv) and distributed to each load according to [3].

Electric power utility works to fulfill the system load as well as the needs of its customers by ensuring minimum operation cost on the condition that is acceptable to continuity and quality of electricity supply should be attained. However, Delivering reliable, cost-effective, and qualified power to the consumers is a challenging task for electrical utilities due to improper network expansion, minimum monitoring, and overutilization [4]. A large amount of losses in a power system occurs in distribution lines; while transmission and sub-transmission lines have only about 30% of the total losses. Therefore, the distribution systems must be appropriately designed to guarantee that the losses are within appropriate limits [5]. Many of the solutions and policies to address the problems Created by these common Centralized traditional power systems have been based on technological advancements. New generation sources have been introduced and pollution mitigation devices installed, but air quality impacts from electricity production still exist. Because of this, traditional systems have remained largely unchanged, with the exception of simple technological upgrades. The model proposed in this thesis is a design-based approach to address the inefficiency of traditional systems. The approach is referred to as network reconfiguration and distributed generation (DG) incorporation, which shift the design and layout of power generation and distribution systems to reduce power losses by increasing efficiency and encouraging the inclusion of renewable energy.

1.2 Distribution system

The distribution system is the important part of the power system which is used to transfer electrical energy to the end user. It is located between the main substation and the local end user's meter terminal. It receives the generated electrical power from the transmission network and steps-down to a lower voltage magnitude that mostly ranges between 2.4 kV and 33 kV using step down transformers which are commonly called step down transformers. Distribution systems have basic components such as distribution substation, feeder, distributor, distribution transformer and service main. A feeder is used to link the distribution system to the place that the electric power is to be distributed. The key attention in the design of a feeder is the current-carrying capacity. The second core part is a distributor which is a conductor which is the main connector between the distribution system and the end user. The current through a distributor is not the same because tapings are taken at different space through its length. A service main is usually a small conductor which links the distributor to the end users. There are various types of distribution systems depending on the criteria of classification. According to its nature, a distribution system could be either

DC distribution or AC distribution type whereas based on its construction, there are overhead and underground types of distribution systems. When the scheme of connection is considered, distribution systems can be categorized into three major parts [6].

- Radial structure
- loop structure
- mesh structure

1.2.1 Radial distribution system

The radial network is the regularly used system for power distribution grids. The radial distribution network is a structure like a tree shape and it doesn't have any closed loop. This kind of structure is the easiest and inexpensive structure for an electrical distribution system but, with this structure, if a line is detached by various cases, all the downstream systems will also miss the power. Radial system has a structure that starts from the reference node where the source is linked. The lateral line connected to the reference node or central node in the radial distribution system. This line starts from the central feeder and is connected to the load. The sub-lateral line starts from the lateral line. Finally, the minor lines start from the sub-lateral line. Distribution system with radial network structure may be considered somewhat as an extension of conventional power network distribution system hence it is normally used methods in a power distribution system [7].

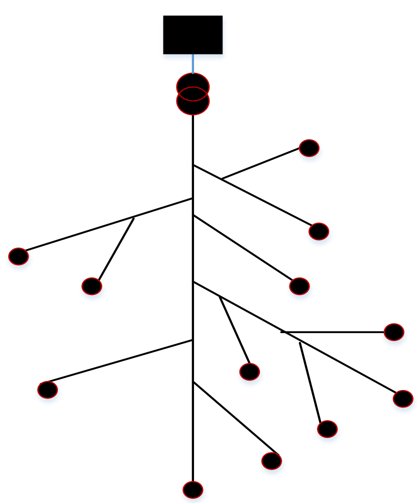

Figure 1.1: Radial distribution system configuration representation [8]

1.2.2 Loop structure

A loop configuration or also known as a double end-fed system where the power can flow through entire loads before being returned to the starting point. The loop network originates from the central substation bus then going through the region to be served and returns back to the central substation. The loop line can either be linked to a similar source or more than one source. To offer better supply reliability, the entire system can be fed from two sources. A loop structure distribution system may be operating either in an open loop or closed loop system. The configuration is acted as a radial system when operating in an open loop. In case of power from one direction is interrupted, the power will flow to service substations from the other source. The power can be easily restored when the fault occurs in the system by easily switching off the normally open switches or switching on the normally closed switches. Therefore, the system restoration will be faster and the additional routes provided by the loop system make it more reliable compared to the radial system. This condition makes the system has less voltage variation at consumers terminals. However, this system is more expensive because more switches, circuit breakers, and conductors are required to construct this system [9].

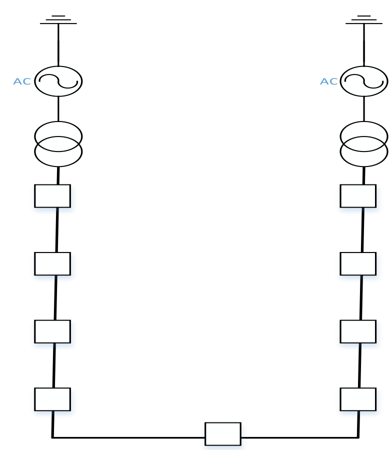

Figure 1.2: loop distribution system configuration representations [8]

1.2.3 Mesh structure

A mesh configuration network system or also known as a ringed network system. It is the combination of different loop systems in one network. This network configuration is interlocking loop systems, which is the more robust system than the other but is the more complex network configuration than the other two. The service feeders may be fed from more than one source. The presence of several path among all stages in mesh configuration system can make the system instantly and automatically re-routed its supply path when there are power interruption happen. The complexity of the network makes the mesh system more expensive system. For this reason it is normally used only in congested and high load density areas.

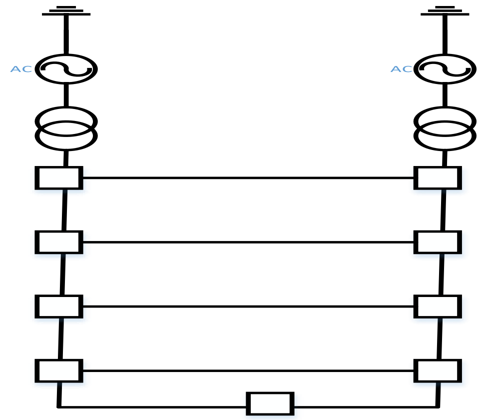

Figure 1.3: mesh distribution system configuration representations

1.3 Statement of the Problem

The electric power demand in Ethiopia is increasing from time to time due to population growth, industrial growth, social and economic developments, which results in increased current drawn from the source, voltage drop and power loss in radial distribution systems. Because of these, power plants are not sufficient to satisfy the people's fundamental services of the country and both utility and connected customers suffer from these power loss and voltage drop problems. The people in the yirgalem city, which consists of many industry loads, residential and commercial customers, are victims of such problems. Especially for factories and industries, it is really challenging to tolerate such problems since it causes many revenue losses. Therefore, there must be new system facilities, and improvements in production and use of electricity to tackle such problems in the power distribution system. Simultaneous Network reconfiguration and Distributed generation sizing and siting is one way of addressing such problems in power distribution systems. However, the non-optimal configuration of the network and improper sizing and siting of the DG unit can increase power loss and causes a bad effect on the voltage profile of the distribution systems. Therefore, this thesis presents the optimal network reconfiguration and distributed generation allocation simultaneously for power loss minimization and voltage profile enhancement using salp swarm optimization algorithm (SSA) in yirgalem substation for selected abosto feeder.

The followings are some of the research question lists that is answered in this thesis paper

- What is the best optimal network configuration in a yirgalem distribution system?
- How to determine the optimal size of DG connected in a yirgalem distribution system?
- Where is best position of DG in yirgalem distribution system?

1.4 Objectives of the thesis

1.4.1 General objective

The main objective of this thesis is to determine optimal structure of the abosto feeder with optimal size and site of DG using salp swarm algorithm to reduce power loss, and voltage profile improvement of the Abosto feeder.

1.4.2 Specific objectives

- To model the distribution system
- To investigate the resource feasibility of DGs in yirgalem
- To determine the optimal location and size of Distributed Generation using SSA.
- To identify optimal locations of tie-switches.
- To determine an optimal network configuration for selected feeder.
- To determine the maximum possible DG integration with respect to the given constraints
- To produce best reconfiguration and DGs sizing together in the distribution network.
- A detailed comparative analysis of SSA with PSO and Whale Optimization is performed in case of only network reconfiguration, only DG allocation and size and simultaneous network reconfiguration with DG

1.5 Scope of the thesis

The paper mainly limited on voltage profile improvement and active power loss reduction of distribution feeders by optimal network reconfiguration with optimally locating and sizing of DG using optimization techniques. This thesis work mainly includes:

- Base case analysis of a power distribution system using backward forward sweep load flow analysis.
- Comparison of the system power loss and voltage profile with only optimal network reconfiguration, only DG sizing and siting and simultaneous network reconfiguration with distributed generation will be performed

- Develop a program for optimal network reconfiguration with DG in MATLAB-R2016a based on salp swarm algorithm optimization techniques for power loss minimization and voltage profile improvement.
- Finally, determine the total saving cost after optimal network reconfiguration with distributed generation and make comparison with the base case system.

1.6 Significance of the thesis

This study have significance important for EEU to identify the existing problem of the distribution system and give measurable solution to the problem. Some of the selected advantages of this thesis is listed below:

- Clearly show the effects of power loss and voltage drop on the customer and the economy of the utility.
- Improve the performance of the proposed distribution system by significantly minimizing the power loss.
- Keep the voltage profile of the system according to IEEE standard so that increase the system efficiency.
- Minimizing the loss of money due to power loss for the electric utility company.
- Increase the reliability of the electric company.

1.7 Research methodology

To achieve the mentioned objectives, various procedural tasks followed by the author, the first method towards processing the work is started with reviewing different literatures and journals where all the theoretical information regarding with power loss minimization and voltage profile improvement will be gathered and a comparison of previous similar research is studied. The overall methodology of this thesis work is shown in the following table.

Table 1.1: research methodology procedures

Methods	Description
1. Literature review	Various paper related with this thesis is reviewed from various source like journals, published documents, lecturers, materials etc.
2. Data collection methods	Different data of this thesis work are collected from the EEU, EEP and yirgalem substation. Some of the data collected are; line resistance, line reactance, active and reactive power at each bus, transformer rating at each bus, single line diagram of the abosto feeder.
3 Modeling and power flow analysis	Modeling of distribution system, modeling of PV type DG is carried out. The high resistance to reactance ratio and convergence problem faced in Gauss seidal analysis and newton Raphson methods, but backward forward sweep power flow analysis has been carried out for the selected radial distribution system
Objective function formulation and constraint	The main objective formulated in this thesis is power loss minimization and voltage profile improvement. Various constraints formulated in this thesis, such as voltage constraint, DG location and size constraint, radially constraint etc.
Simulation result and discussion	In this section, four scenario will be clearly analyzed and compared Scenario 1: base case load flow analysis Scenario 2: only network reconfiguration Scenario 3 only DG allocation Scenario 4 simultaneous network reconfiguration and DG allocation

1.8 Thesis organization

This thesis work is categorized into five chapters:

Chapter one includes the introduction, background of the thesis, brief definition of DG, grid integrating issues of DGs. problem statements, objectives, methodology, and scope and significance of the thesis.

Chapter two present the literature review of preceding works which are related with power loss minimization and voltage profile enhancement in distribution system using different optimization algorithms.

In Chapter three, the data collection and analysis method, modeling of the distribution system, modeling of solar based DG, load flow analysis, was discussed. Optimization algorithm, inverter modeling and control were briefly presented.

Chapter four, in chapter four discuss the simulation result of the thesis by considering four different scenarios.

Chapter five encompass the conclusion, recommendation and future works.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Distribution automation allows flexible control of distribution networks to the utilities, which can increase the efficiency, reliability, and quality of utility. One important application of distribution automation can be distribution network reconfiguration. Network topology changed by opening or closing of the sectionalizing or tie switches constitutes network reconfiguration, while meeting the load requirements and radial constraints of the system. For meeting today’s rising demand of the load, distributed generation is increasingly deployed into the distribution system which also allows the distribution network operators to be more flexible to the change market conditions..

2.2 Literature review

Several researchers have presented different ways to solve the power loss minimization and voltage profile improvement in the distribution system. Related works published in technical literature are described, the concepts of voltage profiles and power losses are reviewed.

Some researchers consider power loss minimization and voltage profile improvement techniques like optimal network reconfiguration and distributed generation separately, Other use optimal network reconfiguration and DG placement and sizing simultaneously to curve the problem related to power loss minimization and voltage profile enhancement. All the literature reviewed on this specific thematic area is presented below by categorizing into three main parts: The first category consists of previous works which considered only distribution network reconfiguration and the second part is DG integration on the existing grid topology whereas the last part incorporates researches that were done using simultaneous network reconfiguration and DG allocation.

2.2.1 Literature review on network reconfiguration

A.V.sudhakaa reddy and M.Damodar Reddy in 2016 proposed the optimization technique to mitigate the network reconfiguration problem with an objective of minimizing real power loss and simultaneously improving the voltage profile in the radial distribution network (RDN). A Meta-heuristic Particle swarm optimization (PSO) is applied to re-structure and find the optimum tie switches position for minimization of active power loss in a radial distribution network. The proposed method is verified on IEEE 33 bus and IEEE 69 bus radial distribution system and the result compares the power loss and voltage profile with the base case [10].

Degarege anteneh in 2020 presented a research work on the reliability assessment and optimal reconfiguration of radial distribution network to minimize the overall distribution losses, to enhance reliability and enhance the voltage profile by using a modified shark smell optimization (MSSO) algorithm and ETAP. The technique is verified on the combolcha distribution system and the results depict that the stated method is effective in its performance. After optimal reconfiguration of the network, power loss of the system minimized by 60%, and maintained all node voltage magnitudes between the permissible limit. The overall result was motivating but the real power loss can be significantly further minimized if the network topology is reconfigured with optimal DG allocation [9].

A.S.Abubakar et al. in 2019 accomplished optimal reconfiguration of radial distribution networks using meta-heuristic techniques. The technique employed is based on improved genetic algorithm to find the best location of tie and sectionalizing switches, in order to increase the performance of the network. The efficiency and validity of the developed model was verified on a 16, 33 and 69 IEEE-Bus distribution feeder. The results depicts that the minimization of 8.86%, 31.15% and 48.8% in real power loss as compared to the power loss of the existing system. The weak side of this paper is that it use the oldest optimization techniques (genetic algorithm) for optimal allocation of tie line and sectionalizing switches.it also don’t made any comparison of genetic algorithm with other optimization algorithm. The result obtained in this paper is poor (below 50%). this result can be improved if the latest optimization algorithm is used with simultaneous network reconfiguration and DG allocation [11].

A.V.Sudhakara et al. in 2017 performed network reconfiguration of distribution network for los reduction using grey wolf optimization algorithm. The objective function is developed to curve the reconfiguration problem which comprises minimization of active power loss and voltage drop reduction. A nature inspired Grey Wolf Optimization Algorithm is employed to reconfigure the power distribution network and to recognize the optimal switches corresponding minimum power loss in the distribution network. The GWO technique has been tested on standard IEEE 33-bus and 69-bus systems and the results are really interesting. But in this work, the result obtained with GWO is not compared with other optimization techniques [12].

Yhiaoui Merzoug et al. in 2020 suggested optimization of distribution feeder reconfiguration for loss minimization using the PSO method. The aim of this work is to search an optimal structure of the system by the help of Meta heuristic technique, namely the particle swarm optimization techniques (PSO) to minimize real power losses and voltage drop by maintaining some crucial constraints. The effectiveness of this techniques is verified on a 33-IEEE test system and the outcome attained are compared with the results of the existing system [13].

Balmukund kumar et al. in 2020 performed optimal distribution network reconfiguration to enhance the network efficiency using PSO with Multi-objectives. He presented an effective method to search the best topology of the distribution system to minimize the real and reactive power losses, voltage deviation and to enhance the reliability of the system. The optimal reconfiguration is performed depending on the multi-objective algorithm, which comprises real and reactive power loss reduction index and voltage drop index by applying Particle Swarm Optimization methods (PSO). He was considered IEEE 69 bus distribution system with different tie-switches for optimal reconfiguration. This work has been performed with MATLAB-R2018b softer and the attained outcomes are compared with the result of the base case system. After discussed the acquired result, he was decided that the network reconfiguration with the multi-objective function using Particle Swarm Optimization is an effective methods [14].

Ayodeji Olalekan et al. in 2020 presented the selective particle swarm optimization (SPSO) to find the optimal place of the tie and sectional switches. He considered power loss minimization and voltage deviation minimization as key objective on his work. The objective function is developed by considering the some of the main constraint like radial constraint, bus voltage constraint line current limit constraint. The SPSO techniques was applied in Matlab R2018a software and tested on IEEE 33-bus radial distribution network (RDN). The acquired results depict that the active power was increased by 98.41%, 89.384%, and 89.437% for three different loading condition.

K.Premdeep Reddy et al. in 2017 proposed harmony search Algorithm for optimal network restructuring in radial distribution system. He considered reduction of power loss and voltage deviation mitigation as a key objectives for his work. Backward forward sweep load flow methods is employed and the objective function is developed to evaluate the power loss and bus voltage. Harmony search Algorithm is applied to find optimal position of the tie and sectionalized switch in the radial distribution network. The methods has been verified on IEEE 33 node and 69 node systems to demonstrate the effectiveness and capability of the methods. The result depict that the real power loss minimization for IEEE 33-node and 69-node systems was 51.93% and 55.72% respectively [15].

2.2.2 Literature review on distributed generation

Mandefro Elias in 2019 worked on performance improvement of radial distribution network by employing the optimally allocated distributed generation. The author had considered the minimization of power loss, reduction of power interruption, and minimization of cost as the core objective for his work. The power losses and voltage deviation evaluation are done based on a power flow method of forward-backward sweep for radial distribution network. The proposed techniques is verified at Gihon 26-node radial feeder of Bahir Dar radial distribution network. The results of this research work depict that proper sizing and siting of PV type of DG increases the efficiency of the network. The minimum voltage is improved from 0.9156pu to 0.965pu.Integrating DG with distribution system reduces the active power loss by 83.8%. The weak side of this thesis paper is particle swarm optimization algorithm (PSO) is employed to search the optimal place and size for distributed generation. It is old optimization algorithm. PSO is not compared with any other optimization algorithm [16].

Yared Bekele in 2018 worked on the effects of distributed resource incorporation in intermediate voltage distribution system. The system is tested on SEB-12 feeder of Sebeta-1 distribution feeder of intermediate voltage distribution network which having 43 node. The impacts of DG integration on total power loss, voltage profile, and voltage stability, loading of line segment, fault level, and protection coordination of the radial distribution network were investigated. The weak side of this thesis paper is, the author did not use any optimization algorithm to find optimal place and size of the DG [17].

B.Venkatesh Reddy in 2014 supposed the placing of DG source by applying the exact loss formula to increase the performance of Radial distribution system. He presented the application of distributed resource on power loss minimization. The two crucial concerns of the appropriate place and suitable size of distributed resource for power loss minimization have been analyzed. Analytical formulas was derived to search the suitable place and size of various types of distributed resource. Methodologies was developed for placing the distributed resource in distribution feeder. The analytic formulas and sizing methodologies was verified on IEEE 33 node network [18].

Adan kedir in 2015 suggested on optimal placing and sizing of distributed resource by considering power loss minimization, reliability enhancement and minimization of voltage deviation as main objective. Analytical methods were used to determining the best place and size of DG. The analytical method was verified on adama distribution system. Results of optimal DG size and place with respect to voltage sensitivity index are presented and determined the best places and size of distributed resource for the Adama distribution network to make the system reliable. Finally for Adama distribution system, the power loss before and after the incorporation of distributed resource is compared and the result show that power loss reduction after DG integrated is 88.63%. Feasibility analysis of Distributed generation is not considered. Cost analysis of the system is not performed. Optimization algorithm is not used to incorporate the distributed generation. This is gap of this thesis paper [19].

Julius Kilonzi Charles in 2011 applied hybrid genetic algorithm and improved particle swarm optimization algorithm to find the optimal place and size of the distributed resource.

The key objective for his work is minimization of the power loss, reduction of the voltage deviation and the minimization of the total operation cost of the feeder. He optimized the three objective by maintain the various constraint like node voltage constraint, DG sizing and position constraint line current limit constraint and power balance constraints.

The developed model was simulated inside Matlab 2019b application and verified on IEEE radial system, IEEE 33-bus test system and IEEE 57-bus test system by taking three kinds of DGs. The outcomes achieved were compared to those attained by the other researchers. It was seen that GAIPSO techniques have more effective in terms of minimizing both active and reactive power losses as compared to Heuristic, GA, PSO and IPSO techniques [20].

Derebe yeshambel amare in 2019 stated optimal placing and sizing of distributed resource in radial distribution feeder for voltage profile improvement and power loss reduction.

He considered the crucial objective of this thesis as active power loss minimization and voltage deviation minimization in case of Bahir Dar radial distribution feeder by applying distributed resource. The improved Particle swarm optimization (IPSO) based methodology has been used to allocate and sizing of DGs at the appropriate location(s) along the feeder of weakest candidate buses of the system decided by loss sensitivity index and power flow analysis. Cost analysis is not performed. Old optimization algorithm was employed to size and allocate distributed generation. The result obtain by IPSO is not compared with other optimization algorithm. These are the gap of this thesis paper [21].

Khaled Abo –Al-Ez and Xiaohua xia in 2014 published on optimal smart interconnection of a PV/wind DG micro grid with the power distribution system. Smart interconnection control strategy was developed for a grid connected PV/fixed speed wind type distributed resource developed smart monitoring approach of the distributed generation is depending on the control of the PV coupling Voltage Source Inverter (VSI). They proposed control algorithm is in the form of current controller implemented in synchronous rotating dq-frame. This allows decoupled control of active and reactive current components. Test system and controller operation and verification are implemented using MATLAB/Simulink [22].

Afroz Alam et al in 2018 applied distributed resource for power loss minimization in a radial distribution feeder. The main aim of this work is minimization of the loss and voltage profile enhancement by keeping various constraints. IEEE 33-bus and 69-bus Radial Distribution System (RDS) was verified for the similar aims, by applying backward forward sweep load flow techniques in Matlab R2016b softer. After simulated a load flow, a Distributed resource was put on the node which is having worst voltage value. After the application of the proposed methodologies on the case study, they concluded that appropriate sizing and placing of the distributed resource can minimize the loss and increase the voltage profile of the system according to [23].

M.V.LIKISH KUMAR et al in 2018 came up with optimal allocation of Distributed resource in distribution system considering variation in active power load. They proposed new method for optimally allocating the DG units in the distribution network to curtail distribution system losses and improve voltage profile. Also, the variation in active power load in the system is considered for effective utilization of DG units. To validate the reduction in losses of the proposed method, simulation was done on the IEEE-33 bus system and practical Vastare 116 bus system using MATLAB. The results show considerable energy saving when DG units are optimally allocated [24].

2.2.3 Literature review on simultaneous optimal network reconfiguration with DG

Wardiah Mohd Dahalan, Hazlie Mokhlis in 2012 applied PSO to reconfigure the structure of the feeder with the DG. The author proposed the efficient method based on Particle Swarm Optimization (PSO) to distinguish the switching for selected feeder reconfiguration and optimal size of DG. He considered the main objective as reduction of active power losses and bus voltage drop reduction in the system at the same time maintaining all the necessary constraints. The IEEE 33 distribution system with four distributed generation is used to check the effectiveness of the proposed system. The result obtained with PSO is compared with GA and he concluded that PSO has better performance in power loss reduction and voltage profile enhancement [25].

Habtemariam Aberie in 2019 come up with PSO to restructure the feeder with optimum sized and located DG. He considered three various power loss minimization techniques. (Network reconfiguration alone, DG insertion alone, DG insertion simultaneous with network reconfiguration) and also simulated to distinguish the dominance of the selected techniques. A proficient Meta heuristic PSO is used in the optimization process to reconfigure the network and DG insertion. The selected techniques is verified on Bahir Dar radial feeder specifically on BATA feeder at normal load condition. The author can reduce active power loss by 54.42% and the minimum voltage profile is improved to 0.9600pu. He concluded that concurrent network reconfiguration and DG incorporation method is more efficient in minimizing power losses and enhancing the voltage profile compared to remaining techniques. But some of the weakness of this thesis paper is the old optimization algorithm is used for simultaneous optimal network reconfiguration and DG placing and sizing. Result obtained with PSO is not compared with other optimization algorithm [6].

Alembrhan mekonen in 2020 studied network reconfiguration in distribution system with consideration of distributed generation. He also considered four different techniques to minimize power loss and improve voltage profile (base case load flow, only network reconfiguration, only DG insertion, DG insertion simultaneous with network reconfiguration) and also matlab simulation was done to check the dominance of the selected techniques over the other. A particle swarm optimization (PSO) is used in the optimization process of the network reconfiguration and distributed resource allocation. The proposed techniques is verified on Addis west distribution network. The researcher deduced that the combination of network reconfiguration together with DG installation method in the radial distribution network is more powerful than in power loss minimization and voltage profile improvement of the system [26].

Arun Onlam et al in 2019 proposed a novel adaptive optimization algorithm to reconfigure the network of the feeder and to allocate the distributed resource. The main objective of his work is minimizing the power loss, amendment in voltage stability index (VSI) and the operation cost minimization. He selected the methods called Adaptive Shuffled Frogs Leaping Algorithm (ASFLA) and used to reconfigure the feeder with distributed resource allocation in IEEE 33- and 69-bus distribution network with five various scenarios. The effectiveness of ASFLA was compared with the other techniques like Fireworks Algorithm (FWA), whale optimization algorithm WOA) and Shuffled Frogs Leaping Algorithm (SFLA). After compared all scenarios, the power loss minimized by the selected techniques in IEEE-33bua and IEEE 69 bus was 74.56% and 76.47% respectively [27].

Sarmad Ibrahim et al. in 2019 presented the Enhanced Water Cycle Algorithm (EWCA) to optimally restructure the network and to size and locate the distribute resource concurrently. The main objective of this work is power loss minimization and voltage stability index improvement. Various scenarios for feeder reconfiguration and DG insertion was simulated to assess the effectiveness of the selected method. The performance of the proposed techniques is evaluated in IEEE 33-bus radial feeder. After simulated the proposed algorithm, he concluded that the concurrent network reconfiguration with distributed resource allocation provide the good result compared to the base case system [28].

R.Srinivasa Rao et al in 2013 applied the Meta heuristic Harmony Search Algorithm (HSA) to find the optimal tie and sectionalizes switch combination and DG sizing and siting. Sensitivity analysis is applied to distinguish best position for incorporation of DG source. Various case of DG allocation and reconfiguration of network was considered to verify the effectiveness of the selected techniques. The constraints of bus voltage limit and line current limit are involved in the simulation of the objective function. The techniques was verified on 33-node and 69 node radial network distribution systems at three various load stages to depict the effectiveness and efficiency of the proposed techniques. The results found by HSA was compared with the genetic algorithm (GA) and the HAS shown the superiority over the GA [29].

The literature review related with network reconfiguration only, DG sizing and siting only and simultaneous network reconfiguration and DG sizing and siting for the aims of power loss minimization and voltage profile improvement was reviewed. All literature reviewed realize that power loss and voltage deviation (drop) have major problem in power distribution system, therefore appropriate attention is paid for power loss minimization and voltage drop reduction in power system.

Table 2.1: summary of different review

Authors	Titles	Advantages	Limitation
B.Venkatesh Reddy	Sizing of DG units Using Exact loss formula to improve Efficiency of radial distribution system	Used DG for power loss and voltage profile improvement	No model is used for load flow analysis. Cost analysis is not done.
Habtamu Eshete	Study loss minimization for distribution network reconfiguration using GA	Minimize power loss and improve voltage profile of network	more result can be attained if both reconfiguration and DG is used Increase switch number to minimize power loss which is not recommended for economic case
Wardiah Mohd Dahalan	Network reconfiguration for loss reduction with Distributed Generations using PSO	Simultaneous network reconfiguration and DG allocation improve system more than only DG or only reconfiguration	PSO have slow convergence speed compared to SSA
Seid Ahmed	Optimization of power distribution system with distributed generation using harish hawks	Used latest optimization algorithm Control of DG is analyzed	more result can bring if both reconfiguration and DG is used Backward forward sweep algorithm have simple and

	optimization techniques		good convergence than newton raphson method
Afroz Alam	Power loss reduction in a radial distribution network using distributed generation	DG is used for loss minimization. Worst bus voltage was improved	Types of DG used is not cited No optimization algorithm was used for optimal placement and sizing of DG
Yared Bekele	Study on impacts of distributed generation integration in medium voltage Radial distribution system	Briefly analysis negative and positive impacts of DG. Minimize power loss by using DG	DG feasibility analysis was not considered

Research gap obtained from the literature review is describe as follow:

Majority of the researcher used only network reconfiguration and other researcher used DG sizing and siting only for the power loss minimization and voltage profile improvement, but the best result can be obtained by simultaneous network reconfiguration and DG allocation. Most of the literatures reviewed are not compared the obtained result from the proposed optimization algorithm with other optimization to select the best optimization algorithm techniques. These reduce the performance of the distribution system and it also have the negative effect on the installation cost of the DG and network reconfiguration. Some of the researcher did not consider modelling of the solar type DG, modeling of the inverter, and grid interfacing issues of the solar types DG, therefore all above gap is incorporated in this thesis work.

2.3 Network reconfiguration

Power distribution systems have two categories of switches used for both protection and Reconfiguration purposes: normally open switches (or tie-switches) and normally close switches (or sectionalizing switches) whose position determines the topological configuration of the system. Network reconfiguration is the action of opening and closing tie and sectionalizing switches in distribution systems to change the topology of the system, and therefore the power flowing from the distribution system to the loads. In normal operation, reconfiguration of a distribution system is needed for two key reasons, load matching, and real power loss minimization. Load matching refers to transferring loads from heavily loaded feeder to lightly loaded feeder by altering the topology of the system through a reconfiguration procedure. While reconfiguration for real power loss minimization is fundamentally altering the network topology of a distribution system to search optimal radial structure that reduces the real power loss which is the main point of this work [30].

2.3.1 Tie line and sectionalize switch

Distribution system comprises the normally closed switches (sectionalized switches) and normally open switches (tie switches).

Tie switches: normally operate as ‘’radial networks ’’and connect between loops type laterals or two substations.

Sectionalize switches: connect the line sections between busses. These switches are used to permit configuration management and alternative protection functions.

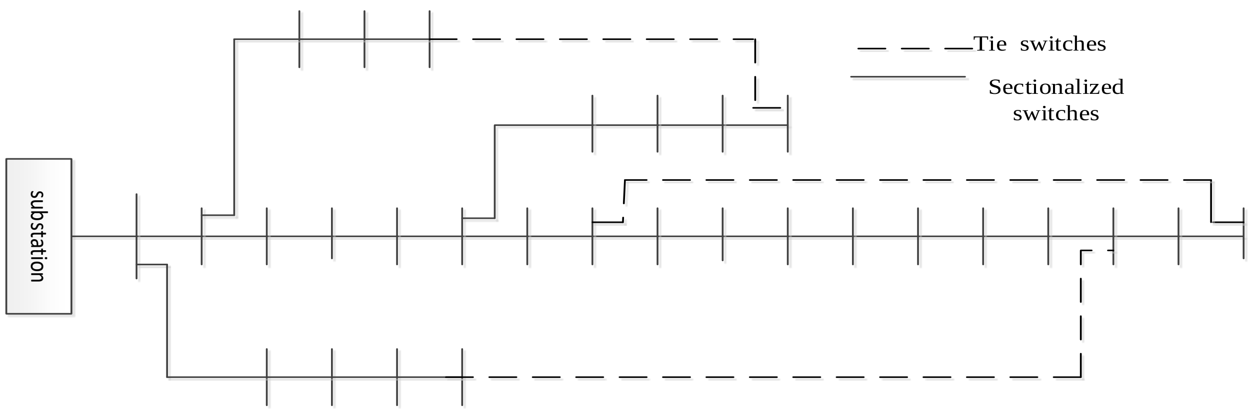

Figure 2.1: simple representation of the tie line and sectionalize switches [31].

2.4 Distributed generation

There are different definitions of DG in different literature. Distributed generation is named as a decentralized generation, site generation that generates electrical energy through alternate energy-producing resources close to the customer side to reduce the expansion of the present expensive electric transmission system. IEEE defines DG as the generation of power by facilities that are adequately less than the main generating station (conventional plant) to permit interconnection at closely any point in a conventional power system [32]. The International Energy Agency (IEA, 2002) agree that Distributed generation is an electric energy generation unit that is sited and linked to the distribution side of the network. While the Electric Power Research Institute (EPRI) accepts a definition for Distributed

Energy Resources (DER), as smaller power sources that can be combined to offer power essential to meet regular need (EPRI, 2015) in [33].

Radial distribution system without DG source is said to be passive and unidirectional as referred at Figure 1.5, since the electrical power is fed by the main grid system to the customers embedded in the distribution networks. The passive system is converted to the active when DG sources are incorporated into the radial distribution system which leads to bidirectional flow of power in the system as shown in figure 1.6. In an active distribution system, the amount of power lost in transmitting the power is less than the passive distribution system due to the power is produced very close to the load center. DG units are larger in number than the more massive conventional power stations (typically located closer to the load center) and are linked to the distribution system, consequently, bidirectional power flow starts in the distribution system [4].

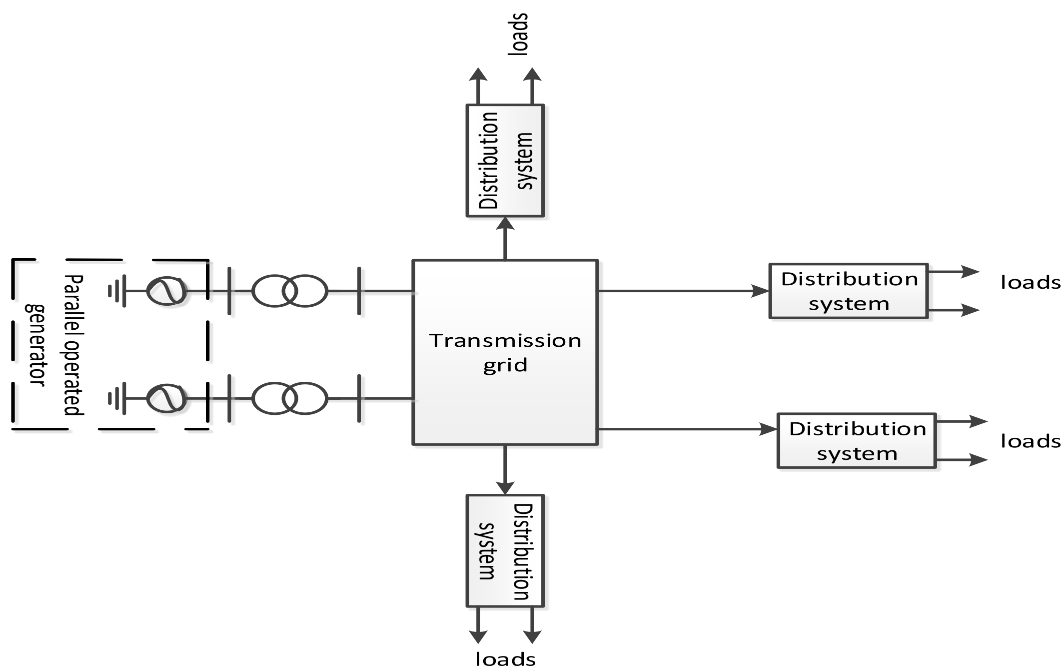

Figure 2.2: traditional power systems (unidirectional power flow) [4].

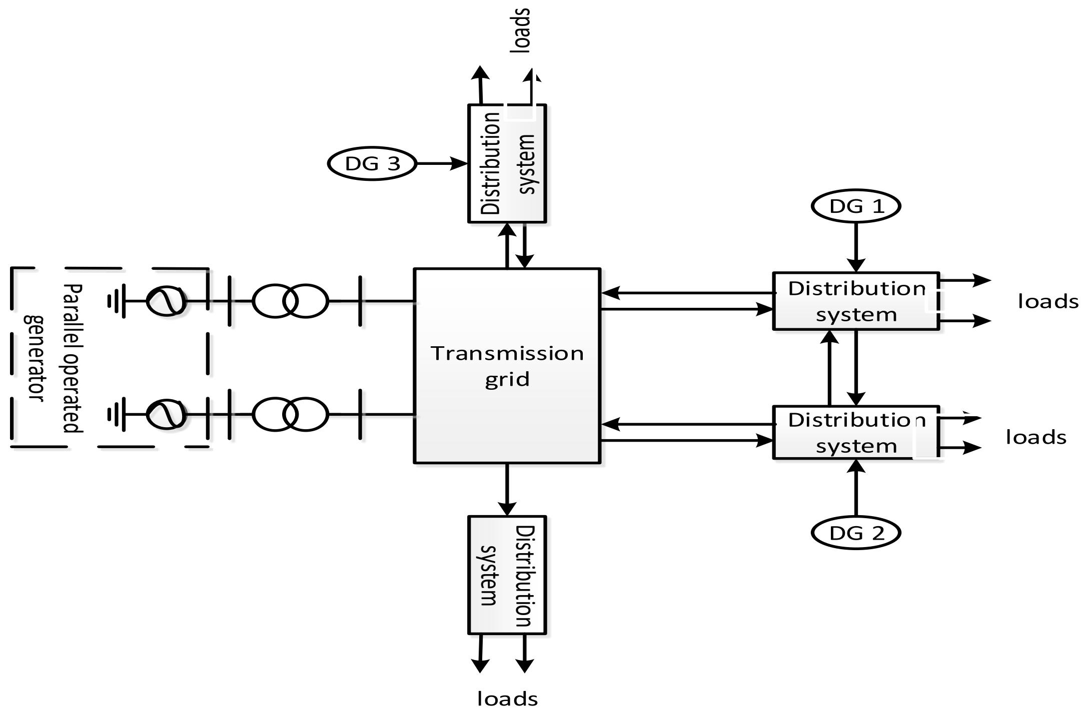

Figure 2.3: Modern power system (bidirectional power flow) [4].

2.4.1 Advantages of distributed generation

In the centralized way of transmission and distribution system, a large number of residential, commercial, and industrial loads are supplied from long distances by the large size of sources, which is costly and wastes electricity because of aging transmission equipment, system outage, and growing congestion. Unlike large central power plants, DG required less investment cost for connecting the source to the load as it is installed near the load center by decreasing the distance it travels and the amount of the power loss. Some of the major benefit gained through the interconnection of DG units into electric power networks is listed below [34].

- DGs can be installed in a very short period at any location as modules and its capacity can be increased or decreased by adding or removing more modules, respectively.
- Lowering cost by avoiding long-distance high voltage transmission and promote competitive markets.
- Distributed generation supply power during peak demand periods (Peak Shaving) which contributes to avoiding electricity price fluctuations and provides a flexible reaction in evaluating electricity prices

- Improving availability and reliability of the power supply network by having a backup generation.
- Voltage regulation support and Power-loss reduction
- Give benefit to utility system such as system security by diversifying the energy sources and solving power quality problems, such as voltage sags, as the installation of a DG increase the voltage level in the network.
- Running costs more or less constant over the period with the use of renewable sources.
- In addition, the planning of DG is a short-term investment approach due to low capital cost and reducing time for installation and hence minimizing investment risk.

2.4.2 Grid interfacing issue of distributed generation

The operation of distribution systems originally radial and designed to operate without any generation on the distribution system, and power flow is unidirectional, but the introduction of DG in distribution system makes bidirectional power flow and causes several issues in the distribution system, these issues are:

- Issue related to power quality.
- Issue related to power loss.
- Protection issue
    - ✓ Short circuit level change.
    - ✓ Reverse power flow.

2.4.2.1 Issue related to power quality

Distributed renewable systems such as solar PV systems, which have power electronic components such as inverters, at some point in the energy conversion process, may inject current harmonics accompanied by voltage distortion. The order and magnitude of the current harmonics will largely depend on the kinds of the converter, inverter characteristics, and mode of operation. Nonetheless, the majority of the latest inverters linking DGs to the power system have the capability of actively adjusting the current of their output to a suitable value, although certain injected harmonic currents can disturb the voltage profile of the system, which may spread throughout the entire grid. In summary, the existence of harmonics in a grid gives rise to diverse issues including temperature rise in the equipment, a drop in the power factor of power system components, a reduction in the performance of electrical devices, faulty responses of protective devices, communication signal interference, noise, undesired vibration of electrical motors, etc. [35]. Soft switching control of inverter, active and passive filters are implemented to eradicate the above harmonics

2.4.2.2 Issue related to power loss

Normally the active power loss minimization required to pay more attention for the utility, as it decrease the efficiency of transferring power to end user. The placement of DG along the network feeders can help both the customers and the utility to reduce system loss as it provide both active and reactive power to the system. The incorporation of DG may increase or decrease the loss in the distribution systems depending on the capacity and position of DG on each part of the distribution network. At the lower size of DG, the loss is decreased, however as the size increases, the power loss begins to increases. This means there is a maximum DGs size limit beyond which the DG will cause loss in the network. Locating and sizing the DG units should be as optimum as possible to achieve a better reliability of the system with reduced losses and to reach an optimal performance of the power network. The studies presented the positive effects of the small capacity of DGs on loss reduction when connected to feeders having high losses in the system, and it is a great benefit for the utilities. Different penetration levels used to know the effects of increased DG penetration on grid losses. Grid losses decreased at lower DG penetrations and showed an increase in grid losses with increased penetration [36].

2.4.2.3 Issue related with fault current level increment

The presence of DG in a network can increase the short circuit level of the network. It can rise the fault currents when compared to the normal state at which no DG is inserted in the distribution system. The effect of DG on faults current level increment depends on some issues like the installing size of the DG, the distance of the DG from the fault point, and the kinds of DG. These can affect the reliability and efficiency of the distribution network. The fault current flow to the fault point (fault location) is only from the main source when no DG is implemented on the feeder. But, the fault current flow to the fault point is the sum of the fault current flow from the main source and the fault current flow from the DG when the DG is incorporated as referred in the figure 1.7 it can be concluded from the above explanation that short circuit current level increases when DG is incorporated to the radial distributed feeder [17].

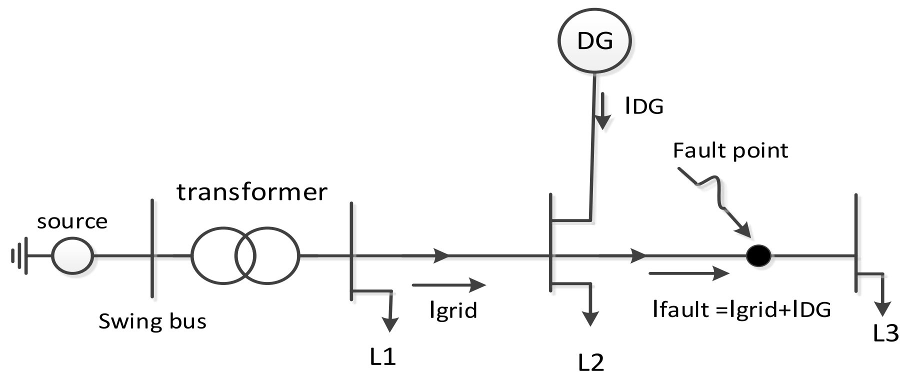

Figure 2.4: fault current contributions from one DG

The fault current contribution in case of one DG connected to the distribution network may be small, but when many smaller power source are connected to the distribution grid, the short circuit levels can be increase enough to cause miss-coordination among protective devices, like fuses or relays. This could disturb the reliability and security of the distribution network [17].

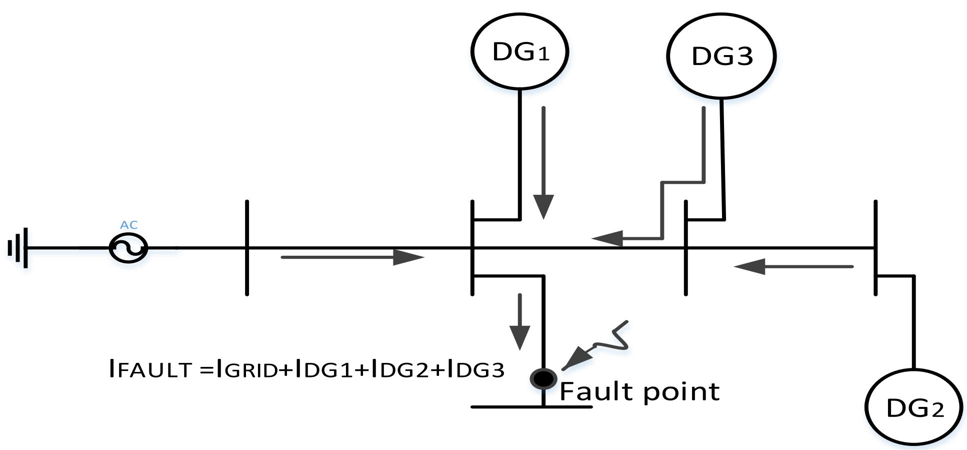

Figure 2.5: fault current contribution from more than one DG [17]

2.4.2.4 Issue related with the reverse power flow

The connection of a DG unit at some connection point along a radial distribution feeder will inject a certain amount of power. At any interval if this power exceeds the demand or if the fault occurs at some point of the network, the huge amount of power will flow in the reverse direction towards the substation. Reverse power can disturb the inherent integrity of existing protection and regulation systems of the radial system that is designed to work with power flow in one direction. This may include the automatic voltage regulators and the unidirectional protection devices. Also, it may increase undesirably the voltage level and current at some parts of the feeder. Additionally, it can result in increased feeder power losses on the upstream side. Reverse power flow complicates the islanding protection of inverter based DG units. Upgrading the control system of the substation with intelligent bidirectional protection and control devices could deal with the above issues.

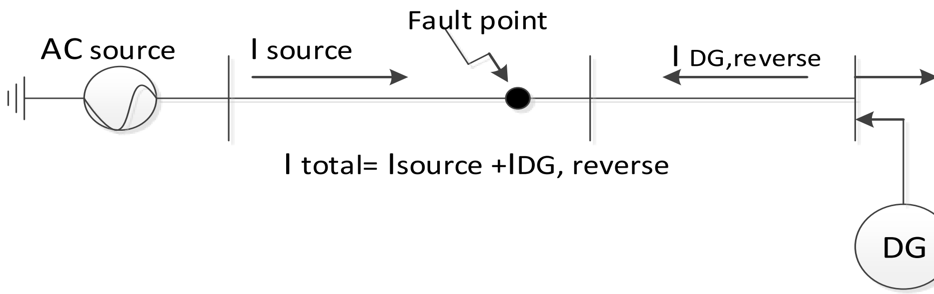

Figure 2.6: reverse power flow due to DG

2.4.2.5 Islanding

Islanding is a main interfacing issue in DG. Islanding is a condition where one or more generators (or group of distributed generators) continue to energize a part of the utility system that has been separated from the main utility system and operate separately from the other part of the distribution system. DG may run effectively in islanding conditions if there is a balance between demand and generation. Islanding operation is usually not permitted for some main reasons.

1. The utility company wants to restore the failed part of the network, but this is complicated due to the presence of islanded generators within the utility grid. Since automatic reclosing has normally been employed to restore power to the end-user. The presence of islanded generators complicates both automatic and manual switching, which needs synchronizing the generator.

2. Power quality normally cannot be maintained by the islanded generators to the desired level, and these may harm the customer equipment [17].

2.5 Backward forward sweep load flow analysis

The feeder of specifically radial distribution network (RN) power flow from only one direction, therefore, X/R ratio of RDS is small and linked load is usually unbalanced. Therefore, variables of distribution networks are different during load flow computation as compared to the transmission system and don't converge effectively by conventional power flow algorithms according to [37], therefore backward/forward sweep load flow was selected in this work and the basic equation of this algorithm was derived from figure 1.10.

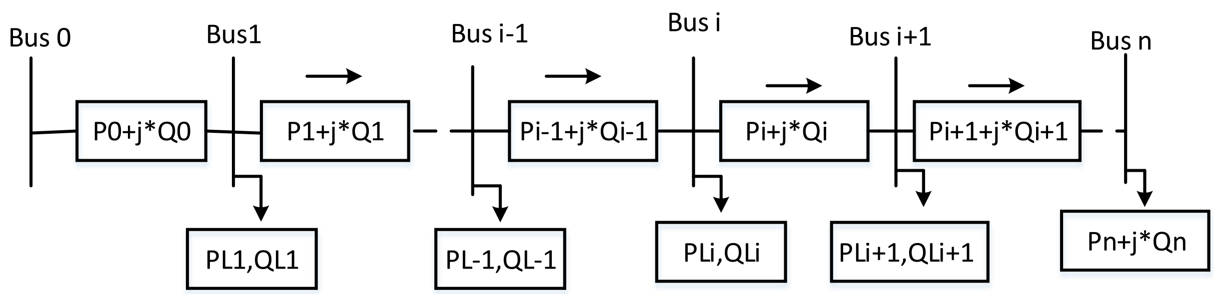

Figure 2.7: Single line diagram of RDS [38]

The impedance of the line connecting bus i and i+1 is given by

$$Z_{i,i+1} = R_{i,i+1} + jX_{i,i+1} \tag{2.1}$$

Forward sweep: forward sweep start at reference bus and propagate forward up to the last bus,

the active and reactive power flow at the branch (Pi+1 and Qi+1)and the voltage magnitude at the bus i+1 (Vi+1) was given by the following set of recursive equations:

$$P_{i+1} = P_i - P_{Li+1} - \mathrm{R_{i,i+1}}\frac{(\mathrm{P_i^2+Q_i^2})}{|\mathrm{V_i}|^2} \tag{2.2}$$

$$Q_{i+1} = \mathrm{Q_i} - Q_{Li+1} - \mathrm{X_{i,i+1}}\frac{(\mathrm{P_i^2+Q_i^2})}{|\mathrm{V_i}|^2}$$

$$|\mathrm{V_{i+1}}|^2 = |\mathrm{V_i}|^2 - 2\left(\mathrm{R_{i,i+1}} * \mathrm{P_i} + \mathrm{X_{i,i+1}} * \mathrm{Q_i}\right) + \left(\mathrm{R_{i,i+1}^2} + \mathrm{X_{i,i+1}^2}\right) * \frac{(\mathrm{P_i^2+Q_i^2})}{|\mathrm{V_i}|^2} \tag{2.3}$$

Backward sweep: backward sweep start at the last bus and propagate back to the reference bus, so by using this method, the transmitted power through each branch is given by set of recursive equations as follow:

$$\mathrm{P_{i-1}} = \mathrm{P_i} + \mathrm{P_{Li}} + \mathrm{R_{i,i+1}}\frac{(\mathrm{P_{i1}^2+Q_{i1}^2})}{|\mathrm{V_i}|^2} \tag{2.4}$$

$$\mathrm{Q_{i-1}} = \mathrm{Q_i} + \mathrm{Q_{Li}} + \mathrm{X_{i,i+1}}\frac{(\mathrm{P_{i1}^2+Q_{i1}^2})}{|\mathrm{V_i}|^2} \tag{2.5}$$

$$|\mathrm{V_{i-1}}|^2 = |\mathrm{V_i}|^2 + 2\left(\mathrm{R_{i-1,i}} * \mathrm{P_{i1}} + \mathrm{X_{i-1,i}} * \mathrm{Q_{i1}}\right) + \left(\mathrm{R_{i-1,i}^2} + \mathrm{X_{i-1,i}^2}\right) * \frac{(\mathrm{P_{i1}^2+Q_{i1}^2})}{|\mathrm{V_i}|^2} \tag{2.6}$$

Where; $P_{i1} = p_i + P_{Li}$ and $Q_{i1} = Q_i + Q_{Li}$

The active power loss of the branch linking between buses i and i+1 is given as

$$W_{L(i,i+1)} = \mathrm{R_{i,i+1}}\frac{(\mathrm{P_i^2+Q_i^2})}{|\mathrm{V_i}|^2} \tag{2.7}$$

2.6 Power loss

Currently most utility highly affected with electrical power loss. Power system consist of technical losses and non-technical losses. The non-technical losses are caused by actions external to the power systems such as inaccurate meter reading, non-payment of electricity bills, inaccurate estimation of no metered supplies, inefficiency in business and technology management systems. The technical losses occur in numerous small components in the distribution systems from the step up transformers through all different stages until the consumer end. Most losses are experienced during peak demand when all the resources are operating at maximum to match up with the power needed by the end user. As the load increases, the copper losses become more significant. The active power loss in the distribution system is mostly due to copper losses since these losses are functions of the square of current flowing through the line as shown in equation (2.8).

$$P_{LOSS} = I^2 * R \tag{2.8}$$

Where;

P_{LOSS} is the real power loss in the distribution system

I is the line current

R is the line resistance

CHAPTER THREE

3. SYSTEM MODELING AND METHODOLOGY

3.1 Introduction

Distribution networks power-flow is one of the important issues in most tasks relating to the things like designing system, placing protective equipment etc., therefore distribution power flow analysis must be performed by using the algorithm specifically designed for the distribution system analysis like backward forward sweep. Due to the scheme of connection, distribution system network has its 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. The yirgalem distribution system have a radial distribution system that all load feed from one source. However, after optimal network reconfiguration and DG incorporation, the yirgalem distribution system have no longer radial because power flow from main source as well as DG.

3.2 Overview of study area

Yirgalem is found in south center Ethiopia in sidama region. It has latitude and longitude of $6^0 45' \, N \; 38^0 25' \, E \; / \; 6.75^0 \, N \; 38.4167^0 \, E$ respectively. It has located an elevation of 1,777 meters above sea level. Distribution substation located at the yirgalem city and supply power to the different loads (residential, commercial and industrial load). Yirgalem distribution system consists of 33KV and 15KV medium voltage distribution system having step down transformer rated at 132/33KV and 132KV/15. Low voltage customers are supplied by 400V or 220V with frequency of 50 Hz using 3-phase and 1-phase distribution line respectively.

3.3 Data collection

In this thesis work of yirgalem distribution system, various data have been collected from different sources. These data is categorized two major part: the first is the primary data and the other is secondary data. The Primary data is a data that are collected from yirgalem distribution system and EEU South region district. It includes the collection of information through direct observation of the yirgalem distribution substation. The secondary data, on the other hand, is the result of other people’s research in the same problem area. It includes the study of documents and archival records, web-sites and other historical and documentary records relevant for the research. The necessary data’s for this thesis work are collected from different sources through, conducting interviews with the respective personnel of the substations. And from Ethiopian electric power (EEP) and Ethiopian electric utility (EEU) engineering office.

The collected data will include line impedance, line reactance, line length, Bus connected ID (From Bus to Bus), bus description, bus nominal voltage, reactive and active power flow, transformers data, actual voltage level of the line and peak load data of the distribution network of case study.

3.4 Data analysis

The yirgalem substation supplied from hawassa substation at 132 KV line and formed two outgoing line (shakiso and dilla outgoing line by 132kv). The incoming 132KV from Hawassa substation is stepped down and feed into 33KV and 15KV feeders. The study area is served by 132/33 kV, and 132/15 kV three winding step down transformer. Yirgalem distribution system have six radial feeders, 15kv side have three radial feeders namely 1 abosto feeder, 2 yirgalem city feeder, 3 Aletawondo feeder, and 33kv side also have three feeder namely 4 bensa feeder, 5 kurchancho feeder, and 6 Awdando industry feeder. The following single line diagram shows the above explanation.

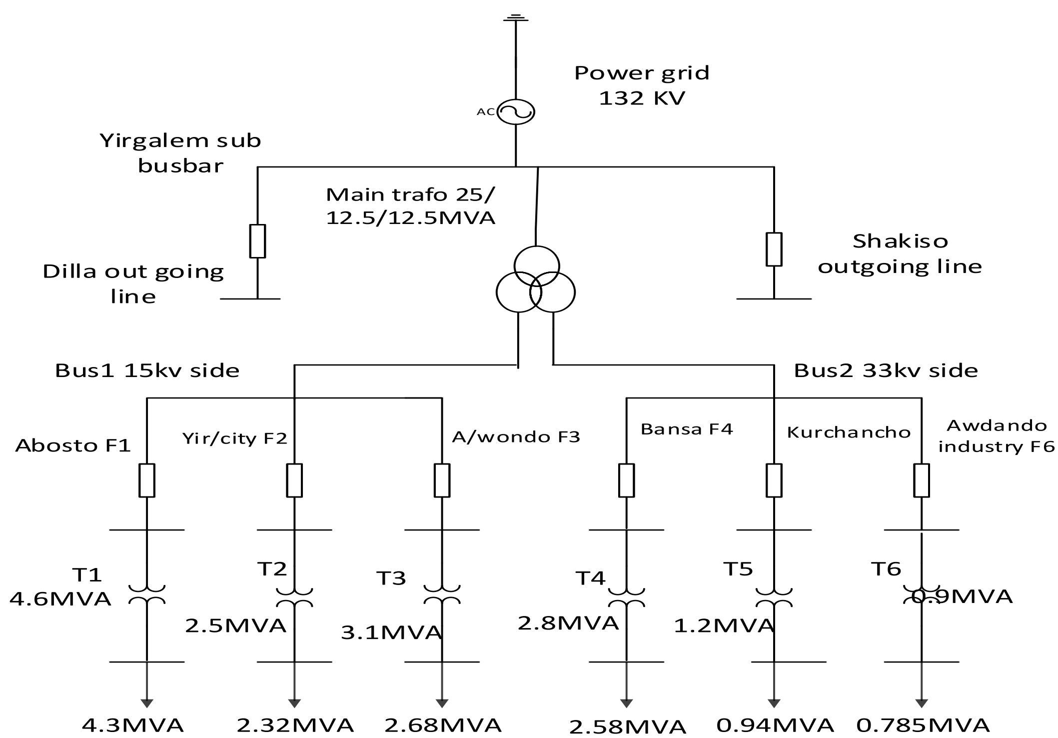

Figure 3.1: single line diagram of the yirgalem distribution feeders

3.5 Base case load flow analysis to decide test feeder

Analysis of all feeder in distribution system is too long and time consuming, so that to further specify the test feeder, base case load flow analysis was performed at each feeder using backward forward sweep algorithm and total power loss and voltage profile of each feeder is obtained. Depending on the load flow result, feeder that have higher power loss and lower minimum voltage profile was selected for this thesis. The base case power loss and minimum voltage obtained from backward forward sweep algorithm of the six feeder of yirgalem substation is depicted in the following table.

Table 3.1: power loss and minimum voltage at each feeder

Parameter	Abosto feerder	Yirgalem feeder	A/wondo feeder	Bensa feeder	Kurchancho feeder	Awadda feeder
Power loss(kw)	401.3	70.1	104.3	106.3	10.23	12.32
Minimum voltage(pu)	0.87	0.94	0.95	0.91	0.96	0.94

The above table shows that the abosto feeder have highest power loss and the lowest minimum voltage, so that the abosto feeder was selected to test this thesis work.

3.6 Single line diagram representation of the proposed Abosto Feeder

Single line diagram or one line diagram is the basic modelling of distribution system that is required for the analysis of the distribution system. So that it is necessary to understand single line diagram of the proposed distribution feeder since the real information is depicted from the single line diagram. The radial structure of the abosto feeder contains 62 bus, out of this bus one is considered as swing bus and it have 61 branch. The proposed abosto feeder have a voltage level of 15KV and transfer power to all types of loads using both wooden and steel pole overhead distribution system.

The abosto feeder is selected in this thesis work due to:

- High total power loss and voltage drop occur compared with other feeder as obtained from load flow analysis.
- This feeder supply power to all residential, commercial, and industrial load.

- In addition, for selection of distribution feeder longest rout length, High demand for power, High peak load current and large loads during a year with recorded data were considered for this study.

The one line diagram of the proposed yirgalem distribution system abosto feeder drawn using Microsoft Visio 2013 as shown in figure 3.2.

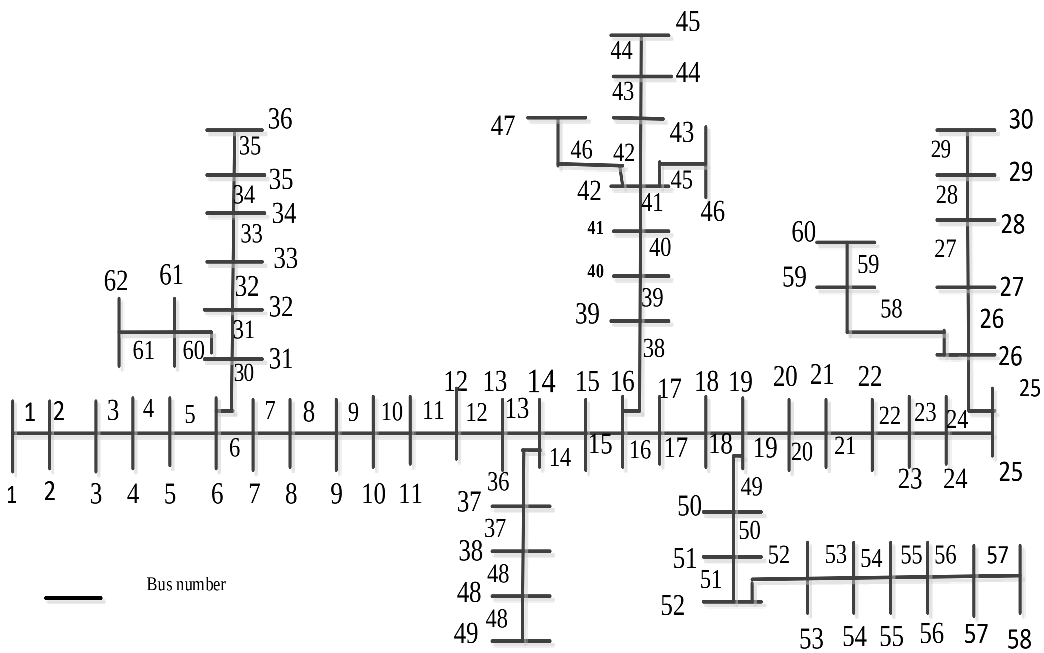

Figure 3.2: single line diagram representation of abosto feeder

3.7 Description of the proposed Abosto feeder

This thesis is done on the radial network with data given by Yirgalem distribution substation. The selected system is on feeder 1 and it have radial configuration distribution system. The yirgalem distribution system far 42km from Aleta chuko which found southern of Yirgalem town. A load is connected to all buses except root node in the system. The total active and reactive power of the abosto feeder is 3.68MW and 2.28KVAr respectively. The voltage on this network drop blow the IEEE standard level on distribution bus system due to the residential, commercial and industrial nonlinear loads. A summary of the collected data in the test system is shown in table 3.2.

Table 3.2: data of the proposed abosto feeder

Description	Abosto feeder
Number of bus	62
Number of branch	61
Number of lateral line	5
Active power (MW)	3.68
Reactive power (MVAr)	2.28
System voltage(KV)	15
Frequency (HZ)	50
transformer	1) 132Kv/15 2) 15kV/0.4kv (for each transformer)

3.8 Resource feasibility study of wind and solar power plants

The solar and wind power plant energy outputs are strongly dependent on the sun radiation and the wind speed respectively which are stochastic in nature. Therefore, the feasibility of resources for either solar and or wind type DG installation has to be first studied before the study of their optimal size and appropriate bus location.

3.8.1 Solar energy resource assessment

Feasibility of solar power based DG installation on a given area should be studied before installing a solar panel at a given place. The sunshine hour and solar irradiance must enable to generate electricity from PV cells. The solar irradiance (kw-hr/m2/day) data of the five years taken from NASA is shown in the table 3.3

Table 3.3: monthly average data of the solar irradiance (kWh/$\boldsymbol{m^2}$/day) of the yirgalem

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	5.42	5.04	5.79	5.97	5.31	5.07	4.56	5.31	4.96	5.11	5.48	5.37
2017	5.31	5.71	5.96	6.02	5.47	4.67	4.59	4.83	4.94	5.02	5.97	5.01
2018	5.27	5.23	5.64	5.97	5.82	4.63	5.03	5.08	5.07	5.78	5.24	5.48
2019	5.39	5.62	5.76	5.98	5.73	5.09	4.58	4.67	4.98	5.32	5.07	5.17
2020	5.33	5.47	5.91	5.94	5.62	4.76	4.55	4.97	5.67	5.14	5.61	5.15
Monthly average	5.34	5.41	5.81	5.97	5.59	4.84	4.66	4.97	5.12	5.27	5.47	5.23

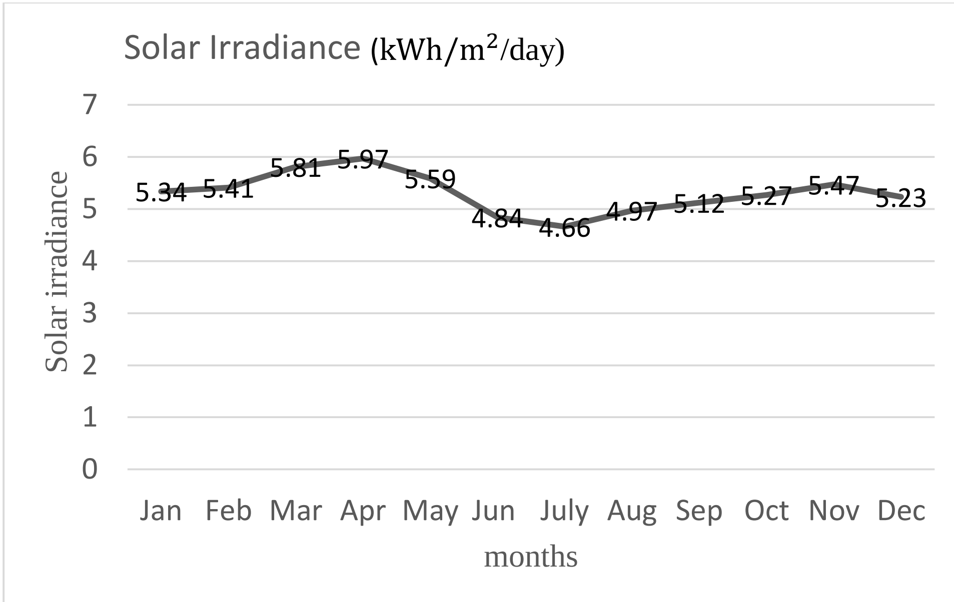

Figure 3.3: monthly average insolation of yirgalem city

3.8.2 Wind resource assessment

The consumption of energy increases from day to day and the issue of the environment is getting worse. Therefore, wind power is one of the solutions to reduce environmental stress. The availability of wind energy depends mainly on wind speed which is a random variable.

3.8.2.1 Wind Turbine Power Output Variation with Wind Speed

The power that can be generated by a wind energy conversion system (WECS) is directly proportional to the cube of the wind speed at the height of the wind turbine as shown in figure 3.3. Therefore, the accurate determination of wind speed at a particular site is essential for determining wind turbine size and energy output. The wind speed and direction are continuously varying with time. The monthly average wind speed is considered as good indicators for the wind potential. In addition to that, the cut-in and cut-off speed of wind turbine should be known before installation.

Cut-in speed is a very low wind speed at which the turbine first starts to rotate and generate power.

Cut-out speed is the maximum wind speed at which the forces on the turbine structure are high as a result there is a risk of the damage to the rotor.

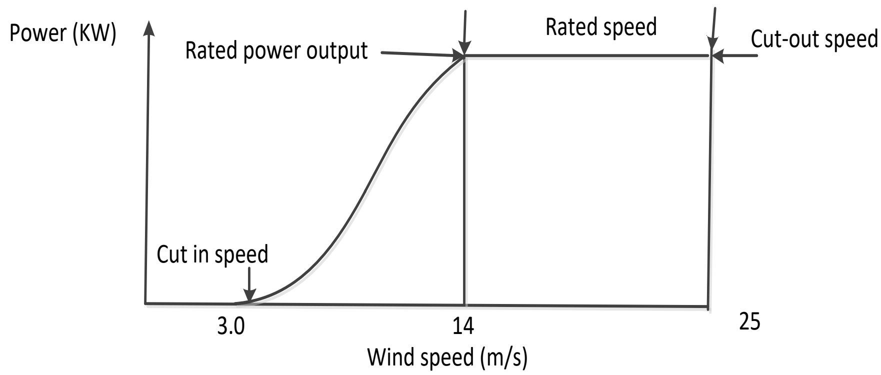

Figure 3.4: typical wind turbine power output versus wind speed [4]

The average wind speed (m/s) of the yirgalem town at 10m height is recorded from the NASA is given in the table 3.4

Table 3.4: Monthly average wind speed (m/s) at ten meter height

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	1.79	2.29	2.07	1.72	1.92	2.51	3.14	2.81	2.06	1.62	2.22	2.88
2017	2.76	2.11	2	2.52	1.86	2.3	3.01	2.72	2.16	1.66	2.06	2.35
2018	2.21	2.25	2.08	1.61	2.16	2.83	2.96	2.8	1.77	1.84	2.18	2.31
2019	2.78	2.3	1.88	1.76	2.09	2.68	2.77	2.62	2.21	2.52	2.16	2.19
2020	1.99	2.2	1.79	2.02	1.81	2.71	3	2.86	2	1.91	2.26	2.31
Monthly average	2.3	2.23	1.96	1.92	1.96	2.6	3.72	2.76	2.04	1.91	2.17	2.40

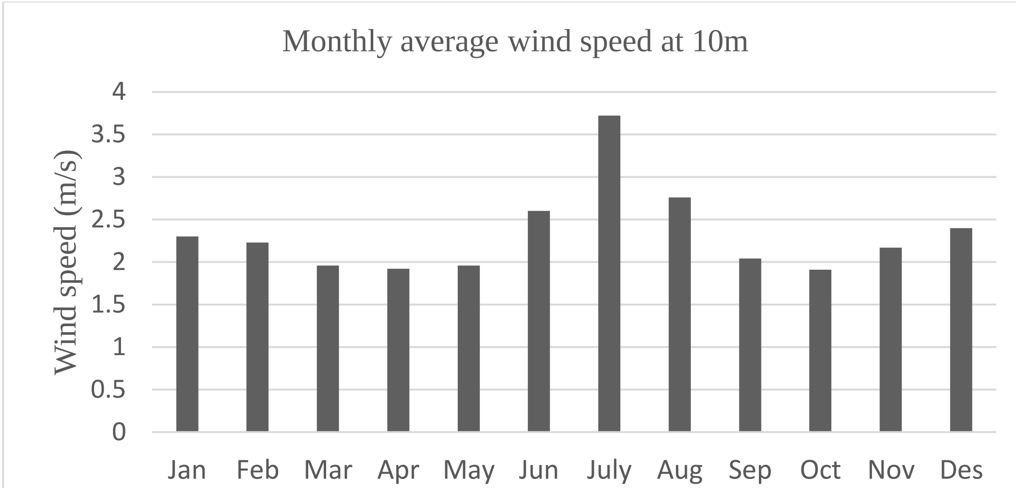

Figure 3.5: Monthly average wind speed of yirgalem city at 10 height

Depending on the monthly average wind speed data at 10m height provided in table 3.4, the wind speed at 10m is below the cut in speed, so that the wind typed DG is not feasible at the 10m height. The wind speed at ten-meter height is below the cut-in speed which is the minimum requirement for wind power generation. To facilitate the evaluation of the wind speed at desired height, the relation of the wind speed and height of the tower is provided at equation (3.1).

$$S_{new} = S_{old}\left(\frac{X_{new}}{X_{old}}\right)^{\alpha} \tag{3.1}$$

Where

S_{old} is measured wind speed

S_{new} is wind speed at the desired height

α is ground surface friction coefficient and usually its value is 0.143

To see the feasibility of the wind type DG, the speed is evaluated at the desired height that is 40m using the equation (3.1).

Table 3.5: Monthly average wind speed at the forty meter height

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	2.18	2.79	2.52	2.09	2.34	3.06	4.15	3.42	2.51	1.97	2.7	3.51
2017	3.36	2.57	2.43	3.07	2.26	2.80	3.66	3.31	2.63	2.02	2.51	2.86
2018	2.69	2.74	2.53	1.96	2.63	3.45	3.6	3.41	2.15	2.24	2.65	2.81

2019	3.38	2.8	2.29	2.14	2.54	3.26	3.37	3.19	2.69	3.07	2.63	2.67
2020	2.42	2.68	2.18	2.46	2.20	3.30	3.65	3.48	2.43	2.32	2.75	2.81
Monthly average	2.8	2.71	2.39	2.34	2.39	3.17	3.68	3.36	2.48	2.32	2.64	2.93

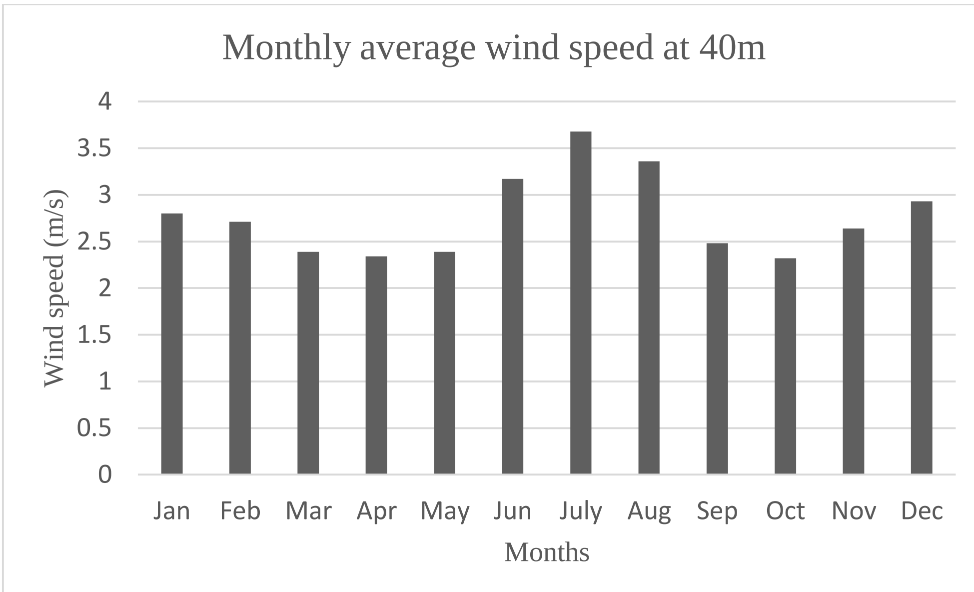

Figure 3.6: Monthly average wind speed of yirgalem city at 40m height

Table 3.5 show that the monthly average wind speed of the yirgalem town is below the cut in speed even if the tower height is increased to the forty meter. Based on the above analyzed data the solar type DG is feasible and the wind type DG is not feasible.

3.9 Mathematical modeling of load flow Analysis using backward forward sweep load flow algorithm

Algorithms like a newton-Raphson or Gauss-Seidel is not recommended for the solution of distribution systems. The backward forward sweep load flow algorithm is better to analysis the radial distribution system, due to the programs is designed for radial systems for two main reasons:

- Programs designed for power systems normally assume a high R/X Ratio.
- A program developed specifically for distribution system will be more efficiency and simpler than those developed for high – voltage systems. Thus, it will leads to low

memory requirement s and good accuracy. Moreover, it is simple in implementation and has good convergence speed.

In a radial network consideration, the backward/forward sweep method in load flow computation is mainly consists two major stages, the first stage is backward sweep (formation of BIBC matrix) and the second stage is forward sweep (formation of BCBV matrix) [39].

3.9.1 Step 1 Formation of BIBC Matrix (Backward Sweep)

For each iteration k, branch currents are aggregated from loads to origin. But first, the current injected at each bus is given as follow

$$\mathrm{I}_i^k=\left(\frac{s_i}{V_i^k}\right)^*=\left(\frac{P_i+jQ_i}{V_i^k}\right)^* \tag{3.2}$$

Where V_i^k and I_i^k are the bus voltage and equivalent current injection of the i^{th} bus at the K^{th} Iteration respectively. Matrix development for relating branch current and bus injected current at each bus is explained in the following few lines.

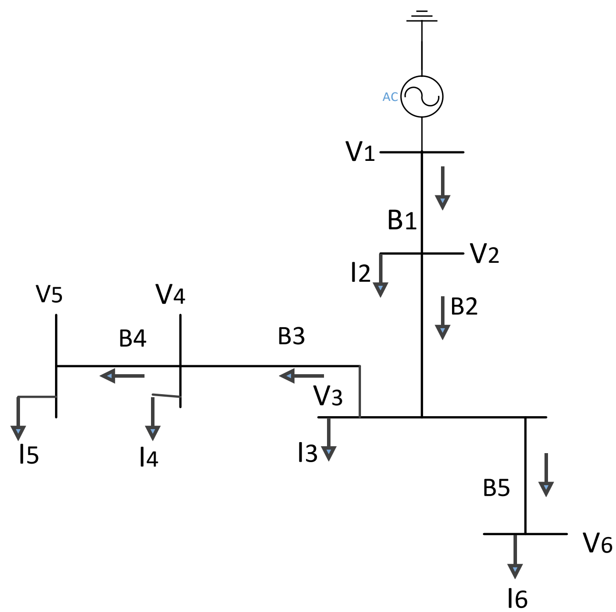

Figure 3.7: radial distribution system representation

By applying Kirchhoff's current `law (KCL) to figure (3.4), the branch current is calculated as function of equivalent current injection at each bus.

$$B_5 = I_6 \tag{3.3}$$

$$B_4 = I_5 \tag{3.4}$$

$$B_3 = I_4 + I_5 \tag{3.5}$$

$$B_2 = I_3 + I_4 + I_5 + I_6 \tag{3.6}$$

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \tag{3.7}$$

Arranging all equation (3.3-3.7) and formed matrix as follow equation (3.8).

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1\ 1\ 1\ 1\ 1 \\ 0\ 1\ 1\ 1\ 1 \\ 0\ 0\ 1\ 1\ 0 \\ 0\ 0\ 0\ 0\ 1 \\ 0\ 0\ 0\ 0\ 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \tag{3.8}$$

From the equation (3.8), we can represent the BIBC matrix in general form as follow

$$[B] = [BIBC][I] \tag{3.9}$$

$$[BIBC] = \begin{bmatrix} 1\ 1\ 1\ 1\ 1 \\ 0\ 1\ 1\ 1\ 1 \\ 0\ 0\ 1\ 1\ 0 \\ 0\ 0\ 0\ 0\ 1 \end{bmatrix} \tag{3.10}$$

Where; BIBC is the bus injection to branch current

3.9.2 Step 2 Formation of BCBV (matrix forward sweep)

Nodal voltage vector V is updated from the origin to loads according to the Kirchhoff voltages law (KVL), using previously calculated branch currents vector I branch and branch current to bus voltages (BCBV).

By using the figure 3.4 we calculate the BCBV matrix as follow

$$V_2 = V_1 - (Z_{12}B_1) \tag{3.11}$$

$$V_3 = V_2 - (Z_{23}B_2) = V_1 - (Z_{12}B_1) - (Z_{23}B_2) \tag{3.12}$$

$$V_4 = V_3 - (Z_{34}B_3) = V_1 - (Z_{12}B_1) - (Z_{23}B_2) - (Z_{34}B_3) \tag{3.13}$$

$$V_5 = V_4 - (Z_{45}B_4) = V_1 - (Z_{12}B_1) - (Z_{23}B_2) - (Z_{34}B_3) - (Z_{45}B_4) \tag{3.14}$$

$$V_6 = V_3 - (Z_{36}B_5) = V_1 - (Z_{12}B_1) - (Z_{23}B_2) - (Z_{36}B_5) \tag{3.15}$$

Arranging the equation (3.11-3.15) give equation (3.16)

$$\begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} Z_{12}\ 0\ 0\ 0\ 0 \\ Z_{12}\ Z_{23}\ 0\ 0\ 0 \\ Z_{12}\ Z_{23}\ Z_{34}\ 0\ 0 \\ Z_{12}\ Z_{23}\ Z_{34}\ Z_{45}\ 0 \\ Z_{12}\ Z_{23}\ 0\ 0\ Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \tag{3.16}$$

BCBV matrix was formed from the equation 3.16) as follow in equation (3.17)

$$[BCBV] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ 0 & Z_{23} & 0 & 0 & 0 \\ 0 & 0 & Z_{34} & 0 & 0 \\ 0 & 0 & 0 & Z_{45} & 0 \\ 0 & 0 & 0 & 0 & Z_{36} \end{bmatrix} \tag{3.17}$$

Transposing the left side matrix of the equation (3.17) will give

$$[BCBV] = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}^T \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ 0 & Z_{23} & 0 & 0 & 0 \\ 0 & 0 & Z_{34} & 0 & 0 \\ 0 & 0 & 0 & Z_{45} & 0 \\ 0 & 0 & 0 & 0 & Z_{36} \end{bmatrix} \tag{3.18}$$

The transposed left side matrix is called as BIBC matrix and given in equation (3.19)

$$[BCBV] = [BIBC]^T[Z_D] \tag{3.19}$$

Where; $Z_D$is diagonal impedance.

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \tag{3.20}$$

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ 0 & Z_{23} & 0 & 0 & 0 \\ 0 & 0 & Z_{34} & 0 & 0 \\ 0 & 0 & 0 & Z_{45} & 0 \\ 0 & 0 & 0 & 0 & Z_{36} \end{bmatrix} \tag{3.21}$$

$$\Delta V = [BCBV][B] \tag{3.22}$$

$$\Delta V = [BCBV][Z_D][B] \tag{3.23}$$

$$\Delta V = [BIBC]^T[Z_D][B] \tag{3.24}$$

The general form for the bus voltage at $(K+1)^{th}$ iteration from equation (3.16) can be expressed as:

$$[V^{k+1}] = [V_1] - [BCBV][B] \tag{3.25}$$

Equating equations (3.8) and (3.10), the relations between the node current injections and node voltages could be expressed follow:

$$\Delta V = [BCBV]\ [BIBC][I] \tag{3.26}$$

$$\Delta V = [BIBC]^T[Z_D][BIBC][I] \tag{3.27}$$

The distribution load flow matrix (DLF) is formulated by combining the BCBV and BIBC matrix as follow

$$[DLF] = [BCBV][BIBC] = [BIBC]^T[Z_D][BIBC] \tag{3.28}$$

Substituting equation (3.28) into equation (3.27), we have

$$[\Delta V] = [DLF][I] \tag{3.29}$$

The iterative solution for the radial system load flow can be obtained as:

$$[\Delta V^{K+1}] = [DLF]I^K \tag{3.30}$$

$$[\mathrm{V}^{\mathrm{K+1}}] = [\mathrm{V}_1] + [\Delta \mathrm{V}^{\mathrm{K+1}}] \tag{3.31}$$

3.9.3 Load flow algorithm steps

The working of the backward forward sweep load flow algorithm explained above was described in the following step.

Step 1: Read the line data and bus data of the distribution network.

Step 2: Calculate each node current injection matrix using equation (3.2).

Step 3: Calculate the BIBC matrix by using steps given in section 3.8.1 and determine the branch current.

Step 4: Form the BCBV matrix using steps given in section 3.8.2

Step 5: Calculate the DLF matrix by using the equation (3.28).

Step 6: initialize the iteration to 0.

Step 7: Iteration k=k+1

Step 8: Update voltages by using equations (3.30) and (3.31)

Step 9: if max $\left(\left|V^{(k+1)}\right| - \left|V^{(K)}\right|\right) >$tolerance, go to step 5

Step 10: Calculate branch currents, and losses from final node voltages.

Step 11: Display the node voltage magnitudes and angle, branch currents and losses.

Step 12: stop.

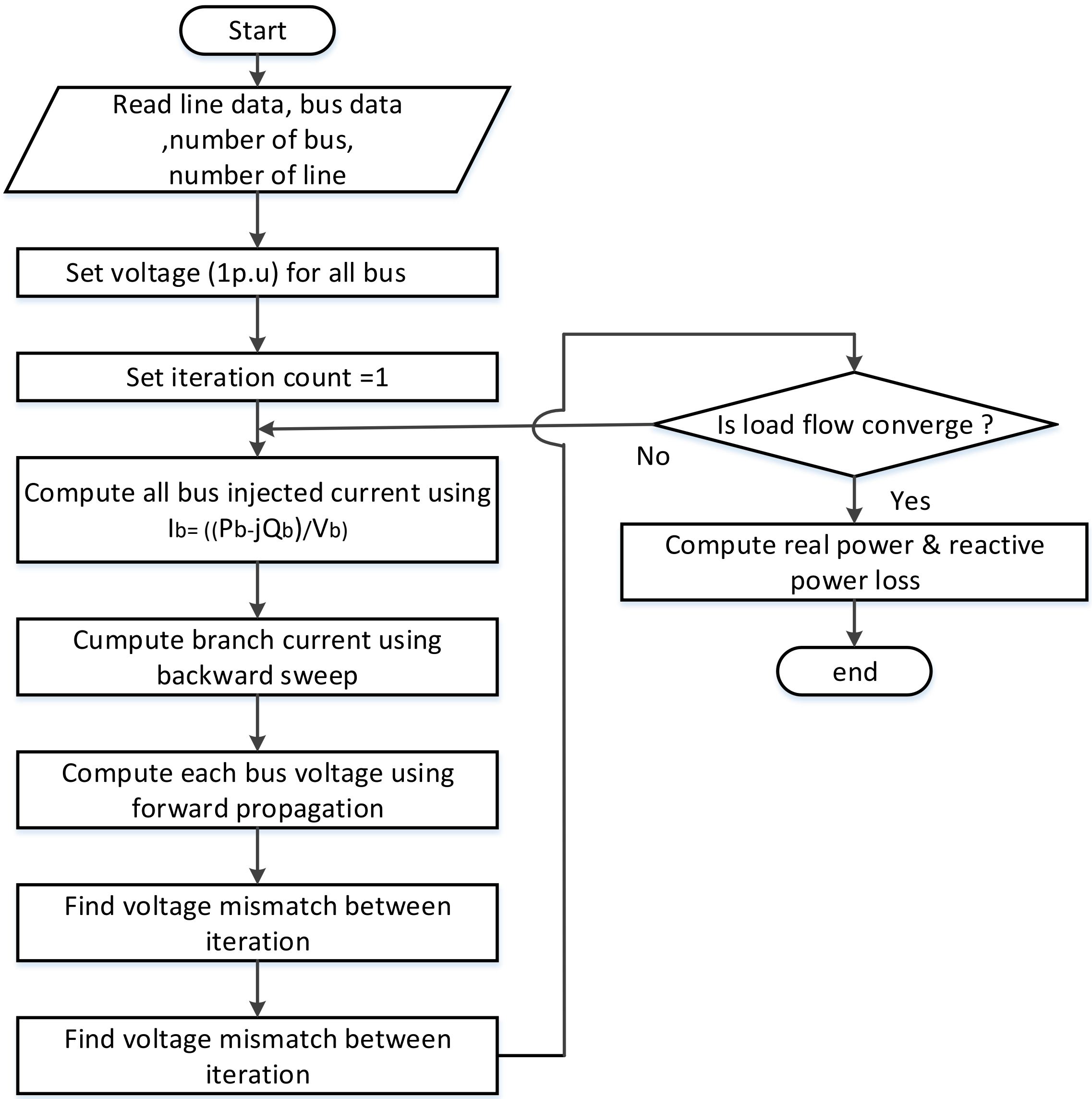

Figure 3.8: flow chart of proposed load flow methods

3.10 objective function formulations

The main purposes of the network reconfiguration and incorporating the DG in radial distribution system is to minimize the power loss, voltage drop and maintaining the reliability of the system. In this thesis, multi objective salp swarm optimization algorithm method is used to minimize power loss voltage deviation, and total operating cost of the distribution system. The mathematical formulation of the all objective function is discussed as follow.

3.10.1 Minimizing power loss by using network reconfiguration

The radial structure of the power system increase active power losses in the distribution system hence, it is important to reduce the active power losses.

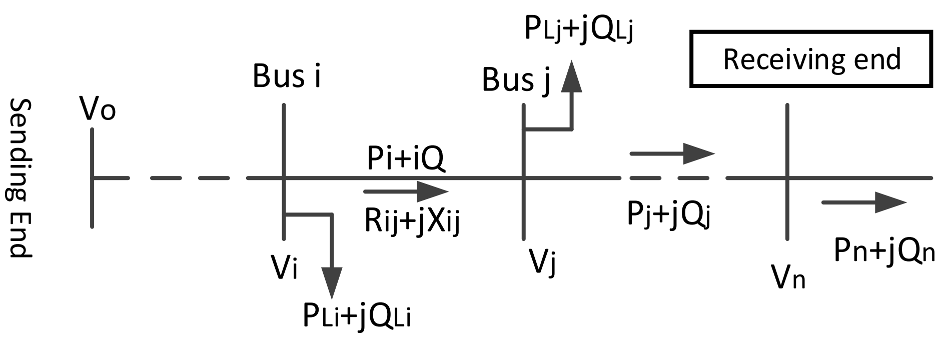

Figure 3.9: typical single line diagram of radial distribution feeder [37]

The active power loss of the branch from bus i to bus j referring figure 3.6 is given by

$$P_{loss}(i\,j) = R_{i,j}\,\frac{(P_i^2+Q_i^2)}{|V_i|^2} \quad (3.32)$$

The total power loss of the feeder is obtained by summing up each branch loss and is given by

$$P_{T,loss} = \sum_{ij=1}^{n} P_{loss,ij} \quad (3.33)$$

The power loss after optimal network reconfiguration is given by

$$P_{loss,ij}^{R} = R_{i,j} * \frac{(P_i'^2+Q_i'^2)}{|V_i'|^2} \quad (3.34)$$

The total power loss after reconfiguration is

$$P_{T,loss}^{R} = \sum_{ij=1}^{n} P_{loss,ij}' \quad (3.35)$$

The total power loss reduced after network reconfiguration is obtained by subtracting equation (3.33) from equation (3.35) as

$$\Delta P_{loss}^{R} = \sum_{ij=1}^{n} P_{loss,ij} - \sum_{ij=1}^{n} P_{loss,ij}' \quad (3.36)$$

3.10.2 Minimizing power loss by using DG

Optimal size and location of DG minimize power loss in the radial distribution system, the following short description shows how DG minimize power loss in the radial distribution system.

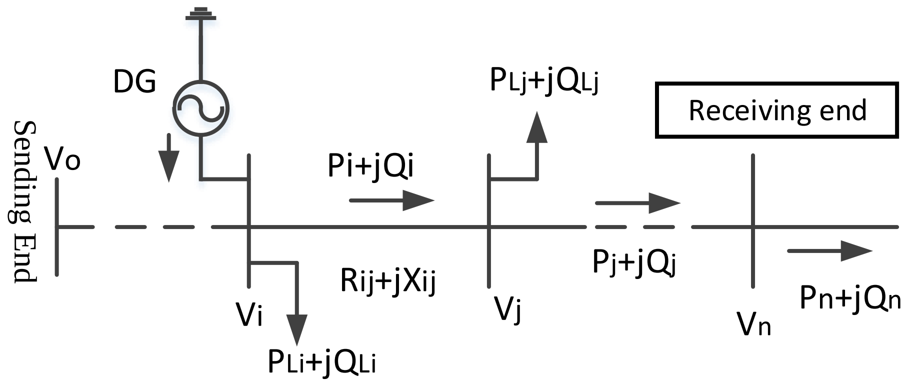

Figure 3.10: radial distribution system with incorporation of DG at bus i [37]

Considered that DG inject real power P_{DG} at bus i, then load at that bus deviate from P_{Li} to $(P_{Li} - P_{DG})$. Mathematically active power loss with DG inserted in branch ij is given by

$$P_{Loss,i,j}^{DG} = \frac{R_{i,j}}{V_i^2}[(P_i - P_{DG})^2 + Q_i^2] \quad (3.37)$$

The total power loss after insertion of DG is sum of loss at each branch and given by

$$P_{T,loss}^{DG} = \sum_{ij=1}^{n} P_{Loss,i,j}^{DG} \quad (3.38)$$

The total power loss reduction ΔP_{loss}^{DG} with the incorporation of DG in the network is obtained by subtracting the eq (3.38) from eq (3.33) as

$$\Delta P_{loss}^{DG} = \sum_{ij=1}^{n} P_{loss,ij} - \sum_{ij=1}^{n} P_{Loss,i,j}^{DG} \quad (3.39)$$

If ΔP_{loss}^{DG} is positive, this shows that the power loss is reduced by DG incorporation on the other hand, if ΔP_{loss}^{DG} is negative, this shows DG insertion causes higher power loss, therefore improper placement and sizing of DG on the distribution system causes higher power loss rather than reducing the loss in the system.

The total power loss minimization during simultaneous network reconfiguration and DG incorporation is given as

$$minF_2 = \min(P_{T,loss}^{R} + P_{T,loss}^{DG}) \quad (3.40)$$

3.10.3 Minimizing voltage drop

Simultaneous network reconfiguration with DG will optimize the network by bringing the all bus voltage to the IEEE standard. Therefore, it improves the voltage stability and the network performance.

$$min, F_2 = \sum_{i=1}^{N_b} (V_{ni} - V_{rated})^2 \quad (3.41)$$

Where;

N_b is total number of bus

V_{ni} is Voltage at bus Ni

V_{rated} is the rated voltage

3.10.4 Minimizing annual energy cost loss

The problem is finding the best combination of the tie switches, sectionalized switches, and DG size units from all possible combination and placing them on suitable location in order to minimize both power loss and annual energy cost loss.

Total annually energy loss in money in the base case system without network reconfiguration and installing DGs is given by

$$C_{base\ case} = PL_{BC} * T_e * 8760 \tag{3.42}$$

Where;

$C_{base\ case}$ Is the total annually loss of money due to power loss.

PL_{BC} Base case system power loss

T_e is the birr per KWh

Total annually energy loss of money after network reconfiguration and integration of solar type DGs is calculated as

$$F_3 = C_{R\&DG,PV} = PL_{R\&DG,PV} * T_e * 8760 + \frac{T_{DG,PV} \sum_{i=1}^{N_{DG,PV}} P_{DG,PV}}{L_{t,PV}} \tag{3.43}$$

Where:

$N_{DG,PV}$ is the number of DG

$P_{DG,PV}$ is the power generated by PV type DG

$T_{DG,PV}$ is the cost of PV type DG generated power per kw

$L_{t,PV}$ is the total DG life time.

So that total annually saving is equal to base case cost minus cost after network reconfiguration and DGs integration.

$$\text{Saving}= \mathrm{C}_{base\ case} - F_3 \tag{3.44}$$

3.11 Objective function index

To achieve the performance evaluation of distribution system with optimal network reconfiguration and DGs, the following objective function index must be evaluated.

3.11.1 Power loss reduction index using network reconfiguration

The network reconfiguration problem in a distribution system is to search a best configuration of radial network that provides lowest power loss while the imposed network constraints are maintained, which are voltage profile of the feeder, current capacity of the line, and radial structure of the distribution network.

The power loss reduction index is defined as the total base case power loss minus power loss after reconfiguration to the base case power loss,

$$PLRI^{R} = \frac{P_{T,loss} - P'_{T,loss}}{P_{Tloss}} \tag{3.45}$$

Where;

$P_{T,loss}$ is the total base case power loss

$P'_{T,loss}$ is the total power loss after network reconfiguration

3.11.2 Power loss reduction index using DG integration

The total active power loss reduction index is the total Base case power loss minus total power loss after DG incorporation to the total base case power loss.

$$PLRI^{DG} = \frac{P_{T,loss} - P^{DG}_{T,loss}}{P_{T,loss}} \tag{3.46}$$

Where;

$P_{T,loss}$ is the total base case power loss

$P^{DG}_{T,loss}$ is the total power loss after DG incorporation

3.11.3 Power loss reduction index after both case

The objective function of the problem is formulated to maximize the power loss reduction index of the abosto feeder in both case, which is given by

Maximize U(R, DG) =max$(PLRI^{R} + PLRI^{DG})$ (3.47)

Where,

U is the total power loss reduction index in both cases

$PLRI^{R}$ is power loss reduction index during optimal network reconfiguration

$PLRI^{DG}$ is the power loss reduction index during optimal DG incorporation

3.12 Mult - objective function formulation

The separate objective functions listed above combined together to form the mult-objective function of the distribution networks using the weighting factor. The MOF is a multiple objective function proposed to simultaneous optimal network reconfiguration and DG placement and sizing to enhance the overall performance of the radial distribution network. The main problem here is the finding the minimum value of the power loss, voltage drop and reduction of the cost without affecting one objective the other objective and given by

$$\text{MOF}=\min(W_1F_1 + W_2F_2 + W_3F_3) \tag{3.48}$$

Selecting the weighting factor: The allocation of the various weights in a given multi-objective function varies according to the engineer's concern. In this thesis work, more emphasis is given to real power loss reduction since this results considerable decrease in total cost of operation and this is not to mean that the other two factors are not important. Thus taking this into consideration a study of the effect of the weights on the fitness was done so as to determine the best weights combination to adopt in coming up with the multi-objective function. During this study, the values of the weights were assumed positive and given in the following table.

Table 3.6: variation of the fitness with weighting factor

N1	N2	N3	Fitness
0.6	0.25	0.15	0.1832
0.5	0.25	0.25	0.3426
0.7	0.2	0.1	0.1375
0.6	0.2	0.2	0.175
0.5	0.2	0.3	0.2491

The sum of three weight must equal to one i.e.

$$W_1 + W_2 + W_3 = 1 \tag{3.49}$$

Table 3.6 present the effects of each weighting factor on the fitness function .The combination of the weighting factor that give minimum fitness is selected. Thus the weighting selected is N1=0.7, N2=0.2, N3=0.1

Where;

N1 is the weighting assigned for the power loss minimization

N2 is the weighting assigned for the voltage drop minimization

N3 is the weighting assigned for the cost minimization

By using the above weight the combination of the three objective function is given as

MOF=min$(0.7F_1 + 0.2F_2 + 0.1F_3)$ (3.50)

3.13 Constraints formulation

In the optimal reconfiguration of distribution network with optimal sizing and siting of DG, the system required to maintain certain equality and inequality constraints. They can be enumerated and mathematically expressed in the following subsections.

3.13.1 Equality constraint

Power balance constraints: The power balance is one of the constraints to be satisfied in order to keep the system stable and given as:

$$\sum P_{DG} + P_{grid} = \sum P_{loss} + P_d \quad (3.51)$$

Where:

P_{DG} is the power generated by DG

P_{grid} is power delivered by the source

P_d is the total load in the system

P_{loss} is the real power loss in the system

3.13.2 Inequality constraint

Bus voltage constraint: This includes the upper and lower voltage magnitude limit and at each node. Bus Voltage magnitude is to be within acceptable operating limits throughout the optimization process to maintain power quality failure of electric device.

The bus voltage constraint can be written as follow

$$V_{lb} \leq V_i \leq V_{ub} \quad (3.52)$$

Where;

V_i is the bus voltage

V_{lb} and V_{ub} is the lower bound and upper bound respectively

Branch Current constraint: Current at each branch must be less than or equal to its maximum capacity. This constraint can be described as:

$$\mathrm{I_i} \leq \mathrm{I_{imax}} \quad (3.53)$$

Where;

$\mathrm{I_i}$ Is the branch current.

$\mathrm{I_{imax}}$ is the maximum limit of the branch current.

System Radial constraint: Distribution networks must be stay radial before and after reconfiguration. To assure the radial structure of the proposed feeder, the following constraint must be implemented.

The determinant of the incident matrix must be 1:

Det(M)=1 (radial system) (3.54)

Det(M)=0 (not radial system) (3.55)

Where;

Det is determinant of the bus incident matrix.

DG sizing and position constraint: The DG capacity of each unit should be defined around its nominal value to operate the system within the acceptable limit. So that each DG unit is maintained within an acceptable limit.

$$P_{DG,min} \leq P_{DGi} \leq P_{DG,max} \quad (3.56)$$

Where;

$P_{DG,min}$ is the minimum real power generation from DG

$P_{DG,max}$ is the maximum real power generation from DG

The Position of DG is restricted as follow

$$2 \leq bus \leq N_{bus} \quad (3.57)$$

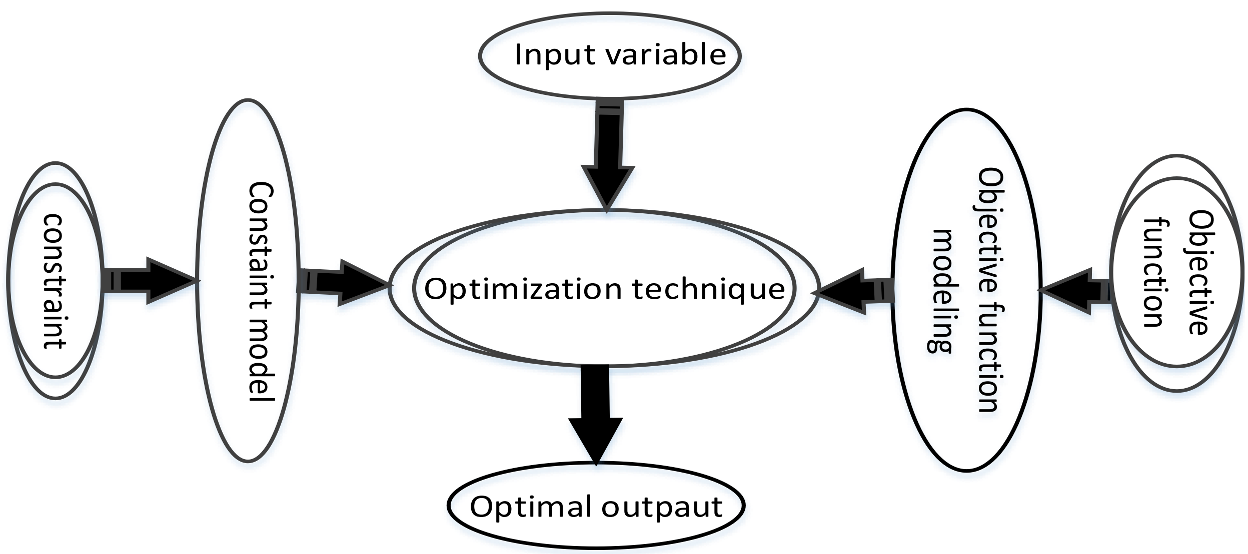

Figure 3.11: problem formulation expression

3.14 Salp swarm algorithm

The population of the salp is categorized into two main groups: the leader salp and follower salp. The leader is the salp which occur at the in front of the chain, while the reaming salps are taken as followers. As the name of these salps indicates, the leader leads all the salps and the followers follow the leader salp and each other. Just other swarm-based methods, the population of these salps are described in an n-dimensional search space where n is the number of decision variable of a given objective function. So that, the population of all salps are defined in a two-dimensional matrix called x. the other main parameter of the salp swarm algorithm (SSA) considered is the food source, it is the main target of the salps.

3.14.1 Mathematical modeling of SSA

As seen on the above topic the leader is cited at the first number in the population number and updated using the following equation in [40].

$$X_j^1 = \begin{cases} F_j + c_1\left(\left(ub_j - lb_j\right)c_2 + lb_j\right) & c_3 \geq 0 \\ F_j - c_1\left(\left(ub_j - lb_j\right)c_2 + lb_j\right) & c_3 < 0 \end{cases} \tag{3.58}$$

Where

X_j^1 Refers the location of the leader salps in the j^{th} dimension,

F_j is the population vector of the food source in the jth dimension,

ub_j And lb_j represents upper and lower bounds respectively

Equation (3.58) shows that the leader only updates its position with respect to the food source.

The coefficient c_1 is the most essential parameters in SSA because it balances exploration and exploitation and defined as:

$$c_1 = 2e^{-\left(\frac{4l}{L}\right)^2} \tag{3.59}$$

Where; l is the current iteration and L is the maximum number of iterations.

c_2 And c_3 is the random number uniformily generated in the interval [0, 1].

The position of the follower salp is updated using the following equation.

$$x_j^i = \frac{1}{2}\left(x_j^i + x_j^{i-1}\right) \tag{3.60}$$

Where i ≥2 and x_j^i shows the position of ith follower salp in jth dimension.

In case of some salps move outside of the search space, we can bring them back to the search space by using following equation.

$$x_j^i = \begin{cases} l^i & if\ x_j^i \le l^i \\ u^i & if\ x_j^i \ge u^i \\ x_j^i & other\ wise \end{cases} \tag{3.61}$$

Flow chart of the SSA optimization is drawn as follow for more description.

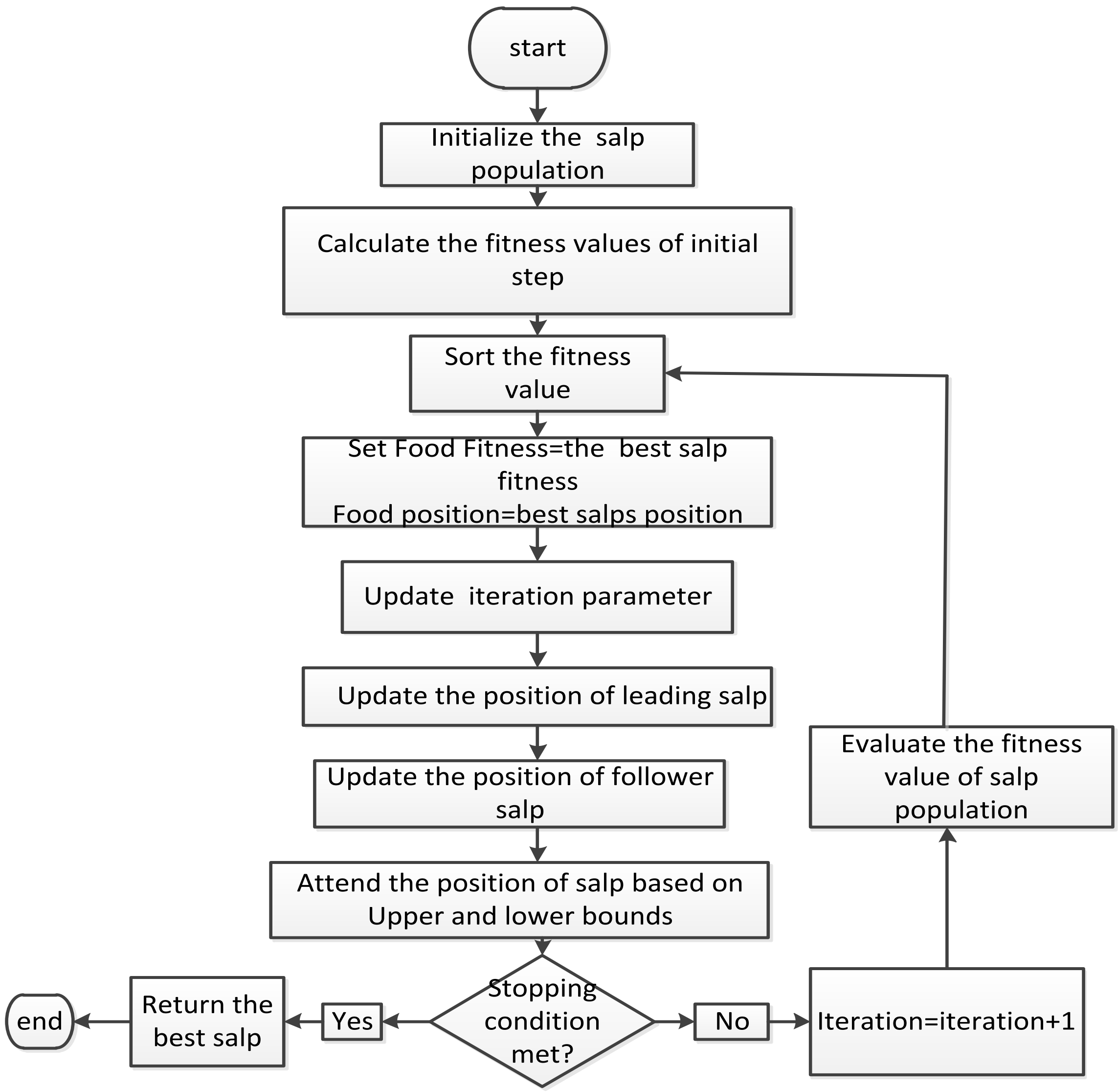

Figure 3.12: flow chart of the SSA [41]

3.15 Decision vector formulation for SSA techniques to solve scenario two to four

In this thesis, the three decision vector or problem control variables are the tie switches, DG location and DG capacities, which control the fitness function. These three variables must satisfy the various constraints discussed in the above subtopic. The solution vector to optimize the three techniques (only network reconfiguration, only DGs placing and sizing, simultaneously network reconfiguration and DG sizing) to solve scenario two up to four is provided as below.

- ✓ Scenario2 only network reconfiguration

$$X = [SW_1 \quad SW_2 \quad SW_3 \; SW_4 \; SW_5] \tag{3.62}$$

Where:

X is the decision vector

SW is the tie switch

- ✓ Scenario 3 only DG sizing and location

$$X = [DG_{L1} \; DG_{L2} \; DG_{S1} \; DG_{S2}] \tag{3.63}$$

Where;

L1 is the location of the first DG

L2 is the location of the second DG

S1 is the size of the first DG

S2 is the size of the second DG

- ✓ Scenario 4 simultaneous network reconfiguration and DG placement

$$X = [SW_1 \quad SW_2 \quad SW_3 \; SW_4 \; SW_5 \; DG_{L1} \; DG_{L2} \; DG_{S1} \; DG_{S2}] \tag{3.64}$$

3.16 Application of SSA

SSA have several application in engineering field. In this thesis, the application of SSA in network reconfiguration, DGs sizing and siting, and network reconfiguration and DGs sizing simultaneously will be discussed.

3.16.1 Application of SSA in network reconfiguration

The application of the SSA into optimal network reconfiguration can be summarized in the following steps:

Step 1 read system data (line data, bus data), initialize the algorithm parameter: C_1, C_2, C_3 maximum iteration number T_{max},population size N dimension of your problem D, upper bound lb and lower bound ub.

Step 2 initialize the salp population based on the given population size .in this case open tie switch before reconfiguration is the initial population. The proposed population vector can be written as.

$$X = [SW_1 \quad SW_2 \quad SW_3 \; SW_4 \; SW_5] \tag{3.65}$$

Step 3 run the load flow and Evaluate power losses at each population vector and take it as initial fitness (power loss). Take the best solution as the food solution and best fitness as the food fitness F_{fit}.

Step 4 update the C_1 according to equation (3.59) and generate random numbers C_2, C_3

Step 5 if i =1 update the position of the leader salps using equation (3.58).if i≥1 update the position of the followers salp by using equation (3.60).Where i is the current position in the population number.

Step 6 Check the newly generated population weather violating its lower bound and upper bound using equation (3.61)

Step 7 check (if $T \leq T_{max}$) go to step 3

8 the final best solution is the food vector at the last iteration and the best fitness is the food fitness at the corresponding food solution (tie switches at minimum power loss).

Step 9: Run the power flow and obtain the voltage profile, then plot
voltage profile versus bus number.

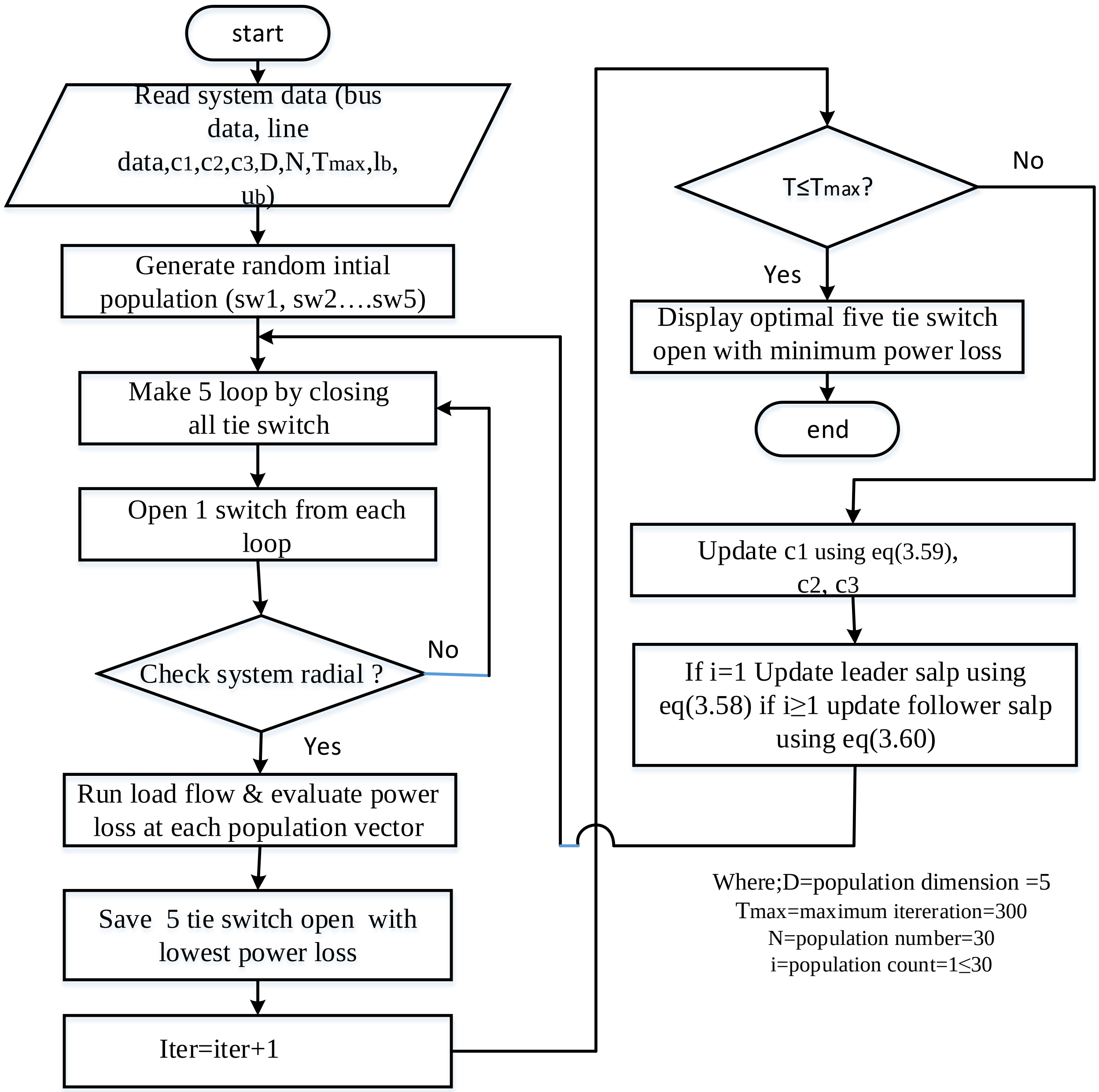

Figure 3.13: flow chart of network reconfiguration using SSA

3.16.2 Application of the SSA in DG allocation and sizing

Step 1 read system data (line data, bus data), initialize the algorithm parameter: C_1, C_2, C_3 maximum iteration number T_{max}, population size N dimension of your problem D, upper bound ub and lower bound lb.

Step 2 generate the random salp population within the upper and lower bound based on the given population size. In this case the randomly generated DG location and DG size is the initial population (see scenario 2 above).

The population vector in case of only DG allocation can be written as

$$X = [DG_{L1}\ DG_{L2}\ DG_{S1}\ DG_{S2}] \quad (3.66)$$

Step 3 run the load flow and Evaluate power losses at each population vector and take it as initial fitness (power loss). Store the best solution as the food solution and best fitness as the food fitness F_{fit}

Step 4 update the C_1 according to equation (3.59) and generate random numbersC_2, C_3

Step 5 if i =1 update the position of the leader salps using equation (3.58).if i≥1 update the position of the followers salp using equation (3.60).Where i is the current position in the population number.

Step 6 Check the newly generated population weather violating its lower bound and upper bound using equation (3.61).

Step 7 check (if $T \leq T_{max}$) go to step 3

Step 8 the final best solution is the food vector at the last iteration and the best fitness is the food fitness at the corresponding food solution (DG location and size at minimum power loss).

Step 9: Run the power flow and obtain the voltage profile, then plot voltage profile versus bus number.

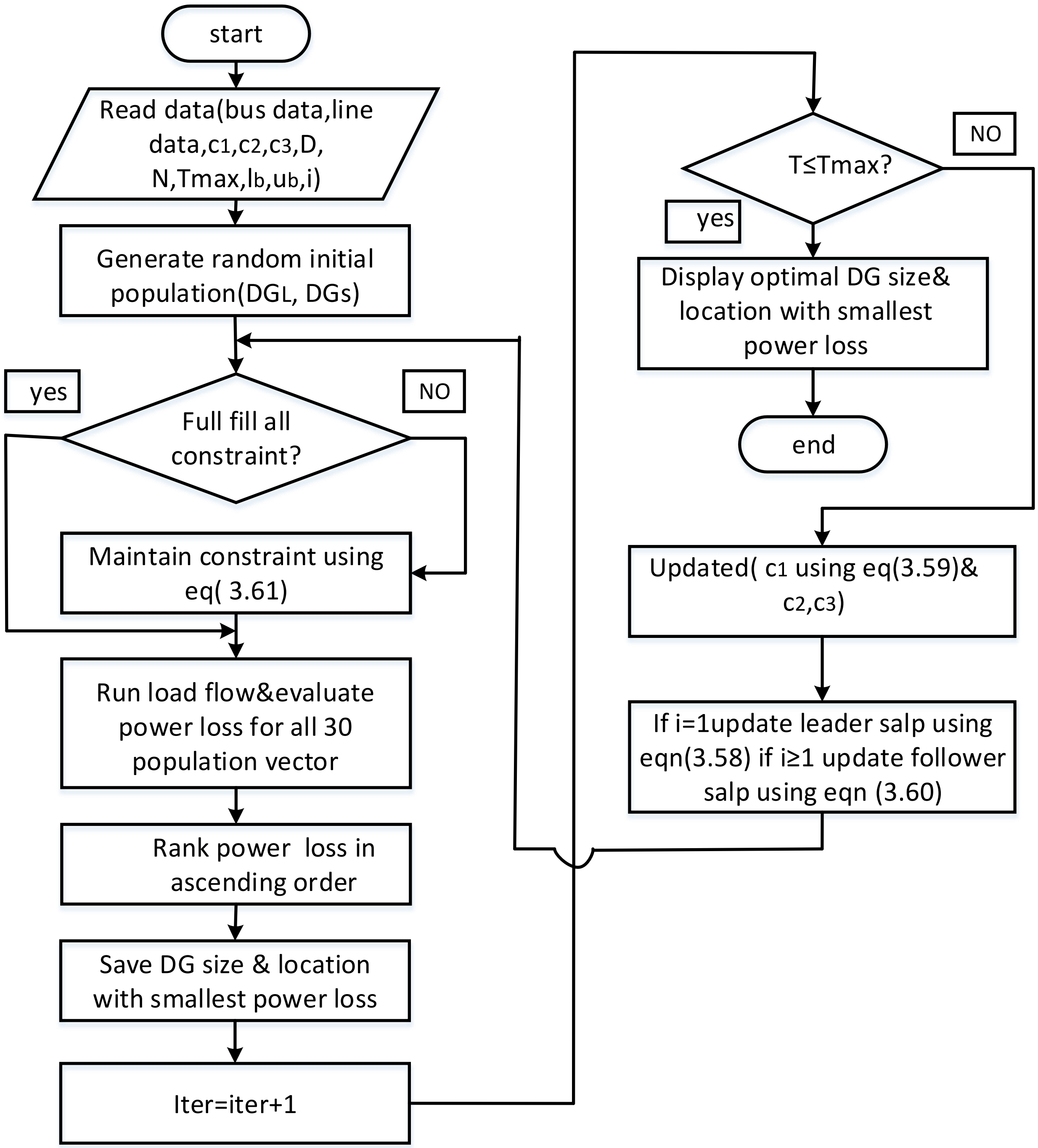

Figure 3.14: flow chart of DG incorporation using SSA

3.16.3 Application of SSA in network reconfiguration and DG allocation simultaneously

Step 1 read system data (line data, bus data), initialize the algorithm parameter: C_1, C_2,C_3 maximum iteration number T_{max},population size N dimension of your problem D, upper bound lb and lower bound ub.

Step 2 initialize the salp population based on the given population size .in this case open tie switch before reconfiguration and randomly generated DG location and size is the initial population. The position vector of this scenario is the combination of tie switch and DG location and size, this is form given as

$$X = [SW_1 \;\; SW_2 \;\; SW_3 \; SW_4 \; SW_5 \; DG_{L1} \; DG_{L2} \; DG_{S1} \; DG_{S2}] \tag{3.67}$$

Step 3 run the load flow and Evaluate power losses at each population vector and take it as initial fitness (power loss). Take the best solution as the food solution and best fitness as the food fitness F_{fit}.

Step 4 update the C_1 according to equation (3.59) and generate random numbers C_2, C_3

Step 5 if i =1 update the position of the leader salps using equation (3.58).if i≥1 update the position of the followers salp using equation (3.60).Where, i is the current position in the population number.

Step 6 Check the newly generated population weather violating its lower bound and upper bound using equation (3.61).

Step 7 checks (if $T \leq T_{max}$) go to step 3

Step 8 the final best solution is the food vector at the last iteration and the best fitness is the food fitness at the corresponding food solution (tie switches and DG position and size at minimum power loss).

Step 9: Run the power flow and obtain the voltage profile then plot voltage profile versus bus number.

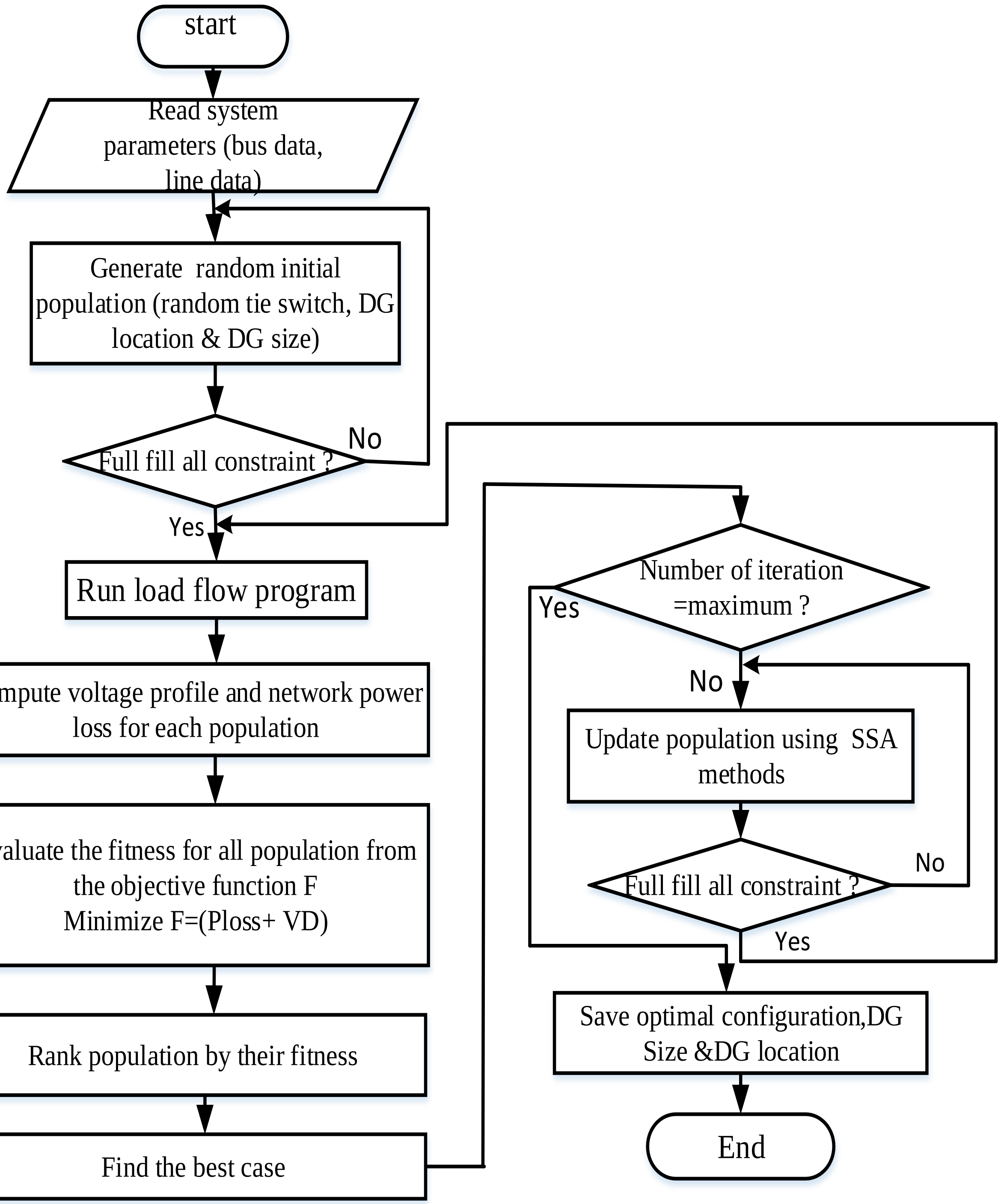

Figure 3.15: flow chart of simultaneous network reconfiguration and DG allocation

Table 3.7: comparison of SSA with real system

General algorithm	Real system			SSA algorithm
	Reconfiguration case	DG case	Simultaneous reconfiguration and DG case	_
Decision variable	Number of tie switches	DG size and location	Tie switch, DG location and size	Randomly generated position
Initial solution	Tie switch before reconfiguration	Initially generated DG location and size	Initial tie switch and DG location and size	Initial generated population of salps
New solution	Updated switch	Updated DG location and size	Updated tie switch, DG location and size	Updated salps population
Best solution	Tie switch at least power loss	DG location and size at least power loss	Tie switch, DG location and size at least power loss	Food solution
Fitness function	Power loss	Power loss	Power loss	Food fitness
Process of generating new solution	Based on best switches vector	Based on best location and size vector	Based on best tie switch, DG, location, and size	Based on food solution

3.17 Modeling of grid connected photovoltaic system

3.17.1 Modeling of solar photovoltaic system

The output features of PV cell based on the environmental conditions. For all solar cell, the model variable are function of the irradiance and the temperature values of the area where the model is located. PV cell is modeled either ideal or practical, however in this section, only non-ideal PV cell is modeled, since non-ideal PV have used in real world.

3.17.2 Modeling of non-ideal photovoltaic system

Generally practical PV cell is modelled with series and shunt resistance. Series resistance is small enough, which rises from the ohmic interaction among the metal and semiconductor internal resistance. But shunt resistance is very huge and denotes the surface quality along the periphery. Non ideal model of photovoltaic cell containing the series and shunt resistance are shown in the figure below.

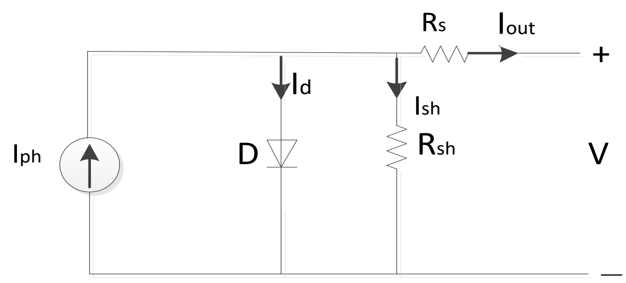

Figure 3.16: circuit diagram of non-ideal PV cell [42]

Applying the Kirchhoff's current law in figure 3.13 where $I_{ph}, I_d, I_{out}, I_{sh}$ meet as follow

$$I_{out}=I_{ph} - I_d - I_{sh} \tag{3.68}$$

$$\mathrm{I_d} = I_S \left[exp^{\left(\frac{V}{nV_T}\right)} - 1\right] \tag{3.69}$$

From the above figure shunt current is equal to

$$I_{sh} = \left[\frac{V+IR_S}{R_{sh}}\right] \tag{3.70}$$

$$I_{out}=I_{ph} - I_S \left[exp^{\left(\frac{V}{nV_T}\right)} - 1\right] - \left[\frac{V+IR_S}{R_{sh}}\right] \tag{3.71}$$

Where;

$\mathrm{I_d}$ is diode current

I_{sh} is shunt current

R_s is series resistor

R_{sh} is shunt resistor

V is terminal voltage

3.18. Block diagram representation of two stage grid connected PV system

A two-stage grid-connected PV inverter consists of separate modular blocks that collectively form the grid-connected system of PV generation. These modular blocks can differ based on the purpose of a study and its complexity. The different blocks mostly used for grid connected PV system are PV arrays, a boost controller, DC-link, an inverter, an LCL filter, and the grid in [43]. The combination of these blocks is shown in Figure 3.14, which formulates the common but complex system desired for the thesis work.

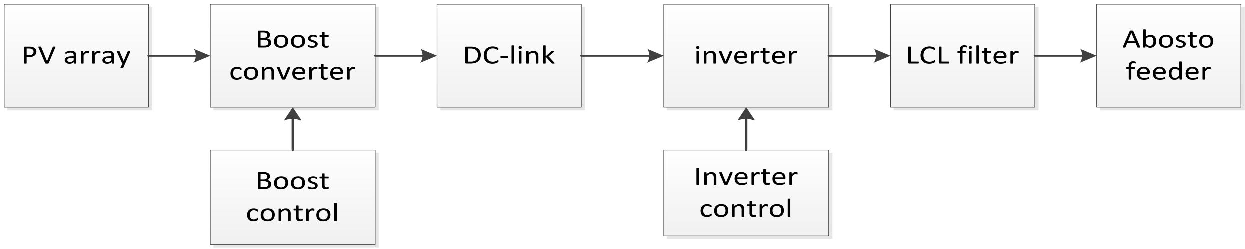

Figure 3.17: block diagram representation of grid connected PV system [43]

The above block diagram can be represented in other form in Figure 3.15, which represents the schematic diagram of the three-phase grid connected PV system. It is the two stage structure of the PV system, namely DC-DC conversion and DC-AC conversion. The output from the solar PV is connected to the boost converter, which has two functions:(1) Extract the maximum power from the PV source (2) Boost and regulate the DC output voltage from PV. The next stage is the DC-AC conversion, which takes the DC input from the boost converter and injects the AC power into the grid. In between the inverter and the grid, an LCL filter is connected to eliminate the higher frequency harmonics from the inverter output

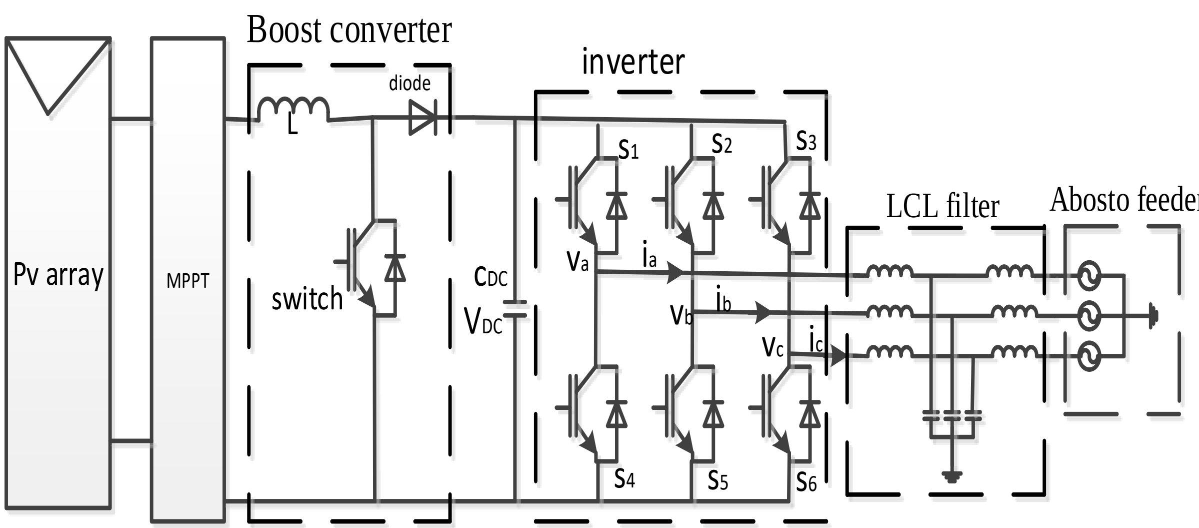

Figure 3.18: two stage three phase PV system configuration [43]

The description of the various parameters is defined as follows: V_{DC}indicates the DC input voltage to the inverter $C_{DC}$is the capacitance for maintaining the constant DC input voltage to the inverter also called as DC-link. V_a , V_b, And V_c respectively represents the output per-phase voltages of the inverter I_a, $I_b$and I_c are the three-phase output current from the grid-connected inverter.

3.19 Maximum power point tracking

The electrical energy converted by a conventional PV is only about 30 to 40 percent of the incident sunlight in [44] . In order to obtain the desired amount of power, it is necessary to increase the power output from a solar module. A solar cell has non-linear behavior and hence cannot generate a constant power. Moreover, ambient conditions like irradiation level and the temperature keeps changing, which changes the power characteristics of the solar cell. To obtain maximum power, the output voltage of a solar cell should be tracked such that it will be close to the maximum power point at different irradiation and temperature conditions. By means of MPPT, the overall efficiency of a solar cell can be increased since maximum power will be extracted from the PV array during normal daylight hours. MPPT algorithms are gaining popularity because of the high efficacy and improved version to extract the maximum power from the solar cell in [43]. In this thesis, perturb and observe method is applied to track the maximum power from the PV module. Because in this methods, it is not essential to have the previous knowledge of PV generator characteristics and also it is quite simple comparing to other methods. The cost of the material is inexpensive as the P&O engages only the voltage sensor which detect the PV output voltage and therefore amicable in handling and assembling in [44] .

3.19.1 Perturb and observe technique

The working principle of perturb and observe technique is explained as follow: First read the working voltage (V) and the working current (I) on the PV module at the time instance (k-1) .next, after a few time, read another working voltage and working current of the PV panel at time instance (k).then change of power (ΔP) of the solar module is calculated between two instance by using the voltage and current measured. Now we decides on the value of change of the power (ΔP), if the change of power is positive, then the working voltage need to be changed in line to the perturbation. If the change of power is negative, then it need to be moved in the direction that is the opposite of the perturbation as it is the case of the system working voltage move away from the point of the maximum power. The operating voltage could display the change if the photovoltaic output shows change, in the identical way, when the output power decreases then the voltage should display decrement.

Table 3.8: control actions for perturb and observe method [44]

case	ΔP	ΔV	ΔP/ΔV	Direction of tracking	Voltage control
1	_	_	+	wrong	increase V by ΔV
2	+	+	+	right	increase V by ΔV
3	+	_	_	wrong	decrease V by ΔV
4	_	+	_	right	decrease V by ΔV

For more description, the flow chart of the perturb observe method is provided below.

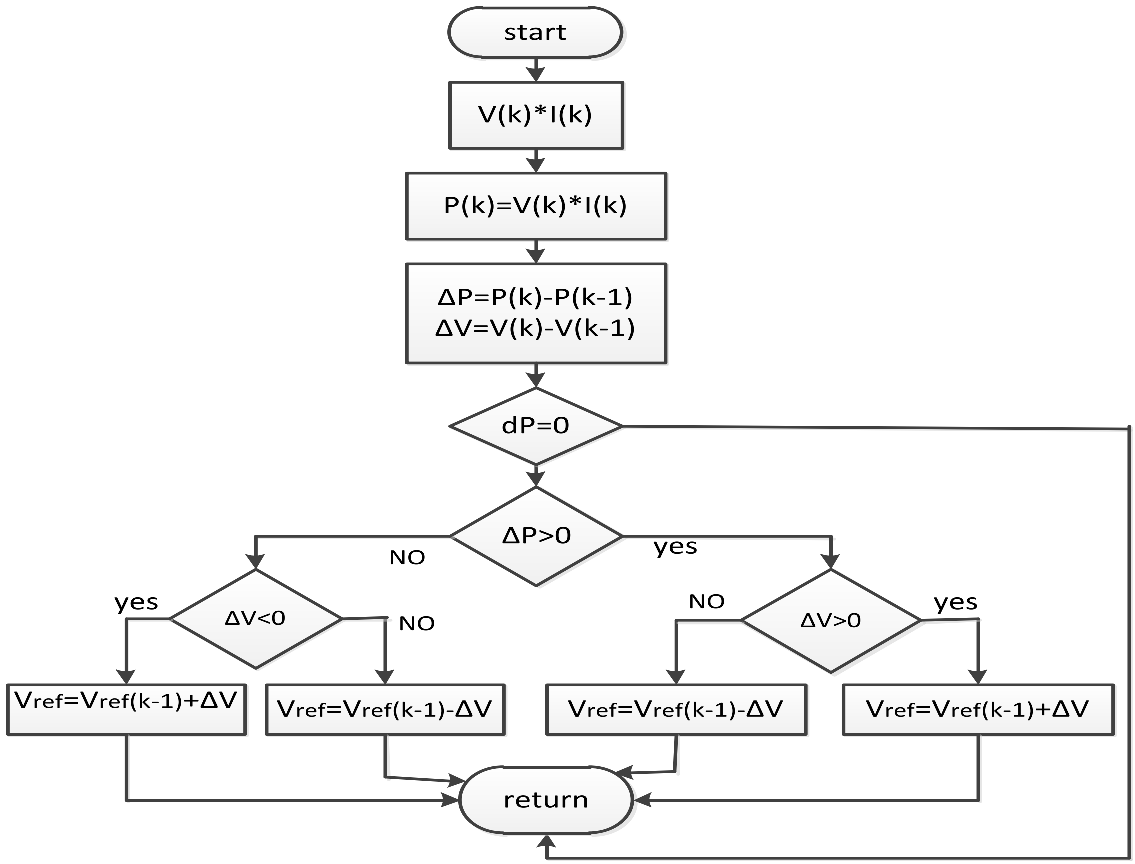

Figure 3.19: flowchart of the perturb and observe techniques

3.20 Design of boost converter

A boost converter is used widely in renewable energy application such as solar generation and wind generation. Because of intermittency of solar and wind generation, it is very important to make the overall system efficient to counterbalance the effect of intermittency. A boost converter converts a low-voltage level to a high-voltage level. Additionally, it adjusts the power generated from PV array along with the constant voltage application at the terminal output. The two-stage PV array linked to the grid will need a constant current flow in the DC-link, which is the output capacitor of the boost converter. A constant current flow will ensure the constant voltage of the DC-link and limited fluctuation in the output voltage variation. Hence, the inverter will get the constant input DC voltage, which is necessary to improve the performance and efficiency of an inverter.

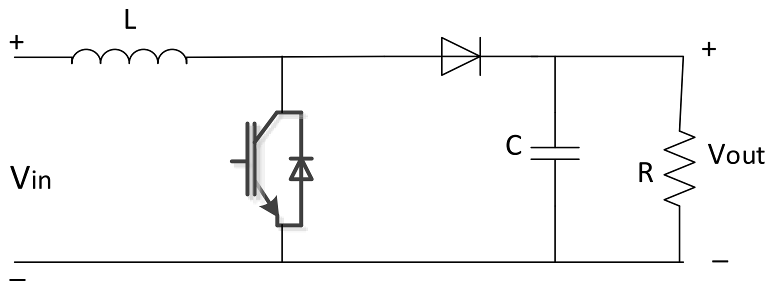

Figure 3.20: boost converter configuration [43]

Figure 3.17 represents a basic illustration of a boost converter having input voltage Vin and output voltage Vout. During on switching, the diode will be reversed biased, and hence input current would be same as the inductor current. The output voltage during on-interval would be the voltage across the capacitor. The value of the capacitor should be sufficiently large enough to maintain the constant voltage across the load. The output voltage of the boost converter is given by

$$V_o = \frac{V_{in}}{(1-D)} \quad (3.72)$$

Where;

D =T_{on}/T_{off} is the duty ratio of the on-time interval over the switching time

V_{in} Is the input voltage of the boost converter.

V_o Is the output voltage of the boost converter.

The two main factors for the boost converter design are the inductor and capacitor selection. The main equation that governs the selection of an inductor for the boost converter design is

$$L = \frac{D(1-D)V_{dc}}{f_{sw}\Delta I_L} \quad (3.73)$$

Where;

D Is the duty cycle of the boost converter.

V_{dc} is the DC link voltage.

f_{sw} is the switching frequency of the boost converter.

ΔI_L is the current ripple of the inductor

The selection of the capacitor is a very critical factor in regards to the overall performance of the boost converter. It should be sufficiently large to limit the power oscillation towards the grid, and if not, then it may cause oscillation in the real and reactive power towards the grid. In addition, it should limit the voltage ripples of the DC link to increase the life of an inverter.

The equation used to selected the capacitor in boost converter design is given by

$$C_{DC} = \frac{P_{in}}{\omega V_{dc} \Delta v_{dc}} \quad (3.74)$$

Where;

P_{in} is power entered to the grid

Δv_{dc} is the voltage ripple.

ω is the angular frequency

3.21 Modeling of grid connected LCL filter

LCL filter are linked among power inverter and the utility grid. The main functions of a grid connected filter are: to minimize high frequency harmonics resulted by the PWM modulation to amend the power quality fed to the grid, linking the impedances between two voltage sources that is power inverter and utility grid, avoiding the existence of short circuit by connecting directly power inverters to the grid. The equivalent circuit of the grid connected LCL filter is given as follow.

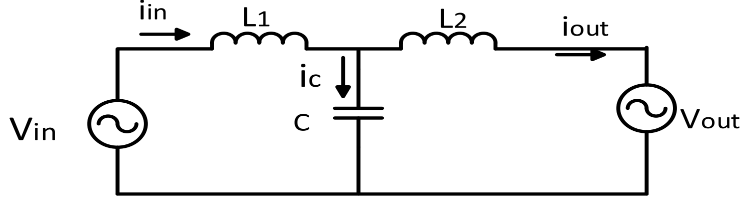

Figure 3.21: LCL filter equivalent circuit [45]

Applying KLC for the circuit at the fig 3.18, the current equation becomes

$$i_{in} = i_c + i_{out} \quad (3.75)$$

Applying KVL to the left side, the equation becomes

$$v_{in} = SL_1 i_{in} + \frac{1}{SC} i_c \quad (3.76)$$

And from the right side, the equation becomes

$$v_{out} = -SL_2 i_{out} + \frac{1}{SC} i_c \quad (3.77)$$

And arranging the equation (3.77) the capacitor current becomes

$$i_c = S^2 CL_2 i_{out} + SCv_{out} \quad (3.78)$$

Substituting equation (3.75) and (3.78) in equation (3.76) and solving to get the transfer function that model the behavior of the LCL filter becomes

$$\frac{i_{out}}{v_{in}} = \frac{1}{S^3 CL_1 L_2 + S(L_1 + L_2)} \quad (3.79)$$

Resonance frequency of the LCL filter is given by

$$f_o = \frac{1}{2\mu} \sqrt{\frac{L_1 + L_2}{L_1 L_2 C}} \quad (3.80)$$

The capacitive reactance of the LCL filter is presented by

$$X_c = \frac{1}{\omega C} \quad (3.81)$$

3.21.1 Design of LCL filter

The parameter required for LCL filter design is line to line RMS voltage (inverter output), rated active power, DC link voltage, grid frequency, switching frequency and resonance frequency according to [46]. The design procedure for LCL filter is explained in the following steps

Step 1: The design of the filter capacity proceeds from the fact that the maximal power factor variation acceptable by the grid is 5% [47]. The filter capacity can therefore be calculated as a multiplication of system base capacitance Cb;

$$C_f = 0.05C_b \quad (3.82)$$

The base capacitance of the system can be calculated using the following formula:

$$Z_b = \frac{V_{LL\,rms}^2}{P_{rated}} \quad (3.83)$$

$$C_b = \frac{1}{2\mu f_g Z_b} \quad (3.84)$$

Where;$V_{LL\,rms}$ is rms line to line voltage, P_{rated} is the rated power of the system, $Z_b$is the base impedance,f_g is the grid frequency.

Step 2 the inverter side inductor minimize the ripple of the inverter current and calculated using the relationship between the ripple current and inverter inductor in [48].

$$L_i = \frac{V_{DC}}{8\Delta I f_s} \quad (3.85)$$

Where; ΔI is the ripple current, usually limited up to 10% of rated current [47], f_s is switching frequency. The ripple current of the inverter (ΔI) can be selected as 10% of base current. The base current (Ib) of the system is given by:

$$I_b = \frac{P_{rated}}{\sqrt{3}V_{LL\,rms}} \tag{3.86}$$

The inverter side inductor is given as

$$L_i = \frac{V_{DC}}{8f_s(10\%)I_b} \tag{3.87}$$

Step 3: the grid side inductor can be found based on the required ripple attenuation factor (RAF) at switching frequency, so the grid side inductor is given by in [48].

$$L_g = \frac{RAF_s + 1}{RAF_s \omega_s^2 C_f} \tag{3.88}$$

Step 4: The last step in the design is the control of the resonant frequency of the filter, the resonance frequency should be far away from the grid frequency and switching frequency. A suitable range of resonance frequency is given by the following equations in [47].

$$f_{res} = \frac{1}{2\pi} * \sqrt{\frac{L_i + L_g}{L_i * L_g * C_f}} \tag{3.89}$$

Step 5: to avoid the resonance phenomenon, a damping resistor (Rf) is usually connected in series with filter capacitor. The damping resistor can be evaluated using the following formula according to [48].

$$R_d = \frac{1}{3(2\pi f_{res} C_f)} \tag{3.90}$$

3.22 Reference frame transformation

The voltage and current control are required to obtain the control flow of the active and reactive power. Controlling three-phase in the stationary reference frame is very challenging because it involves different phases separated by 120 degree. The process of the reference frame transformation reduces the number of the phases involved in the control process, which improves the control methods by reducing the challenges involved with the three-phase control [43]. The two most common reference frame transformation are α β (stationary reference frame) and dq (rotating reference frame) transformations.

3.22.1 Stationary (αβ) reference frame transformation

The three phase quantities are translated from the three phase reference frame to the two-axis orthogonal stationary reference frame using Clarke transformation.

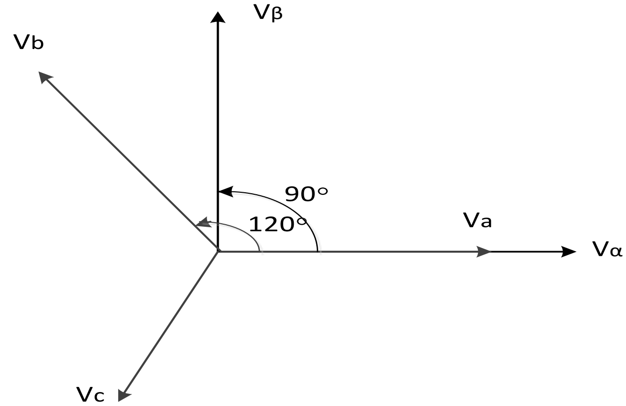

Figure 3.22: abc to stationary reference frame (αβ) conversion [43]

$$\begin{pmatrix} V_\alpha \\ V_\beta \end{pmatrix} = \frac{2}{3} \begin{pmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{pmatrix} \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \tag{3.91}$$

The above transformation is called clerk transformation or abc to αβ transformation [49]. The transformation from stationary ($\alpha\beta$) reference frame to natural abc reference frame is called inverse transformation and is given by

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{3.92}$$

The most prominent advantage of utilizing the αβ-transformation, compared to the natural abc-natural reference frame, is that the reduction of one phase-variable implies the same reduction in the number of controllers required.

3.22.2 Rotating (dq) reference frame transformation

The Park transformation, also referred to as the d q-transformation, transforms a stationary system to a rotating orthogonal system, synchronizing it with some system quantity. The transformation to the d q-reference frame from the stationary αβ-frame is given by [50].

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{3.93}$$

The inverse dq reference frame is give as follow

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \tag{3.94}$$

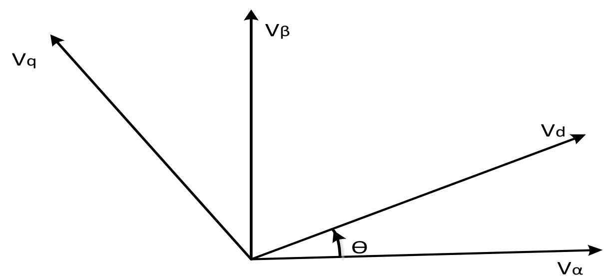

Figure 3.23: stationary reference frame to synchronous rotating reference frame conversion

3.23 Grid connected inverter

Grid-connected inverter is a special type of DC-AC converter, its output is linked to the available electrical grid. Grid connected inverter is always connected to the electrical grid. Therefore, grid-connected inverter should always produce output that maintain the synchronization condition with the electrical grid. Failing to ensure the synchronization will make the DC-AC converter be lost in synchronism state and will make inverter and grid connection impossible. Grid-connected inverter have either single-phase or three-phase topology, however this section only discusses three-phase grid-connected inverter. Figure 3.21 depicts basic representation of grid-connected inverter idea. It is linked to the AC grid through inductance. The control block processes the desired output variables through feedback from its terminal. It control any types of parameter, such as active power, reactive power, voltage, phase angle, or DC-voltage, based on the grid-connected inverter's specific function. Synchronization block receive and processes the grid's variable into control block offering the essential information to retain the DC-AC converter synchronized with AC grid [51].

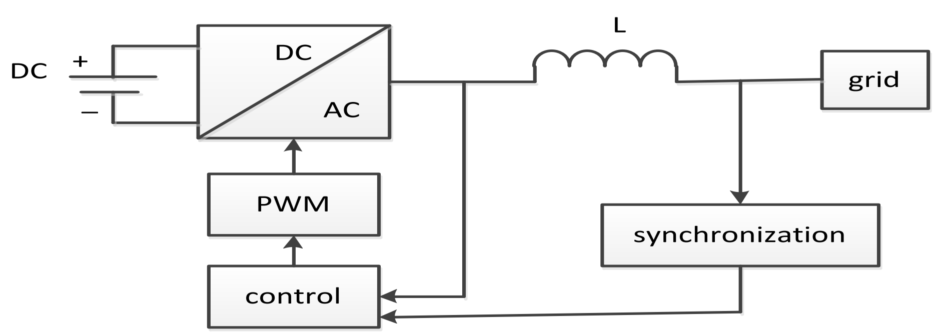

Figure 3.24: basic representation of the grid connected inverter [51]

3.23.1 Modeling of three phase grid connected inverter

The inverter circuit consists of three legs and each leg has 2 switches. The inverter can inject power into the grid at different power factors (lagging, unity and leading) with proper inverter control. The three phase inverter circuit is shown in figure 3.22 below.

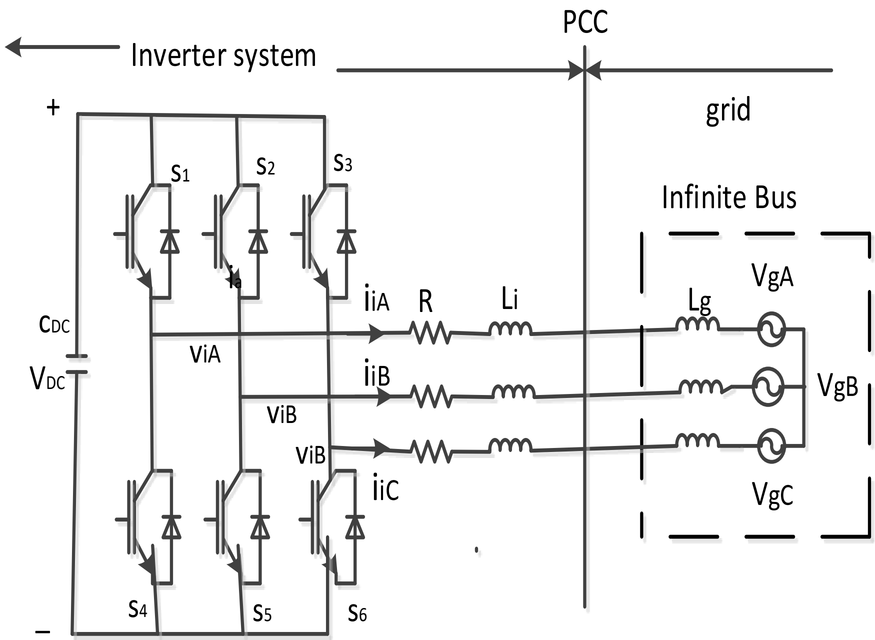

Figure 3.25: three phase grid connected inverter

The three phase grid connected inverter equivalent circuit representation in single line diagram is shown in figure 3 23 below.

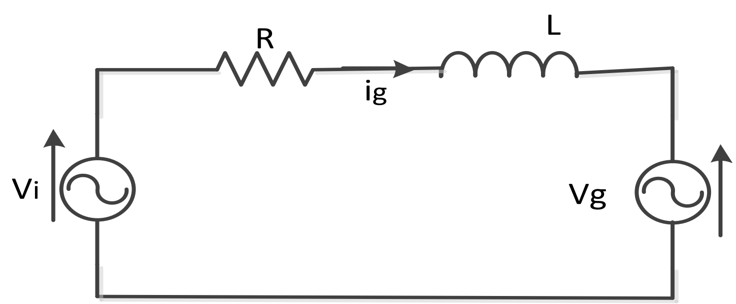

Figure 3.26: equivalent circuit of grid connected inverter

Three phase grid voltage in fig 3.26 is given by:

$$V_{gA} = V_g \sin\theta \tag{3.95}$$

$$V_{gB} = V_g \sin\left(\theta - \frac{2\pi}{3}\right) \tag{3.96}$$

$$V_{gC} = V_g \sin\left(\theta + \frac{2\pi}{3}\right) \tag{3.97}$$

Where;

V_g is peak value of line voltage.

$\theta = \omega_g t$, ω_g is the AC system grid frequency

By applying KVL, figure 3.23 is defined by the following equation.

$$V_i = V_g + Ri_g + L\frac{di_g}{dt} \tag{3.98}$$

Where;

V_i is the inverter output voltage .

V_g is the grid voltage .

R is the line resistance.

L is the line inductance.

In three phase system we have

$$V_{iA} = V_{gA} + Ri_{gA} + L\frac{di_{gA}}{dt} \tag{3.99}$$

$$V_{iB} = V_{gB} + Ri_{gB} + L\frac{di_{gB}}{dt} \tag{3.100}$$

$$V_{iC} = V_{gC} + Ri_{gC} + L\frac{di_{gC}}{dt} \tag{3.101}$$

This equation is expressed in matrix form as follow

$$\begin{bmatrix} V_{iA} \\ V_{iB} \\ V_{iC} \end{bmatrix} = \begin{bmatrix} V_{gA} \\ V_{gB} \\ V_{gC} \end{bmatrix} + R\begin{bmatrix} i_{gA} \\ i_{gB} \\ i_{gC} \end{bmatrix} + L\frac{d}{dt}\begin{bmatrix} i_{gA} \\ i_{gB} \\ i_{gC} \end{bmatrix} \tag{3.102}$$

A common and often adopted approach in analyzing three-phase systems is to use a stationary or rotating frame. In the first case the frame will be converted to $\alpha\beta$ and in second case to dq and it is also is called synchronous. In fact, the dq frame is synchronized with the angular speed ω_g the space vectors that express the inverter electrical quantities are projected on the α axis and β axis or on d axis and q axis.

The mathematical model in the $\alpha\beta$frame is given by

$$V_{i\alpha} = V_{g\alpha} + Ri_{g\alpha} + L\frac{di_{g\alpha}}{dt} \tag{3.103}$$

$$V_{i\beta} = V_{g\beta} + Ri_{g\beta} + L\frac{di_{g\beta}}{dt} \tag{3.104}$$

It should be noted that the particular feature of the dq frame is that is a space vector with constant magnitude rotates at the same speed of the frame, it has constant d and q component.

The mathematical model in the dq frame is given by

$$V_{id} = V_{gd} + Ri_{gd} + L\frac{di_{gd}}{dt} - L\omega_g i_{gq} \quad (3.105)$$

$$V_{iq} = V_{gq} + Ri_{gq} + L\frac{di_{gq}}{dt} + L\omega_g i_{gd} \quad (3.106)$$

The reference current component i_d^* is controlled to manage the active power control; while the reference current component i_q^* controls the reactive power exchange and it is typically used to impress a desired power factor:

$$P_{dq} = \frac{3}{2}\left(V_{gd}I_{gd} + V_{gq}I_{gq}\right) \quad (3.107)$$

$$Q_{dq} = \frac{3}{2}\left(V_{gq}I_{qd} - V_{gd}I_{gq}\right) \quad (3.108)$$

Assuming that the axis is perfectly aligned with the grid voltage$V_{gq} = 0$, the active power and the reactive power will therefore be proportional to I_{gd} and I_{gq}respectively:

$$P_{dq} = \frac{3}{2}\left(V_{gd}I_{gd}\right) \quad (3.109)$$

$$Q_{dq} = -\frac{3}{2}\left(V_{gd}I_{gq}\right) \quad (3.110)$$

3.23.2 Grid synchronization

The phase information of the grid voltage can be obtained by using phase locked loop (PLL). The necessary phase information which is required for synchronizing the three phase inverter current with the three phase grid voltage is must be obtained to keep synchronization of inverter with grid [48]. The grid voltage and inverter output current must be in phase to inject active power to the grid as shown in fig 3.27.

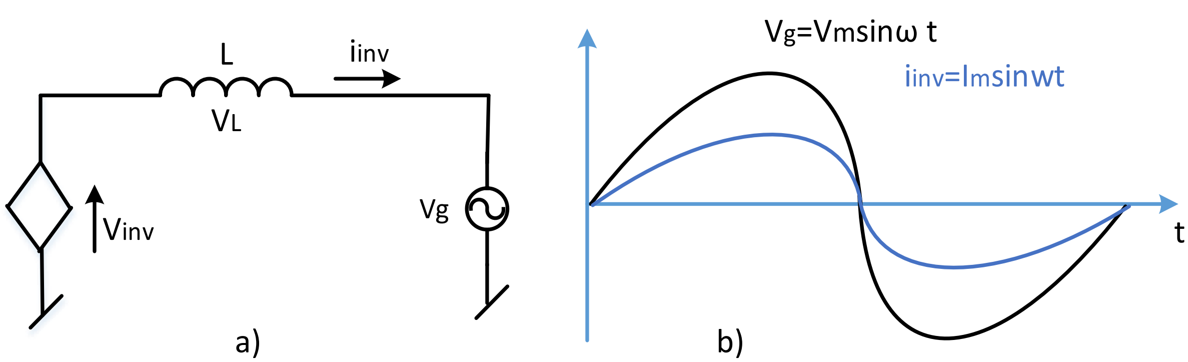

Figure 3.27: grid connected inverter: a) equivalent circuit b) waveform

By applying KVL on figure 3.24 a

$$V_g + V_L = V_{inv} \tag{3.111}$$

$$V_g + L\frac{di_{inv}}{dt} = V_{inv} \tag{3.112}$$

Substituting its value give as

$$V_m \sin \omega t + \omega L I_m \cos \omega t = V_{inv} \tag{3.113}$$

The inverter must generate the controlled voltage according to equation (3.113) to keep Synchronization with grid.

The inverter must inject the current to the grid according to the equation (3.114)

$$I_{inv} = \frac{1}{L}\int\left(V_{inv} - V_g\right)\mathrm{dt} \tag{3.114}$$

3.23.3 Control of two stage three phase grid connected photovoltaic system

A grid connected photovoltaic system is electricity generating solar PV power system that connected to the utility grid. For this system, a grid connected PV system consists of solar panel, MPPT, boost converter, DC-link capacitor, three- phase inverter, LCL filter and the grid [43]. The three phase grid connected inverter converts DC power produced by DC power generator into three phase AC power suitable for injecting into an electrical power grid and additionally acts as active power compensation. The complete control system of the grid connected photovoltaic system is represented in figure 3.25 below.

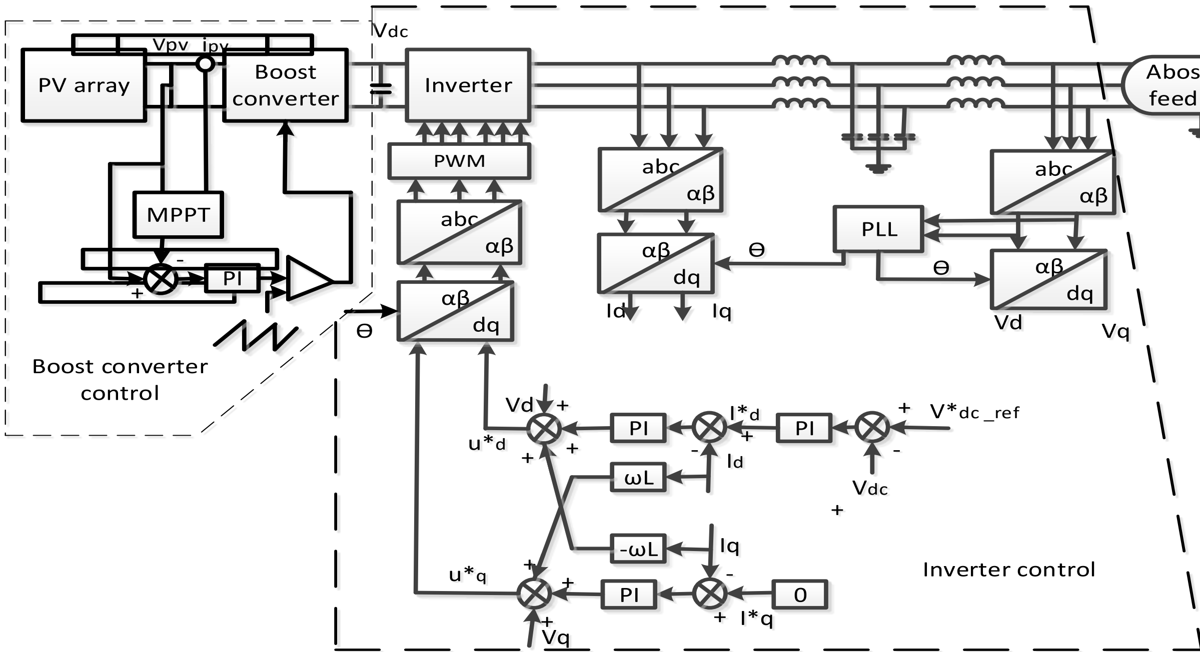

Figure 3.28: control system of the grid connected PV system [52]

For more clarification various parameters available on the circuit is described as: Vpv & ipv is voltage and current generated from PV respectively, Vdc is DC-link voltage, Vd and Vq is grid voltage in form of dq reference frame, Id and Iq is the inverter output current in the dq reference frame, V*dc _ref is the reference voltage, θ is angle between αβ and dq reference frame.

The two main control device for grid connected photovoltaic system is the boost converter control and the inverter control [53]. In the boost converter control, first the PV voltage and PV current is sent to the MPPT to generate the reference voltage. The generated reference voltage compared with PV actual voltage to produce the error signal. This error signal sent to the PI controller to generate the reference signal. The generated reference signal sent to the PWM generator to generate the controller signal for the boost converter. In the inverter control, first the three phase grid voltage is converted into the alpha beta reference frame. Then the voltage signal is send to the PLL to generate the grid angle. The alpha beta reference frame is converted to the d-q reference frame. Similarly the three phase inverter terminal current is converted into alpha beta reference frame and then into d-q reference frame. The main aim here is to maintain DC link voltage constant as much as possible and to maintain the synchronization of the inverter current with the grid voltage. At the dc side, the DC reference voltage is compared with the DC actual voltage of the DC link capacitor to generate the error signal. This error signal sent to the PI controller to generate the reference current to the inverter. The generated inverter current compared with the d-q phase reference inverter actual current to generate the error. Then the error sent to the PI controller to generate inverter terminal voltage. The grid voltage, inverter voltage, and the decoupling component is summed up to generate the reference voltage to the inverter. Finally this reference voltage converted to alpha beta reference frame then to the three phase voltage. This three phase voltage sent to the PWM generation to generate the control signal for the three phase inverter. Matlab Simulink model of grid connected PV is plotted as figure 3.26

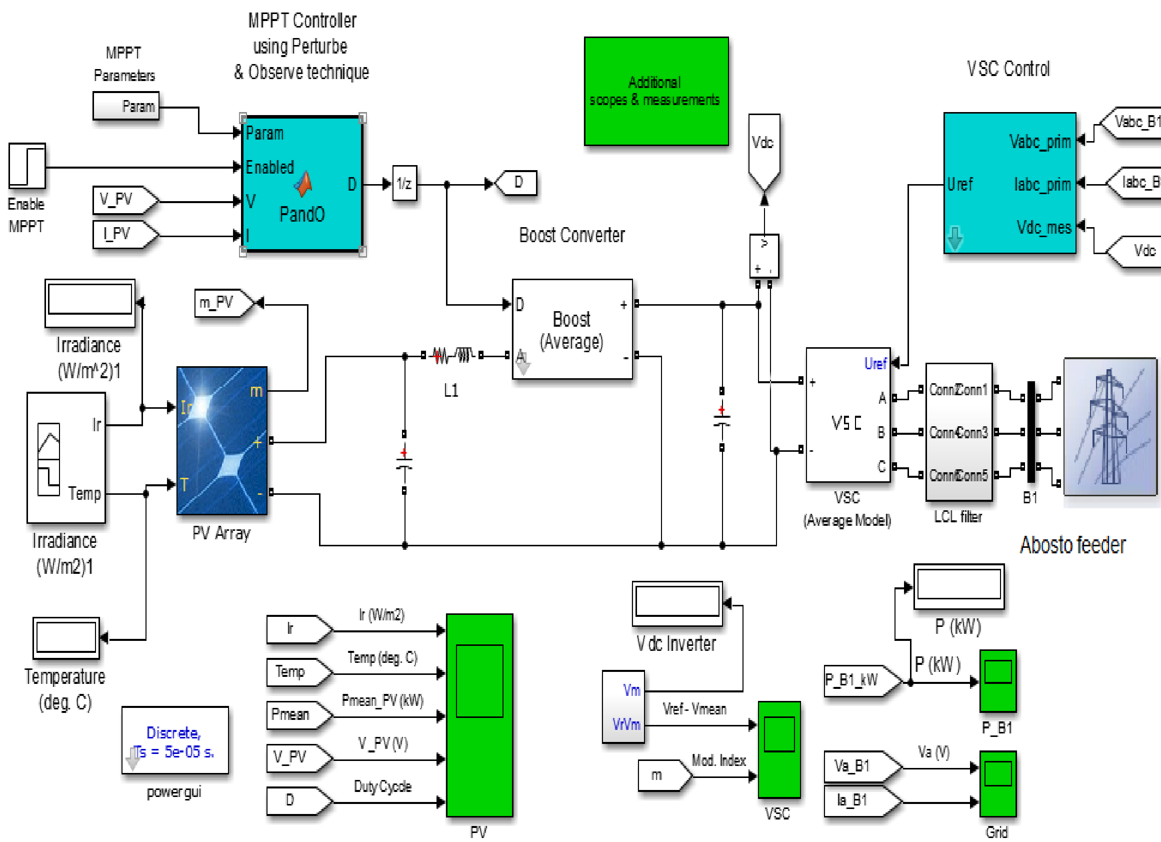

Figure 3.29: matlab Simulink model of grid connected PV

3.24 Solar energy system design

The total optimal size of DG obtained from salp swarm optimization algorithm is 895.3kw, these amount of power is required from the solar PV array. The total energy injected to the grid from DG per day is 21.49MWh. The design has the following major steps. To design the PV system, consider 1.25 in [54] to correct the system loss like panel loss, inverter loss and battery efficiency, so that, 21.49MWh/day **1.25=26.86*MWh/day. Choose inverter DC input voltage; usually 12V, 24V and 48V, this is the DC system voltage.

Note: For energy up to 1kwh use 12v, energy up to 4kwh use 24v and for energy greater than 4kwh use 48v [54], but the total energy generated from PV panel is about 26.86MWh/day, so select 48V.

Chosen DC system voltage = 48V.

The total Ah of the system is obtained as

Total amp hours per day used=$\frac{26.86\text{MWh/day}}{48v} = 559583\text{Ah/day}$

3.24.1 Procedure for PV calculation

1. Determine the total average amp hours per day from the system.

   The average amp hours per day obtained above =559583Ah/day (battery capacity)
2. Determine the average effective sunshine hours per day: Peak sun hours 8 hours/day
3. Obtain Total PV Array Current by dividing average ampere hour to peak sun hour

   Total solar array amps required =$\frac{559583\text{Ah/day}}{8h/day} = 69947.8A$
4. Select PV Module Type.

The ECO-660M-66 module is selected due to the following advantages [55]

- Large area cells based on 210mm silicon wafers and half-cut cell technology
- Low internal current that means lower internal loss.
- Excellent cell efficiency and output.
- Effectively reduces the effects of shadow on the module surface.
- Reduces mismatch loss and improves output
- Eco Delta guarantees that defects will not appears in materials

Specification of the selected module is listed as follow

Chosen PV module:

ECO-660M-66

Max Power =660W

Max voltage=38.08V

Max current=17.33A

Voc=46.03V

Isc=18.73A

Nominal Output Voltage 38Volts

- The total number of the PV module connected in parallel is obtained by

Number of Modules=$\frac{\text{Total PV Array Current}}{((\text{Module Operating Current}) \text{ X } (\text{Module Derate Factor}))}$ (3.115)

Number of Modules =$\frac{69947.8\text{A}}{17.33*0.9}$=4485 panels

So that, the total panel required in this thesis is 4485 panes

- Obtain the total PV panel connected in series by using the following formula:

Modules in series=$\frac{\text{System Nominal Voltage}}{\text{Module Voltage}}$ (3.116)

Modules in series= $\frac{48volt}{38\ volt/module}$ = 2 modules

3.24.2 Steps for battery sizing

The battery capacity for this work is designed to inject the power to the grid for 1.5 day without any sun. The capacity of the battery is given by

$C_{BAh} = \frac{E*AD}{DOD*eff*v_s}$ (3.117)

Where;

AD is the autonomy of the battery

E is the total energy of the PV system

DOD is the deep of discharge of the battery

Eff is the efficiency of the battery.

v_s is the selected total DC system voltage(total battery voltage).

DOD of the lead acid storage battery is 50% [56], Autonomy of the battery is taken 1.5 day and the efficiency of the battery is 80%.

Battery capacity is obtained by equation (3.116) as follow.

$C_{battery} = \frac{26.86Mwh/day*1.5day}{0.5*0.8*48}$ = 2098438Ah.

So, the selected battery must be lead acid battery because these batteries are perfect in solar system.

Batteries chosen.

Lead acid batteries with model of S1900

Rated Capacity = 2900Ah

Battery voltage=12V

$$total\ number\ of\ battery\ required = \frac{system\ battery\ capacity}{rated\ battery\ capacity} \quad (3.18)$$

$$total\ number\ of\ battery = \frac{2098438Ah}{2900Ah} = 723\ battery$$

3.24.3 Inverter Sizing and Rating

The sizing of inverter is basically dependent up on the total demand of the system. There are three types of inverter, from these inverters more preferable one should be selected. These are:

1. Square wave inverters: This is the cheapest type but not suitable for all appliances
2. Modified sine wave: The output is also not suitable for certain appliances like fridge and microwave oven.
3. Pure sine wave: This is preferable for this thesis work.

The power rating of inverter should be equal or more than the total load in watt at any instant. By taking some margin choose an inverter having 48v DC to 15kv/50Hz and minimum power rating of 895.3 kwAC pure sine wave inverter. For the design of the inverter system, the inverter must be large enough to handle the total amount of watts that is generated from the DG. So that the 25%-30% in [54] larger than the DG output power is chosen.

Size of inverter= 895.3kw $*$ 1.3=1163.89kw

Size of inverter ≈1164kw

CHAPTER FOUR

4. SIMULATION STUDIES AND RESULT ANALYSIS

4.1 Introduction

The power loss minimization and voltage profile improvement result of the yirgalem substation selected abosto feeder was performed and recorded in this section using matlab R2016a. The maximum and minimum ratings of DGs are taken as 80% and 10% of total connected loads respectively [57] . All the buses are considered to be possible candidate buses for DG placement except the slack bus. The IEEE standard minimum voltage used is 0.95 and the maximum voltage is 1.05, which is ±5% compared to the rated value.

Figure 4.1 below shows the configuration of the abosto feeder at existing state.

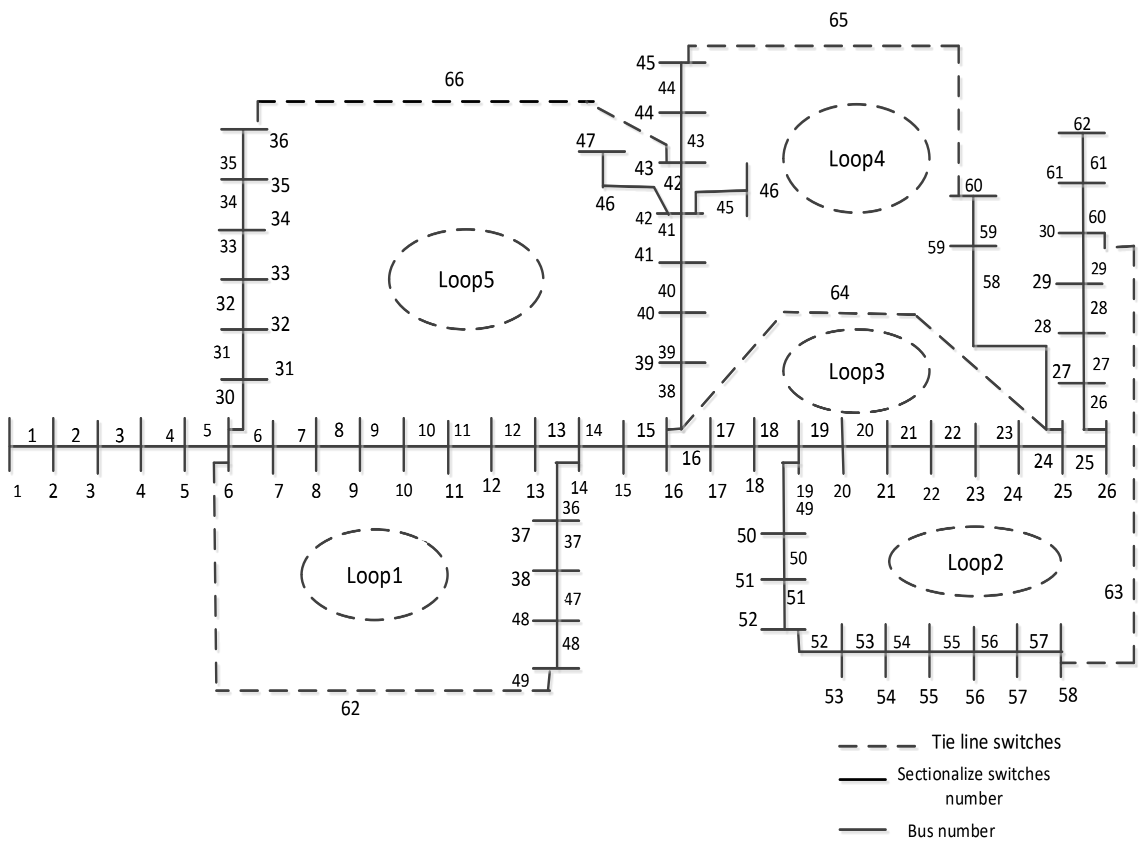

Figure 4.1: single line diagram of abosto feeder with switches

The tap value of all five loop are listed below

Loop1=6 7 8 9 10 11 12 13 36 37 47 48 62

Loop2=25 26 27 28 29 49 50 51 52 53 54 55 56 57 63

Loop3=16 17 18 19 20 21 22 23 24 64

Loop4=38 39 40 41 42 43 44 58 59 65

Loop5=14 15 30 31 32 33 34 35 66

4.2 Simulation result for different scenarios

Scenario 1 Base case load flow (for existing system).

Scenario 2 only network reconfiguration

Scenario 3 only DG placement

Scenario 4 reconfiguration and DG placement simultaneously

4.2.1 Scenario one: Base case simulation result

First, a load flow analysis was performed using forward backward sweep algorithm to determine total power loss and voltage profile on the abosto feeder. Result showed that base case power loss is 401.3KW and the minimum voltage profile at the base case is 0.8702P.U. The voltage profile in base case was plotted in the following figure.

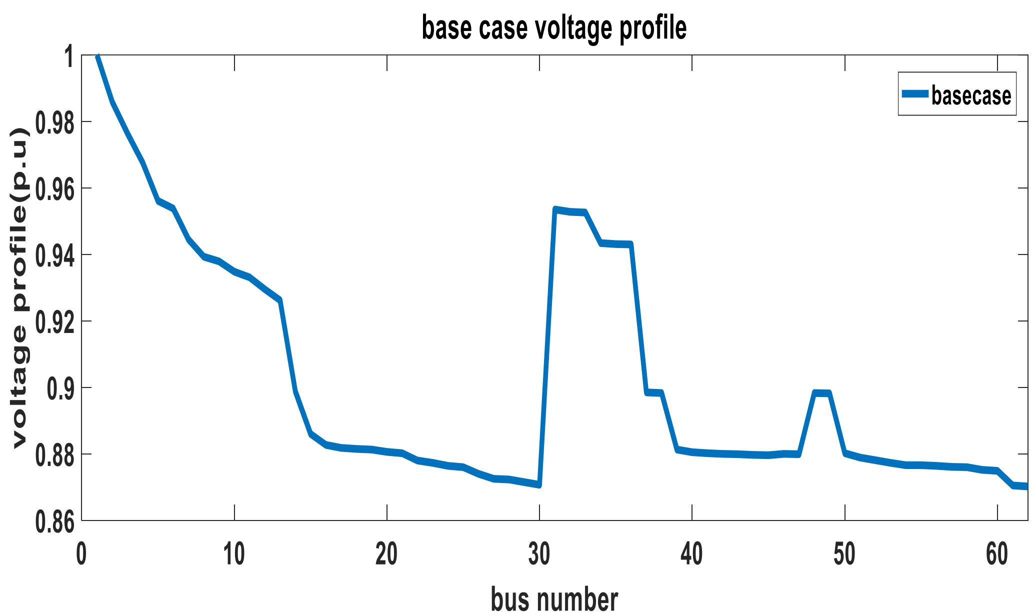

Figure 4.2: base case bus voltage profile

4.2.2 Scenario two: simulation result during only network reconfiguration

In this scenario, The optimal tie switch open for power loss minimization and voltage profile improvement determined using proposed salp swarm algorithm (SSA) is (6, 25,21, 38, 14). The total power losses after only network reconfiguration is reduced to 169.7KW from 401.3KW (base case). The percentage power loss reduction is 57.7% .The whale optimization algorithm (WOA) reduces power loss to 172.2KW from the base case. The percentage power loss reduction by using WOA is 57.1%. By using particle swarm optimization algorithm (PSO), the feeder power losses is reduced to 204.5KW from 401.3KW (base case) .The percentage power loss reduction with PSO is 49%. Based on the above simulation result, all optimization algorithm causes positive effect on the power loss minimization, but SSA have better performance over the other two. Table 4.1 show the summary of the comparison of proposed SSA with WOA and PSO.

Table 4.1: comparison of proposed SSA with base case, WOA, and PSO in scenario two

methods	Tie line switch	Power loss (KW)	%PLR	Minimum voltage (P.U)
Base case	62,63,64,65, 66	401.3	_	0.87
PSO	7, 27,16, 38,32	204.5	49	0.903
WOA	11,25,16,38, 31	172.2	57.1	0.919
SSA	6,25,21,38,14	169.7	57.7	0.922

The percentage power loss reduction during only network reconfiguration was plotted with three different algorithm for more description as follow.

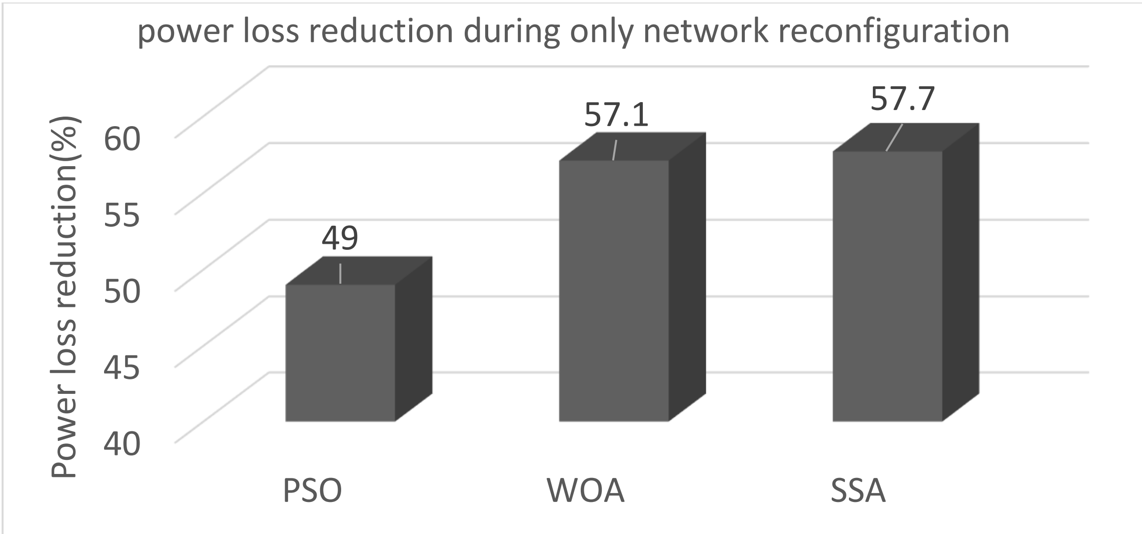

Figure 4.3: power loss reduction after reconfiguration in case of different algorithm

Proposed method does not only provide minimum power loss, but also significantly improve overall voltage profile of the selected feeder after optimal network reconfiguration. Voltage profile of the base case, and after optimal network reconfiguration with SSA, PSO and WOA were plotted against with their respective bus number in order to see the voltage profile improvement after only network reconfiguration is given in figure 4.4

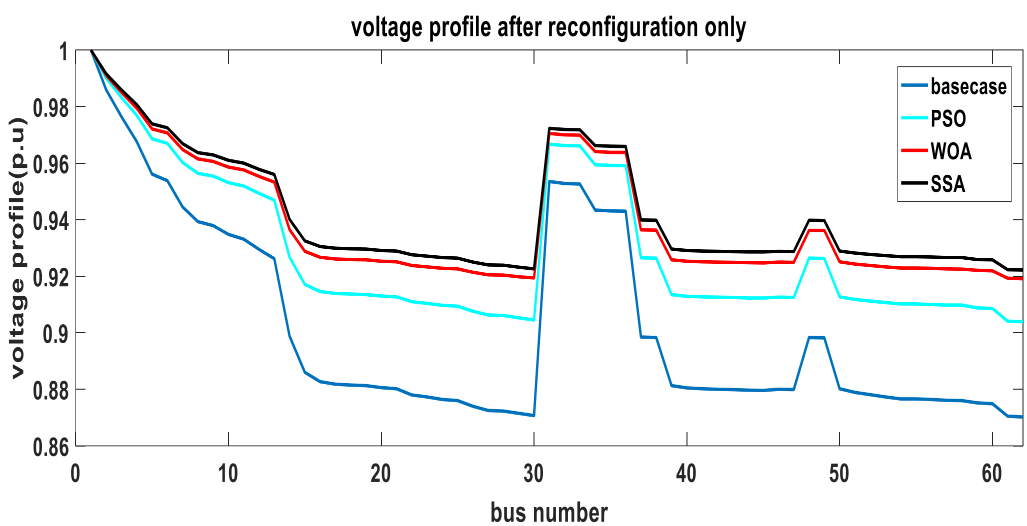

Figure 4.4: voltage profile comparison in base case and after network reconfiguration

The minimum voltage profile in base case is 0.87P.U. After optimal network reconfiguration with proposed salp swarm algorithm (SSA), the minimum voltage profile is improved from base case to 0.922P.U. The WOA improve the voltage profile to 0.919P.U, while PSO improve the voltage Profile to 0.903P.U. The above comparison shows that the proposed SSA has better performance for the voltage profile improvement than the WOA and PSO.

4.2.3 Scenario three: simulation result during only DG incorporation

The distributed generation (DG) minimizes power loss and improves overall voltage profile when only optimally sized and placed. Otherwise it increases power loss and disturb the voltage profile of the system. In this scenario, only optimal DG placement and size without network Reconfiguration bring significant amendment in overall voltage profile and power loss minimization. The Optimal DG location and size attained with proposed salp swarm algorithm (SSA) is 972.4KW at bus 36.The total power loss after optimal DG allocation with SSA is reduced to 146.5KW from 401.3KW (base case). The percentage power loss reduction is 63.5%. Whale optimization algorithm (WOA) reduces the total power loss to 147.8KW from 401.3KW (base case). The percentage power loss reduction with WOA is 63.2%. While PSO reduce the total power loss to 187.9KW from the base case (401.3KW). The percentage power loss reduction with PSO is 53.1%. The above result explanation shows that SSA has better performance than PSO and WOA.

Table 4.2: comparison of proposed SSA with base case, WOA, and PSO in scenario three

Methods	Tie switch	DGL	DG size (KW)	Power loss (KW)	%PLR	Minimum voltage(P.U)
Base case	_	_	_	401.3	_	0.87
PSO	_	31	793.2	187.9	53.1	0.916
WOA	_	28	971.7	147.8	63.2	0.927
SSA	_	36	972.4	146.5	63.5	0.934

For more clarification, the power loss reduction during DG only incorporation was plotted with three different algorithm as follow.

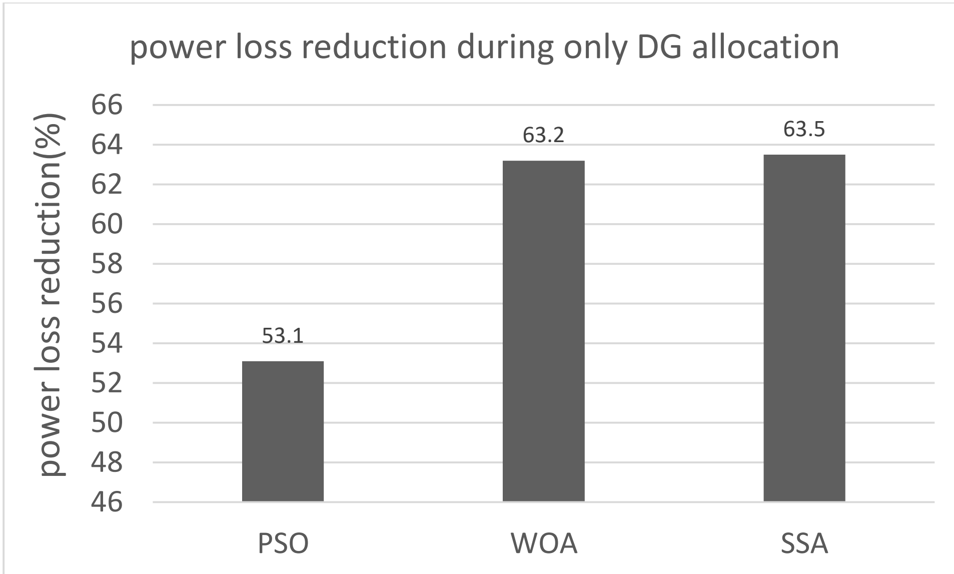

Figure 4.5: power loss reduction after DG incorporation in case of different algorithm

The second main aim of this thesis is voltage profile improvement. The voltage profile improvement using only optimal DG sizing and placing in existing network configuration is explained as follow. Voltage profile of the base case and after optimal DG allocation with SSA, PSO and WOA were plotted against their respective bus number in order to see the voltage profile improvement after only DG allocation.

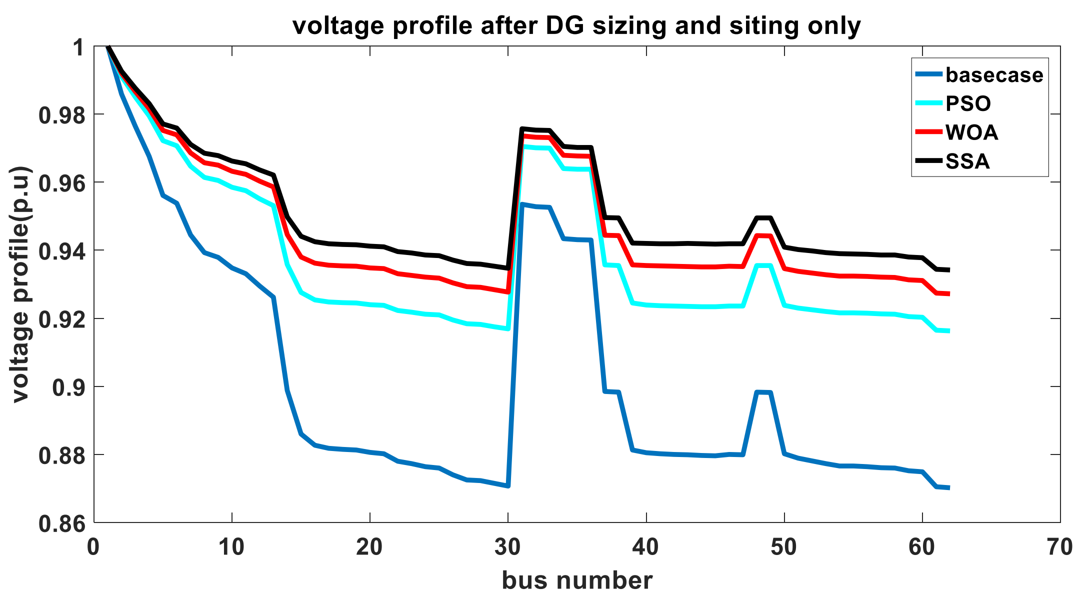

Figure 4.6: voltage profile comparison in base case and optimal DG allocation

Figure 4.6 depict the comparison of the voltage profile for base case, PSO, WOA, and the proposed SSA case after only DG allocation and sizing. The minimum voltage profile in base case is 0.87P.U. After optimal DG allocation and sizing with PSO, the minimum voltage is improved from base case to 0.916P.U. WOA improve the voltage profile to 0.927P.U.The proposed SSA improve the voltage profile to 0.934P.U from 0.87P.U.

4.2.4 Scenario four: simulation result during network reconfiguration and DG allocation simultaneously

At this last scenario, optimal network reconfiguration, DG sizing and allocation simulation was performed simultaneously on selected abosto feeder. As discussed in the chapter three, decision variable here is the tie line switches, DG location and size. These three variables decide the amount of power loss and voltage profile on the selected abosto feeder. The optimal tie line switch open, DG size and location attained with proposed SSA to minimize power loss is (11, 25, 16, 42, 14), 895.3kW, and bus 23 respectively. The total power loss reduced by using proposed SSA to 101.5KW from the base case (401.3KW). The percentage power loss reduction with SSA is 74.7%. Whale optimization algorithm (WOA) reduces the power loss to 104.7KW. The percentage power loss reduction with WOA is 73.8%. PSO reduce the total power loss to 131.2KW. The percentage power loss reduction with PSO is 67.3%. Still SSA result shows that SSA has better performance than the other two.

Table 4.3: comparison of proposed SSA with base case, WOA and PSO in scenario four

methods	Tie switch	DGL	DG size (KW)	Power loss(KW)	%PLR	Minimum voltage(P.U)
Base case	62,63,64,65,66	_	_	401.3	_	0.87
PSO	6,27,16,38,34	27	717.3	131.2	67.3	0.938
WOA	8,25,16,39,14	19	889.7	104.7	73.8	0.964
SSA	11,25,16,42,14	23	895.3	101.5	74.7	0.969

The percentage power loss reduction during simultaneous network reconfiguration and DG allocation was plotted for more description as follow.

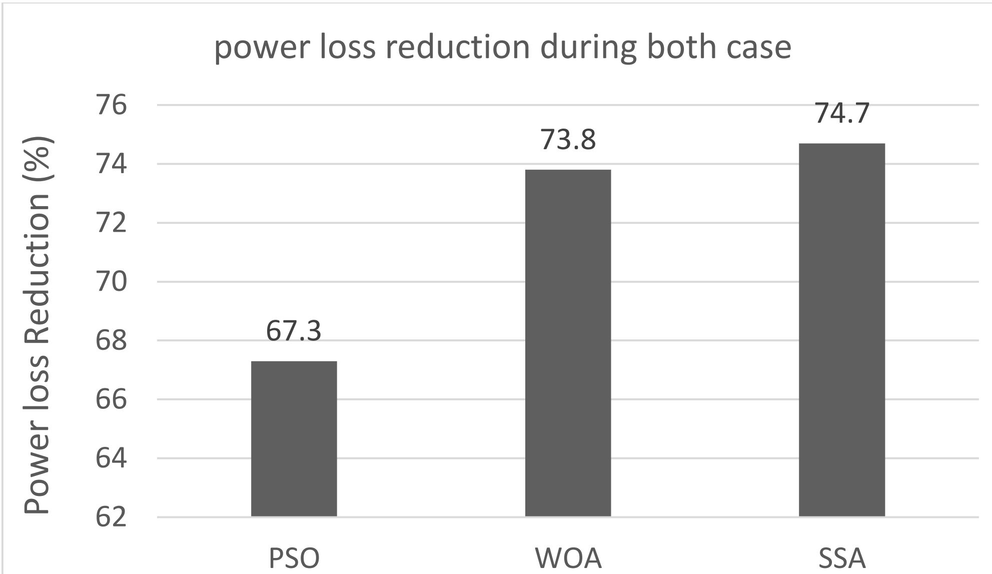

Figure 4.7: Power loss reduction after both case in case of three different algorithm

As other scenario, the voltage profile enhancement of all bus was discussed here also, thus the bus voltage magnitude at each bus at base case and after optimal network reconfiguration, DG sizing and allocation with PSO, WOA and proposed SSA is sketched in the figure 4.8 in order to compare the enhanced voltage profile with the base case voltage profile.

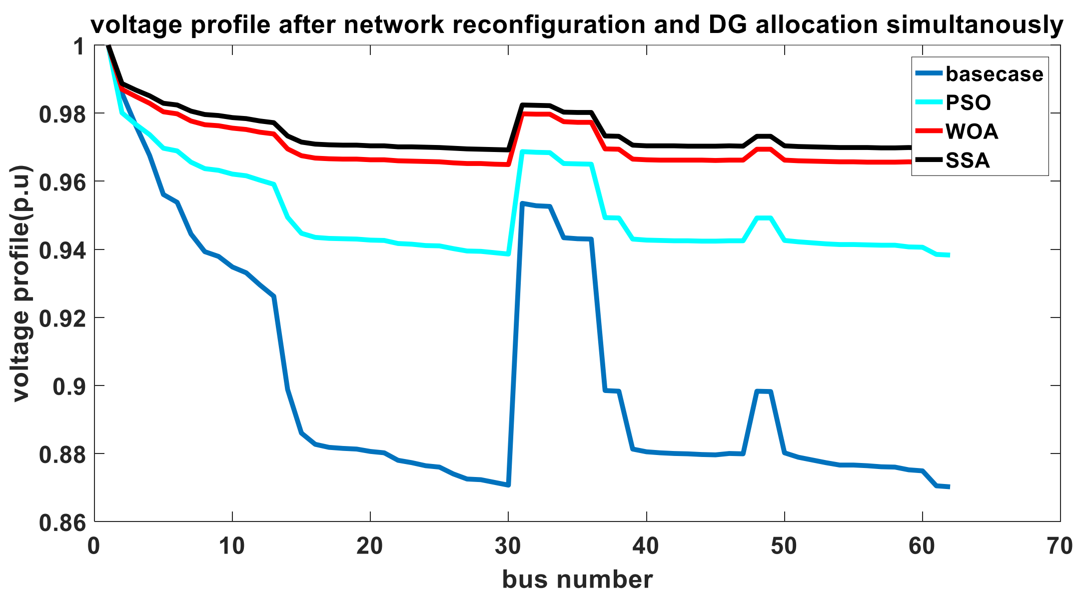

Figure 4.8: voltage profile comparison of base case with simultaneous network reconfiguration and DG allocation

Here, the minimum voltage profile in base case is 0.87P.U. The minimum voltage profile after optimal network reconfiguration, DG sizing and siting with SSA is improved to 0.969P.U from the base case. WOA improve minimum voltage profile to 0.964P.U. While PSO enhanced minimum voltage profile to 0.938P.U from the base case.

4.2.5 Summary of simultaneous network reconfiguration and DG allocation

The simulation result of the proposed feeder in case of power loss minimization and voltage profile enhancement was carried out by comparing SSA with PSO and WOA. The above simulation result show that SSA have better performance than PSO and WOA.

After comparing the three different algorithm, the power loss and voltage profile of the proposed abosto feeder was simulated by using only proposed salp swarm algorithm in case of only network reconfiguration, only DG sizing and siting and network reconfiguration with DG allocation simultaneously. Table 4.4 shows that, the simultaneous network reconfiguration with DG allocation have better performance than only network reconfiguration or only DG allocation.

Table 4.4: summary of the objectives after different scenario with only SSA

Objective	Scenario 1 (base case)	Scenario 2 (reconfiguration)	Scenario 3 (DG only)	Scenario 4 (both case)
Tie switch open	62, 63,64, 65,66	6,25,21,38,14	_	11,25,16,42,14
DG size (KW)	_	_	972.4	895.3
DG location	_	_	36	23
Power loss(KW)	401.3	169.7	146.5	101.5
Power loss Reduction (%)	_	57.7	63.5	74.7
Minimum Bus voltage (p.u)	0.87	0.922	0.934	0.969

The power loss in different scenario using only proposed salp swarm algorithm is plotted as follow.

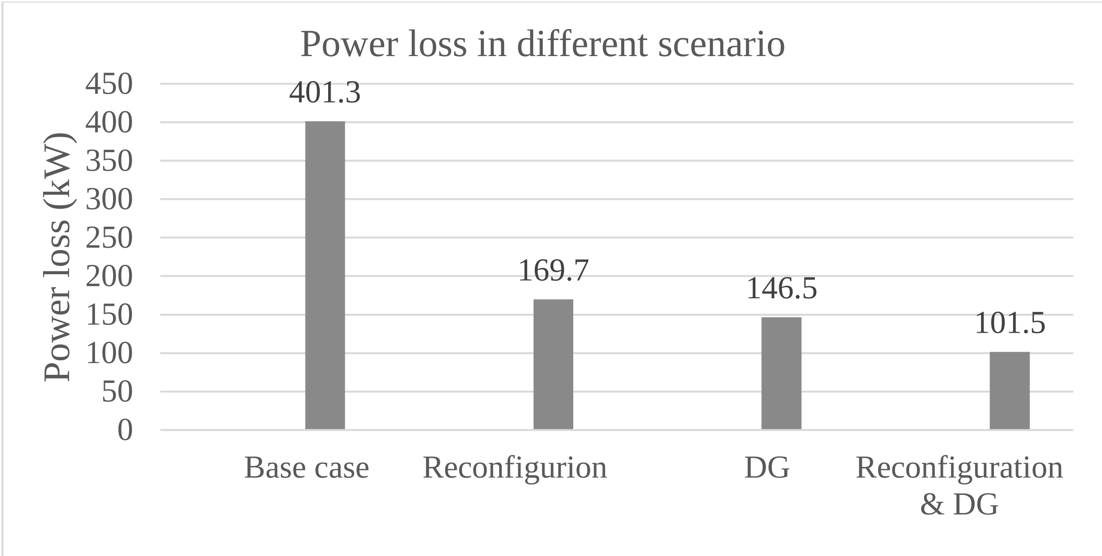

Figure 4.9: Power loss reduction in case of four different scenario using SSA

The voltage profile of the abosto feeder was simulated by comparing the SSA with PSO and WOA and author concluded that SSA show better result than PSO and WOA.

The voltage profile of the abosto feeder was simulated with only SSA in case of only network reconfiguration, only DG allocation and simultaneous network reconfiguration and DG allocation and plotted in figure 4.10.

The following figure depict that the simultaneous network reconfiguration and DG allocation have better performance than network reconfiguration or DG allocation.

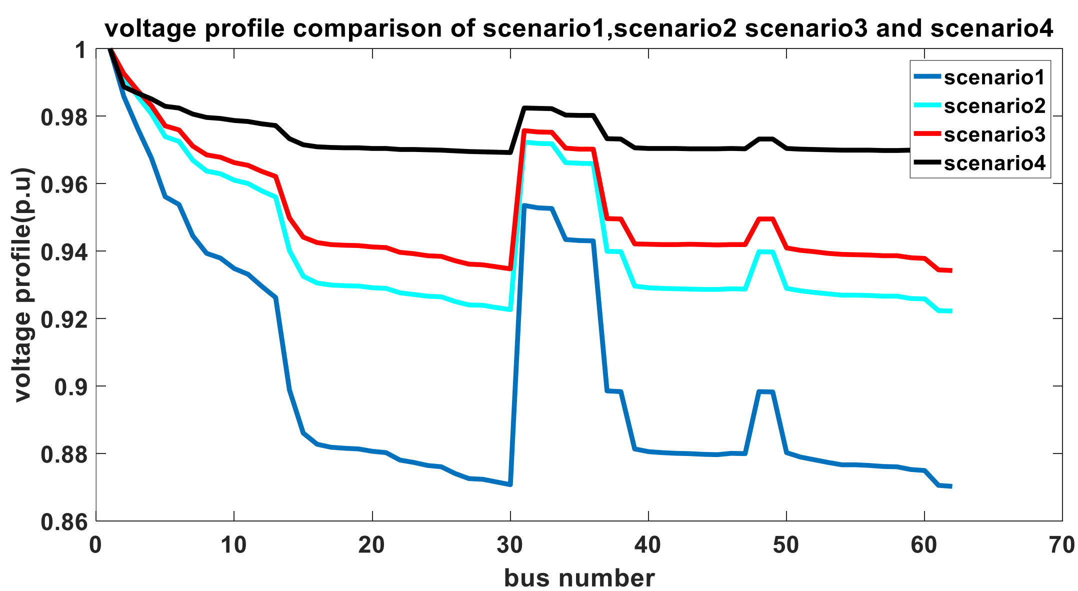

Figure 4.10: summary of the voltage profile of four scenario with SSA

4.3 cost analysis

This thesis focuses on minimizing the economic operation of the distribution network due to simultaneous network reconfiguration and DG allocation. The optimal network reconfiguration and DG incorporation to the existing system benefit both utilities and customers, Because the satisfaction of customer increase while utilities also get the desired payment from the customer.

In general, there is a reduction of network power loss, maintenance, operational costs and improved voltage profile when the overall network is considered thereby giving financial benefit from network reconfiguration and DGs added to the system. The objective function to minimize the cost and the way of analysis was discussed in chapter three. The total investment cost of this thesis includes the total investment cost of DG and costs used for network reconfiguration like labor, materials and including transportation cost. The price of AAAC conductor and wooden pole was obtained from Ethiopian electric utility hawassa branch. The overall material used for network reconfiguration with its cost is given in the table below.

Table 4.5: the material used for reconfiguration

Material type	Price of each Material(ETB)	quantity	Total Cost (ETB)
AAAC conductor	10,000	2 pack	20,000
Pole wood 12 m	2894.3	45	130,243.5
Labor and others	3000	9	27000
sum	_	_	177,243.5

The revised current tariff of Ethiopian Electric Utility is used to calculate the power loss cost of the system. The revised tariff of 2013 of the Ethiopian electric utility is 2.0343 birr/KWH. Based on benchmark data of the USA, the average installed cost of solar power is 883$/KW or (41501birr/KW) that includes capital investment for DG units with installation, operation, and maintenance cost and the average solar DG life is taken as 25 years. The overall cost comparisons of different scenario using three different algorithm was calculated and tabulated in the following table.

Table 4.6: Comparison of annual energy loss saving in different scenarios**.**

scenarios	Method	PL(KW)	DG size(KW)	DG investment cost(ETB)	Annual economic loss (ETB)	Annual economic saving(ETB)
Base case	-	401.3	_	_	7,151,353.8	-
Only reconfiguration	PSO	204.5	_	_	3,821,528	3,329,825
	WOA	172.1	_	_	3,244,145	3,907,207
	SSA	169.7	_	_	3,201,376	3,949,977
Only DG integration	PSO	187.9	793.2	1,316,743	4,665,208	2,486,145
	WOA	147.8	971.7	1,613,060	4,246,925	2,904,428
	SSA	146.5	972.4	1,614,222	4,224,920	2,926,433
Both case	PSO	131.2	717.3	1,190,746	3,706,034	3,445,319
	WOA	104.7	889.7	1,365,714	3,519,983	3,631,369
	SSA	101.5	895.3	1,486,233	3,472,253	3,679,100

4.3.1 Summary of cost analysis

After comparing the cost of the power loss and cost of the DG installation by using various optimization algorithm, the cost analysis at different scenario using proposed algorithm is summarized at table 4.7

Table 4.7: Summary of comparison of annually energy loss saving with only SSA

scenario	PL(KW)	DG size (KW)	DG investment cost	Annual economic loss (ETB)	Annual economic saving (ETB)
Base case	401.3	_	_	7,151,353	_
network reconfiguration	169.7	_	_	3,201,376	3,549,977
DG integration	146.5	972.4	1,614,222	4,224,920	2,926,432
Both case	101.5	895.3	1,486,233	3,472,253	3,679,100

CHAPTER FIVE
5. CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1 Introduction

This chapter presents a summary of this thesis work. Mainly the chapter highlighted the general conclusion, recommendation, and suggestions for further works.

5.2 Conclusion

This thesis work showed the formulation of main equations of electrical distribution systems for power flow analysis and the formulation and implementation of the salp swarm algorithm (SSA). Different loss reduction methods (only network reconfiguration, only DG installation, DG installation simultaneous with network reconfiguration) are simulated for the selected Abosto feeder to establish the superiority of the proposed method. The salp swarm algorithm effectively reduce the system power loss and improve voltage profile of the system by optimally exchanging the branch of the selected feeder and simultaneously sizing and siting of the distributed generation.

In case of only optimal network reconfiguration with SSA, the optimal tie switch open is 6, 25, 21, 38, and 14. The total power loss is reduced to 169.7kW from the base case. The percentage power loss reduction is 57.7% with respect to the base case. The minimum voltage profile during only network reconfiguration is improved to 0.922P.U. During optimal DG sizing and allocation with SSA, the optimal size and location of DG obtained is 972.4 kW and bus 36 respectively. Consequently, the percentage power loss reduction is 63.5%. The minimum voltage profile of the feeder is improved to 0.934P.U. In case of simultaneous network reconfiguration with DG using proposed SSA, the switch open, DG location and size is (11, 25, 16, 42, 14), bus 23 and 895.3KW respectively. The percentage power loss reduction of the system is 74.7%. The minimum voltage profile during both cases is improved to 0.969P.U. Furthermore, the proposed SSA is compared with PSO and WOA which shows that the SSA have higher performance than both algorithm in order to find optimal tie switch, optimal DG placement and sizing. This thesis work conclude that simultaneous network reconfiguration and DG allocation have better performance in power loss minimization and voltage profile improvement than either network reconfiguration or DG allocation independently.

5.3 Recommendation

The following are the recommendations based on the study on power loss minimization and voltage profile improvement for simultaneous network reconfiguration and DG allocation.

- First of the installation of the DG, the protection of distribution system must be updated because integration of DG cause several negative impact on the protection system of the distribution system
- We strongly recommend that EEP must consider either network reconfiguration or distributed generation incorporation for their distribution system such that the utility company can save cost, increase power distribution efficiency and reduce socio-economic problem.

5.4 Future Work

The following items provide a potential for future work:

- Further analysis can also be done by using the developed model of network reconfiguration, DG allocation and FACT device simultaneously for further enhancement of performance of radial distribution system with minimum cost.

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APPENDIX

Appendix-1

Line and Bus Data of the proposed Abosto Feeder

Bus no	From bus	To bus	Resistance	Reactance	Real power (kw)	Reactive power (kvar)	Existing transformer (KVA)
1	1	2	1.3681	1.14507	0	0	
2	2	3	0.2937	0.1582	20.46	12.54	200
3	3	4	0.5132	0.3367	199.6	148.82	630
4	4	5	0.6804	0.5039	26.95	16.50	100
5	5	6	0.2573	0.1571	26.95	16.5	100
6	6	7	0.2519	0.1390	26.95	16.5	100
7	7	8	0.3153	0.2813	0	0	
8	8	9	0.2410	0.1052	20.46	12.54	200
9	9	10	0.3982	0.2501	199.58	148.81	630
10	10	11	0.0514	0.0365	20.46	12.54	200
11	11	12	0.2165	0.1934	49.9	32.3	315
12	12	13	0.1951	0.1718	26.95	16.5	100
13	13	14	1.3173	1.2356	16.83	10.065	25
14	14	15	0.5882	0.3561	49.89	32.22	315
15	15	16	0.3274	0.3199	0	0	
16	16	17	0.5121	0.1305	20.46	12.54	200
17	17	18	0.0216	0.0586	49.89	32.22	315
18	18	19	0.0108	0.0261	199.58	148.81	630
19	19	20	0.1462	0.1157	26.950	16.50	100
20	20	21	0.0480	0.0330	0	0	
21	21	22	0.3721	0.2543	17.820	11.825	50
22	22	23	0.1325	0.1025	49.89	32.22	315
23	23	24	0.1592	0.1104	20.460	12.540	200
24	24	25	0.0813	0.0522	16.830	10.065	25
25	25	26	0.5610	0.3812	26.95	16.5	100
26	26	27	0.4626	0.3285	0	0	
27	27	28	0.0971	0.0651	49.89	32.22	315
28	28	29	0.4863	0.3324	199.58	148.82	630
29	29	30	0.4962	0.3391	26.95	16.5	100
30	30	31	0.2401	0.1636	0	0	
31	31	32	0.2536	0.1781	199.58	148.82	630
32	32	33	0.3504	0.2474	49.89	32.22	315
33	33	34	0.4832	0.3306	48.89	32.22	315

34	34	35	0.2240	0.1560	26.95	16.5	100
35	35	36	0.1925	0.1314	16.83	10.06	25
36	36	37	0.0891	0.0282	26.95	16.5	100
37	37	38	0.1783	0.0759	49.89	32.22	315
38	38	39	0.6679	0.4201	49.89	32.22	315
39	39	40	0.2105	0.1837	0	0	
40	40	41	0.0484	0.0239	20.46	12.54	200
41	41	42	0.0796	0.0283	199.58	148.82	630
42	42	43	0.0461	0.1124	0	0	
43	43	44	0.2497	0.0918	199.5	148.82	630
44	44	45	0.2783	0.2026	26.95	16.5	100
45	45	46	0.0028	0.0023	20.46	12.54	200
46	46	47	0.2895	0.2281	26.95	16.5	100
47	47	48	0.1692	0.1293	26.95	16.5	100
48	48	49	0.2594	0.3546	17.82	11.82	50
49	49	50	0.1890	0.1172	20.46	12.54	200
50	50	51	0.3905	0.3014	49.89	32.22	315
51	51	52	0.2910	0.1877	49.89	32.22	315
52	52	53	0.3941	0.2781	20.46	12.54	200
53	53	54	0.2947	0.1783	199.58	148.82	630
54	54	55	0.0825	0.0390	16.83	10.065	25
55	55	56	0.2543	0.1024	49.896	32.22	315
56	56	57	0.4676	0.3691	20.46	12.54	200
57	57	58	0.3947	0.2786	49.896	32.22	315
58	58	59	0.7152	0.4801	20.46	12.54	200
59	59	60	0.9370	0.6493	26.95	16.5	100
60	60	61	0.2245	0.1562	26.95	16.5	100
61	61	62	0.6913	0.4761	49.89	32.22	315
62					199.58	148.82	630

Appendix -2

SSA matlab code for simultaneous network reconfiguration and DG allocation

```
%% propssed salp sawrm optimization COde for optimal network reconfiguration and DG allocation
clearvars;
clc;
close all
maxiter=1000;
f=zeros (30,1);
dim=7;
 objF=inf;
source_num=1;
n=30;% number of population
x=populatin3; %call of population
voltage_minimum=0.9;
voltage_maximum=1.05;
y=x';
iter=0;
tap=[6 7 8 9 10 11 12 13 36 37 47 48 62 0 0
     25 26 27 28 29 49  50 51 52 53 54 55 56 57 63
     16 17 18 19 20 21 22 23 24 64 0 0 0 0 0
     38 39 40 41 42 43 44 58 59 65 0 0 0 0 0
     14 15 30 31 32 33 34 35 66 0 0 0 0 0 0 ];
 ta=tap';
for q=1:maxiter
   for k=1:n
busdata_value=(bus);
  PDG=zeros(size(busdata_value,1),1);
  PDG(x(k,6))=x(k,7)
  load_data=complex(busdata_value(:,2),busdata_value(:,3));
  final_load_matrix=load_data;
```

```
  final_load_matrix=insertDG3(load_data,PDG,bus);
  final_load_matrix=final_load_matrix/(PBASE);
  final_load_matrix(length(source_num))=[];
  y=x';
for i=1:5
 branch(y(i,k),6)=0;%BECAUSE ALL LOOPS CLOSED BEFORE
 bb=find(branch(:,6)==0);
   end
stat=branch(:,BR_STATUS);
branch(find(stat==0),:)=[]; % normal branch matrix that curent flwo
nl=length(branch(:,F_BUS));% Total No. of line in service
nb=length(bus(:,BUS_I));% Total no. of buses
Zbase=(baseKV^2)/baseMVA; % base impedance
R=branch(:,BR_R); % resistance in pu
X=branch(:,BR_X); % reactance in pu
j=sqrt(-1);% defining iota
Z=(R+j*X); % Impedance in p.u.
stat=branch(:,BR_STATUS);
branch (find(stat==0),:)=[];% Actual branch matrix in which current flowing
br=branch(:,1);
nl=length(branch(:,F_BUS)); % Total No. of branches in service
nb=length(bus(:,BUS_I));% total no of bus
f=branch (: F_BUS); % list of 'from' branches
t=branch (: T_BUS);% list of 'to' branches
 [BIBC, BCBV, DLF]=last_makeBIBCandDLF3 (Z,bb,baseMVA,baseKV,bus,branch); % Calling BIBC and DLF matrix
pd=complex(bus(:,2),bus(:,3));
pd(1)=[];
source_num=1;
busdata_value=bus;
linedata_value=branch;
```

```
resistance=R;
reactance=X;
actual_imped=complex(R,X);
imped_value=actual_imped;
initial_volt_value=ones(size(busdata_value,1)-length(source_num),1);
% initial bus voltage
voltage_drop_value=initial_volt_value;
 for ind_lop=1:max_iter
%backward sweep
inject_current_data=conj(final_load_matrix./voltage_drop_value);
IB=BIBC*inject_current_data;
%get the cumulative injected current flowing through each branch
old_volt=voltage_drop_value;
volt_drop_each=DLF*inject_current_data;
%voltage drops along each branch.
voltage_drop_value=initial_volt_value-volt_drop_each;
old_volt1=(old_volt);
new_volt=(voltage_drop_value);
error_volt_tolr=max(abs(old_volt1-new_volt));
ind_lop;
end
final_volt_data=[ones(length(source_num),1); voltage_drop_value];
rvolt=real(final_volt_data);
ivolt=imag(final_volt_data);
final_volt_data=complex(rvolt,ivolt);
vm=abs(final_volt_data);
vm2=vm;
ploss=abs(IB.^2).*(real(imped_value))*10^5;
%%%%%%
ploss_sum=sum(ploss);
qloss=abs(IB.^2).*(imag(imped_value))*10^5;
```

```
qloss_sum=sum(qloss);
powerloss_data=complex(ploss,qloss);
loss_mag=abs(powerloss_data);
ploss_w_reco=ploss_sum;
f(k,1)=ploss_w_reco;
 end
 f;
 a=min (f);
for z=1:k
    If f(z) < objF
     objF = f(z);   % update of food fitness
      Xf   = x(z,:); % update of the food source
      End
  end
  c1 = 2 * exp(-(4 * q / maxiter) ^ 2);
  for i = 1:k
    if i == 1
      for d = 1:dim
        c2 = rand();
        c3 = rand();
        if c3 >= 0.5
          x(i,d) = Xf(d) + c1 * ((ub(d) - lb(d)) * c2 + lb(d));
        else
          x(i,d) = Xf(d) - c1 * ((ub(d) - lb(d)) * c2 + lb(d));
        end
       % x(i,d)=ceil(x(i,d));
       end
    else
      for d = 1:dim
        x(i,d) = (x(i,d) + x(i-1,d)) / 2;
       % x(i,d)=ceil(x(i,d));
```

```
    end
   end
  x(:,6)=ceil(x(:,6));
  u=repmat(ub,Np,1);
 l=repmat(lb,Np,1);
 x=max(x,l); % lower limit of DG
 x=min(x,u);
 for i=1:n
 for k=1:5
  r=length(nonzeros(ta(:,k)));%alex
  sig(i,k)=length(nonzeros(ta(:,k)))/(1+exp(-x(i,k)));
  o=ceil(sig(i,k));
  x(i,k)=ta(ceil(sig(i,k)),k);
  end
  end
end
  pl_after=objF;
 end
lossreduction=pl_after/pl_base*100;
 loss_reduction=100-lossreduction;
 ploss_affter=objF;
 qloss_after=qloss_sum;
  s=1:62;
 result{1}=pl_base;
 result{2}=ql_base;
 result{3}= ploss_affter;
result
 vmin2=min(vm2)
 plot(s,vm_base,'r',s,vm2 ,'k')
plot(s,vs1,s,vs2,'c',s,vs3,'r',s,vs4,'k')
  legend('scenario1','scenario2','scenario3','scenario4');
```

```
xlabel('bus number')
 ylabel('voltage profile(p.u)')
 title('voltage profile comparison of scenario1,scenario2 scenario3 and scenario4')
```

Appendix-3

Voltage profile after optimal network reconfiguration with DG.

Bus number	Voltage (P.U)	Bus number	Voltage (P.U)
1	1.0000	33	0.9822
2	0.9887	34	0.9803
3	0.9868	35	0.9802
4	0.9851	36	0.9802
5	0.9829	37	0.9733
6	0.9824	38	0.9732
7	0.9806	39	0.9706
8	0.9796	40	0.9704
9	0.9793	41	0.9704
10	0.9787	42	0.9704
11	0.9784	43	0.9703
12	0.9777	44	0.9703
13	0.9772	45	0.9703
14	0.9733	46	0.9704
15	0.9715	47	0.9703
16	0.9709	48	0.9732
17	0.9707	49	0.9732
18	0.9706	50	0.9704
19	0.9706	51	0.9802
20	0.9704	52	0.9701
21	0.9704	53	0.9700
22	0.9701	54	0.9699
23	0.9701	55	0.9699
24	0.9700	56	0.9699

25	0.9699	57	0.9698
26	0.9697	58	0.9698
27	0.9695	59	0.9699
28	0.9694	60	0.9698
29	0.9693	61	0.9691
30	0.9692	62	0.9691
31	0.9824		
32	0.9823		