OPTIMAL SIZING AND PLACEMENT OF CAPACITOR AND DISTRIBUTED GENERATION FOR LOSS MINIMIZATION IN UNBALANCED DISTRIBUTION NETWORK

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As members of the Board of Examiners of the final Master's degree open defense, we certify that we have read and evaluated the thesis prepared by **Bawoke Simachew** under the title OPTIMAL SIZING AND PLACEMENT OF CAPACITOR AND DISTRIBUTED GENERATION FOR LOSS MINIMIZATION IN UNBALANCED DISTRIBUTION NETWORK and recommend that it be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Electrical Engineering with Specialization in Power System and Energy Engineering.

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Candidate's Declaration

I hereby declare that all information in this thesis entitled ''Optimal Sizing and Placement of Capacitor and Distributed Generation for Loss Minimization in Unbalanced Distribution Network'' is my own work conducted under the guidance of Dr. Baseem Khan and Mr. Issaias Giday, Department of Electrical and Computer Engineering, Hawassa University Institute of Technology, Hawassa, Ethiopia.

I further declare that to the best of my knowledge the thesis does not contain any part of work that has been submitted for the award of any degree either in this university or of any other university without proper citation.

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This is to certify that the statement made by the candidate is true to the best of my knowledge.

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Certification

This is to certify that the work entitled "Optimal Sizing and Placement of Capacitor and Distributed Generation for Loss Minimization in Unbalanced Distribution Network", submitted by Bawoke Simachew (PGEng/006/09), Department of Electrical Engineering, Hawassa University Institute of Technology, Hawassa, Ethiopia is a record of a Bonafide research carried out by him under my supervision and guidance. The thesis work in my opinion, has reached the requisite fulfilling the requirement of Master of Science Degree. The results contained in the thesis have not been submitted in part or full to any other University or institute for the award of any degree.

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Abstract

Power loss reduction is an important problem that needs to be addressed as generating electrical power. It is important to reduce power loss using locally generated power sources and/or compensations. This thesis presents a method of maximizing energy utilization, feeder loss reduction and voltage profile improvement for radial distribution network using the active and reactive power sources. Distributed Generation (DG) (wind and solar with backup by biomass generation) and shunt capacitor (QG) for reactive power demand are used. Integrating DG and QG at each bus might reduce the loss but it is economically unaffordable for developing countries like Ethiopia. Therefore, this work utilized an optimization method namely Whale Optimization Algorithm (WOA) for finding an optimal size and location at feeder for placing QG and DG, so that the feeder loss is minimized. WOA is a meta-heuristic optimization derived from natural food hunting behavior of biggest mammal fish called whale. To see the performance WOA, it is compared with particle swarm optimization (PSO). In the process of optimization, the feeder carrying capacity is considered as the primary constraint to get the best minimum loss while voltage, position limits and the sum of equality constraints are kept considered. The performance of the applied method is performed on 35 and 40 bus feeders of Bahir Dar distribution network. From the results, the power loss had reduced from 339.5703 kW to 22 kW in Ghion feeder and from 126.2149 kW to 22.4 kW in Bata feeder using WOA. It also had reduced from 339.5703 kW to 27 kW in Ghion and from 126.2149 kW to 51.3 kW in Bata feeder using PSO. Hence, it can be noted that that WOA is superior to PSO in terms of loss minimization.

Keywords: *Whale Optimization Algorithm*, *Particle Swarm Optimization*, *Distributed Generation*, *Shunt capacitor placement, Feeder-integrating capacity limit*

Acknowledgement

In doing this thesis, I had faced the most challenging task in my academic career I have ever had to face. It was very difficult to reach at complete without the guidance of the following people and organizations, it is to them that I want owe my deepest thank next to Almighty God and his mom St. Marry:

- Dr. Baseem Khan to his tireless communication and suggestions in over all work of this thesis, he has undertook everything as my supervisor despite his huge other academic and professional tasks. His wisdom, seeking for knowledge and inspiration clicks me to the sky-high academic motivation in the rest of my career. For this work completion, his approach, patience, cares and commitment was great.
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At last, I would like to thank the coordinator, department head and all members of Hawassa University power system and energy engineering staffs who gave me permission to go for solution to this problem.

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List of Acronyms

AAC	All Aluminum Conductor
ACSR	Aluminum Conductor cable Steel Reinforced
BFOA	Bacterial Foraging Optimization Algorithm
BM	Biomass
DG	Distributed Generations
DN	Distribution Network
EEPCo	Ethiopian Electric Power Corporation
EEU	Ethiopian Electric Utility
EPRI	Electric Power Research Institute
FPA	Flower Pollination Algorithm
GA	Genetic Algorithm
HA	Hybrid Algorithm
HAWT	Horizontal Axis Wind Turbine
HOMER	Hybrid Optimization Model for Electrical Renewables
IEEE	Institute of Electrical and Electronics Engineers
MC	Moisture content
MINLP	Mixed Integer Non-Linear Programming
MOPSO	Multi Objective Based Particle Swarm Optimization
NASA	National Aeronautics and Space Administration
PGS	Plant Growth Simulation
PSO	Particle Swarm Optimization

PV	Photo Voltaic
RDS	Radial Distribution System
RFD	Radiant Flux Density (wm^{-2})
RGFA	Random Gradient Free Algorithm
SOS	Symbiotic Organisms Search Algorithms
VAWT	Vertical Axis Wind Turbine
WOA	Whale Optimization Algorithm
WT	Wind Turbine

Chapter One

1. Introduction

1.1. Background

Distribution system is the important component of power system, which supplies power to end users. At this point, system voltage will be step down; as a result, system loss is higher. According to Electric Power Research Institute (EPRI) [1, 2] in New York, the distribution power loss is about 70 percent of all energy loss and this is even higher during peak load conditions. Different researchers [1, 3-12], also indicate that distribution system has more than 13% of the total power generation. It is expected to be worse in Ethiopia since the load configuration and growth is not phase balanced, and the distribution network is old. While industrial and residential load expansions has increased, transmission lines and power plants expansions are mainly focus by Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU) so far. If distribution network and load arrangement is not balanced, the system loss will be higher. This is happened when the drawn current is higher than the proportion of voltage increase. The over increase of demands causes heating, which further increases losses and insulation break down for networks.

Losses are increased due to improper cable size, increasing demand of reactive power or improper current flow to satisfy the demand of active and reactive power. It might be economical to configure the system with new proper sized lines; however, cable sizing only does not bring the required loss reduction and voltage profile improvement.

To reduce power losses and improve the voltage profile, one should consider the active and reactive demands and load characteristics at each buses. To fix the loss issues and improve the voltage profile, both DG for active power and shunt capacitors for unbalanced system would be required. It might be difficult to optimize the varying load and find the exact location. Hence, it is required to consider the load under different loading conditions i.e. during off peak, during peak and in average state. Furthermore it is important to consider the output probability density of DG (wind and solar) and load distribution probability of Bahir Dar distribution network.

Several definitions are given for DG based on plant rating, technology used, generated voltage levels, point of connection, etc. EPRI defined distributed generation as the generation from “a few kilo-watts to 50 MW” [4].

In this thesis, for proper sizing and allocation of shunt capacitor and DG meta-heuristic optimization technique called whale optimization algorithm is used. Both active and reactive power demands are analyzed. For this DG availability, probability density are considered.

Bahir Dar is located at latitude of 11.5742° N, longitude 37.3614° E, and elevation of 1800 m. With this according to NASA table 2.1 [13], it has over 1.23 m/s annual average wind speed at 5 m [appendix D1] and 5.96 kWh/m^2/d global irradiance. The biggest issue in DG design is the resource availability. In this work also, per day solar availability and wind speed variation would affect the power output. To solve the DG output probability density variation it might be quite effective if one use battery storage device. However, the charging and discharging process may bring another challenge. In this work to mitigate this issue, along with wind and solar a non-intermittent renewable energy source called biomass energy is used as backup. Biomass energy is one of the forms of renewable energy with good efficiency of output by which the output power is constant and monitored by the input feedstock.

Integration of DG’s in the distribution systems with biomass has environmental and economic benefits. Cities like Bahir Dar especially can use this as entrepreneurships beyond using carbon free renewable resources to clean the city and satisfying the load demand with relatively less expensive investment.

1.2. Statement of Problem

In the last two decades, EEP has done impressive work on constructing large power plants and transmission lines to connect main grid for the domestic and foreign export. This brings significant economic transition in the country especially in energy area. However, in distribution area EEU has yet to begin improvement. While world, most power losses are observed higher in distribution system and increased load growth has changed the voltage level, our system is somewhat an outdated (old) and had shown a character of frequent line outage without registered fault. Hence, it is expected[1] to have higher than 13% of power generated or 70% of total power loss. This load growth and unbalanced[2] power demand will further causes:

- Increase of voltage drops along the distribution lines-as the load demand increases both losses due to these increased loads and losses happened by increased length of distribution lines, would affect the voltage profile of the system.
- Increase of power losses and heating- as the power demand increases transformer tap changers are forced to change position so that it will deliver maximum current. This however create heat on feeder and on lines due to corona effect and skin effect.
- Insulation break down in one way or another if the current in the system goes to maximum and heating effect happened means it will losses the contact of insulated devices and insulated lines in the system.
- Reduction of line loading capacity

1.3. Objective

1.3.1. General Objective

The general objective of this thesis is to reduce distribution active power loss and improve system voltage profile using optimal placement of capacitors and distributed generations in unbalanced distribution network.

[1]*Studies [1, 3-12] has shown that distribution system power loss is about 13% of power generated or 70% of total power loss. Here distribution system loss include all losses happened in all medium and low voltage lines and losses happened due to industrial and residential load, so it is difficult to quantify these all losses in Bahir Dar.*

[2]*Unbalanced system is a system, which requires compensation (reactive power) and integration (active power) to improve the losses and voltage profile.*

1.3.2. Specific Objective

The specific objectives of this work are:

- Determination of the optimal location and size of the capacitor and DG
- Reducing the feeder loss after optimization
- Improving voltage profiles
- Reducing overall voltage deviation
- Comparing with other optimization technique i.e. PSO

1.4. Research Methodology

The procedures used to execute this thesis are:

- Literature Review: Published works about loss minimization and active and reactive power optimization, and optimal allocations from books, papers, articles, journals, lecture notes are reviewed.
- Data collection: The present voltage profile, cable length and cross sectional area (CSA) of Bahir Dar radial distribution network (RDN).
- Modeling: Modeling of single line diagrams of load configurations in Bahir Dar distribution feeders and distributed generation availability.
- Result Analysis: The data is analyzed using MATLAB codes.

1.5. Scope of the Study

This study focused on total real power loss minimization and voltage profile improvement of two critical feeders[3] in Bahir Dar unbalanced distribution network by optimal sizing and placement of DG and shunt capacitors using whale optimization algorithm.

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[3] *The study is focused on two critical feeders. As can be seen from load flow result the power loss is higher on the network/feeder even without considering different loses in industrial machines and residential unused power. Workers in the substation also complained about the frequent line outage without registered fault on these feeders. Due to this, the two feeders are taken as critical.*

1.6. Significance of the Study

This work has great importance for distribution loss minimization and for voltage profile improvement to distribution system.

This research has the following additional contributions:

- Improve the network load carrying capacity without any abnormal voltage drop
- Decrease stress on feeders
- Safe guard for insulation breakdown
- Bring clean Bahir Dar city and promote carbon free energy
- Increases the diversity of energy source
- Entrepreneurship for Bahir Dar city youths

1.7. Thesis Organizations

This thesis consists six chapters. Chapter one is the general introduction and background about distribution network losses. This chapter introduces the basic idea of the distribution network and designed solutions, which are keys to solve this problem in the main body of document. Reviewing different published literatures, conference papers of different authors to address the power loss and voltage profiles issues are mentioned. In chapter two, assessment of the availability of distributed energy and the capacitor modeling process are discussed. In the third chapter, method of load flow solutions and solution algorithms are presented. General overview of meta-heuristic optimization techniques, particle swarm optimization, and whale optimization algorithm are presented. In chapter four, the technique of research data analysis, problem formulation for optimal placement and sizing of DG and shunt capacitors is presented. In chapter five simulation results before optimization, after sizing and siting of DG and shunt capacitors using PSO and finally optimal sizing and siting of DG and shunt capacitors using whale optimization is discussed. In the last chapter, chapter six conclusions from proposed modeling, the future work and recommendations are presented. The limitations that influence on the quality of the study are also mentioned.

1.8. Literature Review

In earlier times, the focus of power engineers in distribution system was very less; their attempt is only bounded on the transmission and generation area.

However, in recent times scholars gave attention in unbalanced distribution system with computational facilities to solve the power loss, voltage stability, and load voltage profile to maintain the system sustainable by performing distributed modeling and simulations. Distribution network is the critical link, which connect power users and the power suppliers, hence if balanced and reliable supply is required, it is at this place the load profile and the loss conditions should be closely monitored. To do this researchers attempt different analytical [14], intelligent [15], and meta-heuristic techniques [3-18], to make the distribution load flow optimum using optimal sizing and location of shunt capacitors, DG and/or the combination of both.

Optimization of the distribution system is an open research that is undergoing on the current era. Unbalanced distribution network computing methods are ongoing to find optimum solution for radial and mesh distribution systems. Power engineers are keep finding computation algorithms to make the system more optimum. To do this proper shunt capacitor placement [5, 10-12] developing better load flow solution [19], network reconfiguration, maintains feeder losses and DG placement [5, 11, 17] are some of the tasks developed by researchers.

If there is single phase, two phase and three-phase configuration in radial distribution networks the system would be unbalanced. Distribution optimization need repeated, solution in very complex radial network configuration, solution techniques are quite essential for operation analysis and planning to create reliable and efficient operation. The solution technique should be quite efficient with maximum speed and accuracy. Hence, care should be taken for special treatment to solve this type of load flow solution.

Hasibuan, et al. (2018) [20] had used genetic algorithim to place DG in radial distribution system using critical voltage point. They had identified the buss with lower profiles and tried to mitgate by sizing using GA for appropriate size of DG to support the the slack bus voltage. However, they had used the conventional Newton Raphson method. This is only be applicaple and near efficient to find the appropriate load voltage in balanced system only however, such system is not able to exist in radial distribution system. In a very large number of nodes and branches since radial system has unbalanced phase configuration and has very high resistance to reactance value conventional transmission load flow solutions like Gauss Seidel, Newton Raphson, and Fast Decoupled solution techniques are not robust and has less accurate performance and sometimes may not converge at all.

S.Ghosh, et al. (1999) [21] proposed a solution for radial distribution system using the method nodes beyond branches using voltage convergence by considering flat voltage profiles. They have considered the influence of charging admittance to reduce loss and improve voltage profile. However, the nodes are stored beyond each branch, calculating each branch current by adding load currents of nodes beyond the respective branch assumes the system is balanced and the load is constant while such system especially the former is impossible to happen.

During distribution integration, system operational performance will be affected. The power loss will be improved when it is at proper size. However, when the introduced system is high, power loss and voltage drop increases because the increase of DG produces reverse power flow, over heating of feeders [14]. Short circuit current increases to the damaging levels, protection desensitization, and incorrect operation of control equipment are some other expected problems due to reverse power flow [14, 18].

It is found that shunt capacitors are crucial for reactive power compensation so that voltage levels would be kept maintained however, in [5, 10-12, 17] it has been indicated improper shunt capacitors placement would also increases power losses. Some load bus voltage might violate their upper or lower limits during system operation due to disturbances and/or system configuration changes [2, 7].

Hence, the non-optimal location and size of DG and Capacitor leads to more losses in the system than the system without DG and capacitor. As a result, selection of optimal location and size has become a complex optimization problem [4]. Different scholars use different methods for placement of DG and shunt capacitor. In [14] load concentration approach is used for optimal sizing and allocation of multiple distribution generation. Meta heuristic optimization technique is currently attracting attention due to its iterative search space has bring significant effect on optimization and search for allocation. Some of the most optimization techniques used by different authors are FPA [5], [17], MOPSO [11]. Due to the critical issues in sizing and location of DG, QG or combination of both, there had been a number of researches. Here under are some of the studies forwarded by different scholars to reach at optimum of distribution power loss and voltage profile improvement.

HassanzadehFarda, et al. (2018) [22] uses particle swarm optimization for optimal sizing and location of renewable energy based DG units in distribution systems considering load growth. To avoid the intermittency nature of wind and solar output they have combined wind, solar and fuel cell units in the distribution system. Using backward/forward sweep technique and harmonic power flow algorithm they had minimized the total harmonic distortion (THD), the total power losses, the total cost of DG units (including investments, replacement, operation, and maintenance costs) and greenhouse gas emissions.

Ali, et al. (2016) [3] used mixed-integer optimization (MINLP) by a genetic algorithm to optimize 33-node distribution network to meet increasing energy requirements with minimal environmental impact. For solving the optimization problem to estimate the output from PV modules, 15-year solar irradiance data was modeled using the beta probability density function. They had used batteries to store the excess electricity produced from PV modules during the daytime and supply electricity at night and during non-sunny times. With the introduction of batteries, they had reduced more than 41% of total energy losses in industrial loads, which was 20% higher than the reduction of energy losses with PV alone.

Lalitha, et al. (2016) [4] have applied Symbiotic Organisms Search (SOS) technique to find out the optimal locations and sizes of DG and QG to be placed in distribution systems to reduce the real power loss and to improve voltage profile are obtained.

Abdelaziz, et al. (2016) [5] had used flower pollination optimization algorithm for capacitor optimal location and sizing, to minimize the total cost and power loss. Proposed algorithm are compared with other algorithms like GA, PSO, Plant Growth Simulation Algorithm (PGSA), Direct Search Algorithm (DSA), Teaching Learning-Based Optimization (TLBO), Cuckoo Search Algorithm (CSA), Artificial Bee Colony (ABC) and

Harmony Search Algorithm (HSA) to highlight the benefits of the proposed algorithm. Moreover, it provides a promising and preferable performance over other algorithms in terms of voltage profiles, active and reactive power losses, total cost, and net saving.

Reddy, et al. (2017) [6] had used Whale optimization algorithm (WOA) for optimal sizing of renewable resources. They had performed using a novel metaheuristic algorithm, to find optimal DG size. They had discovered significant Power loss reductions and voltage profile improvement in applied distribution systems.

Nallagownden, et al. (2017) [15] had proposed a methodology for optimal placement and sizing of renewable distributed generation(s) (i.e., wind, solar and biomass) and capacitor banks into a radial distribution system using multi objective based particle swarm optimization. They have considered the intermittent nature of renewable energies and proposed the time varying load Profile values for each hour at typical season using IEEE 33 radial distribution system and this optimization has notified to encourage the utility to provide safe and reliable power delivery to the customers using DG and capacitor banks.

Meseret (2017) [7] had used PSO for sizing of capacitor in 25 and 40 buses of radial distribution feeders are used for analysis of reactive power optimization problem to determine the optimal location and size of capacitor banks. Loss sensitivity and normalization factor are used for further selection of buses.

Bhulla, et al.(2018) [8] had proposed optimal integration of multi distributed generation sources in radial distribution networks using artificial bee colony and cuckoo search Hybrid Algorithm to maximize voltage profile and minimize power loss. In this phase the random initialization of distribution grids' bus data (food sources) is done. The random initial data contain the location, size, and number of DG. The optimization process is repeated until the maximum number of iterations is attained. If the iteration number is maximum, the process is stopped and the current best solution is retained. Then the DG is placed at that appropriate location.

Xie, et al. (2018) [9] had used Distributed Random Gradient-Free Algorithm for reactive power optimization for distribution network. This scheme allows distributed implementation of operating or regulation by local information interaction and adjusting reactive power distribution automatically. The result from random gradient-free optimization algorithm a global optimal solution including power loss minimization and voltage profiles improvement by the way of local communication and local computation.

Thang, et al. (2017) [12] has made optimal allocation and sizing of capacitors for minimizing the life cycle and cost of the investment project in distribution systems. They used reinforcement based on considering uncertainties. For this load of the distribution systems, normal probability density function (PDF) for modeling the uncertainties of the load at each bus for optimal placement of capacitor to upgrade feeders and transformer are used.

Kumar, et al. (2017) [11] has used Multi-objective PSO based optimal placement of solar power DG in radial distribution system for power loss reduction and voltage stability improvement. To get the exact probability distribution of solar energy an hourly, 15 years real time data for solar irradiance is performed. The intermittency of solar irradiance is further processed with Beta probability distribution function for each hour. Using this the power losses reduces to 60.75 percent, whereas the voltage stability index is improved as 28.47 percent.

Prakash, et al. (2017) [17] used Whale Optimization Algorithm for optimal siting of capacitors in radial distribution to reduce the operating cost, the line losses and maintain the bus voltages. The proposed algorithm optimization had been tested on IEEE-34 bus and IEEE-85 bus systems and the results obtained are compared with PSO, PGS, MINLP and BFOA. The results show that WOA is more effective in bringing down the operating costs and in maintaining better voltage profile.

In this work a power flow method, which can be used in unbalanced distribution network configuration called forward/back ward power flow technique, proposed by (Haque 1996) is used. In this radial network since parallel voltage across terminal is same while it becomes diminished as go for the load, the node voltage would be computed forward from the sending end and the branch current would be summed from the receiving end to the slack with power is also summed in back ward way.

For proper optimization, this work will use the special food hunting mechanisms of whales search for proper site and size of shunt capacitor and DG discovered by (Mirjalili, et al. 2016) called whale optimization algorithm (WOA). It is used in [17] for optimal location capacitor and sizing of capacitors in [6] for optimal siting and sizing of DG to reduce power loss and improve voltage profile. In this thesis, it would be the first time WOA is used for optimum sizing and siting of DG and shunt capacitor placement.

Sizing and placement of battery-coupled distributed photovoltaic generations [3] using branch to total power ratio to find the loaded section, optimal distributed generation and capacitor placement for loss minimization and voltage profile improvement using symbiotic organisms search algorithm [4], [10], [11], [17], etc. are used to find the total system power loss reduction, it is quite advisable to consider the whole system to find the minimum possible power loss. However for developing coutries like Ethiopia which needs to plan different projects, it will not be economical.

In this thesis a mechanism called feeder carrying capacity limit according to electric power research is used as a limit of DG and QG sizing [1]. It is mentioned the DG/QG size should be less than the total power demand of the distribution network, for purpose of network security in this study, 80% of the total power demand is taken as upper limit of DG and QG. Using the mentioned concept the proposed matlab program of WOA will search the lowest possible minimum loss without bounding the DG and QG limits intialy. Hence this work is a search for maximum possible power optimization by taking the network capacity as the upper limt for optimization rather than designing upper and lower limit of DG and QG for loss minimization.

Chapter Two

2. Distributed Generation and Shunt Capacitor Assessment

2.1. History of Renewable Energy Forms

The main types of renewable energy are wind energy, solar photovoltaic, hydroelectric, and geothermal. As the demand of electricity grows every year to meet increased demand, countries have to decide what form of generation will provide reliable power that will fulfill the future needs. The earliest forms of renewable energies that harness the power of world are wind turbines and hydroelectric power plants. Photovoltaic energy has only been around a few decades, and came about through advancements in the space program [23].

2.2. Solar Energy

The sun's source of solar radiation, is a sphere of hot gaseous matter with a diameter of about $1.39\ x\ 10^{9}\ m$ a grows mass of $1.99\ x\ 10^{30}\ kg$, and on the average $1.50\ x\ 10^{11}$ m far from the earth. Nuclear fusion reactions in the active core of the Sun produce inner temperatures of about $10^{7}K$ and an inner radiation flux of uneven spectral distribution. The outer passive layers consume the inner radiation produced which are heated to about 6000 K and so become a source of radiation with a relatively continuous spectral distribution. The radiant flux (W/m^2) from the sun at the earth's distance varies through the year by ±4 percentage because of the slightly non-circular path of the Earth around the sun. The solar constant (SC) which is the average of power of suns radiation (irradiance G) that reaches to unit area is $GSC = 1367\ Wm^{-2}$ (± 1% measured uncertainty). This is the radiant flux density (RFD) perpendicular to a plane directly facing the Sun outside the atmosphere at an average distance of 1.496×10^{8} km from the Sun (i.e. at the Earth's mean distance from the Sun). The maximum solar flux density reaching from solar radiation at wavelength of short wave radiation that includes visible radiation (figure 2.1 and 2.2) between 0.3 and 2.5 µm is approximately $1.0kWm^{-2}$. The 6000 K surface temperature of the sun is determinant for spectral distributions [24], [25], [26].

The elliptic natures of earth will only have small variation of solar radiation reaching to the earth. Out of 600 TW suns, generating capacity it has only 10 percent of conversion efficiency. The solar electricity generated from this has two forms [25], [27].

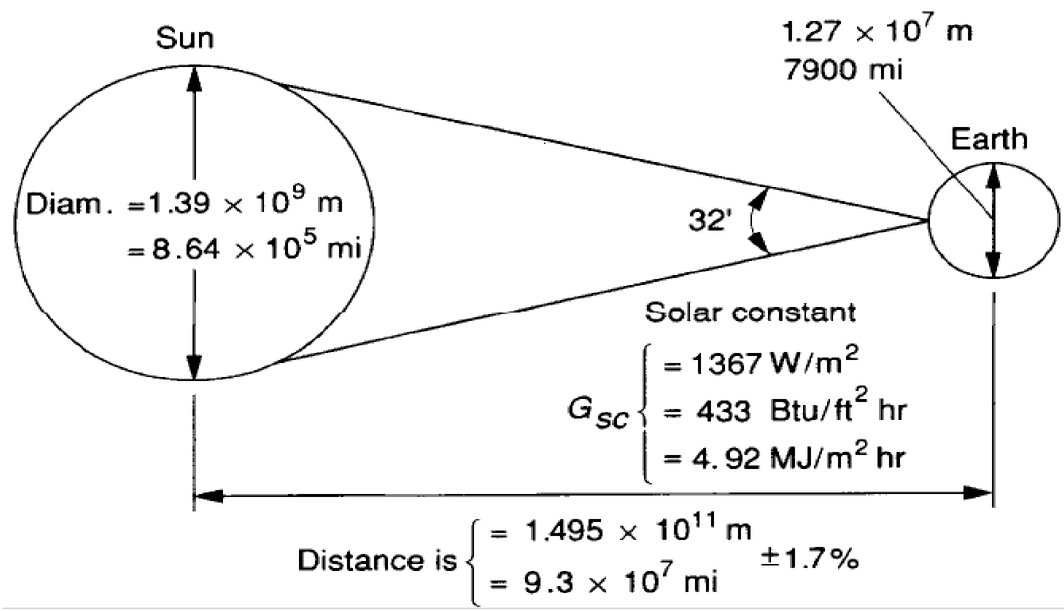


Figure 2. 1: Mean earth-sun distance [26], [27].

Solar-thermally generated electricity: it is the mechanism of producing steam to rotate turbines for electricity from arrangement of complex solar radiation collectors to get high temperature. It has around 35 percent efficiency and lowest cost [27].

Photovoltaic energy: It is the direct conversion of sun's rays to electricity. About 17% of conversion efficiency made of silicon is currently available [27].

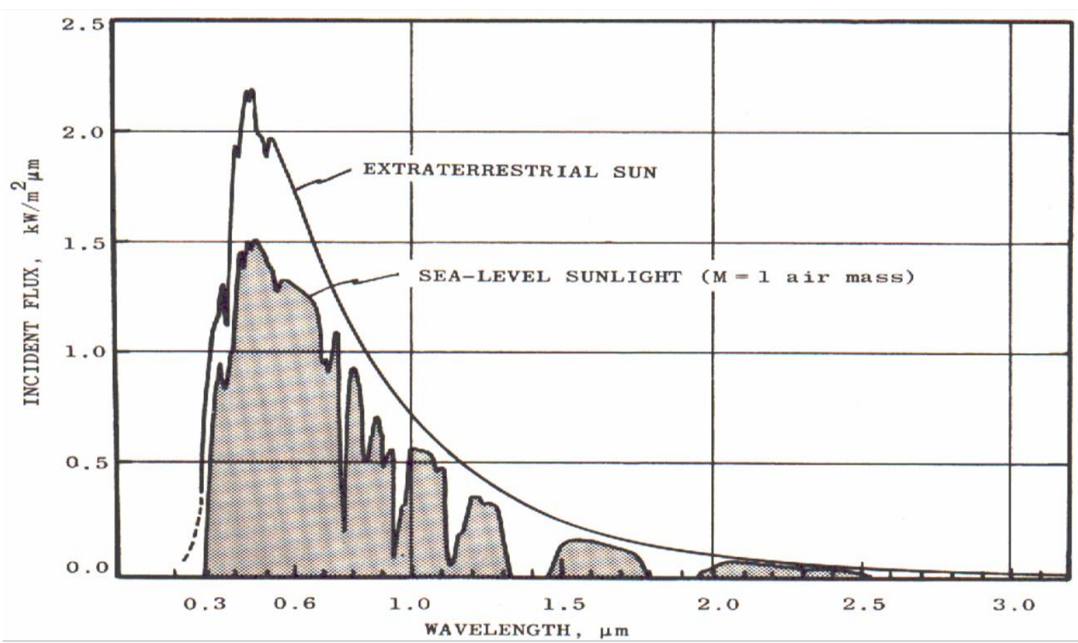


Figure 2. 2: Solar radiation effects [25]

2.2.1. Solar Photovoltaic System

Solar panels produce electricity through individual photovoltaic cells connected in series. This form of energy collection is viable in regions of the world where the sun is plentiful, and can be used in isolated regions or on houses to supplement the rising cost of electricity from a power grid [23].

The photovoltaic (PV) effect is the electrical potential developed between two dissimilar materials when their common junction is illuminated with radiation of photons. The PV cell, thus, converts light directly into electricity [28], [29].

2.2.1.1. Equivalent Electrical Circuit

The equivalent electrical circuit shown in Figure 2.3 can represent the complex physics of the PV cell. The circuit parameters are as follows. The current I at the output terminals is equal to the light-generated current I_L, less the diode current Id and the shunt-leakage current I_{sh}. The series resistance R_s represents the internal resistance to the current flow, and depends on the pn junction depth, impurities, and contact resistance. The shunt resistance R_{sh} is inversely related to the leakage current to ground. In an ideal PV cell, Rs = 0 (no series loss), and Rsh = ∞ (no leakage to ground). In a typical high quality 1 in 2 silicon cell, Rs varies from 0.05 to 0.10 Ω and Rsh from 200 to 300 Ω. The PV conversion efficiency is sensitive to small variations in Rs, but is insensitive to variations in Rsh. A small increase in Rs can decrease the PV output significantly [28], [29].

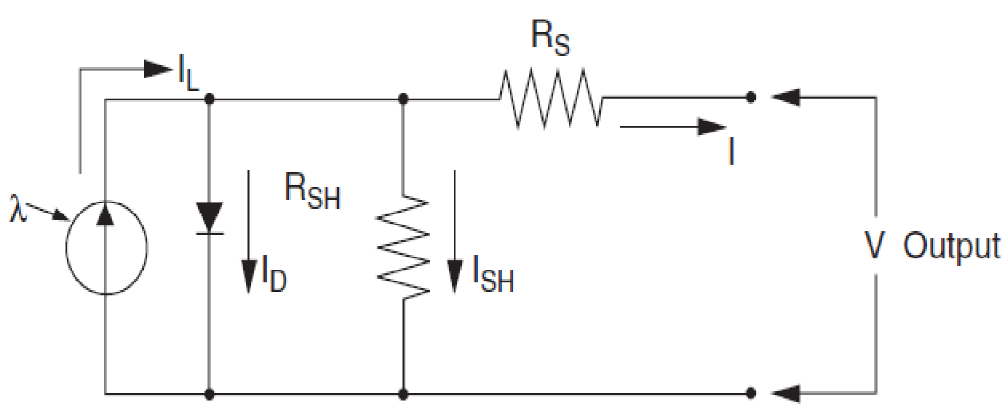


Figure 2. 3: Equivalent circuit of PV module [28], [29]

In the equivalent circuit, the current delivered to the external load equals the current I_L generated by the illumination, less the diode current Id and the shunt leakage current Ish.

The open-circuit voltage *V*oc of the cell is obtained when the load current is zero, i.e., when *I* = 0, and is given by the following [28], [29]:

$$V_{oc} = V + IR_{sh} \tag{2.1}$$

The diode current is given by the classical diode current expression [28], [29]:

$$I = I_L - I_D - I_{SH} \tag{2.2}$$

$$I = I_L - I_o\left[exp^{\left(\frac{q(V+IR_S)}{AKT}\right)-1}\right] - \frac{V+IR_S}{R_{SH}} \tag{2.3}$$

Where

I = the load current (A)

*I*D = the diode current (A)

IL = current produced by the cell (A)

q= electron charge = 1.6×10^{-19} C

V = output voltage (V)

Rs = series resistance

A = curve-fitting constant

k = Boltzmann constant = 1.38×10^{-23} J/°K

T = temperature on absolute scale °K

The load current is therefore given by the expression:

2.2.1.2. Open-Circuit Voltage and Short-Circuit Current

The current-voltage (I-V) and power-voltage (P-V) characteristics of a typical PV module are shown in Figure 2.4 with the short circuit current at radiation level $G, Isc(G)$, the maximum power current (Imp), maximum power point (Pmp), maximum power voltage (Vmp), and open circuit voltage (Voc) labeled at their respective points. Pmp is the maximum power that can be obtained from the module and it corresponds to the maximum rectangular area under the I-V curve. Voc Increases logarithmically, whereas Isc increases almost in proportion to the radiation as long as the current axis do not intersect the curved portion of the I-V characteristic [24], [28].

$$P_{pv} = A_C \eta_{MP} \eta_E G_T \tag{2.4}$$

Where:

P_{pv}= power output of PV array

A_C= the array area

η_{mp} = the maximum power point efficiency of the array (≈ 14%)

η_e = the efficiency of power conditioning equipment (≈ 90%)

G_T = the incident solar radiation on the array

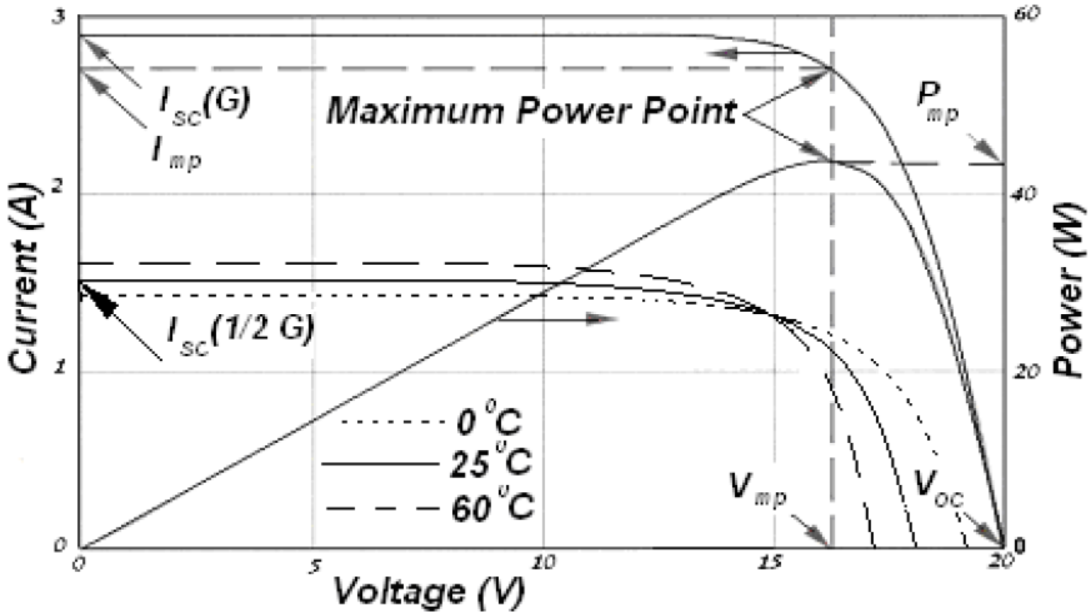


Figure 2. 4: V-I characteristics of PV cells against temperature [24]

2.2.2. Solar Radiation Estimations

For any solar-based system design, the most important factors are the position of the sun in the sky, the slope, and orientation of a collecting surface, and obstruction and reflection properties of neighboring structures. Figure 2.5 shows the geometry describing orientation of a collector and position of the sun in the sky. A point on the earth's surface is expressed by its latitude and longitude. The angle between the collector surface and the horizontal is called slope, β $with$ $(0^{\circ} < \beta < 90^{\circ})$ for a surface facing towards the equator;$90^{\circ} < \beta < 180^{\circ}$ for a surface facing away from the equator). Surface azimuth angle, γ is the angle between the normal to the surface and the local longitude meridian, projected on the horizontal plane. In either hemisphere, γ equals 0° for a surface facing due south, 180° due north, 0° to 180° for a surface facing westward and 0° to 80° eastward. For a horizontal surface,γ is always 0° [24], [28].

Location of the sun in the sky in reference to a point on the ground can be defined in terms of two angles: the solar altitude, α_s(or its complement the solar zenith angle,(θ_z) and the solar azimuth γ_s. Solar altitude α_s is angle of solar beam to the horizontal. Solar azimuth γ_s is the angle between the solar beam and the longitude meridian projected on the horizontal plane [24], [27], [28].

Sign convention is the same as for surface azimuth angle (γ). Solar altitude and solar azimuth are functions of location (latitude,ϕ), time of the year (declination angle,δ) and time of the day (hour angle,ω). Solar declination angle (δ) is the angle between the earth's equatorial plane and the earth sun line. Solar hour angle ω is the angle Earth has rotated since solar noon. The relation between these angles is given [24], [25], [26], [27], and [28].

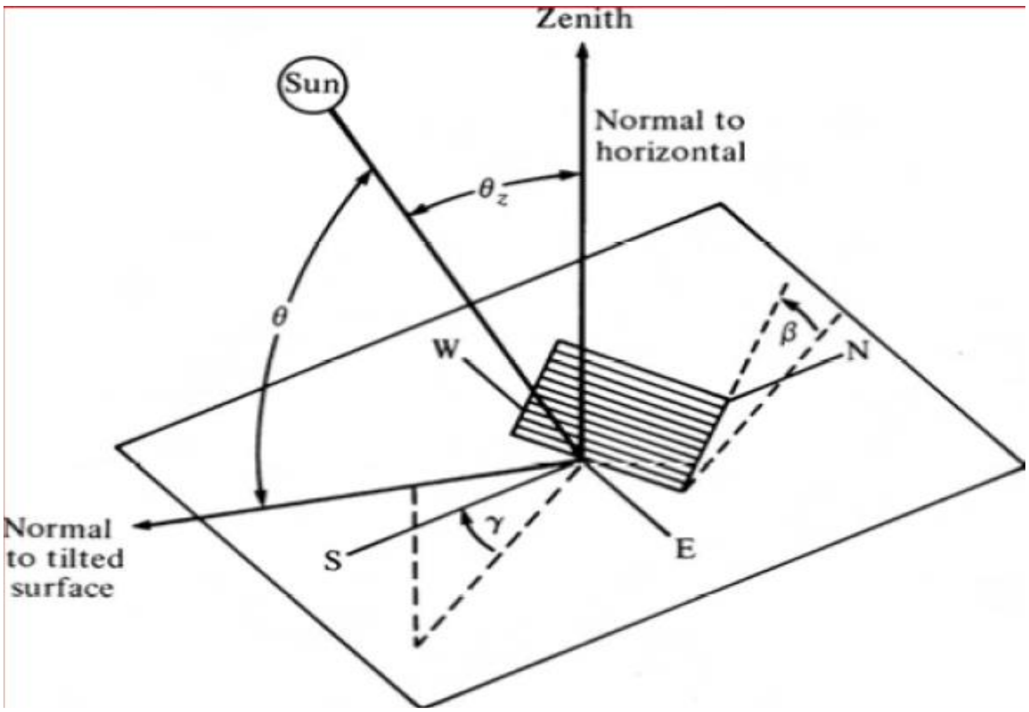


Figure 2. 5: Geometry of solar collector and location of sun relative to earth [24], [26], [27]

$$\delta = 23.45 \sin(360 \frac{284+n_d}{365}) \quad (2.5)$$

δ =Solar declinations angle (°)

n_d=day number of the year starting at January 1^{st} as 1

ω =$(t_s - 12hr).15^{\circ}/h_r$

t_s = Is the solar time $[hr]$

ω =Solar hour angle (°)

The value of t_s is 12hrs at solar noon and 13.5 hours ninety minutes later. The above equation follows from the fact that the sun moves across the sky at 15 degrees per hour [24], [25], and [26].

$$\sin(\alpha) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(\omega) \quad (2.6)$$

Where: α_s = solar altitude (°)

ϕ=latitude (°)

$$\sin(\gamma_s) = \left[\frac{\cos(\delta)\sin(\omega)}{\cos(\alpha_s)}\right] \quad (2.7)$$

Where

γ_s=solar azimuz (°)

The sunset/sunrise angle is given by

$$\omega_s = cos^{-1}(-\tan\phi\tan\delta) \quad (2.8)$$

The solar angle of incident θ_i is the angle between the solar beam and normal to the solar panel, which is given by [24], [25], and [26]:

$$\cos(\theta_i) = [\sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega] \quad (2.9)$$

The intensity of solar radiation incident per unit area exposed normally to the sun's rays at the average sun-earth distance (about$1.5 \times 10^{11} m$), measured outside the earth's atmosphere is called the solar constant, Gsc (1367W/m^2). The intensity of radiation received outside the earth's atmosphere varies as the inverse square of the earth-sun distance and can be expressed in relation to time of the year. The extraterrestrial irradiance on a surface at normal incidence (Gon) may be expressed as [24], [25], [26], [28].

$$G_{on} = G_{sc}\left[1 + 0.033\cos\frac{2\pi n_d}{365}\right] \quad (2.10)$$

[24], [25], [28] give the extraterrestrial irradiance incident on a horizontal plane at an arbitrary angle of incidence, and [26]:

$$G_o = G_{on}\cos(\theta_z) \quad (2.11)$$

Where: θ_z is zenith angle between the solar beam and the vertical. θ_z *and* θ are not usually in the same plane. Integrating the solar constant (extraterrestrial irradiance) over the day length gives us the daily solar radiation on the horizontal surface [24], [26], [28].

$$H_o = \left(\frac{24\times3600}{\pi}\right) G_{sc} \left[(1 + 0.033 \cos(\frac{360 n_d}{365})) \times \left(\cos\phi \cos\delta \sin\omega_s + \frac{2\Pi}{360}\omega_s \sin\phi \sin\delta\right)\right] \quad (2.12)$$

Where:

n_d= day number starting from January 1^{st} as 1

$G_{sc} = (the\ solar\ constant) = 1367\ {}^{W}/_{m^2}$

ϕ= latitude of location

δ= declination angle (°)

ω_s=sunset hour angle (°)

2.2.3. Solar Energy Resource in Bahir Dar

Since Bahir Dar is located near the equator, its solar resource is obviously of significant potential. The annual average daily radiation in Bahir Dar reaching the ground is estimated to be 6 ${}^{Kwh}/_{m^2}/day$ which varies from a minimum of 5.26 ${}^{Kwh}/_{m^2}/day$ in July to a maximum value of 6.86 ${}^{Kwh}/_{m^2}/day$ in February [13].

To get the correct result of global solar radiation installing pyrometers or photovoltaic sensors at different location is advisable. However, the cost would not be affordable for countries like Ethiopia whom economies are not developed. Indirect estimation of solar radiation can be used in two ways: Based on satellite observation and ground level measurement.

Mid of Month	N_d	δ(°)	ω_s(°)	N(hours)	n	n/N	Ho(Kw/m2/d)	NMSA(Kw/m 2/d)	NASA Kwh/m2/d	SWERAREL Kwh/m2/d
Jan	15	-21.270	87.326	11.644	9.78	0.84	9.25	6.40	6.27	6.335
Feb	45	-13.620	88.336	11.778	9.85	0.836	9.85	6.79	6.86	6.885
Mar	74	-2.819	89.662	11.955	9.56	0.8	10.36	6.98	6.78	7.072
Apr	105	9.415	91.138	12.152	8.91	0.733	10.47	6.76	6.01	6.491
May	135	18.792	92.337	12.312	7.23	0.587	10.22	5.95	5.78	6.089
Jun	166	23.314	92.960	12.395	6.83	0.551	9.22	5.66	5.35	5.867

Jul	196	21.517	92.708	12.361	5.87	0.475	9.98	5.36	5.26	5.392
Aug	227	13.784	91.685	12.225	6.79	0.555	10.04	5.85	5.91	6.122
Sep	258	2.217	90.266	12.035	8.35	0.694	10.29	6.50	6.29	6.68
Oct	288	-9.599	88.839	11.845	7.83	0.661	10.34	6.13	5.39	6.108
Nov	319	-19.148	87.616	11.682	8.57	0.734	9.98	6.05	5.69	6.258
Dec	349	-23.335	87.037	11.605	9.56	0.824	9.38	6.18	6.01	6.138
Avg	181.42	-0.752	89.99				9.04	6.218	5.96	6.286

Table 2. 1: Estimated Monthly solar Radiation for Bahir Dar District (Lat= 11.4)

For the renewable hybrid power system design of Bahir Dar, the estimated monthly average global solar radiation from the ground measured sunshine hour data from NMSA summarized listed on the 9th column is taken for feasibility study of the proposed hybrid RES using HOMER.

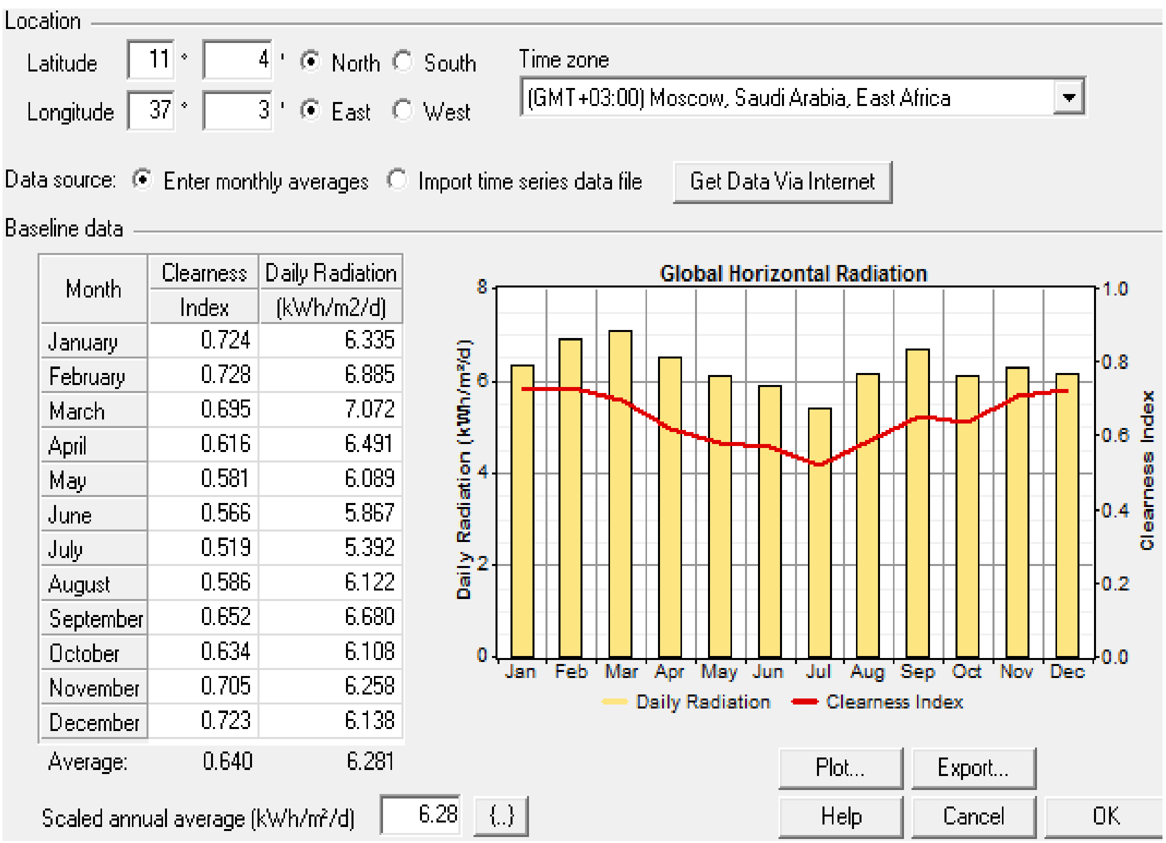


Figure 2. 6: Monthly average solar radiation

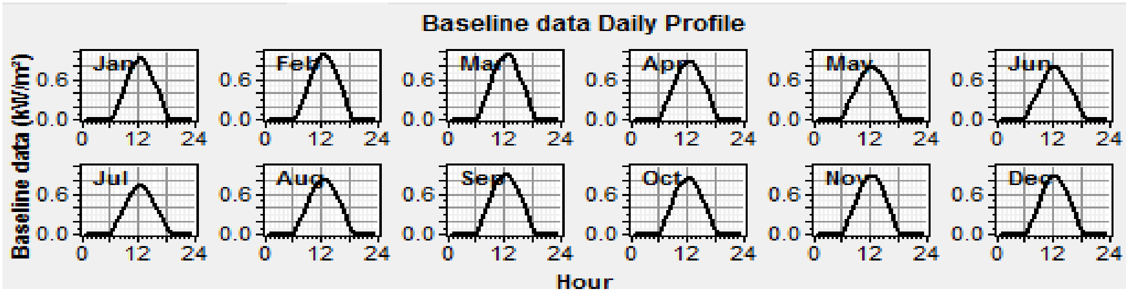


Figure 2. 7: The daily sunlight radiation in kwh/m2

2.3. Wind Energy

Converting the movement of air into electricity is the fastest growing technology of renewable energy. Wind farms produce massive amounts of power that provide an environmentally friendly option to counteract the growing need of power [30].

2.3.1. Speed and Power Relations

The kinetic energy in air of mass *m* moving with speed *V* is given in joules [28]:

$$kinetic\ energy = \frac{1}{2}mV^2 \tag{2.13}$$

The power in moving air is the flow rate of kinetic energy per second in watts [28]:

$$power = \frac{1}{2}(mass\ flow\ per\ second)V^2 \tag{2.14}$$

If: P = mechanical power in the moving air (watts),

ρ = air density (kg/m3),

A = area swept by the rotor blades (m2), and

V = velocity of the air (m/sec),

Then the volumetric flow rate is AV, the mass flow rate of the air in kilograms per second is ρAV, and the mechanical power coming in the upstream wind is given by the following in watts [28]:

$$p = \frac{1}{2}(\rho AV)V^2 = \frac{1}{2}\rho AV^3 \tag{2.15}$$

Power density of the site is used to compare two potential wind sites in watts per square meter, and is given by the following expression in watts per square meter of the rotor-swept area [28]:

$$specific\ power\ of\ the\ site = \frac{1}{2}\rho V^3 \tag{2.16}$$

This is the power in the upstream wind. It linearly varies with the density of the air sweeping the blades and with the cube of the wind speed. The blades cannot extract all of the upstream wind power, as some power is left in the downstream air that continues to move with reduced speed [28].

2.3.2. Wind Speed Distribution

In probability theory and statistics, the Weibull distribution is a continuous probability distribution. It is named after Waloddi Weibull who described it in detail in 1951, although it was first identified by Fréchet (1927) and first applied by Rosin & Rammler (1933) to describe the size distribution of particles. In probability theory, a probability density function (PDF) that describes the relative likelihood for this random variable to occur at a given point in the observation space. The probability of a random variable falling within a given set is given by the integral of its density over the set. In most locations worldwide, the distribution of wind speeds keeps fairly close to a Weibull or (simplified). Rayleigh distribution of wind speeds, as shown below in Figure 2.8. There are non- Rayleigh locations where the curve takes on other shapes, but these are relatively rare. The distribution shown here is relatively common [24].

If the probability density is known, alternatively, the mean wind speed can be determined.

$$V_{av} = \int_0^\infty v f(v) dv \tag{2.17}$$

The wind speed probability distributions and the functions representing them mathematically are the main tools used in the wind-related literature. The variation in wind speed is best described by the Weibull probability distribution function f *with* two parameters, the shape parameter *k*, and the scale parameter *c*. The following, [11], [15], [24], [28] give the probability of wind speed being v during any time interval:

$$f(u) = \left(\frac{k}{c}\right)\left(\frac{u}{c}\right)^{(k-1)} e^{-\left(\frac{u}{c}\right)^k} \; for \; 0 < u < \infty, k > 1, c > 0 \tag{2.18}$$

Thus, the cumulative distribution $F(u)$ is the integral of the probability density function. The cumulative probability function is [24]:

$$F(u) = 1 - e^{\left(\frac{u}{c}\right)^k} \tag{2.19}$$

Where: u is the wind speed, $u > 0$ is the shape parameter, and $c > 0$ is the scale parameter of the distribution.

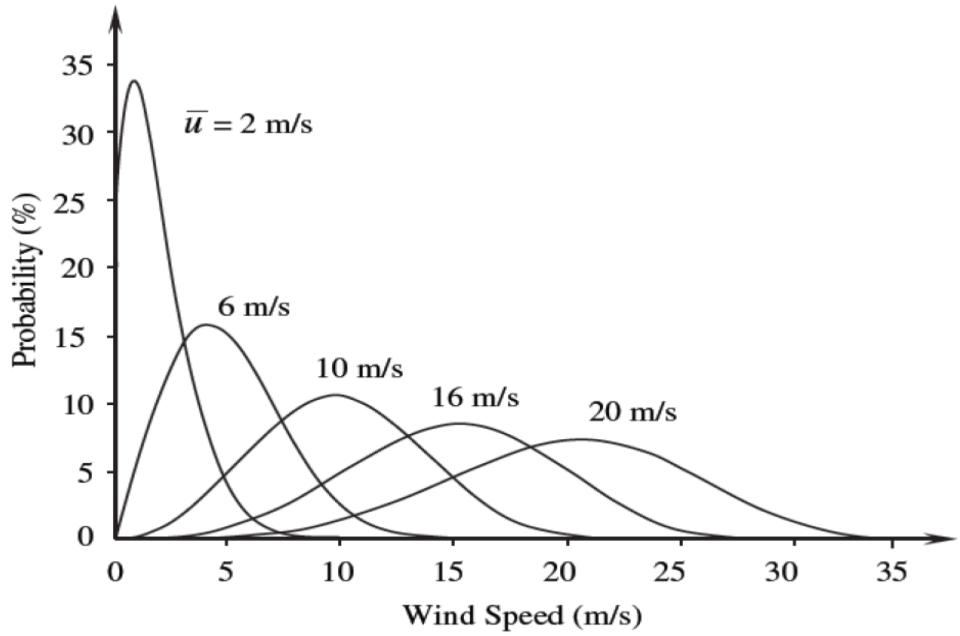


Figure 2. 8: Weibull distributions for Various Mean Wind speed [26]

The shape factor will normally range from 1 to 4. These typical values are known from experience and multiple observations of sites where wind speed measurements have been taken. These wind types are categorized as inland, coastal, and trade wind (offshore) sites.

Types of wind	Shape factor (K)
Inland Winds	1.5 to 2.5
Coastal Winds	2.5 to 3.5
Trade Winds	3 to 4

Table 2. 2: Typical Shape Factor Values [24], [31]

If Weibull k is not known, k = 2 can be used for inland sites, 3 for coastal sites, 4 for island sites and trade wind regimes [11], [15].

$$V_{ave} = \Gamma(1 + \frac{1}{k}) \quad (2.20)$$

$$\Gamma(x) = \int_0^{\infty} \xi^{x-1} \exp(-\xi)\, d\xi \text{ and } \Gamma(x) = \Gamma(x+1) = x\Gamma(x) \quad (2.21)$$

For k=2;

$$C = \frac{2}{\sqrt{\pi}} V_{ave} \quad (2.22)$$

Average wind speed and scale factor in equation (2.22) are used to find the probability distribution using homer software. The wind probability distribution obtained from average of appendix E is shown below.

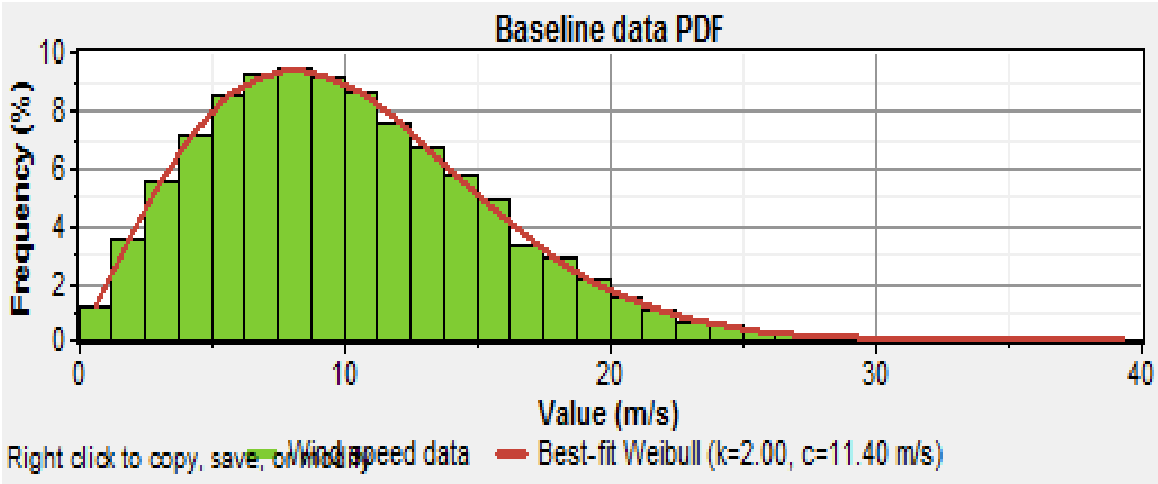


Figure 2. 9: Wind probability distribution

One of the most distinct advantages of the Rayleigh distribution is that the probability density and the cumulative distribution functions could be obtained from the mean value of the wind speed.

Moreover, the diurnal pattern strength is a measure of how strongly the wind speed tends to depend on the time of day. Because the wind is typically affected by solar radiation, most locations show some diurnal (or daily) pattern in wind speed. Each of the 24 values of the average diurnal profile represents the annual average wind speed for that hour. It then fits a cosine function to this average diurnal profile. The cosine function fitted to the average diurnal pattern is of the form [24], [32]:

$$v_i = \bar{v}\left\{1 + \delta \cos\left[\left(\frac{2\pi}{24}\right)(i - \phi)\right]\right\} \tag{2.23}$$

Daily wind profile obtained at height of 78 m of mean *Wind Speed of Bahir Dar is:*

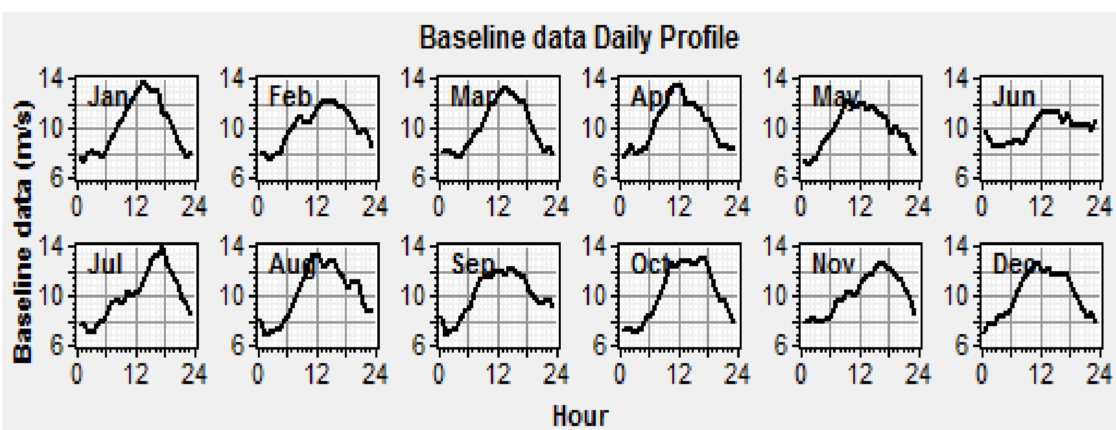


Figure 2. 10: Daily wind profile in m/s of Bahir Dar city taken from appendix E

2.3.2.1. Wind Power Density Distributions and Mean Power Density

The monthly average wind speed using Weibull distributions is determined as in Equation (2.24), [24], [32]:

$$V_{ave} = C\Gamma(1+\frac{1}{k}) \tag{2.24}$$

The power of the wind per unit area is given as [24], [32]:

$$P = \frac{1}{2}\rho V^3 \tag{2.25}$$

The average power density for each month is calculated using actual probability density distribution for the specified month, which is calculated using Eq. 2.26, and is given as [24], [32]:

$$\sum_{i=1}^{n}\frac{1}{2}\rho {V_{mi}}^3 f(V_i) \tag{2.26}$$

Where, the subscript m stands for the month and *n* is the number of records for the specified month. The average power density using Weibull probability distribution is calculated as follows [24], [32]:

$$P_{wm} = \frac{1}{2}\rho C^3\Gamma(1+\frac{3}{k}) \tag{2.27}$$

$$V_{ave} = C\Gamma(1+\frac{1}{k}) \tag{2.28}$$

Γ is the gamma function and given as:

$$for\ k = 2\ and\ \Gamma\left(1+\frac{3}{2}\right) = \frac{3}{2} * \frac{\sqrt{\pi}}{2} = 3\frac{\sqrt{\pi}}{4}$$

The air density varies with the altitude and therefore the formula that governs this is [24], [32]:

$$\rho = \rho_o e^{-(\frac{0.297H_m}{3048})} or\ simply\ \rho = \rho_o - 1.194 * 10^{-4}H_m \tag{2.29}$$

Finally, power density for each month is calculated using the following equation (2.30) [24], [32]:

$$P_{wm} = \frac{1}{2}\rho C^3\frac{3\sqrt{\pi}}{4} \tag{2.30}$$

The power density values of each month for Bahir Dar city is calculated and listed in table 2.3 and 2.4 below. Where $\rho = 1.225\,{}^{kg}/{}_{m^3}$.

Month	Bahir Dar city with k=2		
	Monthly AV.wind speeds(m/s)	Scale factor	Power density(W/m2) [Elev=78m]
Jan	10.1	11.4519	1222.9
Feb	10.1	11.3535	1191.6
Mar	10.1	11.3706	1197
Apr	10.2	11.4745	1230.1
May	10.0	11.3070	1177
Jun	10.0	11.2623	1163.1
Jul	10.0	11.3396	1187.2
Aug	10.2	11.4853	1233.6
Sep	10.1	11.3492	1190.2
Oct	10.2	11.4870	1234.1
Nov	10.1	11.4345	1217.3
Dec	10.1	11.3606	1193.8
Monthly annual Av.	10.1	11.3897	1203

Table 2. 3: The energy density is 920 and above and is in excellent list

The energy density characteristics at the height of 50 meter is presented in table 2.4 below

Wind resource category	Wind	Wind power density (W/m2)	Wind speed at 50m(m/s)
Poor	1	50-200	3.5-5.6
Marginal	2	200-300	5.6-6.4
Moderate	3	300-400	6.4-7.0
Good	4	400-500	7.0-7.5
Excellent	5	500-600	7.5-8
Excellent	6	600-800	8-8.8
Excellent	7	Above 800	Above 8.8
Total area covered by marginal to excellent wind regions			

Table 2. 4: Wind energy output category benchmark

Observing the table 2.4, the power density category of Bahir Dar city is on the seventh category, which indicates the region, has very great potential for grid connected electric power generation.

2.3.3. Wind Turbines

A wind turbine is a machine that converts the kinetic energy from the wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill. If the mechanical energy is then converted to electricity, the machine is called a wind generator [24].

There are a number of different wind turbine types available. The horizontal axis turbine (HAWT), HAWT is by far the most common type of turbine. They come in two different types: the upwind, which face the wind (tower behind rotor) and the downwind arrangement that works away from the wind (tower in front). Another kind of turbine is the vertical axis (VAWT), VAWT arrangement that uses drag and lift as the driving forces; the horizontal also uses drag and lift, but in different proportions. The advantages with upwind turbines are that the tower does not act as an obstacle for the wind hitting the rotor. Beside this, the flow behind the passing blade is affected by the tower and causes a slight drop in power. When the blade passes the tower, it also decreases the drag on the construction which can cause an on / off bending process causing fatigue stress. This has of course been taking into account when designing the turbine. The upwind design needs a control system that helps the nacelle turn straight to the wind. In downwind turbines, the tower shades a rotor blade each time it passes by and causes greater power losses compared to the upwind design. An advantage with downwind turbines is that the nacelle is self-adjusting and is not in need of a control system. One drawback with this is the problem with untwisting the cable inside when the nacelle has turned same direction repeatedly. The VAWT´s are not as commercial and economically competitive as the HAWT´s. Some of the VAWT types suffer from low efficiency due to design difficulties as well as the problem with operation close to the ground. Parts of the vertical turbines will therefore receive low quality winds causing power losses. To keep the construction upright it also needs to be supported with guy-cables attached to the ground. The vertical turbine is not in need of yaw control, which of course is an advantage and the wind always hits the turbine tangentially [24].

The modern wind turbine is a sophisticated piece of machinery with aerodynamically designed rotor and efficient power generation, transmission and regulation components. The size of these turbines ranges from a few watts (small wind turbines) to several million watts (large wind turbines). The modern trend in the wind industry is to go for bigger units of several MW capacities in places where the wind is favorable, as the system scaling up can reduce the unit cost of wind-generated electricity. Most of today's commercial machines are HAWT with three bladed rotors.

2.3.4. General Workings

The blade, using aerodynamic lift, capture energy from wind in order to turn the shaft. In small wind turbines, the shaft usually drives the generator directly. The generator converts the mechanical energy into electricity. The shaft power causes coils to spin past alternate poles of magnets allowing electric current to flow. If a permanent magnet device is, being used the opposite occur: current flow as magnets spin past coil windings. Most small wind turbines use a permanent magnet alternator. Large wind turbines usually use either induction generator or a synchronous generator. In addition, in large wind turbines the shaft connected to the generator via a gearbox to steps up the rotational speed for the generator. In off-grid application, it is difficult to keep the frequency of the resulting current constant, as it depends on wind speed, which is highly variable. Therefore, the current is usually rectified to give DC. Most wind turbines have two or three blade. Two blade machines are somewhat less expensive. Three bladed machines suffer less mechanical stress and are less vulnerable to fatigue problem. The Yaw bearing allows a wind turbine to rotate in order to face to the wind from any direction. A tower support wind turbine and places it above any obstruction [24].

2.3.5. Wind System Design

If the generator is undersized, the turbine will reached peak power at relatively low wind speed and stay until the cut out speed reached. If the turbine is oversized, then power will increase until the cut out speed reached. The energy output of a wind turbine can be calculated by determining the frequency distribution of local wind speed and then computing the expected range of power outputs for each wind speed by using power curve. The wind turbine load and hence speed governed electrically by voltage controller and mechanically by counterweights which reduce the pitch of the blade in the event of excess wind speed or energy production [24].

Wind turbine single-source systems tend to produce highly variable and therefore unreliable power supply due to the irregular wind speeds. If the wind turbine is combined with other sources such as solar PV and IC engine diesel generator (hybrid system), the produced energy can become more regular, improves system performance and cost effectiveness [24].

2.3.6. Wind Turbines Efficiency and Power Curve

The German aerodynamicist, Albert Betz, derived the theoretical limit of power extraction from wind, or any other fluid. Betz's law, states that 59% or less of the kinetic energy in the wind can be transformed to mechanical energy using a wind turbine [24].

In practice, wind turbines rotors deliver much less than Betz limit. The factors that affect the efficiency of a turbine are the turbine rotor, transmission and the generator. Normally the turbine rotors have efficiencies between of 40% to 50%. Gearbox and generator efficiencies can be estimated to be around 80% to 90%. In addition, efficiency of a turbine is not constant. It varies with wind speeds. Many companies do not provide their wind turbine efficiencies. Instead, they provide the power curve [24].

A power curve is a graph that represents the turbine power output at different wind speeds values. The advantage of a power curve is that it includes the wind turbines efficiency. The power curve is normally provided by the turbine's manufacture. Figure 2.11 presents a Vestas brand V82 model wind turbine power curve (which is used in this study) [24].

Specification for VESTAS V82 Wind Turbine	
Available towers	59/70/78
Rotor	82 m diameter, 5.281 m^2 swept area, 14.4 rpm
Cut-in wind speed	3.5 m/s
High wind speed	20 m/s
Rated power wind speed	1.65 MW at 13 m/s

Table 2. 5: Technical Data for Vestas V82 Wind Turbine Manufacturers' data sheet

The output power of the WTG is between 0 and its power rating of 1.65 MW. Major technical data for Vestas V82 Wind Turbine are given in Appendix C 1. From the characteristic curve, there are three important points at which much attention is paid for the speeds and the corresponding turbine output powers for every wind turbine.

Power curve

	Wind Speed (m/s)	Power Output (kW)
1	0.00	0.000
2	1.00	0.000
3	2.00	0.000
4	3.00	0.000
5	4.00	18.000
6	5.00	140.000
7	6.00	289.000
8	7.00	477.000
9	8.00	690.000
10	9.00	941.000
11	10.00	1,210.000
12	11.00	1,453.000
13	12.00	1,607.000
14	13.00	1,650.000
15	14.00	1,650.000
16	15.00	1,650.000

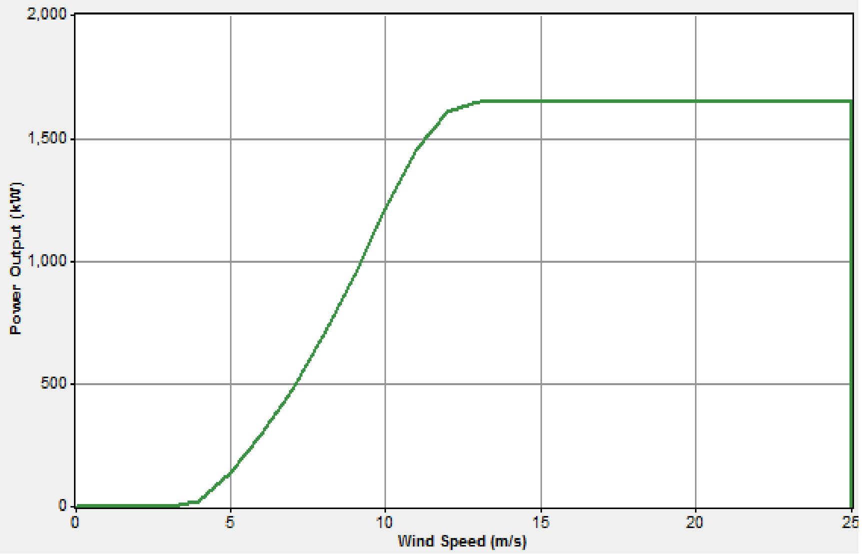


Figure 2. 11: Power output curve with wind speed of Vestas V82 wind turbine [24]

These are the cut-in speed, rated output speed, and cutout speed. The important terms characterizing the turbine power-speed (Figure 2.11) characteristics are described below [24]:

Cut-in speed – at very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate is called the cut-in speed and is typically between 3 and 4 meters per second [24].

Rated output power and rated output wind speed – as the wind speed rises above the cutting speed, the level of electrical output power rises rapidly. However, typically at 13 meters per second, the power output reaches the limit that the electrical generator is capable. This limit to the generator output is called the rated power output and the wind speed at which it is reached is called the rated output wind speed. At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power. How this is done varies from design to design but typically, with large turbines, it is done by adjusting the blade angles to keep the power at the constant level [24].

Cutout speed – as the speed increases above the rated output wind speed, the forces on the turbine structure continue to rise and at some point, there is a risk of damage to the rotor.

As a result, a braking system is employed to bring the rotor to a standstill. This is called the cutout speed and is usually around 25 meters per second [24].

A furling speed (v_f) is approximately twice that of the rated speed (v_R).This means the turbine control system is able to maintain a constant power output over an eight to one range of wind power input [25].

2.3.7. Wind Speed - Height Correction

For idealized smooth plane surface, the average wind speed increases with height approximately as the 1/7th power [24], [28].

$$\frac{v(z_2)}{v(z_1)} = \left(\frac{z_2}{z_1}\right)^{\alpha} \tag{2.31}$$

Where: $V(z_2)$ is the wind speed at the desired height of z_2; $v(z_1)$ is the wind speed measured at a known heightz_1, and α is a coefficient known as the wind shear exponent.

The wind shear exponent varies with pressure, temperature, and time of day. A commonly used value is one-seventh (1/7) and which is more applicable over open land surfaces. Because available power varies as velocity cubed, the higher position can increase turbine power by 24.5%, an appreciable improvement. As a result, selection of the tower height is a major cost-benefit trade-off. Other factors complicate this choice, for example: Topography and vegetation alter the wind speed. Crest of treeless hills are advantageous, however, the flow above hills does not follow the 1/7th power law [24].

There is also another formula, wind speed on height correction. As it is known, wind speed always affected by local factor, which are hills, building and topography where the wind turbine is installed. This formula is for best estimation of the wind speed at hub height. It uses logarithmic law of wind speed correction since it includes local factors that affect the wind speed. The most general equation to calculate wind speed at hub height is [24].

$$\frac{v(z_{hub})}{v(z_{anem})} = \frac{\ln(z_{hub}/z_o)}{\ln(z_{anem}/z_o)} \tag{2.32}$$

The surface roughness length is a parameter that characterizes the roughness of the surrounding terrain. The table below contains representative surface roughness lengths taken from Maxwell, McGowan, and Rogers [24].

Description	Very smooth ice or mud	Calm open sea	Blown sea	Snow surface	Lawn grass	Rough pasture	Fallow field	Crops	Few trees	Many trees, few buildings	Shrubs	City center, tall buildings
Z_0 (m)	10^{-5}	2×10^{-4}	0.0005	0.003	0.008	0.01	0	0.1	0.25	0.5	1.5	3

Table 2. 6: Representative surface roughness lengths for different terrain [29]

2.3.8. Wind Power

The power (P) in the wind is a function of air density (ρ), the area intercepting the wind (A), and the instantaneous wind velocity (V), or the speed. Increasing these factors will increase the power available from wind. Equation 2.33 shows the relationship between these parameters but all these parameters are included on the power curve of any wind turbines.

$$P = \frac{1}{2}\rho V^3 \qquad (2.33)$$

Where P is the power output in (watts); ρ is the air density in (kg/m³); A is the area where wind is passing (m^2) and V is the wind speed in m/s.

To calculate the output of the wind turbine in a particular hour, it follows a three-step process:

- It takes that hour's wind speed from the wind resource data and adjusts it to the hub height using either the logarithmic profile or the power law profile, as described in Wind Shear Inputs.
- It refers to the wind turbines power curve to calculate the power output under standard conditions of temperature and pressure.
- It multiplies that value by the air density ratio. It calculates the air density ratio using equation 2.34 [24].

$$\frac{\rho}{\rho_o} = \left(1 - \frac{BZ}{T_o}\right)^{g/RB} \left(\frac{T_o}{T_o - BZ}\right) \qquad (2.34)$$

The air density under standard conditions (sea level, 15 degrees Celsius) is $1.22kg/m3$. The average power output from a wind turbine is the power produced at each wind speed times the fraction of the time that wind speed is experienced, integrated over all possible wind speeds. The electric power output of a WTG in the up state depends strongly on the wind regime as well as on the performance characteristics and the efficiency of the generator. Given the hourly wind speed variations, the next step is to determine the power output of the WTG as a function of the wind speed. This function is described by the operational parameters of the WTG. The parameters commonly used are the cut-in wind speed (at which the WTG starts to generate power), the rated wind speed (at which the WTG generates its rated power), and the cutout wind speed (at which the WTG is shut down for safety reasons). The hourly output of a WTG can be obtained from hourly wind speed by applying Equation 2.35 becomes.

$$\begin{cases} P_e = 0 & (u < u_c) \\ P_e = a + bu^k & (u_c \leq u \leq u_R) \\ P_e = P_{eR} & (u_R \leq u \leq u_f) \\ P_e = 0 & (u > u_f) \end{cases} \tag{2.35}$$

The coefficient a and b is given by:

$$a = \frac{P_{eR} {u_{eR}}^k}{{u_c}^k - {u_R}^k} \ \ and \ \ b = \frac{P_{eR}}{{u_R}^k - {u_c}^k}$$

2.3.8.1. Swept Area

As shown in equation 2.36, the output power is also related to the area intercepting the wind, that is, the area swept by the wind turbines rotor. Double this area and you double the power available. For the horizontal axis turbine, the rotor swept area is the area of a circle [24], [28].

$$A = \frac{\pi D^2}{4} \tag{2.36}$$

Where: D is rotor diameter in meter. The relationship between the rotor's diameter and the energy capture is fundamental to understand wind turbine design. Relatively small increases in blade length or in rotor diameter produce a correspondingly bigger increase in the swept area, and therefore, in power. The wind turbine with the larger rotor will almost invariably generate more electricity than a turbine with a smaller rotor, not considering generator ratings [24].

2.3.9. Annual Wind Energy Production and Capacity Factor

The average power output of a turbine is a very important parameter of a wind energy system since it determines the total energy production and the total income. It can be obtained by multiplying the power produced at each wind speed and the fraction of the time that wind speed has been experienced, integrated overall wind speeds. Whereas Capacity factor is, a term used to denote the utilization rate of a wind turbine or any power-generating source for that matter. It is the ratio between powers produced to the power that could have been produced, if the generation source operates at 100% efficiency. A conventional plant utilizing fossil fuels will naturally have a larger capacity factor, as it is a continuous process. If the plant is laid, idle or under maintenance then only will the capacity factor drop down [24].

For a wind turbine however it is more of a question of the availability of the wind, as the wind is random in speed and direction, therefore a wind turbine may not always operate at maximum output condition. A reasonable capacity factor would be 0.25–0.30 and a very good capacity factor would be around 0.40. In fact, wind turbine capacity factor is very sensitive to the average wind speed. The capacity factor of wind turbines for any site can be given as [24]:

$$C_F = \left\{ \frac{exp^{\left[-\left(\frac{u_C}{c}\right)^k\right]} - exp^{\left[-\left(\frac{u_R}{c}\right)^k\right]}}{\left(\frac{u_R}{c}\right)^k - \left(\frac{u_C}{c}\right)} - exp^{\left[-\left(\frac{u_F}{c}\right)^k\right]} \right\} \tag{2.37}$$

From manufacture, the rated and cut in values are mentioned at table 2.5 and appendix figure C1 [33], the cumulative speed as given by appendix E table E1 is 10.43 m/s.

$$U_c = 3\frac{m}{s}, U_R = 13\frac{m}{s}, U_F = 20m/s\ C = 10.43$$

$$CF = 0.4568$$

The annual energy production of a single wind turbine is given as [24],

$$E = P_{eR} \times C_F \times 8760 \tag{2.38}$$

$$Taking\ the\ rating\ power\ 1650\ of\ nominal$$

$$E = 6602587.2kwh$$

The minimum output power from cut in speed (i.e. 3 m/s) is 26.27 kW power. The estimated capacity factor and annual energy production using equation 2.37 and 2.38 from a single Vestas V82 wind turbine is summarized in Table 2.7.

District	Scale factor(C)	*Vav*	*K*	*CF(capacity factor)*	*E(GWh)*
BDR	*11.3897*	*10.1*	*2*	*0.47*	*6.602587*

Table 2. 7: V82 wind turbine estimated capacity factor and annual energy production [24]

The estimated capacity factor (see Table 2.7) indicates that all values are within the acceptable or reasonable range and the annual energy production from a single Vestas V82 wind turbine that is used. In this thesis also reveals the fact that the areas of study is reach in wind power resource that can be harnessed by stand alone or grid connected wind farm [24].

2.4. Biomass Energy

Biomass is a main type of renewable energy, which has not get consideration other than its traditional use in Ethiopia. In modern era, energy storing mechanisms is the unsolved issue. Biomass this case can be an alternative solution since energy from the sun is stored by photosynthesis during plants food production. This organic compound is synthesized as glucose($C_6H_{12}O_6$). This photosynthesis process can be written in the following chemical reaction [34].

$$6CO_2 + 6H_2O + energy \rightarrow C_6H_{12}O_6 + 6O_2 \tag{2.39}$$

This glucose can be converted to complex molecules like protein, cellulose, lignin etc. Root of trees absorbs minerals to go for catalyzing reaction. The stored energy is released by natural decomposition (also called cold combustion) or by actual combustion by the following chemical reaction [34].

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + energy \tag{2.40}$$

The oxygen produced is now consumed. This makes unique character than other renewable energy source and can be used as fossil fuels. It also has balanced co_2 supply if properly managed since the co_2 released by plants is extracted and reused by other plants for food production. This is also another advantage when compared with conventional fossil energies, which supply harmful products like acid depositions and brings global warming [34].

2.4.1. Biomass Resource Assessment in Bahir Dar

Bahir Dar is located in the north west of Ethiopia in which most of countries agricultural crops are cultivated. Apart from huge availability of maize, beans, teff, barley, wheat …etc. in Gojjam and Gonder which are near locations, the forest around the city, solid waste (MSW), municipal bio solids, industrial waste, animal manures, forestry residual, landscaping and tree clipping etc. can be used as biomass resources.

Figure 2. 12: Crop residue biomass resource in Gojjam

District	Total area (ha)
Yilmama Densa [35]	99,180
Quarit [35]	61,473
Gozamin [35]	121,807
Sinan [35]	38,640
Farta [35]	107,077
Lai-gaint [35]	154,866
Banja [35]	45,618
Guagusa-shikudad [35]	30,432
Awi-zone [36]	271,000
Sum	930,093

Table 2. 8: Crop cultivation areas in some parts of Amhara region near Bahir Dar

2.4.2. Biomass Conversion Process and Output

The steps that biomass resource passes to get useful energy output can be categorized into three: thermochemical, biochemical conversion, and extraction. The way is product and feedstock's character but as a whole biomass, inputs with lower moisture content (MC) are good to thermochemical processing and high MC biological conversion [37].

The whole process occurs essentially in three stages:

1. Drying;

2. Thermal degradation (pyrolysis/gasification);
3. Actual combustion or oxidation

Gasification($800 - 1000°c$): with up to 30 atmospheric pressure used to upgrade the quality of the fuel by further gasifying the feedstock and gas cleaning [37].

Pyrolysis($400℃ - 800℃$): is a thermochemical process, mainly applied to lignocellulose materials, consisting in a degradation of organic polymers and mineral substances of biomass obtained by means of heat supplied in absence of oxygen, at temperatures varying between 400°C and 800°C. The main product is normally considered the liquid phase (bio-oil), essentially composed of tars, oils and water, but solid char and a gaseous phase (a mixture of CO, CO2, CH4, etc.) are also produced. These products are then used in substitution of conventional fuel in many applications.

2.4.3. Physical Properties of Biomass

The chemical and energy output characterization is directly related with its moisture and density during conversion process of biomass [35].

The moisture content can be evaluated on dry (1.5) and wet basis wb (1.6) the latter is largely used [38].

Wet basis

$$moisture\ content(MC) = \frac{mass\ of\ water}{mass\ of\ wet\ biomass} = h_{wet} = \frac{m_{tot}-m_{dry}}{m_{tot}} \times 100\% \qquad (2.41)$$

Dry basis

$$moisture\ content = \frac{mass\ of\ water}{mass\ of\ dry\ wood} = h_{dry} = \frac{m_{tot}-m_{dry}}{m_{dry}} \times 100\% \qquad (2.42)$$

Where: $mtot$ = the total mass, thus including moisture,

$mdry$ = the mass of the dry Substance,

$m_{tot} - m_{dry}$=the moisture mass.

The moisture content of wood is different in seasons and its species and typical values 40 to 50 percent. This can be further decrease to below 20 percent using natural drying.

2.4.4. Energy Properties

From an energy point of view, the most important feature of a fuel is its heating value that quantifies the heat generated by complete combustion of a unit mass of the material. Heating value (calorific value) is the heat released by the fuel when completely burnt, and may be determined at constant volume or constant pressure, and flue gas is cooled back to the initial temperature (ambient temperature).

2.4.5. Heat Balance in a Complete Combustion

Heat released from combustion (Heat of Combustion) = heat to vaporize existing water + heat to vaporize water product + heat loss to environment

Higher/Gross Heating/Calorific Value(HHV, Hs) - assumes that the water vapor in the products condenses and thus includes the latent heat of vaporization of the water vapor in the products.

- HHV or GHV = Heat of Combustion per unit mass

Lower/Net Heating/Calorific Value (LHV, Hi) - does not contain the latent heat, the water in flue gas remain in steam form at the initial temperature.

- LHV or NHV = (Heat of Combustion - heat to vaporize existing water - heat to vaporize water product) per unit mass
- Possible dimensions: MJ/kg, MJ/m^3, kWh/kg, kWh/m^3

$$LHV_{dry} = HHV_{dry} - 9Hq \tag{2.43}$$

Where:H is hydrogen content in dry biomass(5 to7 percent) and q is water condensation heat, that is equal to 2.4 MJ/kg; the subscript dry obviously indicates that the values are referred to dry basis, while the factor 9 relates to the fact that the produced water quantity is nine times higher than the hydrogen content. It must be noted that, precisely because discussion has been done on dry basis, here water vapor is only related to the presence of hydrogen in the structure of the fuel that gives water in the combustion process, and is not associated to the moisture content: thus the formula. The difference between HHV and LHV is typically equal to 1 to 1.5 MJ/kg [35].

The lower heating value is highly influenced by chemical composition of biomass. Substances with higher carbon and hydrogen has higher lower heating value (LHV), on the other side if it has high oxygen and nitrogen it has lower LHV. Hence, the lower heating value is varied in limited range between 18 to 20 MJ/kg and HHVdry results 19 to 21.5 MJ/kg). It can be seen the real parameter strongly influence the LHV is moisture in two ways. One its physical presence diminishes fuel ratio on total mass and secondly energy losses due to latent evaporation heat that is absorbed by water during combustion process and is not recovered. The actual LHV can be calculated from LHVdry as follows [34]:

$$LHV = (1-h)LHV_{dry} - hq = LHV_{dry} - h(LHV_{dry} - h(LHV_{dry} + q)) \quad (2.44)$$

Where h is moisture (on wet basis, naturally). The relation shows that real LHV, thus the energy actually recoverable from a combustion process, linearly decreases with increasing moisture and falls to zero with $h \cong 88 \div 90\%$ [34].

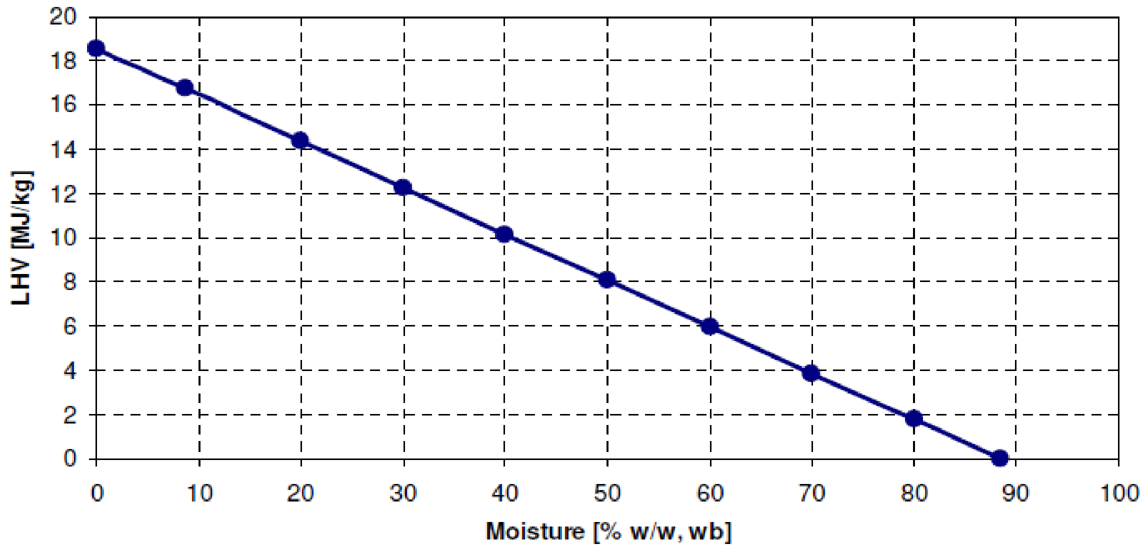


Figure 2. 13: LHV versus moisture content character of biomass

The ratio of dry matter at anthesis and final grain was between 1.29-1.50 t/ha of dry matter to each ton of grain. The light grazing had the highest conversion ratio, while the heavy grazing had the lowest [39].

Let's take the average=1.4 ton/hectare

$$Total\ tons\ of\ biomass\ available = 1.4 ton/ectare * 931{,}093$$

$$= 1{,}302{,}130.2 tons$$

Matter	Mwb	Mdb
Bagasse	50%	100%
Barley Straw	16%	19%
Corn Stover	30%	42%
Rice Straw	67%	200%
Wheat Straw	12%	14%
Forest Residues	44%	78%
Primary Mill Residues	48%	91%
Urban Wood Residues	10%	14%

Table 2. 9: Default Biomass Moisture Contents [40]

Energy source	LHV(KJ/Kg)
Brad level plants (20%)	14,200
Brad level plants (dry)	19,000
Conifers (20%)	14,900
Conifers (20%))	20,000
Wheat straw (10%)	15,500
Coal (10%)	27,200
Oil	41,860
Diesel	41,860
Butane	45,600
Methane	50,200 ($35,000KJ/Nm^3$)

Table 2. 10: Biomass LHV variation with moisture [34]

The efficiency and capacity of power plant decrease as co firing ratio of biomass increases

$$eff\ drop = -0.4(co - fire\ ratio)^2 + 0.12(co - fire\ ratio)$$

Co-firing rate	Drop in efficiency (% points)
0%	0.0%
5%	0.5%
10%	0.8%
15%	0.9%

Table 2. 11: Co-firing and plant efficiency

$$P_e = P_{e.org} = \frac{\eta_{Biomass}}{\eta_{org}} \tag{2.45}$$

In equation 2.46 the capacity of the power plant with biomass combustion is equal to the original capacity of the plant times the ratio of biomass efficiency of the plant (at 100 coal combustion). The drop in capacity of biomass co-fired and fired power plant is used for when regulating the model's results per KWh of electricity generated [39]:

For the fuel cycle emissions and energy analysis the power plant size, co-fire ratio, fuel heat rate, and heat rate (efficiency) of the plant are used to determine the mass of biomass and coal that is required for each power plant scenario and biomass feedstock. The equation below was used to calculate the mass of biomass and coal (for coal the percent of coal fired with biomass is used in equation 2.46 and vice versa when calculating the mass of biomass) required in each co-firing scenarios. For this analysis, the capacity factor is 80% [39].

$$\frac{t.biomass}{year} = power\ plant\ size * \%cofire * capacity\ factor * 8760\ {}^{hrs}/_{yr} * heat\ rate * [HHV]_{biomass}{}^{-1} \tag{2.46}$$

2.5. Shunt Capacitor Modeling

Shunt capacitors are mainly installed to provide capacitive reactive compensation. The use of QGs has increased because they are relatively inexpensive, easy and quick to install and can be deployed virtually anywhere in the network. Its installation has other beneficial effects on the system such as: improvement of the voltage at the load, better voltage regulation (if they were adequately designed), reduction of losses and reduction or postponement of investments in another distribution system [41].In shut capacitor (QG) design the standards stipulate that:

a) Capacitor units should be capable of continuous operation up to 110% of rated terminal rms voltage and a crest voltage not exceeding 1.2 x √2 of rated rms voltage [41].

b) Capacitors units should not give less than 100% nor more than 115% of rated reactive power at rated sinusoidal voltage and frequency [41].

c) Capacitor units should be suitable for continuous operation at up to 135% of rated reactive power caused by the combined effects of [41]:

- Voltage in excess of the nameplate rating at fundamental frequency, but not over 110% of rated rms voltage.
- Harmonic voltages superimposed on the fundamental frequency.
- Reactive power manufacturing tolerance of up to 115% of rated reactive power.

The discrete size of capacitors would be taken for optimal planning of Renewable-based DGs in the distribution system. The capacitors available on the market are smaller units (150 kvar), which are further integer multiples of factor U. Hence, the required amount of capacitor size can be determined using Equation (2.47) as reported in [11]:

$$Q_{max} = U \times Q_o \tag{2.47}$$

Where U is an integer

Chapter Three

3. Study Area Analysis

3.1 Introduction

Amhara regional state is one and the most where tourists are interested to visit due to its rich natural, religious and cultural heritages. Among those places in the region, Bahir Dar is the most important place chosen by tourists. This further attracts investors over a time and now a days Bahir Dar is home of industrial and commercial sectors. Bahir Dar has two substations. Substation-I is from Tis Abay I, Tis Abay II, and substation-II is from Alamata, Tana Beles, and Fincha. The cities loads get supply mainly from substation-II. In Bahir Dar, there are seven feeder in total. The first and the highest supply is substation-II there are 123/230/15 kV and 230/66/15 kV buses which are power sources of four feeders (i.e. Airforce, Bata, Ghion and Papyrus) and the other substation-I supply for three feeders (i.e. Sematate, Boiler and Industry).

The workers of the station have a reading in each hour especially reading related to interruption and fault incidents commonly ground fault. In Ethiopian winter season Tis Abay I will stop generating power since it is from natural waterfall, the water capacity is not enough to rotate turbines. The increase in demand of power in the switchyard, reduce further the voltage profiles. This is observed in all feeders especially in Ghion and Bata feeders. There is no dought that the drop in voltage profile will increase the loss in the system. Hence, these feeders (i.e. Ghion and Bata feeders) are critical and needs some mechanism to improve the voltage profile and the power loss. To reduce the loss in the system source of reactive power and active power is required. This will reduces the demand from the main feeder by supplying the required amount locally. By doing so the stress due to overloading in lines will decrease, consequently the total active power loss of feeders will also decrease.

For this thesis, data is collected from different areas and sources. Among these Bahir Dar office of distribution business and wire, conductor standard data sheets, researchers on area[7] and active measurements using Microvip3 plus power quality and harmonic analyzer for finding the active and reactive power are used as tool for data collection.

3.2. Load Flow of Radial Distribution System

For operational analysis and distribution, planning purposes distribution load flow is quite essential. Distribution system is part of power system, which has very high resistance to reactance ratio. Hence, in radial distribution network the traditional Gauss-Seidel, Newton-Raphson and fast-decoupled methods are inconvenient due to its unbalanced loading i.e. its composition of single-phase and two-phase branches and high branch current. These characteristics of distribution system bring difficulties when applying conventional load flow method in planning operation and analysis of distribution system in last few years.

Recent extensive efforts by researchers in balanced/unbalanced distribution system forward and/or backward sweep processes distribution power flow solution has been developed using Kirchhoff's laws. In this method, the branch currents would be calculated using the backward sweep and the bus voltage would be computed in forward sweep.

3.3. Bahir Dar Distribution Line Data Impedance Computations

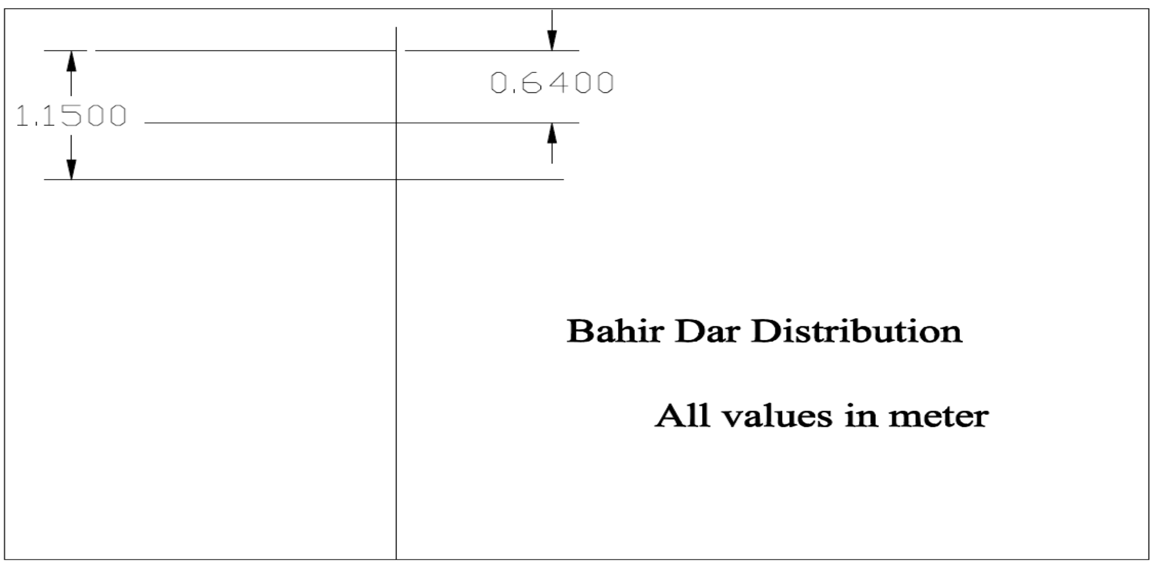


Figure 3. 1: Overhead MV distribution line at Bahir Dar

Conductor type	Nominal area(mm^2)	Actual area (mm^2)	Stranding and wire diameter	Overall diameter (mm)	Actual diameter (mm)	GMR (mm)	Resistance (Ω/km)
AAC	50	49.48	7/3	9	7.9377	2.88	0.5785
AAC	95	93.27	19/2.5	12.5	10.8975	4.129	0.3085

Table 3. 1: Overhead medium voltage conductor size

3.3.1. Impedance Calculation of Overhead Line

Since the conductors that are used in Bata and Ghion, distribution feeders are stranded conductors. For stranded conductors, the GMR is given by:

$$GMR = k.r \ [7] \tag{3.1}$$

Where: k = the GMR factor

r = actual conductor radius

Strands	GMR factor, K
1(solid)	0.7788
3	0.6778
7	0.7256
19	0.7577
37	0.7678
61	0.7722

Table 3. 2: GMR Factor (k) and Strand Relationship for AAC & ACSR conductor

The inductive reactance will be assumed to be at a frequency of 50Hz, and the length of the conductor will be assumed one kilometer, with these assumptions the self and mutual impedances without distinguishing the ground efficiency (for initial mode) in the distribution network overhead lines can be debated as (Rade M. ciric, 2004) [42].

$$Z_{aa} = r_a + j4\pi \times 10^{-4} f * ln\left(\frac{2h_a}{GMR_a}\right) \Omega/km \tag{3.2}$$

$$Z_{ab} = j4\pi \times 10^{-4} f * ln\left(\frac{\sqrt{d_{ab}{}^2 + (h_a + h_b)^2}}{\sqrt{d_{ab}{}^2 + (h_a - h_b)^2}}\right) \Omega/km \tag{3.3}$$

Where:

r_a= the resistance of phase-a wire in a unit length ($\Omega/_{km}$)

h_b, h_a= the height of wires a and b wire of meter from ground (10m)

d_{ab}= the horizontal distance between a and b wire in terms of meter

Using positive sequence impedance the self-impedance will be computed as:

$$Z_s = \frac{1}{3}(Z_{aa} + Z_{bb} + Z_{cc})\ \Omega/_{km} \tag{3.4}$$

Mutual impedance is:

$$Z_m = \frac{1}{3}(Z_{ab} + Z_{bc} + Z_{ca})\Omega/km \quad (3.5)$$

Positive sequence impedance

$$Z_+ = Z_S - Z_m \quad (3.6)$$

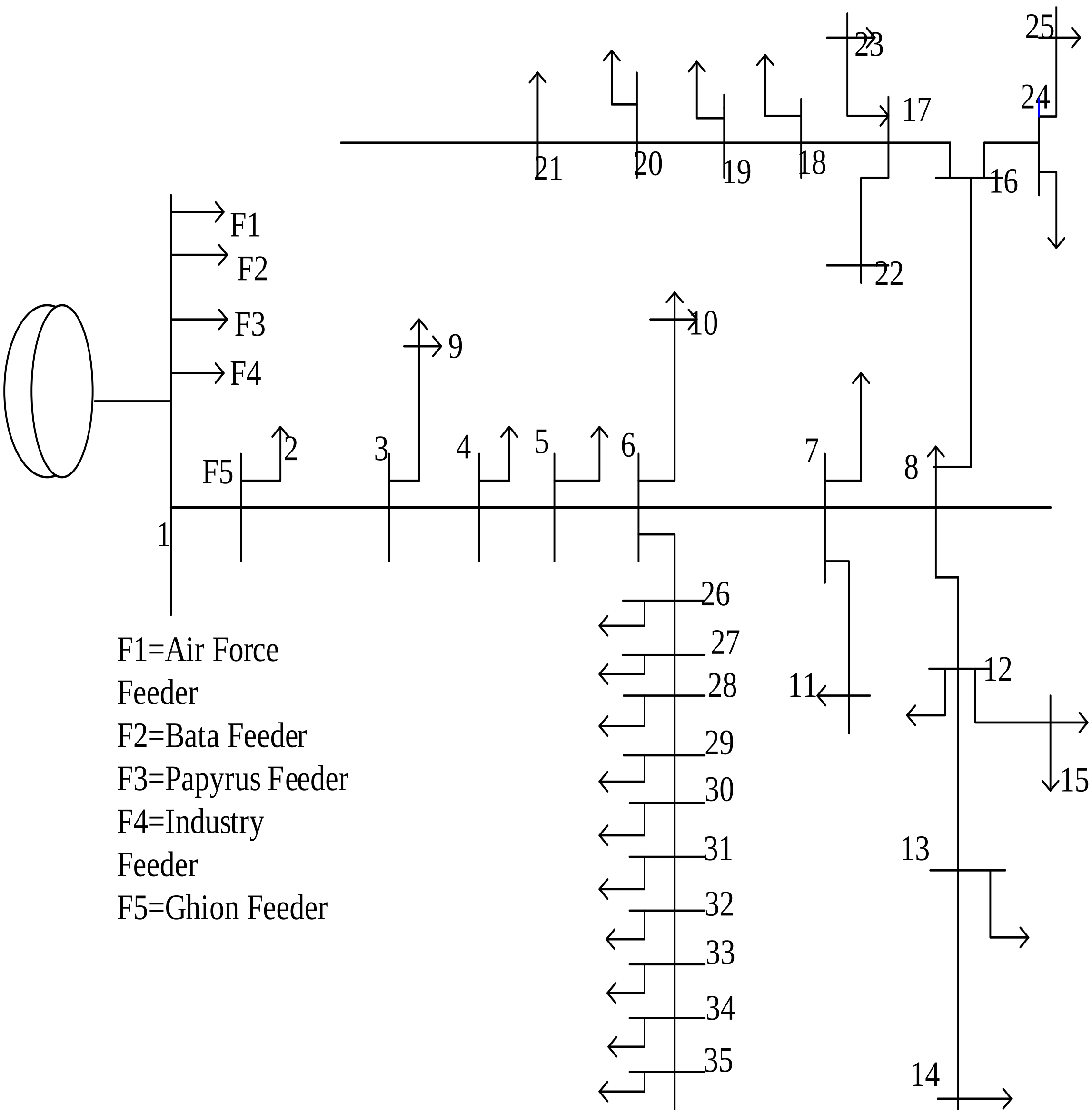
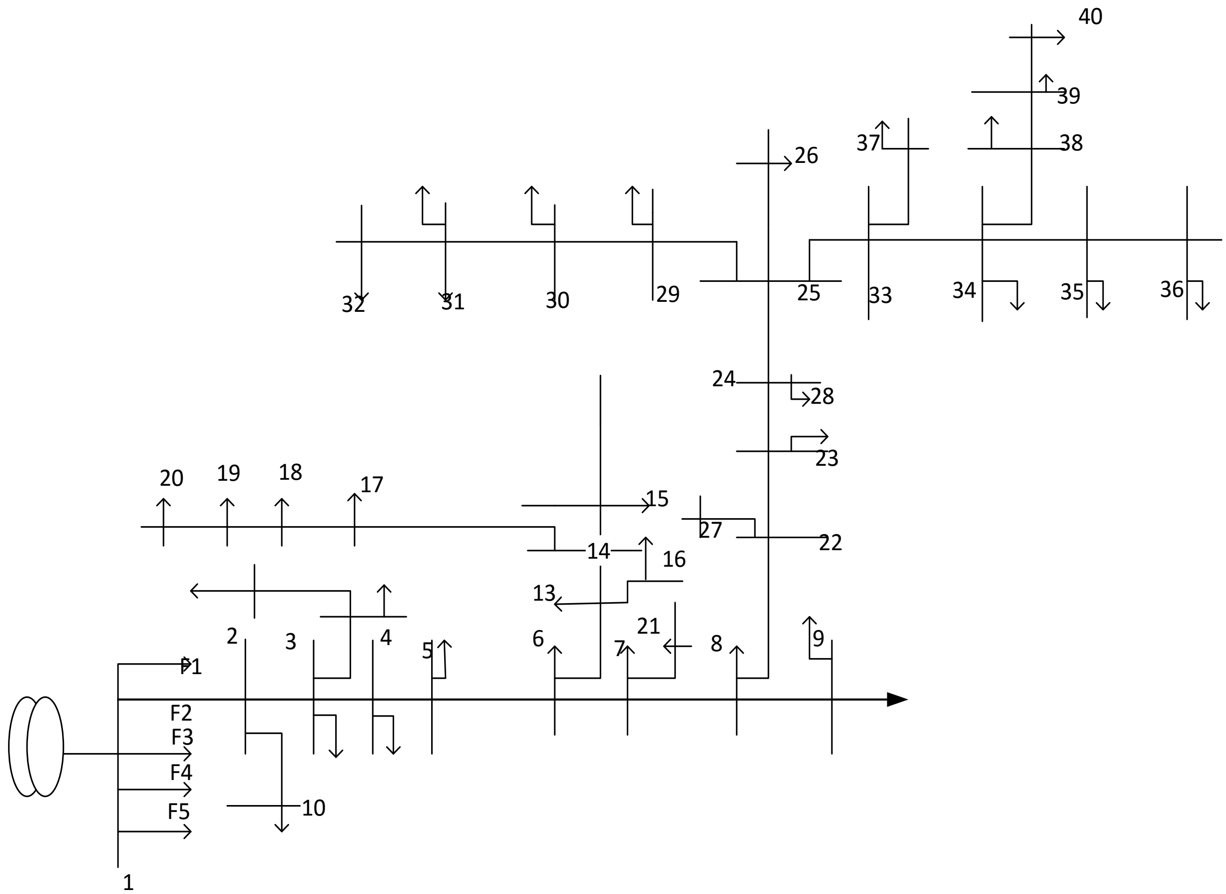


Figure 3. 2:35 Bus of Ghion feeder of bahir Dar distribution system

Sending End	Receiving End	Conductor Type	Length in km	Resistance(Ω)	Reactance in (Ω)	Receiving End Load(KW)	Receiving End Load(KVar)
1	2	AAC-95	1.687	0.5760	0.0845	0	0
2	3	AAC-95	0.209	0.0645	0.0095	25.60	19.20
3	4	AAC-95	0.423	0.1305	0.0191	11.62	7.80
4	5	AAC-95	0.857	0.2644	0.0388	17.62	32.90
5	6	AAC-95	0.577	0.1780	0.0261	47.15	0
6	7	AAC-95	0.085	0.0262	0.0038	0	0
7	8	AAC-95	0.457	0.1410	0.0207	0	222.30
2	9	AAC-50	0.191	0.1105	0.0130	260	20.88
6	10	AAC-50	0.430	0.2488	0.0292	29.93	28.32
7	11	AAC-50	0.170	0.0983	0.0115	68.0	51.00
8	12	AAC-50	0.897	0.5189	0.0609	130.8	88.68
12	13	AAC-50	0.229	0.1325	0.0155	43.20	32.40
13	14	AAC-50	0.334	0.1932	0.0227	108.3	72.26
12	15	AAC-50	0.474	0.2742	0.0322	164.92	141.01
8	16	AAC-50	0.944	0.5461	0.0641	0	0
16	17	AAC-50	0.221	0.1278	0.0150	0	0
17	18	AAC-50	0.204	0.1180	0.0138	51.48	44.02
18	19	AAC-50	0.345	0.1996	0.0234	55.82	46.25
19	20	AAC-50	0.174	0.1007	0.0118	92.78	76.87
20	21	AAC-50	0.344	0.1990	0.0234	73.61	60.98
17	22	AAC-50	0.180	0.1041	0.0122	99.30	79.12
17	23	AAC-50	0.399	0.2308	0.0271	69.81	51.73
16	24	AAC-50	0.791	0.4576	0.0537	33.62	23.46
24	25	AAC-50	0.179	0.1036	0.0122	17.01	11.43
6	26	AAC-50	0.2184	0.2999	0.0352	60	20
26	27	AAC-50	0.268	0.2129	0.0250	120	70
27	28	AAC-50	0.184	0.2221	0.0261	200	600
28	29	AAC-50	0.22	0.0706	0.0083	150	70
29	30	AAC-50	0.338	0.1237	0.0145	210	100
30	31	AAC-50	0.168	0.1254	0.0147	60	40
31	32	AAC-50	0.26	0.1250	0.0147	460	250
32	33	AAC-50	0.184	0.2221	0.0261	256	120
33	34	AAC-50	0.228	0.1319	0.0155	36	15
34	35	AAC-50	0.388	0.1435	0.0168	342	122
						138	60

Table 3. 3: Bahir Dar 35 bus 15 kv distribution line characteristics



F1=Air force Feeder
F2=Bata Feeder
F3=papyrus Feeder
F4=industry Feeder
F5=Ghion feeder

Figure 3. 3:40 Bus of Bata feeder of bahir Dar distribution system

Sending End	Receiving End	Conductor Type	Length in km	Resistance(Ω)	Reactance in (Ω)	Receiving End Load(KW)	Receiving End Load(KVar)
1	2	AAC-95	1.784	0.550364	0.081071974	0	0
2	3	AAC-95	0.427	0.13173	0.019404559	9.96	6.69
3	4	AAC-95	0.229	0.070647	0.01040666	59.34	62.26
4	5	AAC-95	0.114	0.035169	0.005180608	15.77	10.59
5	6	AAC-95	0.236	0.072806	0.010724768	0	0
6	7	AAC-95	0.621	0.191579	0.028220682	0	0
7	8	AAC-95	0.543	0.167516	0.024676055	0	0

8	9	AAC-95	0.143	0.044116	0.006498482	38	28.5
2	10	AAC-50	0.336	0.194376	0.022874473	146.76	124.08
3	11	AAC-50	0.833	0.481891	0.056709632	71.71	71.11
11	12	AAC-50	0.894	0.517179	0.060862438	136.74	103.84
6	13	AAC-50	0.481	0.278259	0.032745898	0	0
13	14	AAC-50	0.297	0.171815	0.020219401	0	0
14	15	AAC-50	0.65	0.376025	0.044251213	53.39	44.65
13	16	AAC-50	0.211	0.122064	0.014364625	65.45	54.22
14	17	AAC-50	0.268	0.155038	0.018245116	70.40	52.8
17	18	AAC-50	0.324	0.187434	0.022057528	31.98	21.8
18	19	AAC-50	0.402	0.232557	0.027367673	78.28	66.93
19	20	AAC-50	0.893	0.516601	0.060794359	40.8	30.6
7	21	AAC-50	0.314	0.181649	0.02137674	159.75	158.43
8	22	AAC-50	0.326	0.188591	0.022193685	0	0
22	23	AAC-50	0.264	0.152724	0.0179728	75.07	62.2
23	24	AAC-50	0.134	0.077519	0.009122558	0	0
24	25	AAC-50	0.25	0.144625	0.017019697	0	0
25	26	AAC-50	0.21	0.121485	0.014296546	17.22	12.02
22	27	AAC-50	0.314	0.181649	0.02137674	113	96.82
24	28	AAC-50	0.188	0.108758	0.012798812	45.6	38.99
25	29	AAC-50	0.121	0.069999	0.008237534	18.04	12.59
29	30	AAC-50	0.275	0.159088	0.018721667	45.81	37.96
30	31	AAC-50	0.43	0.248755	0.02927388	64.6	55.23
31	32	AAC-50	0.33	0.190905	0.022466001	36.52	24.54
25	33	AAC-50	0.328	0.189748	0.022329843	18.4	13.8
33	34	AAC-50	0.318	0.183963	0.021649055	8.3	5.58
34	35	AAC-50	0.197	0.113965	0.013411522	24.45	17.37
35	36	AAC-50	0.242	0.139997	0.016475067	57.75	48.74
33	37	AAC-50	0.379	0.219252	0.025801861	12.3	8.58
34	38	AAC-50	0.091	0.052644	0.00619517	68.5	47.8
38	39	AAC-50	0.418	0.241813	0.028456934	88	66
39	40	AAC-50	0.727	0.42057	0.04949328	93.5	86
						94.6	88.0

Table 3. 4: Bahir Dar 40 bus 15 kv distribution line characteristics

3.4. Forward and/or Backward Sweep Load Flow

This algorithm is based on configuration nature of radial distribution network using forward and/or backward sweep processes. In the forward sweep process, the node voltage is computed from the sending end to the far end of the branches, and using backward sweep process the branch current or branch current and power summation from the far end to the sending end of the feeder and branches would be computed.

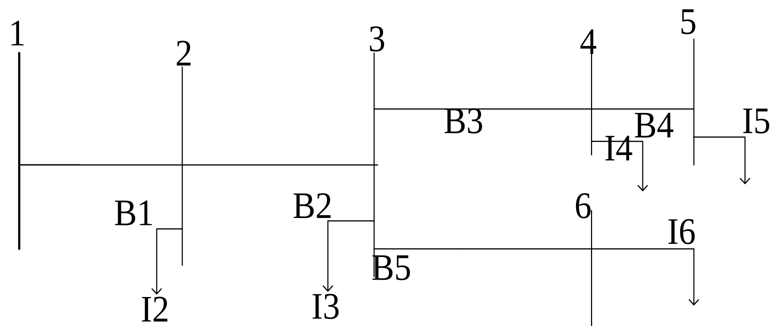


Figure 3. 4: Sample distribution system

3.4.1. Algorithm for Forward Backward Sweep Load Flow

The forward and backward sweep computation process is made by two derived matrices. The first is bus-injection to branch-current matrix (BIBC) and branch current to bus-voltage matrix (BCBV), and the other is equivalent current injections. In distribution system, equivalent current-injection based model is more practical [7], [43]. For thee given feeder bus, the total load Si can be given by:

$$S_i = (P_i + jQ_I) \tag{3.7}$$

3.4.1.1. Backward Sweep

For each iteration i, branch currents are aggregated from loads to origin. However, before finding the branch current we need to find the current injected at each bus and the bus-injection to branch-current (BIBC) which relates the bus injected current to the branch current [7].

A. Bus Injection to Branch Current (BIBC) matrix [43]

$$I_i = \left({S_i}/{V_i} \right)^* \tag{3.8}$$

The vector of current injections for the above sample system is given as below [43]

Bus No	2	3	4	5	6
Current Injection	I_2	I_3	I_4	I_5	I_6

For the system shown in Figure 3.4, apply Kirchhoff's current law (KCL), the branch currents can then be formulated as functions of equivalent current injections. For example, the branch currents B2, B3, B4 and B5 can be expressed as [7], [43].

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \tag{3.9}$$

$$B_2 = I_3 + I_4 + I_5 + I_6 \tag{3.10}$$

$$B_3 = I_4 + I_5 \tag{3.11}$$

$$B_4 = I_5 \tag{3.12}$$

$$B_5 = I_6 \tag{3.13}$$

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \tag{3.14}$$

The above branch current equations can be rearranged in the generalized as below [7], [43]

$$[B] = [BIBC][I] \tag{3.15}$$

Where: BIBC is a bus injection to branch current matrix, which is the upper triangular matrix and always has 0 and 1 values only.

Step 2 Forward sweep

Nodal voltage vector V is updated from the origin to loads according the Kirchhoff Voltage Laws (KVL), using previously calculated branch currents vector B and branch-current to bus-voltage (BCBV) [7], [43].

B. *Branch Current to Bus Voltage (BCBV) Matrix*

The relationship between the branch currents and bus voltages are expressed as [7], [43]:

$$V_2 = V_1 - B_1 Z_{12} \tag{3.16}$$

$$V_3 = V_2 - B_2 Z_{23} \tag{3.17}$$

$$V_4 = V_3 - B_3 Z_{34} \tag{3.18}$$

$$V_5 = V_4 - B_4 Z_{45} \tag{3.19}$$

$$V_6 = V_3 - B_5 Z_{36} \tag{3.20}$$

Where Vi is the voltage of bus i, and Zij is the line impedance between bus i and bus j.

From equation (3.16) to (3.20), it can be seen that the bus voltage can be expressed as a function of branch currents, line parameters, and the substation voltage. Similar procedures can be performed on other buses; therefore, the relationship between branch currents and bus voltages can be expressed as:

On substitution of (3.18) to (3.19) in (3.20), [7] give the voltage at bus 4, [43]

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \tag{3.21}$$

Similarly, the other bus voltages can be rewritten as [7], [43]

$$V_3 = V_1 - B_1 Z_{12} - B_2 Z_{23} \tag{3.22}$$

$$V_5 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} - B_4 Z_{45} \tag{3.23}$$

$$V_6 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} - B_4 Z_{45} - B_5 Z_{36} \tag{3.24}$$

Equations (3.21) to (3.24) are rearranged as below [44]:

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \tag{3.25}$$

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

In general for kth iteration as:

$$[V^{k+1}] = [V_1] - [BCBV][B] \tag{3.27}$$

3.4.1.2. Procedure Forming BIBC and BCBV Matrix

As seen above the BIBC and BCBV matrices are developed based on the topological structure of distribution systems. The BIBC matrix represents the relationship between bus current injections and branch currents. The corresponding variations at branch currents, generated by the variations at bus current injections, can be calculated directly by the BIBC matrix. The BCBV matrix represents the relationship between branch currents and bus voltages. The corresponding variations at bus voltages, generated by the variations at branch currents, can be calculated directly by the BCBV matrix. So the procedures for forming the BIBC and BCBV are shown below [7]:

Procedure 1: Forming BIBC:

Step 1: For a distribution system with m-branch section and n-bus, the dimension of the BIBC matrix is $m \times (n-1)$.

Step 2: If a line section (Bk) is located between bus i and bus j, copy the column of the i^{th} bus of the BIBC matrix to the column of the j-th bus and fill a 1 to the position of the k^{th} row and the j^{th} bus column.

Step 3: Repeat step (2) until all line sections are included in the BIBC matrix.

Procedure 2: Forming BCBV:

Step 1: For a distribution system with m-branch section and n-bus, the dimension of the BCBV matrix is $(n-1) \times m$.

Step 2: If a line section is located between bus i and bus j, copy the row of the i-th bus of the BCBV matrix to the column of the j-th bus and fill the line impedance (Zij) to the position of the k-th column and the j-th bus row.

Step 3: Repeat step (2) until all line sections are included in the BCBV matrix.

3.5. Metaheuristic Optimization Methods

The Meta heuristic method is an iterative generation process that helps the search process to efficiently locate near-optimal solutions using learning strategies and intelligently combining different concepts that will help exploit and scour the search space. This strategy is utilized to find the exact or near exact optimal solutions. This method can be divided into two distinct categories: Single (unique) solution and Population solution [2].

3.5.1. Single (Unique) Solution Meta Heuristic Method

This type of method provides one solution at a time. This section presents the utilized algorithms in this work pertaining to this method [2].

3.5.2. Whale Optimization Algorithm (WOA)

3.5.2.1. Introduction

Whale optimization algorithm is a latest meta heuristic algorithm developed by Mirjalili and Lewis [45] in the year 2016. The whales are considered to be as highly intelligent animals with motion. The WOA is inspired by the unique hunting behavior of humpback whales. Usually the humpback whales prefer to hunt krill or small fishes, which are close to the surface of sea. Humpback whales use a special unique hunting method called bubble net feeding method. In this method, they swim around the prey and create distinctive bubbles along a circle or 9-shaped path [6].

From basic characters hunting, the following are observed in Whale optimization algorithm.

1. Encircling prey
2. Bubble net hunting method
3. Search the prey

1. Encircling prey: One of the characters of Whales predicts the current position is exact and in circles the prey. This character of social behavior is transformed in the mathematical equation, as the present best candidate solution set is the objective solution. All other social groups will try to update their position status towards the best hunter. The behavior modeled is as:

$$\overrightarrow{X(t+1)} = \overrightarrow{X^*(t)} - \vec{A}.\vec{D} \tag{3.28}$$

$$\vec{D} = \left|\vec{C}.\overrightarrow{X^*}(t) - \vec{X}(t)\right| \tag{3.29}$$

$$\vec{A} = 2.\vec{a}.\vec{r} - \vec{a} \tag{3.30}$$

$$\vec{C} = 2.\vec{r} \tag{3.31}$$

Where $\overrightarrow{X^*}, \vec{X}$ represent current position of best solution and position vector. Current iteration is denoted by t. $\vec{A}, \vec{C}$ are coefficient vectors. $\vec{a}$ is directly decresed from 2 to 0.$\vec{r}$ is random vector [0,1].

2. Bubble net hunting method: In this hunting character of whales, they used two methods.

2.1. This time the whale encircles the prey and then shrinks from the far to the center: Here $\vec{A} \in [-a, a]$ where $\vec{A}$ is decreased from 2 to 0. Position $\vec{A}$ is setting down at random values in between [-1, 1]. The new position $\vec{A}$ is computed in between preveous position and position of the current best agent. Figure 3.5 shows the possible positions from (X,Y) toward (X^*, Y^*) that can be achived by $0 \le A \le 1$ in 2D space represented by equ.3.30

2.2. Spiral position updating: The whale shows a mimic helix-shaped movement to the prey, this property of whale can be represented in spiral equation:

$$\vec{X}(t+1) = \overrightarrow{D'}.e^{bl}.\cos(2\pi l) + \overrightarrow{X^*} \tag{3.32}$$

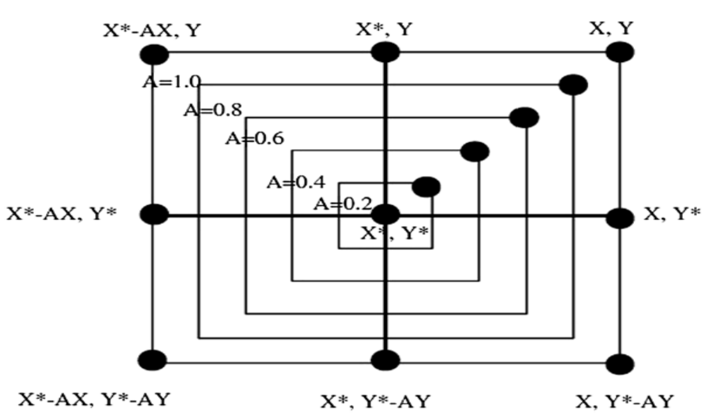


Figure 3. 5: Bubble net search shrinking encircling mechanism [45]

In hunting, whales swim around the prey in more than two paths simultaneously. This case to update whale's positions 50% probability is taken for above two methods.

$$\vec{X}(t+1) = \begin{cases} \overrightarrow{X^*}(t) - \vec{A}.\vec{D}, & if\ P < 0.5 \\ \overrightarrow{D'}.e^{bl}.\cos(2\pi l) + \overrightarrow{X^*}, & if\ P \geq 0.5 \end{cases} \quad (3.33)$$

Where $D' = \left|\overrightarrow{X^*} - \vec{X}(t)\right|$ represents the distance between whale and the prey (best position). b is constant, $l \in [-1,1]$. P is the random number [0, 1]. Figure 3.6 shows the spiral updating position approach represented by eq.3.33.

3. Search for prey: To get the global possible optimum values updating has done with randomly chosen search agent rather than the best agent.

$$\vec{D} = \left|\vec{C}.\overrightarrow{X_{rand}} - \vec{X}\right| \quad (3.34)$$

$$\vec{X}(t+1) = \overrightarrow{X_{rand}} - \vec{A}.\vec{D} \quad (3.35)$$

$\overrightarrow{\boldsymbol{X_{rand}}}$ is the random whale in current iteration. The symbol ‖ denotes the absolute values.

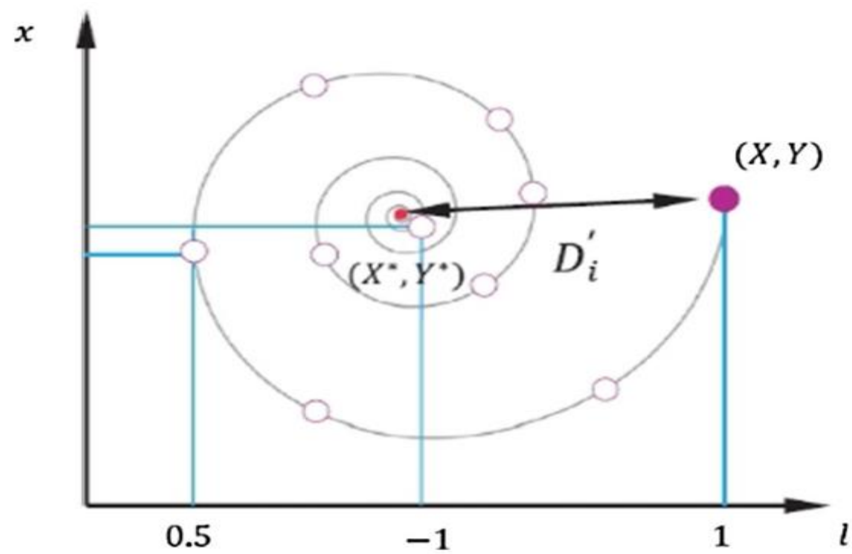


Figure 3. 6: Bubble net search spiral updating position mechanism [45]

3.5.2.2. Implementation of WOA

The detailed algorithm is as follows [45]:

Step 1: Read 80% integrating capacity (peak load) of the bus, load data of the system

Step 2: Solve the feeder-line flow for the system using load flow method.

Step 3: Initialize the population/solutions and itmax = 10, number of DG and QG locations dim = 1 for, DGmin = 0, DGmax = 4MW. dim = 1 for, QGmin = 0, QGmax = 4Mvar respectively

Step 4: Generate the population of DG/QG sizes randomly using equation population = (DG/QGmax – DG/QGmin) × rand () + DG/QGmin where DG/QGmin and DG/QGmax are minimum and maximum limits of DG/QG sizes.

Step5 Set similar program out and call it to step 4.

Step 6: Find power losses for generated population.

Step 7: If there is possible minimum power loss search out of DG/QG limit, consider only the network limit.

Step 8 Current best solution is DG and QG values with low losses.

Step 9: By using Eqs. 10–13 update the position of whales.

Step 10: For updated population repeat step 6 and 7 determine losses by performing load flow.

Step 11: If obtained losses are less, then replace current best solution with it or else go back to step 11.

Step 12: Record the results if tolerance is <0.001 or maximum iterations reached.

3.5.3. Particle Swarm Optimization

3.5.3.1. Introduction

Particle Swarm Optimization (PSO) is one of the attractive areas in a metaheuristic evolutionary programming introduced by James Kennedy & Russell Eberhart in 1995 for optimizing continuous nonlinear functions.

The concept of PSO is an inspiration from the collective behavior of birds, fishes, insects and their communities. This behavior studied about how they manage as a group, how they are recreating themselves and adapting in accordance with the changes in the surrounding environment, in order to search for food or to migrate as a group rather than individual. Hence, it is a repeated social behavior of organisms in pattern that live and interact within large group and how the members of the entire population are maintained through the search procedure.

Figure 3. 7: School of fish and flock of birds [46]

In PSO, each possible solution is considered as a particle and the collection of particles is called swarm. All particles have their own fitness values and velocities. These particles fly through the D dimensional problem space by learning from the historical information of all the particles. The possible potential solution is represented by a particle, which will latter adjust its position and velocity to the group. This latter best position of a given particle has ever achieved is called *particle best (pbest).* In occasions, the particle may track the best position achieved so far by any particle of the swarm. This position is called *global best (gbest).* In all occasions the particle will change their velocities with individualistic moves or toward *particle best* and *global best*, the particles change their positions. According to Onwubolu & Clerc definition, the movement of a particle is a composite of three possible choices. These are:

- To follow its own way,
- To go back to its best previous position and
- To go towards its best neighbor's previous or present position

3.5.3.2. Particle Swarm Optimization Algorithm

In PSO algorithm, each member is called "particle", and each particle flies around in the multi-dimensional search space with its velocity, which is constantly updated by the particle's own experience and the experience of the particle's neighbors or the experience of the whole swarm. Two variants of the PSO algorithm are developed, namely PSO with a local neighborhood, and PSO with a global neighborhood. According to the global neighborhood, each particle moves towards its best previous position and towards the best particle in the whole swarm, called *global best* model it uses a star social network topology.

On the other hand, according to the local variant so called *local best*, each particle moves towards its best previous position and it reflects a ring social topology.

The potential solutions are particles that through hyperspace. Each particle initializes first with a random position and random velocity, and then keeps track of its coordinates in hyperspace in order to associate with other particles that will combine to achieve the best solution (fitness). This value is called best and this value must be stored. The p_{best} is not the only the best possible value for the system; there is another best value called gbest. This is the global version of the particle swarm optimizer that keeps track of the overall best value and its position, obtained so far by any of the particles in the same population.

Particle Swarm Optimization algorithm consists of two main equations on which the new velocity and the new position will be calculated. At each step of the iteration, the velocity of each particle will change towards its pbest and gbest in global version. After that, the new position for each particle will be calculated by adding the last position to the new velocity, as we explained above. The two main equations according to Kennedy and Eberhart (1995) are as follows [7]:

$$v_i(I+1) = w * v_i(I) + c_1 * r_1 * (p_{bi} - x_i) + c_2 * r_2(gb_i - x_i)$$

$$x_i(I+1) = x_i(l) + v_i(I+1) \tag{3.36}$$

Where:

Vi-velocity for the particle i.

w -is the inertia weight that controls the impact of previous velocity of particle on its current one

I –is iteration

c1& c2-are positive constant parameters called acceleration coefficients that control the maximum step size, their range is [0, 4]

pb_i- the best previous position

x_i-the present position of the particle

r1&r2-the uniformly distributed random variables; their range is [0, 1].

g_b-the best position between all particle in the population.

The PSO technique can be briefly stated and defined as follows:

1. Particle x(I): It is a candidate solution represented by a D dimensional real valued vector. Where D is the number of optimized parameters. At time the ith particle xi(I) can be described as xi(I)=[xi,1(I); xi,2(I);…… xi,D(I)]. Each particle modifies its position according to:

- Its current position,
- Its current velocity,
- The distance between its current position and p_{best} and
- The distance between its current position and g_{best}

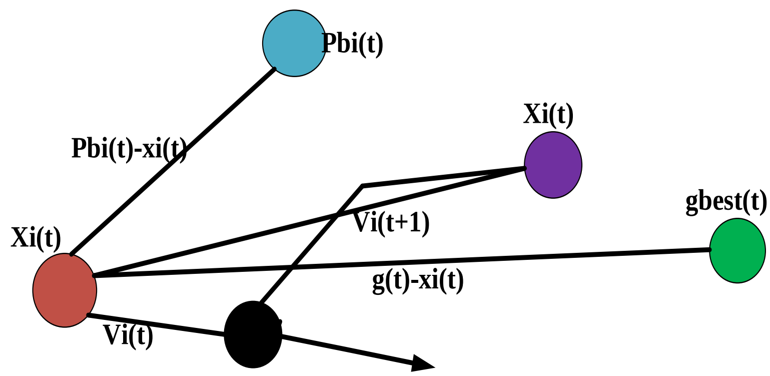


Figure 3. 8: Particle flying model

2. Population: it is a set of x particles at time t.

3. Swarm: it is an apparently disorganized population of moving particles that tend to cluster together while each particle seems to be moving in a random direction.

4. Particle velocity V (I): it is the velocity of the moving particles represented by a D-dimensional real valued vector. At time t, the ith particle vi (I) can be described as [7]:

Vi(I)=[vi,1(I); vi,2(I);…… vi,D(I)].

5. Inertia weight w (I): it is a control parameter that is used to control the impact of the previous velocity from the current velocity.

6. Individual best (pbi): As the particle moves through the search space, it compares its fitness value at the current position to the best fitness value it has ever attained at any time up to the current time. The best position is associated with the best fitness encountered so

far is called the individual best xt for each particle in the swarm,xt, can be determined and updated during the search.

7. Global best (gbi): It is the best position among all of the individual best positions achieved so far.

8. Stopping criteria: The search process will terminate under these conditions. In this work, the program will end either the number of the iterations. Since the last change of the best solution is greater than a pre-specified number or the number of iterations reaches the maximum allowable number.

The Pseudo-code of particle swarm optimization can be summarized as:

“Read the load and line data

Limit the 80 percent of the load

Initialize each particle

END

For each particle, calculate fitness value

If the fitness value is better than the best fitness value (pbest) in history set current value as the new pbest

End

Choose the particle with the best fitness value of all the particles as the gbest

For each particle

Calculate particle velocity

Update particle position

End”

Chapter Four

4. Research Modeling

4.1. Optimal Location and Size of DG and QG on RDN Using WOA

Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function. WOA is one method of optimization recently developed is applied here to minimize real power loss of distribution network. As have been described the total loss in the system is less than the loss wasted in the distribution level. One reason for this loss is caused by the increase in demand reactive current in the network. Due to limited capacity of generators while the demand of reactive power had increased the generators will try to generate much than normal to get more reactive current to reactive loads, this will create stress on feeders and most of the power is dissipated as a heat. This can be considerably reduced through the installation and control of reactive support, such as shunt capacitor, reducing reactive currents flowing in distribution feeders and reactive power optimization. Capacitors are widely installed in distribution systems for reactive power compensation to achieve power and energy loss reduction, power factor correction, system capacity release and to maintain a voltage profile within permissible limits [7]. The other reason is the increase in load demand, this time transformer tap changers will change position to supply the required current. When the network experience such condition at the same time all transformers will be forced to change tap position and the system might be forced to feed the load demand by violating the minimum voltage limits due to the increase in current is much higher than the increase in voltage. To maintain such condition optimal location and size of DG and QG will reduce the loss.

In this thesis, the active and reactive power from DG and reactive power sources from QG are injected based on feeder integrating capacity. According to feeders capacity standard [47] the feeder carrying capacity[4] should be less than the feeders peak load to protect the reverse current flow. This is done to get the maximum possible minimum total active power losses in the network such that it is better to limit the network carrying capacity of DG and QG than limiting the DG and QG to find the minimum loss.

While we are performing system optimization for radial distribution network using load flow, we should satisfy all the conditions above to meet the objective for proposed problem. This conditions are called constrains. Constraints are pre conditions that should not be violated and these are presented below:

Hence, the objective function of this study is minimizing the total active power loss in the system. This can be can be given as:

$$minP_{loss} = \sum_{i}^{N} I_i^2 R_i \tag{4.2}$$

Where Ii is current, Ri is resistance, and N is number of buses. Objective taken in this work is total real power loss minimization.

To bring the above objective function true the power flow equation should satisfy the all equality constraints:

The equality constraints are

$$P_{sub} + P_{DG} = P_{loss} + P_{load} \tag{4.3}$$

$$Q_{sub} + Q_{shunt} = Q_{loss} + Q_{load} \tag{4.4}$$

Where P_{sub} and Q_{sub} are the total real and reactive power injection by sub-station into the network P_{DG} and Q_{shunt} are the total real and reactive power, injected by DG and shunt capacitor respectively. P_{loss} and Q_{loss} are the total real and reactive power losses in the network. P_{load} and Q_{load} are the total real and reactive power losses of the network.

---

[4] *Feeder carrying capacity is less than the peak load i.e. sum of power loss and power demand. In this work to make the integration/compensation safe from reverse current flow, it is taken 80% of the limit as a network optimization constraint*.

The inequality constraints are

Voltage constraints

$$V_{min} \leq V_i \leq V_{max} \tag{4.5}$$

Where: $V_{min} = 0.95$ and $V_{max} = 1.05$

Line Capacity Constraints [15], [16]: the line capacity constraints of line *i* is limited by its maximum thermal rating limit as:

$$I_{li} \leq I_{li,rated} \tag{4.6}$$

Position of DG

Bus 1 is the substation or slack bus, so the position of the DG should not be used at bus 1:

$$2 \leq DG_{position} \leq n_{buses} \tag{4.7}$$

Chapter Five

5. Result and Discussion

Active power optimization using active and reactive power source is applied on two critical feeders of Bahir Dar radial distribution network. These feeders are arise from Bahir Dar substation II 400/230/66/15 kV bus. Feeder 5 is named as Ghion has 35 buses and the other named feeder 2 is named as Bata feeder.

Using the line and load data of radial distribution network mentioned in Table 3.3 and Table 3.4 backward forward sweep load flow is performed to get the total feeder loss and initial voltage profile of the bus. Before any optimization is undergoing the total loads of Bata feeder is 1.8262 Mw of active power and 1.5353 Mvar reactive power and Ghion feeder is 3.43257 Mw of active and 2.5776 Mvar of reactive power. In addition to this, the initial loss of the Bata feeder is 0.1262149 MW and Ghion feeder is 0.3395703 MW.

For system loss optimization under this work, the two methods of optimizations i.e. Particle Swarm Optimization and Whale Optimization Algorithm for total active power optimization problem was implemented using MATLAB R2016 programming language and computer property using double 2.2 GHZ processer and 7.58 GB installed memory (RAM) PC of core i7. The Matlab programmed code is executed using the pseudo code mentioned in section 3.5. This proposed model was aimed for real power minimization as per the objective function and constraint equations. The parameters of controlling values of PSO were set as: number of iteration is equal to 10, w is equal to 0.95, Cl is equal to 2, C2 is equal 2. In case of WOA the iteration is same with PSO and the dimensions (dm)[5] representing the total active power was set to one and number of bus-1 for computing the voltage profiles each bus mentioned the first bus is slack bus. The results are discussed in the following sections.

---

[5]*Dimensions (dm)-dimensions are output deciders in the program. For finding the total loss dim=1 means the program will consider 80% of feeder integration limit(peak load) so that it will find the size and unit place for DG/QG to set the minimum possible loss.*

5.1 Ghion Feeder Optimization

The load flow program coded in Matlab using line and load data from table 3.3 is performed. The result of this load flow gives the total line losses is 339.5703 kW.

When DG and QG are used as source of optimization in Ghion feeder as seen from the table 5.3 the feeder total active power loss after PSO is 27 kW and the feeder total active power loss after WOA is 22 kW. From the above result, it can be said that the total power saved after PSO is 312.6 kW and after WOA is 317.6 kW power is saved from Ghion feeder.

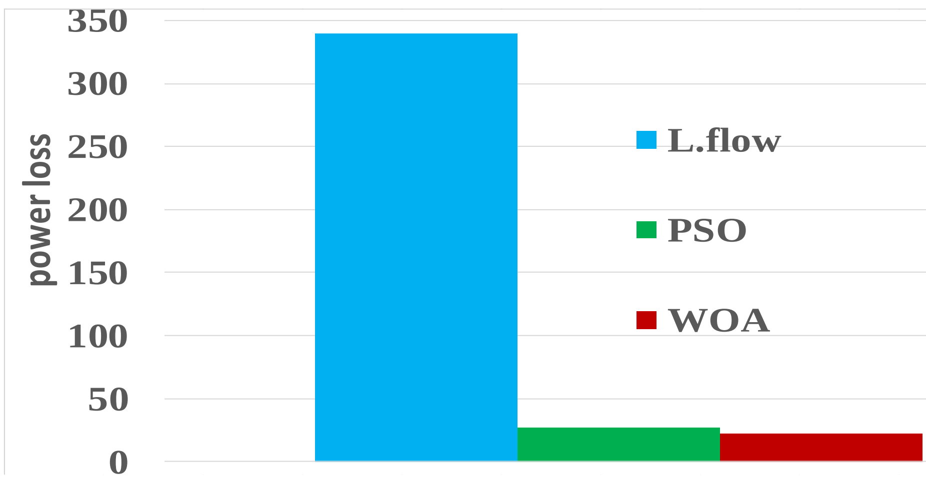


Figure 5. 1: Power loss of Ghion feeder before and after optimization

5.1.1. Voltage Profile Improvement of Ghion Feeder

After the placement of DG and QG, the voltage profile is also improved. The load flow indicates that the average voltage profile of the feeder before optimization was about 0.961 p.u. The voltage profile after optimal sizing and placement of DG and QG using PSO is equal to 0.988 p.u. and the voltage profile after WOA is equal to 1.0258 p.u. The per branch profile of voltage after and before optimization is shown in table 5.1 and figure 5.2.

The minimum voltages before DG and QG placement are 0.9436 p.u (bus 35) and 0.9437 p.u (bus 34). While PSO is used for placement and size of DG and QG these are improved to 0.9955 p.u (bus 35) and 0.9960 p.u (bus 34) and improved to 1.0189 p.u (bus 35) and 1.0194 p.u (bus 34) when WOA is used for optimization. This is seen in the table below

Bus Number	Vbus (p.u.) Before Optimization	Vbus(p.u.) after PSO optimization	Vbus (p.u.) after WOA Optimization
1	1	1	1
2	0.9859	0.9941	1.0095
3	0.9844	0.9935	1.0107
4	0.9812	0.9924	1.0131
5	0.9749	0.9903	1.0182
6	0.9707	0.9891	1.0218
7	0.9705	0.9882	1.0226
8	0.9691	0.984	1.0278
9	0.9683	0.994	1.0095
10	0.9665	0.9887	1.0214
11	0.9658	0.9879	1.0223
12	0.9627	0.9796	1.0236
13	0.962	0.9787	1.0227
14	0.961	0.9778	1.0218
15	0.96	0.9796	1.0236
16	0.9579	0.9759	1.0451
17	0.9575	0.9743	1.0382
18	0.9572	0.9733	1.0381
19	0.9569	0.9718	1.049
20	0.9567	0.9714	1.0415
21	0.9566	0.9708	1.049
22	0.9574	0.9741	1.044
23	0.9574	0.9741	1.044
24	0.9577	0.975	1.0442
25	0.9577	0.9749	1.0441
26	0.9536	0.9978	1.0191
27	0.9509	1.0047	1.0178

28	0.9484	1.0133	1.018
29	0.9477	1.0106	1.0183
30	0.9466	1.0066	1.0195
31	0.9456	1.0027	1.0209
32	0.9449	1.0003	1.0237
33	0.9441	0.9975	1.0209
34	0.9437	0.996	1.0194
35	0.9436	0.9955	1.0189

Table 5. 1: Per unit voltage values of the Ghion feeder before and after optimization

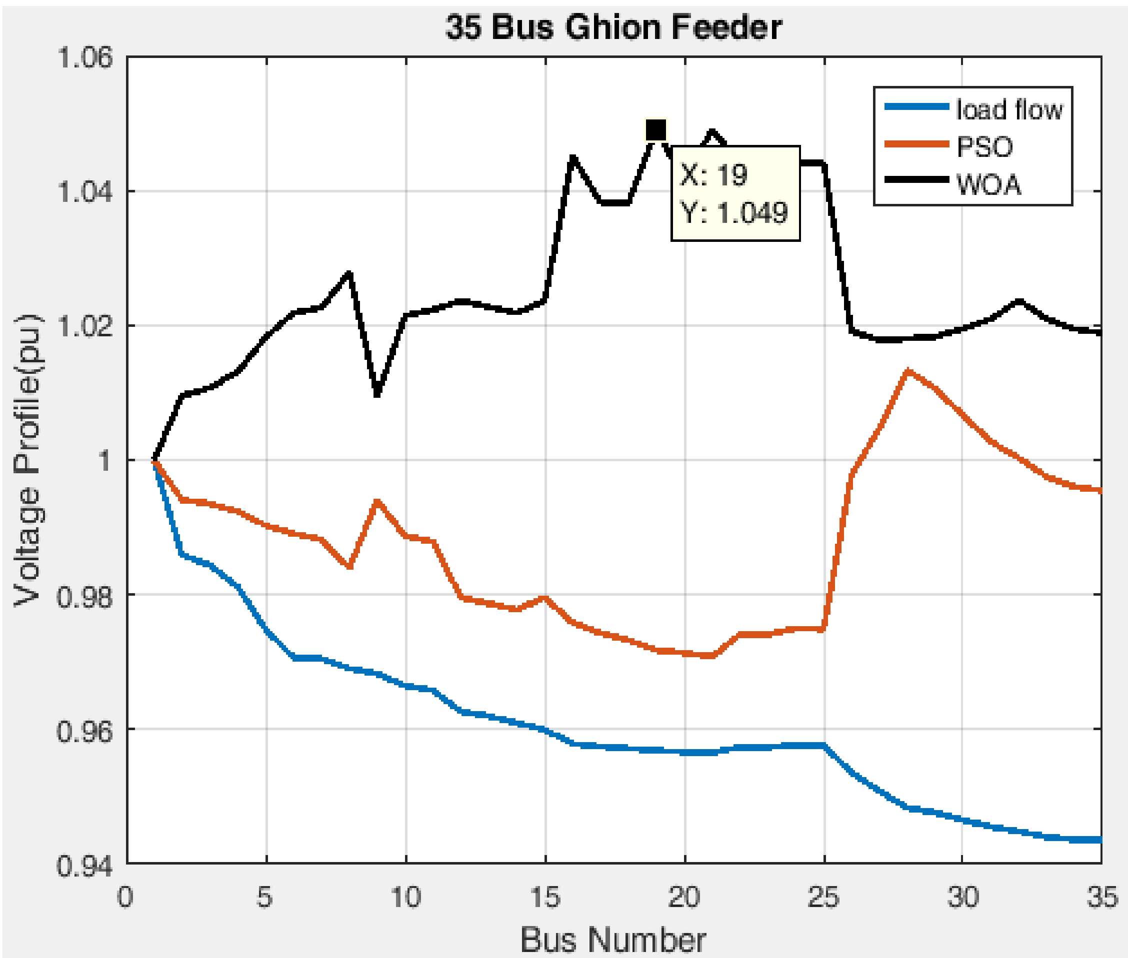


Figure 5. 2: Voltage profile of the 35-bus feeder after and before optimization

5.2. Optimization of Bata Feeder

In optimizing the 40-bus Bata feeder using DG and QG as source of optimization as seen from the table 5.4 the feeder total active power loss before optimization was 126.2149 kW the total active power loss after PSO is 51.3 kW and the feeder total active power loss after WOA is 22.4 kW. This show that the total power saved after PSO is 74.914 kW and after WOA is 103.814 kW power is saved.

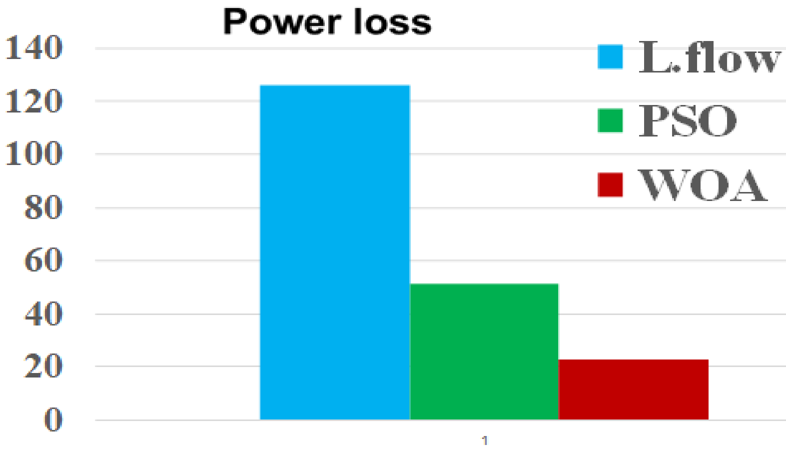


Figure 5. 3: Power loss of Bata feeder before and after optimization

5.2.1. Voltage Profile of Bata Feeder

After the placement of DG and QG, the voltage profile is also improved. The average voltage profile of the feeder before optimization was about 0.9727 p.u. The voltage profile after optimal sizing and placement of DG and QG using PSO is equal to 0.9912 p.u. and the voltage profile after WOA is equal to 1.0206 p.u. The per unit branch profile of buses before and after optimization is shown in table 5.2.

The minimum voltages before DG and QG placement are 0.9645 p.u (bus 40) and 0.9648.9437 p.u (bus 39). While PSO is used for placement and size of DG and QG improved voltage profile of the minimum bus changed to 0.9983 p.u (bus 40) and 0.9981 p.u (bus 39) and improved to 1.0232 p.u (bus 40) and 1.0242 p.u (bus 39) when WOA is used for optimization. The voltage profile of branches is shown below:

Bus Number	Vbus (pu) before optimization	Vbus (pu) after PSO optimization	Vbus (pu) after WOA optimization
1	1	1	1
2	0.9847	0.9986	1.0402
3	0.9813	0.9843	1.014
4	0.9796	0.9837	1.0176
5	0.9788	0.9834	1.0212
6	0.9771	0.9827	0.9991
7	0.9741	0.9886	1.032
8	0.9715	0.9889	1.0108
9	0.9714	0.9886	1.0391
10	0.9847	0.9862	1.0469
11	0.9809	0.9812	1.007
12	0.9809	0.9812	1.0401
13	0.9764	0.9758	1.0182
14	0.9753	0.9721	1.0454
15	0.975	0.9709	1.0089
16	0.9764	0.9754	1.0217
17	0.9751	0.9797	1.0188
18	0.9743	0.9771	1
19	0.9736	0.9747	1.0321
20	0.9724	0.9705	1.0022
21	0.9741	0.986	1.0253
22	0.9707	0.9937	1.0096
23	0.9691	0.9985	1.0014
24	0.9683	1.001	1.0195
25	0.9668	1.0058	0.9974
26	0.9666	1.0051	1.0381
27	0.9707	0.9933	1.0164

28	0.9683	1.0009	0.9987
29	0.9667	1.0057	0.9999
30	0.9664	1.0061	1.0447
31	0.9662	1.0077	1.0206
32	0.9662	1.0076	1.0334
33	0.9664	1.0017	1.0275
34	0.9655	0.9984	1.0258
35	0.9653	0.9981	1.0256
36	0.9653	0.998	1.0255
37	0.9663	1.001	1.0271
38	0.9654	0.9977	1.0254
39	0.9648	0.9981	1.0242
40	0.9645	0.9983	1.0232

Table 5. 2: Per unit voltage values of the Bata feeder before and after optimization

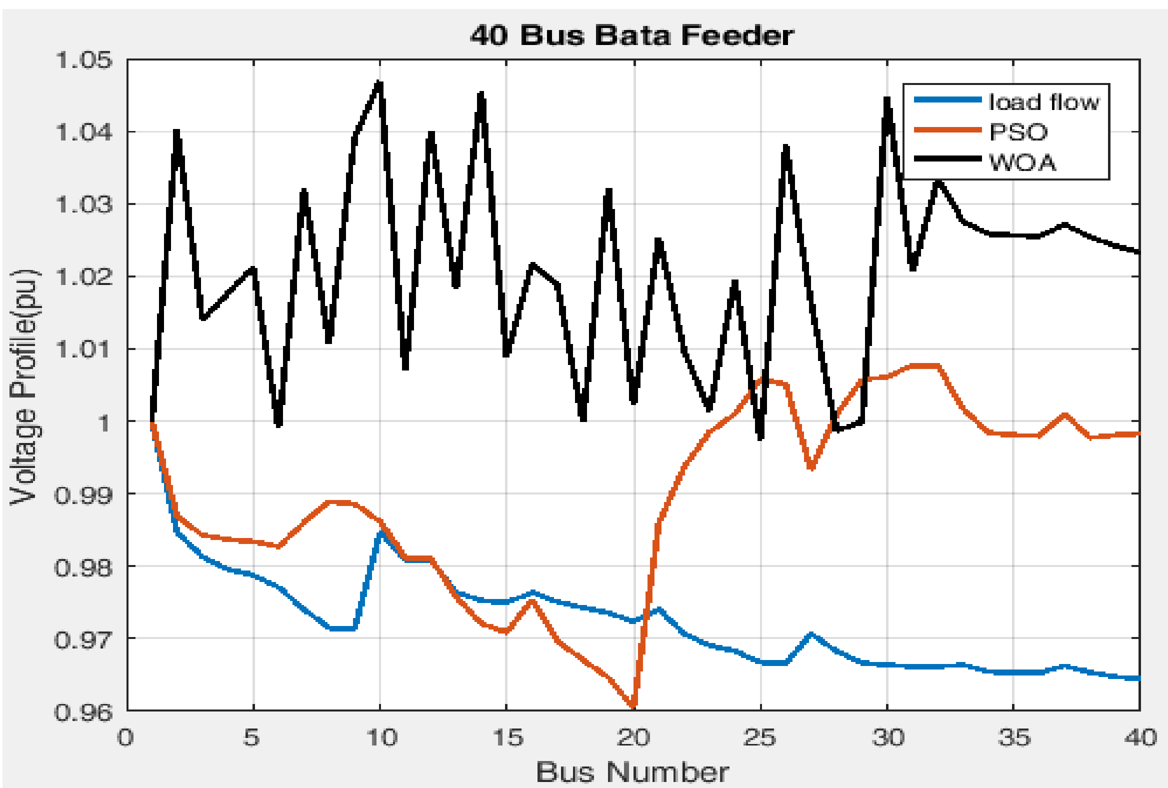


Figure 5.2: Voltage profile of the 40-bus feeder after and before optimization

In this thesis, all the objectives are satisfied. The active power loss is reduced and the voltage profiles are improved. It is often robust to consider feeder voltage regulation related to profiles of feeder voltage. Voltage profile indicates the magnitude of voltage with respect to its location on the feeder. One way to determine the quality of power is maintaining the receiving end voltage magnitude closer the same to the sender end. To bring this achievement practically different method of compensating devices and Distribution generation can be applied for distribution system. Among this distribution generation and shunt capacitor are used in this thesis, these are illustrated using the thirty five-bus and forty-bus feeders. The average voltage profile of these feeders before and after optimization is presented in table 5.3 and 5.4.

Optimization output Ghion feeder summary

Item	Ploss (kw)	DG size	QG size	Location		Vavg
				DG	QG	
Load flow	339.5703	-	-	-	-	0.96
PSO	27	3.1693	1.7088	28	27	0.988
WOA	22	1.822	0.2804	16	17	0.997

Table 5. 3: Size and location result summary of Ghion feeder buses

Optimization output Bata feeder summary

Item	Ploss (kw)	DG size	QG size	Location		Vavg
				DG	QG	
Load flow	126.2149	-	-	-	-	0.9726
PSO	51.3	1.4372	1.1434	25	24	0.989
WOA	22.4	0.82043	1.0703	35	31	0.999

Table 5. 4: Size and location result summary of Bata feeder buses

The wind power density and the capacity factor of Bahir Dar is very interesting. Hence, it is quite important to design two wind turbines in the site and cover the rest of power demand by solar power. The Vestas V82 wind turbine output power at cumulative speed Vavg=10.43 m/s as seen in table E 1 is 1210 kW. Taking the sum of the two turbines the wind turbines would have 2410 KW output power.

The required solar power is 2700 kw-2410 kW = 290 kW. The daily average solar radiation of Bahir Dar city as seen in table 2.1 is 6.286 kwh/m⁻/d. The solar irradiance can be found using equation 2.12 and table 2.1 as:

$$Ho = 1367 * [(1 + 0.033 * \cos((360 * 181.42)/365) * (\cos 11 * \cos(-0.752) * \sin(89.99 + 2\pi/360 * 89.99 \sin 11 \ \sin(-0.752\ )\ )]$$

$=1,322.73\ {}^{W}/_{m^2}$

The solar output at 1322 ${}^{W}/_{m^2}$ given in figure B1 is about 190 W with this about 1527 solar panels are required.

To minimize investment cost of the biomass, biomass distribution generation should be installed between 16th bus of Ghion feeder and 35th bus of Bata feeder. Our concern is WOA, referring table 5.3 and 5.4, it can be seen that the total DG values required for WOA optimization is about 2.7 MW[6]. Since biomass is back up for DG, its value should equal to the total power demanded from DG i.e. 2.7 MW. Applying equation 2.47, for normal operation the total biomass consumed by the power plant to generate 2.7 MW with co firing capacity[7] of 5%, heat rate[8] 80% and HHV=80% is:

$$\frac{t.biomass}{year} = 2700 * 0.05 * 0.8 * 8760\ {}^{hrs}/_{yr} * \frac{1}{0.8}$$
$$= 1{,}182{,}600\ tons/year$$

[6] *2.7 MW- is the sum of DG values required to optimize Ghion and Bata feeders. As it can be observed, it is less than the demand of sum of Ghion and Bata feeders i.e. 5.7MW*

[7] *Co firing capacity-to start generation products like coal are required to be co fired, however as the co firing product increase the efficiency will decrease. Hence, the minimum possible value 5% was taken.*

[8] *Heat rate- It is defined, as the rate of heat/steam flow (kg/hr) required for producing unit shaft output (1 kW), therefore, it is the efficiency of the turbine (80-90%). Here the minimum efficiency was taken.*

The QG value of the two feeder after WOA optimization is 1.35 Mvar the value of QG can be found in multiple of 150 Kvar as given in equation 2.39. Therefore the total where U is equal to nine.

5.3. Investment Cost of Overall Work

For any design of wind, solar and biomass power plant the investment cost and shunt capacitor cost (QG cost) could be summarized in following table:

Technology	Investment cost($/w) [48]	Capacitor cost($/Kvar) [49]
Biomass	1.5-2.5	5
Wind	0.8-1.5	
Solar, PV	6-8	

Table 5. 5: Expected cost of DG and QG in USD per watt and Kvar respectively

The investment cost of this thesis is the optimization result of Whale Optimization Algorithm (WOA) results in the two feeders. Since wind capacity factor is higher, it is reasonable to choose two wind turbines and the rest should be solar energy. The biomass is designed to avoid intermittence nature of wind and solar energy. Hence, it would cover all the power required by solar and wind during off condition. Depending on the simulation result summary (table: 5.3 & 5.4) the total wind energy required is 2.41MW and solar is 0.29MW. Therefore, the biomass output is equal to 2.7MW, which is the sum of power required by solar, and wind power.

Technology	Size	Investment cost($)
Biomass	2.7(MW)	4,050,000-10125000
Wind	2.41(MW)	1928000-2892000
Solar, PV	0.29(MW)	1740000-13920000
QG	1.35 (Mvar)	6750
Total investment cost		7724750-26943750
Average of total investment cost		17,334,250

Table 5. 6: Total investment cost summary of the study

Chapter Six

6. Conclusion, Recommendation and Future Works

6.1. Conclusions

In this thesis, 35 and 40 buses of Bahir Dar radial distribution network were considered for optimization of total active power. Optimal location and size of QG and DG were applied. After optimization, the power loss had reduced from 339.5703 kW to 22 kW in Ghion feeder and from 126.2149 kW to 22.4 kW in Bata feeder using WOA. It also had reduced from 339.5703 kW to 27 kW in Ghion feeder and from 126.2149 kW to 51.3 kW in Bata feeder using PSO. In comparison using PSO it had been saved 312.57 kW in Ghion and 75.085 kW in Bata feeder. In the second case, WOA was used as a tool for optimization, this time 317.57 kW power in Ghion and 103.81 kW power was saved in Bata feeder.

The algorithm developed for power loss reduction by applying shunt compensation of capacitor and DG integration had improved the overall system voltage profile. As a result the voltage profile before any optimization was 0.96, after optimization with PSO was 0.988 and after optimization with WOA was 0.997 p.u in Ghion feeder. The voltage profile of Bata feeder before and after optimization was 0.9726, after optimization with PSO was 0.989 and after optimization with WOA 0.999 p.u in Bata feeder.

The overall average investment cost was calculated $17,334,250.The cost is somewhat higher however, based on the reduction of active power loss and bus voltage profile improvement it is quite important contribution for the security of the system.

Localizing the generation and the capacitor demands had reduced the power loss. This is because the current flowing in each branch of the feeder has reduced this further reduced loss of environmental and electrical effects on the line. Hence, the voltage drop in the branch of feeder is reduced. Therefore, in one way or another if, the voltage profile was improved and the loss in the system had reduced, it can be said that the quality of the power in terms of voltage profile and active power loss is improved. From the above comparison, it can be seen that WOA is an efficient method over PSO in distribution network optimization and voltage profile improvement.

6.2. Recommendation

Distribution network optimization has great role in energy production, maximization and improving network caring capacity. This is very essential as the countries development in manufacturing, energy consumption getting bigger and bigger. Although the investment cost was found higher, having distribution generations, and capacitor banks locally will reduce the construction cost of new switchyards and powerhouses. Furthermore, Ethiopia is highly dependent on hydropower; since renewable energies are affected by natural conditions, it is very important to have generation variation. Therefore, in this thesis apart from the focus of reducing distribution network active power loss, the variations would bring alternative solution in energy production deficiency. Since the sum effect of all distribution network has effect on overall power system, giving special attention to large distribution systems like Bahir Dar will provide significant power loss improvement.

Hence, it is recommend the Ethiopian electric power to implement the loss minimization technique addressed by this study to reduce the loss and improve the voltage profile in the network significantly.

6.3. Future Works

The work of optimization or energy maximization is not something it end today, instead as the tool of optimization has improved or better criteria are exist, it has to be tested again. Therefore, Bahir Dar distribution network active power optimization might be improved by author of this thesis or by any other researcher by considering more constraints like cost and better method of optimization. In addition to this consideration of all the buses and system reconfiguration could be tested to bring the best minimum loss.

6.4. Limitations of the Study

There were various difficulties when doing this thesis some of the problems are:

1. It is very difficult to predict the exact demand of load of feeders since the demand of power is frequently changed. Hence, the average load data should be taken from many years of hourly load demand. However, in this study due to lack of data the one time recorded data is taken as average demand.
2. The biomass data is taken from ministry of food of Amhara regional state data and there is no other biomass data source registered by municipal office or any other

body. On the other hand, the daily solar irradiance is taken from websites and this not accurate as local data’s, since it is affected by environmental factors. The national meteorology however has the duration data only.

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List of Appendixes

A. Mean, Variance and Standard Deviation

A1. Mean

The *expected value* of a random variable is defined to be its average value in statistics it is called mean. Thus if x is observed to take values $x1$, $x2$. . . xn we have [50]

$$E(x) = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where: $E(x)$ denotes the expected value of a random variable x

n is the no of observed values

To define the expected value of a continuous function $f(x)$ over an interval $[a, b]$, divide the interval into n equal sections $[xi, xi+1]$ $(x1 = a, xn+1 = b)$ and approximate the area under the curve by the sum of the areas of the rectangles of height $f(xi)$ and width $\frac{b-a}{n}$ [50]

$$\frac{b-a}{n}\sum_{i=1}^{n} f(x_i) \approx \int_{a}^{b} f(x)dx$$

And so in the limit as n tends to infinity

$$E\big(f(x)\big) = \frac{1}{b-a}\int_{a}^{b} f(x)dx$$

A2. Variance and Standard Deviation

The expected value of a random variable does not necessarily indicate how the values are dispersed. Hence, it is important to introduce *variance* and *standard deviation* as measures of the dispersion of a set of values taken by a random variable. If x is a single random variable having an expected value $E(x)$, *[50] define the variance*, $Var(x)$, *of* x:

$$Var(x) = E([x - E(x)]^2)$$

The definition of variance extends to a set of variables $x1$, $x2$, . . . xn, with mean value $E(x)$ and is usually symbolized by σ^2, [50] where

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n} (x_i - E(x))^2$$

The standard deviation is defined to be the square root of the variance and so variance is often denoted by σ^2 and standard deviation by σ. However, standard deviation is invariably computed according to the formula [50]:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}([x_i - E(x)]^2)}$$

In this case, *E(x)* in the formula is based on just a selection of all possible *xi* values and so is not an independent variable. This restriction reduces the degrees of freedom inherent in the equation from *n* to *n*−1

B. Solar Panels Rating Manufacturers Specification

ELECTRICAL CHARACTERISTICS

Cell	156.5mm Square Polycrystalline silicon
No. of Cells and Connections	60 in series
Open Circuit Voltage (Voc)	36.7V
Maximum Power Voltage (Vpm)	30.2V
Short Circuit Current (Isc)	7.82A
Maximum Power Current (Ipm)	7.13A
Maximum Power (Pm)[1]	Typical 215W
Encapsulated Solar Cell Efficiency (ηc)	14.6%
Module Efficiency (ηm)	13.1%
Maximum System Voltage	DC 1000V
Series Fuse Rating	15A
Type of Output Terminal	Lead Wire with MC3 Connector

Specifications are subject to change without notice
[1] (STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5

MECHANICAL CHARACTERISTICS

Dimensions	994 x 1652 x 46mm
Weight	21.0kg

TEMPERATURE COEFFICIENT

Temp. Coefficient of Pmax	-0.485	% / °C
Temp. Coefficient of Voc	-0.13	V / °C
Temp. Coefficient of Isc	0.053	% / °C

ABSOLUTE MAXIMUM RATINGS

Parameters	Rating	Unit
Operating Temperature	-40 to +90	°C
Storage Temperature	-40 to +90	°C
Dielectric Voltage Withstood	3000 max.	V-DC

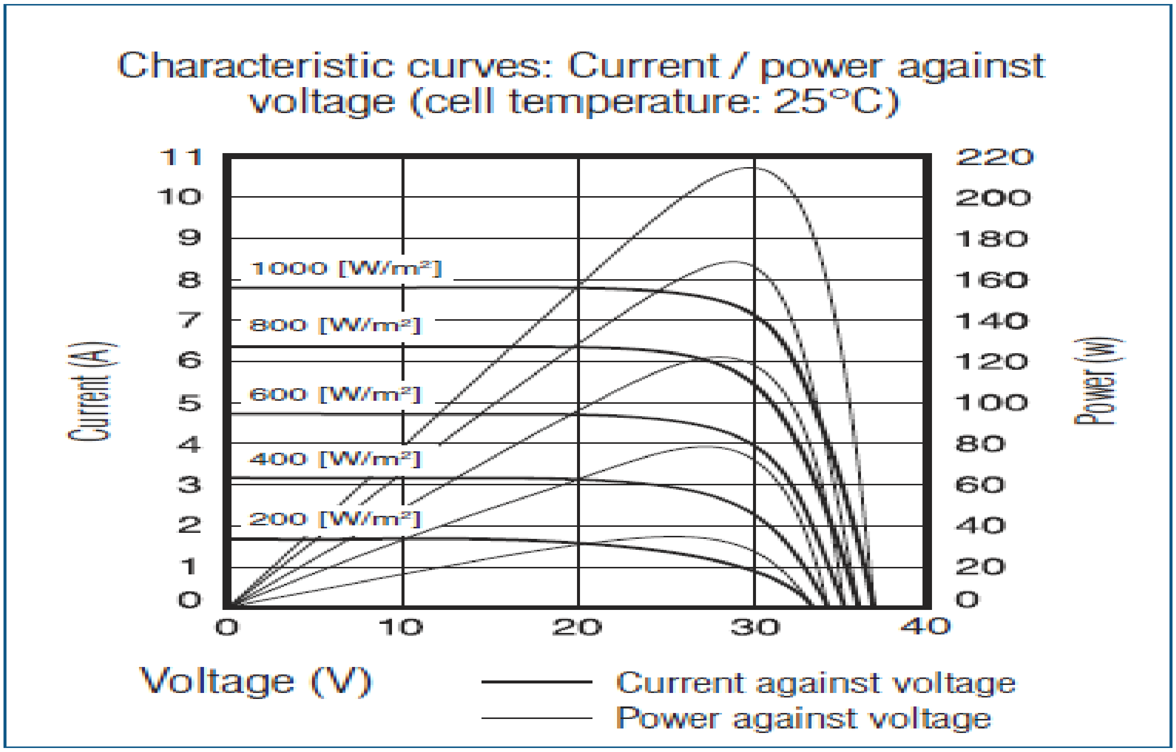
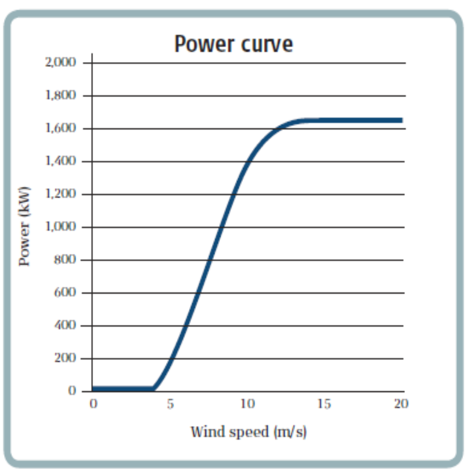


Figure B. 1: Electrical characteristics of solar panels (ND-A215A2)

C. Wind Turbine Rating Manufacturers Specification



Rotor

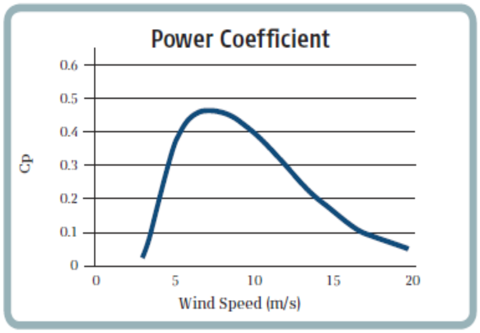
Diameter:	82 m
Area swept:	5,281 m²
Nominal revolutions:	14.4 rpm
Number of blades:	3
Power regulation:	Active-Stall®
Air brake:	Full blade pitch by three separate hydraulic pitch cylinders.

Tower

50Hz, 230V:	Hub height (approx.) 78 m
60Hz, 110V:	Hub height (approx.) 70 m, 80 m

Operational data

Cut- in wind speed:	3.5 m/s
Nominal wind speed:	13 m/s
Cut-out wind speed (10 minutes):	20 m/s



Generator

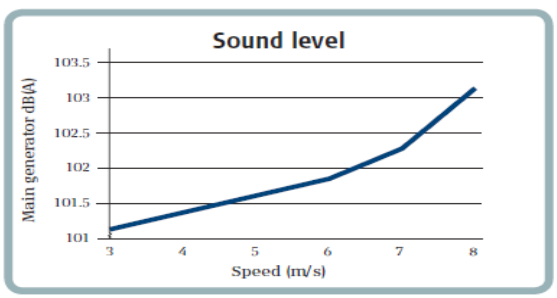
Type:	Asynchronous water cooled
Nominal output:	1,650 kW
Operational data:	50/60 Hz 690/600V

Gearbox

Type:	Planetary/helical stages

Control

Type:	Microprocessor-based monitoring of all turbine functions with the option of remote monitoring. Output regulation and optimisation via Active-Stall®.



Weight

Nacelle:	52 t
Rotor:	43 t
Towers: 50Hz, 230V	
Hub height:	IEC IIA
78 m	115 t
60Hz, 110V	
Hub height:	IEC IIA
70 m	105 t
80 m	125 t

t – metric tonnes.

All specifications subject to change without notice.

Figure C 1: Vestas v82 wind turbine rating manufacturers data

D. Meteorology Agency Wind Data in Bahir Dar

$Reg:$	$Gojjam$	$Lat:$		$11°.4´$							
$Stn:$	$B\_Dar\ SYN$		Lon:	$37°.3´$							
$Element$		$Wind\ speed\ at\ 5m.(m/sec)$									
Year	*Date*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
2013	1	1.204	1.370	1.237	1.137	1.137	1.237	1.204	1.220	1.110	1.220	1.237	1.370
	2	1.370	1.137	1.237	1.124	1.204	1.124	1.370	1.037	1.230	1.370	1.370	1.137
	3	1.237	1.220	1.230	1.350	1.370	1.220	1.237	1.304	1.304	1.204	1.304	1.304
	4	1.137	1.237	1.224	1.137	1.114	1.224	1.122	1.122	1.114	1.334	1.114	1.111
	5	1.224	1.124	1.122	1.337	1.037	1.220	1.137	1.124	1.204	1.370	1.037	1.114
	6	1.170	1.137	1.270	1.337	1.370	1.004	1.110	1.224	1.370	1.145	1.370	1.440
	7	11.009	1.037	1.180	1.370	1.104	1.204	1.137	1.104	1.237	1.237	1.420	1.230
	8	1.250	1.240	1.240	1.203	1.420	1.240	1.250	1.320	1.220	1.225	1.322	1.232
	9	1.420	1.253	1.320	1.453	1.425	1.234	1.200	1.420	1.320	1.330	1.356	1.330
	10	1.223	1.323	1.320	1.323	1.323	1.233	1.213	1.233	1.323	1.323	1.330	1.232
	11	1.370	1.330	1.334	1.400	1.320	1.230	1.320	1.220	1.320	1.322	1.117	1.437
	12	1.237	1.330	1.233	1.223	1.337	1.330	1.330	1.250	1.333	1.332	1.210	1.240
	13	1.220	1.137	1.220	1.220	1.230	1.210	1.120	1.120	1.210	1.220	1.220	1.320

	14	1.104	1.204	1.020	1.200	1.137	1.170	1.137	1.137	1.120	1.153	1.210	1.123
	15	1.120	1.203	1.127	1.239	1.123	1.117	1.117	1.153	1.120	1.304	1.204	1.230
	16	1.145	1.103	1.203	1.204	1.180	1.117	1.112	1.117	1.303	1.320	1.330	0.134
	17	1.350	1.114	1.333	1.334	1.320	1.233	1.323	1.193	1.290	1.303	1.279	1.270
	18	1.303	1.237	1.237	1.224	1.333	1.337	1.303	1.303	1.303	1.303	1.330	1.330
	19	1.330	1.330	1.330	1.360	1.503	1.404	1.420	1.162	1.247	1.267	1.374	1.237
	20	1.403	1.238	1.228	1.224	1.137	1.228	1.227	1.223	1.432	1.237	1.238	1.223
	21	1.330	1.330	1.234	1.304	1.304	1.304	1.237	1.347	1.404	1.437	1.403	1.233
	22	1.453	1.237	1.304	1.238	1.304	1.320	1.372	1.237	1.238	1.217	1.237	1.237
	23	1.370	1.227	1.379	1.337	1.238	1.337	1.404	1.424	1.234	1.237	1.237	1.233
	24	1.223	1.270	1.238	1.228	1.228	1.303	1.504	1.473	1.238	1.320	1.320	1.327
	25	1.320	1.234	1.404	1.404	1.374	1.324	1.137	1.337	1.238	1.237	1.237	1.373
	26	1.404	1.403	1.379	1.138	1.238	1.275	1.237	1.237	1.304	1.237	1.337	1.279
	27	1.303	1.270	1.228	1.238	1.238	1.338	1.237	1.237	1.237	1.237	1.337	0.887
	28	1.470	1.233	1.237	1.238	1.234	1.238	1.237	1.237	1.234	1.372	1.270	1.337
	29	1.403		1.237	1.237	1.237	1.224	1.224	1.224	1.238	1.237	1.237	1.237
	30	1.270		1.304	1.370	1.304	1.238	1.304	1.604	1.404	1.234	1.230	1.320
	31	1.320		1.339		1.224		1.234	1.234		1.373		1.238

2014	1	1.230	1.237	1.320	1.304	1.374	1.238	1.273	1.237	1.237	1.227	1.237	1.224
	2	1.223	1.237	1.233	1.234	1.404	1.237	1.237	1.237	1.304	1.337	1.270	1.038
	3	1.330	1.350	1.233	1.337	1.234	1.333	1.237	1.337	1.237	1.237	1.237	1.238
	4	1.223	1.327	1.337	1.337	1.224	1.237	1.373	1.237	1.234	1.332	1.233	1.304
	5	1.230	1.227	1.224	1.220	1.238	1.204	1.327	1.327	1.228	1.332	1.330	1.337
	6	1.220	1.227	1.229	1.247	1.238	1.337	1.227	1.220	1.304	1.322	1.330	1.330
	7	1.370	1.220	1.339	1.223	1.333	1.338	1.220	1.374	1.333	1.425	1.322	1.224
	8	1.220	1.237	1.223	1.332	1.332	1.237	1.322	1.339	1.223	1.333	1.090	1.270
	9	1.320	1.332	1.228	1.332	1.322	1.345	1.440	1.332	1.442	1.228	1.330	1.227
	10	1.333	1.373	1.227	1.333	1.333	1.238	1.322	1.228	1.404	1.379	1.227	1.234
	11	1.334	1.227	1.334	1.223	1.423	1.333	1.332	1.333	1.337	1.334	1.330	1.337
	12	1.332	1.304	1.332	1.334	1.333	1.223	1.223	1.238	1.227	1.333	1.227	1.330
	13	1.223	1.328	1.337	1.337	1.333	1.332	1.224	1.224	1.334	1.334	1.224	1.333
	14	1.370	1.332	1.332	1.224	1.338	1.237	1.404	1.329	1.333	1.333	1.333	1.334
	15	1.323	1.333	1.332	1.233	1.337	1.437	1.424	1.404	1.428	1.336	1.335	1.237
	16	1.260	1.304	1.379	1.173	1.234	1.237	1.337	1.238	1.238	1.220	1.233	1.224
	17	1.333	1.224	1.223	1.238	1.233	1.370	1.272	1.177	1.237	1.337	1.170	1.230
	18	1.237	1.238	1.328	1.328	1.172	1.327	1.329	1.097	1.035	1.237	1.324	1.327

	19	1.327	1.227	1.333	1.228	1.227	1.237	1.233	1.224	1.233	1.233	1.333	1.233
	20	1.337	1.234	1.224	1.339	1.237	1.237	1.227	1.237	1.234	1.223	1.237	1.224
	21	1.223	1.238	1.333	1.224	1.337	1.123	1.270	1.223	1.332	1.332	1.330	1.330
	22	1.330	1.329	1.239	1.229	1.223	1.225	1.223	1.223	1.333	1.222	1.330	1.222
	23	1.223	1.379	1.222	1.223	1.332	1.325	1.332	1.332	1.332	1.228	1.332	1.332
	24	1.332	1.270	1.337	1.228	1.338	1.227	1.223	1.224	1.237	1.223	1.220	1.333
	25	1.332	1.338	1.338	1.337	1.333	1.332	1.223	1.322	1.337	1.332	1.423	1.272
	26	1.333	1.038	1.338	1.227	1.224	1.372	1.338	1.228	1.333	1.333	1.333	1.011
	27	1.420	1.377	1.223	1.339	1.404	1.237	1.428	1.375	1.247	1.248	1.427	1.427
	28	1.270	1.237	1.327	1.489	1.337	1.337	1.326	1.337	1.067	1.034	1.404	1.324
	29	1.332		1.333	1.324	1.332	1.221	1.033	1.337	1.069	0.895	1.333	1.332
	30	1.112		1.234	1.370	1.232	1.338	1.227	1.221	1.111	1.112	1.111	1.321
	31	1.230		1.224		1.113		1.234	1.223		1.333		1.332
2015	1	1.223	1.237	1.224	1.099	1.099	1.234	1.223	1.333	1.445	1.224	1.334	1.023
	2	1.220	1.304	1.332	1.228	1.337	1.332	1.224	1.222	1.332	1.227	1.112	1.112
	3	1.322	1.332	1.222	1.222	1.332	1.233	1.424	1.432	1.223	1.332	1.404	1.352
	4	1.227	1.102	1.332	1.332	1.223	1.112	1.113	1.332	1.225	1.224	1.223	1.113
	5	1.236	1.223	1.227	1.332	1.223	1.223	1.332	1.332	1.332	1.370	1.333	1.337

	6	1.101	1.004	1.068	1.231	1.033	1.333	1.333	1.237	1.235	1.322	1.113	1.223
	7	1.223	1.170	1.112	1.221	1.223	1.217	1.122	1.234	1.112	1.221	1.333	1.123
	8	1.122	1.038	1.223	1.122	1.112	1.113	1.111	1.112	1.112	1.332	1.113	1.122
	9	1.112	1.113	1.228	1.118	1.221	1.224	1.223	1.114	1.223	1.222	1.111	1.332
	10	1.223	1.114	1.221	1.223	1.452	1.112	1.112	1.337	1.222	1.224	1.452	1.524
	11	1.223	1.333	1.333	1.333	1.337	1.234	1.337	1.366	1.366	1.366	1.327	1.366
	12	1.236	1.636	1.453	1.564	1.366	1.366	1.456	1.457	1.111	1.322	1.456	1.422
	13	1.223	1.337	1.337	1.367	1.366	1.266	1.226	1.112	1.334	1.422	1.336	1.337
	14	1.422	1.222	1.222	1.223	1.222	1.222	1.223	1.333	1.565	1.365	1.366	1.364
	15	1.222	1.222	1.223	1.333	1.267	1.224	1.222	1.224	1.267	1.367	1.367	1.367
	16	1.222	1.222	1.223	1.367	1.267	1.222	1.223	1.463	1.223	1.111	1.223	1.223
	17	1.223	1.447	1.237	1.222	1.222	1.227	1.223	1.227	1.367	1.227	1.223	1.223
	18	1.227	1.467	1.267	1.227	1.227	1.234	1.222	1.223	1.222	1.224	1.223	1.227
	19	1.223	1.283	1.223	1.223	1.112	1.224	1.223	1.223	1.337	1.223	1.223	1.223
	20	1.223	1.228	1.113	1.112	1.227	1.223	1.224	1.337	1.233	1.227	1.227	1.227
	21	1.223	1.282	1.223	1.223	1.227	1.223	1.224	1.423	1.111	1.223	1.111	1.111
	22	1.112	1.227	1.226	1.266	1.267	1.221	1.111	1.221	1.112	1.113	1.327	1.227
	23	1.113	1.336	1.227	1.566	1.115	1.257	1.112	1.224	1.037	1.224	1.113	1.224

	24	1.113	1.404	1.118	1.453	1.457	1.115	1.112	1.422	1.227	1.456	1.447	1.227
	25	1.115	1.224	1.227	1.113	1.112	1.112	1.226	1.116	1.112	1.366	1.456	1.457
	26	1.227	1.446	1.457	1.227	1.224	1.227	1.236	1.111	1.123	1.457	1.112	1.112
	27	1.112	1.456	1.227	1.224	1.224	1.227	1.227	1.227	1.224	1.111	1.223	1.227
	28	1.224	1.227	1.227	1.367	1.267	1.227	1.226	1.227	1.223	1.227	1.226	1.557
	29	1.117		1.113	1.117	1.119	1.411	1.373	1.116	1.224	1.114	1.112	1.233
	30	1.227		1.117	1.113	1.223	1.266	1.267	1.222	1.112	1.442	1.267	1.223
	31	1.227		1.223		1.223		1.223	1.223		1.223		1.221
2016	1	1.117	1.267	1.423	1.222	1.117	1.112	1.223	1.227	1.244	1.227	1.422	1.444
	2	1.111	1.442	1.223	1.115	1.112	1.223	1.177	1.364	1.236	1.112	1.116	1.115
	3	1.070	1.137	1.112	1.117	1.117	1.447	1.446	1.442	1.444	1.442	1.262	1.246
	4	1.366	1.117	1.466	1.269	1.267	1.268	1.288	1.267	1.112	1.221	1.227	1.223
	5	1.229	1.227	1.386	1.389	1.119	1.114	1.222	1.223	1.667	1.372	1.227	1.223
	6	1.337	1.115	1.117	1.227	1.224	1.112	1.119	1.267	1.666	1.669	1.226	1.226
	7	1.114	1.115	1.447	1.422	1.447	1.227	1.429	1.556	1.115	1.116	1.112	1.225
	8	1.117	1.038	1.115	1.227	1.115	1.227	1.404	1.227	1.422	1.227	1.289	1.227
	9	1.227	1.227	1.227	1.467	1.227	1.227	1.269	1.267	1.267	1.115	1.117	1.226
	10	1.117	1.260	1.444	1.117	1.336	1.334	1.227	1.368	1.227	1.267	1.223	1.007

	11	1.115	1.115	1.227	1.227	1.077	1.113	1.117	1.227	1.116	1.227	1.227	1.227
	12	1.117	1.224	1.469	1.469	1.117	1.227	1.227	1.113	1.115	1.115	1.224	1.229
	13	1.227	1.227	1.115	1.117	1.269	1.224	1.112	1.115	1.227	1.225	1.147	1.009
	14	1.117	1.227	1.115	1.117	1.113	1.269	1.226	1.269	1.115	1.115	1.115	1.226
	15	1.475	1.267	1.427	1.189	1.117	1.115	1.117	1.269	1.227	1.167	1.227	1.115
	16	1.375	1.269	1.422	1.224	1.117	1.114	1.117	1.336	1.355	1.224	1.127	1.227
	17	1.275	1.116	1.170	1.227	1.227	1.227	1.227	1.227	1.369	1.227	1.117	1.227
	18	1.275	1.267	1.113	1.227	1.117	1.167	1.169	1.167	1.245	1.668	1.469	1.227
	19	1.375	1.227	1.227	1.227	1.227	1.117	1.117	1.113	1.168	1.269	1.117	1.458
	20	0.745	1.123	1.227	1.227	1.227	1.227	1.237	1.227	1.126	1.167	1.227	1.227
	21	1.225	1.117	1.470	1.227	1.227	1.116	1.227	1.269	1.227	1.227	1.267	1.227
	22	1.370	1.267	1.234	1.267	1.267	1.227	1.267	1.267	1.267	1.116	1.117	1.267
	23	1.370	1.112	1.038	1.117	1.422	1.117	1.172	1.224	1.113	1.227	1.227	1.227
	24	1.370	1.267	1.267	1.237	1.264	1.116	1.117	1.117	1.267	1.267	1.257	1.368
	25	1.370	1.117	1.268	1.269	1.227	1.227	1.267	1.227	1.227	1.267	1.114	1.165
	26	1.370	1.111	1.117	1.456	1.117	1.469	1.117	1.411	1.224	1.267	1.269	1.266
	27	1.370	1.237	1.038	1.422	1.224	1.115	1.227	1.169	1.117	1.114	1.115	1.457
	28	1.370	1.227	1.115	1.234	1.267	1.115	1.267	1.467	1.115	1.469	1.227	1.267

	29	1.370		1.370	1.227	1.227	1.227	1.113	1.117	1.267	1.267	1.227	1.423
	30	1.285		1.038	1.375	1.227	1.366	1.227	1.227	1.225	1.227	1.224	1.237
	31	1.370		1.370		1.269		1.267	1.267		1.447		1.367
2017	1	1.224	1.222	1.336	1.267	1.267	1.267	1.267	1.269	1.223	1.400	1.340	1.269
	2	1.370	1.227	1.037	1.368	1.345	1.127	1.267	1.267	1.369	1.099	1.267	1.227
	3	1.237	1.227	1.104	1.265	1.227	1.267	1.411	1.227	1.087	1.268	1.267	1.423
	4	1.137	1.336	1.104	1.122	1.411	1.167	1.267	1.169	1.167	1.237	1.269	1.227
	5	1.237	1.118	1.379	1.225	1.117	1.225	1.411	1.227	1.227	1.227	1.267	1.227
	6	1.237	1.257	1.370	1.234	1.114	1.113	1.113	1.486	1.109	1.115	1.227	1.267
	7	1.137	1.229	1.370	1.010	1.227	1.267	1.115	1.227	1.113	1.267	1.269	1.227
	8	1.237	1.227	1.037	1.409	1.224	1.227	1.228	1.227	1.227	1.227	1.237	1.268
	9	1.137	1.337	1.224	1.227	1.227	1.227	1.227	1.268	1.227	1.227	1.267	1.239
	10	1.137	1.227	1.337	1.227	1.269	1.268	1.227	1.227	1.227	1.337	1.367	1.337
	11	1.224	1.267	1.110	1.227	1.227	1.434	1.422	1.227	1.113	1.118	1.448	1.168
	12	1.237	1.227	1.117	1.117	1.237	1.411	1.227	1.345	1.227	1.227	1.113	1.267
	13	1.137	1.227	1.227	1.227	1.227	1.227	1.337	1.269	1.227	1.267	1.227	1.227
	14	1.185	1.227	1.115	1.267	1.227	1.227	1.113	1.117	1.149	1.117	1.117	1.224
	15	1.198	1.227	1.224	1.227	1.227	1.227	1.115	1.411	1.224	1.401	1.007	1.442

	16	1.224	1.223	1.337	1.337	1.412	1.226	1.227	1.227	1.267	1.227	1.441	1.422
	17	1.254	1.367	1.227	1.411	1.227	1.223	1.337	1.227	1.227	1.227	1.120	1.411
	18	1.370	1.117	1.113	1.113	1.227	1.227	1.227	1.337	1.267	1.227	1.411	1.227
	19	1.237	1.411	1.334	1.367	1.227	1.422	1.267	1.369	1.422	1.227	1.267	1.227
	20	1.370	1.367	1.339	1.401	1.229	1.267	1.267	1.447	1.400	1.227	1.422	1.227
	21	1.237	1.227	1.423	1.389	1.267	1.227	1.411	1.229	1.288	1.227	1.337	1.337
	22	1.237	1.227	1.227	1.337	1.267	1.227	1.267	1.227	1.268	1.227	1.267	1.227
	23	1.237	1.442	1.400	1.332	1.267	1.267	1.267	1.268	1.267	1.227	1.227	1.337
	24	1.370	1.389	1.234	1.267	1.337	1.268	1.269	1.668	1.224	1.269	1.468	1.227
	25	1.237	1.422	1.227	1.369	1.227	1.267	1.337	1.369	1.367	1.345	1.337	1.337
	26	1.237	1.227	1.227	1.227	1.227	1.224	1.227	1.267	1.227	1.267	1.227	1.337
	27	1.370	1.337	1.227	1.227	1.227	1.227	1.337	1.337	1.227	1.227	1.227	1.337
	28	1.370	1.227	1.411	1.027	1.023	1.234	1.224	1.337	1.337	1.467	1.167	1.227
	29	1.370		1.369	1.337	1.267	1.337	1.389	1.337	1.367	1.229	1.337	1.337
	30	1.345		1.267	1.337	1.227	1.337	1.447	1.367	1.369	1.337	1.337	1.227
	31	1.345		1.224		1.236		1.411	1.227		1.333		1.337

Table D 1: The wind speed meteorology data of Bahir Dar

E. The Wind Speed of Bahirdar at Height of 78 Meter

Reg:	*Gojjam*	*Lat*:		$11°.4'$									
Stn:	*B_Dar SYN*		*Lon*:	$37°.3'$									
Element		*Wind speed at 78m.(m/sec)*											
Year	*Date*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Data (2013-2017)	1.00	9.67	11.01	9.94	9.14	9.14	9.94	9.67	9.81	8.92	9.81	9.94	11.01
	2.00	11.01	9.14	9.94	9.03	9.67	9.03	11.01	8.33	9.89	11.01	11.01	9.14
	3.00	9.94	9.81	9.89	10.85	11.01	9.81	9.94	10.48	10.48	9.67	10.48	10.48
	4.00	9.14	9.94	9.83	9.14	8.95	9.83	9.02	9.02	8.95	10.72	8.95	8.93
	5.00	9.83	9.03	9.02	10.74	8.33	9.81	9.14	9.03	9.67	11.01	8.33	8.95
	6.00	9.40	9.14	10.21	10.74	11.01	8.07	8.92	9.83	11.01	9.20	11.01	11.57
	7.00	11.01	8.33	9.48	11.01	8.87	9.67	9.14	8.87	9.94	9.94	11.41	9.88
	8.00	10.04	9.96	9.96	9.67	11.41	9.96	10.04	10.61	9.80	9.84	10.62	9.90
	9.00	11.41	10.07	10.61	11.68	11.45	9.92	9.64	11.41	10.61	10.69	10.90	10.69
	10.00	9.83	10.63	10.61	10.63	10.63	9.91	9.75	9.91	10.63	10.63	10.69	9.90
	11.00	11.01	10.69	10.72	11.25	10.61	9.88	10.61	9.80	10.61	10.62	8.98	11.55
	12.00	9.94	10.69	9.91	9.83	10.74	10.69	10.69	10.04	10.71	10.70	9.72	9.96
	13.00	9.80	9.14	9.80	9.80	9.88	9.72	9.00	9.00	9.72	9.80	9.80	10.61
	14.00	8.87	9.67	8.20	9.64	9.14	9.40	9.14	9.14	9.00	9.26	9.72	9.02
	15.00	9.00	9.67	9.00	9.88	9.00	8.98	8.98	9.26	9.00	10.48	9.67	9.88
	16.00	9.20	8.86	9.67	9.67	9.48	8.98	8.94	8.98	10.47	10.61	10.69	1.08
	17.00	10.85	8.95	10.71	10.71	10.61	9.91	10.63	9.59	10.37	10.47	10.21	10.21

	18.00	10.47	9.94	9.88	9.83	10.69	10.69	10.47	10.47	10.47	10.47	10.69	10.69
	19.00	10.69	10.69	10.69	10.93	12.08	11.27	11.41	9.32	10.02	10.18	11.01	9.94
	20.00	11.27	9.94	9.86	9.83	9.14	9.86	9.86	9.83	11.49	9.94	9.94	9.83
	21.00	10.69	10.69	9.91	10.47	10.47	10.47	9.94	10.82	11.27	11.49	11.27	9.91
	22.00	11.68	9.94	10.48	9.94	10.47	10.61	11.01	9.94	9.94	9.78	9.94	9.94
	23.00	11.01	9.86	11.01	10.74	9.94	10.74	11.28	11.44	9.91	9.94	9.94	9.91
	24.00	9.83	10.21	9.94	9.86	9.86	10.47	12.08	11.81	9.94	10.61	10.61	10.66
	25.00	10.61	9.92	11.27	11.27	11.01	10.64	9.14	10.74	9.94	9.94	9.94	11.01
	26.00	11.28	11.27	11.01	9.14	9.94	10.21	9.94	9.94	10.48	9.94	10.74	10.21
	27.00	10.47	10.21	9.86	9.94	9.94	10.74	9.94	9.94	9.94	9.94	10.74	7.13
	28.00	11.81	9.91	9.94	9.94	9.91	9.94	9.94	9.94	9.91	11.01	10.21	10.74
	29.00	11.27	9.94	9.94	9.94	9.94	9.83	9.83	9.83	9.94	9.94	9.94	9.94
	30.00	10.21	9.94	10.48	11.01	10.48	9.94	10.48	12.89	11.28	9.91	9.88	10.61
	31.00	10.61	10.85	10.74	10.48	9.83	9.94	9.91	9.91	9.94	11.01	9.94	9.94
	1.00	9.89	10.66	10.61	9.91	11.01	9.94	10.21	9.94	10.48	9.86	10.21	9.83
	2.00	9.83	9.86	9.91	10.74	11.28	10.74	9.94	9.94	9.94	10.69	9.94	8.33
	3.00	10.69	9.86	9.88	10.74	9.91	9.94	9.94	10.74	9.91	9.94	9.91	9.94
	4.00	9.83	9.80	10.74	9.81	9.83	9.67	11.01	9.94	9.86	10.70	10.69	10.48
	5.00	9.88	9.94	9.83	10.02	9.94	10.74	10.66	10.61	10.48	10.69	10.69	10.74
	6.00	9.80	10.70	9.80	9.83	9.94	10.69	9.86	9.81	10.70	10.62	10.62	10.69
	7.00	11.01	11.01	10.69	10.70	10.70	9.94	9.80	11.01	9.83	11.41	8.76	9.83
	8.00	9.80	9.86	9.83	10.71	10.70	10.80	10.62	10.69	11.59	10.70	10.69	10.21

	9.00	10.61	10.48	9.86	10.71	10.62	9.94	11.57	10.70	11.28	9.86	9.86	9.86
	10.00	10.71	10.66	9.86	9.83	10.70	10.71	10.61	9.86	10.74	11.01	10.69	9.91
	11.00	10.72	10.70	10.69	10.69	11.25	9.82	10.70	10.70	9.86	10.72	9.86	10.74
	12.00	10.70	10.70	10.70	10.74	10.71	10.70	9.83	9.94	10.72	10.70	9.83	10.69
	13.00	9.83	10.48	10.74	9.83	10.70	9.94	9.83	9.83	10.70	10.72	10.71	10.71
	14.00	11.01	9.83	10.70	9.91	10.74	11.55	11.28	10.61	11.47	10.71	10.73	10.72
	15.00	10.63	9.94	10.71	9.40	10.74	9.94	11.44	11.28	9.94	10.73	9.91	9.94
	16.00	10.12	9.86	11.01	9.94	9.91	11.01	10.74	9.94	9.94	9.81	9.40	9.83
	17.00	10.71	9.91	9.82	10.66	9.90	10.66	10.21	9.40	8.32	10.74	10.64	9.88
	18.00	9.94	9.94	10.66	9.86	9.40	9.94	10.61	8.81	9.91	9.94	10.71	10.66
	19.00	10.66	10.61	10.71	10.69	9.86	9.94	9.91	9.83	9.91	9.90	9.94	9.91
	20.00	10.74	11.01	9.83	9.83	9.94	9.02	9.86	9.94	10.69	9.83	10.69	9.83
	21.00	9.83	10.21	10.71	9.80	10.74	9.84	10.21	9.82	10.71	10.70	10.69	10.69
	22.00	10.69	10.74	9.88	9.83	9.83	10.65	9.83	9.82	10.70	9.82	10.70	9.82
	23.00	9.83	8.33	9.82	9.86	10.70	9.86	10.70	10.70	9.94	9.86	9.80	10.70
	24.00	10.70	11.01	10.69	10.74	10.74	10.70	9.83	9.83	10.74	9.83	11.25	10.71
	25.00	10.70	9.94	10.74	9.86	10.71	11.01	9.82	10.62	10.71	10.70	10.71	10.21
	26.00	10.71	9.94	10.74	10.69	9.83	9.94	10.74	9.86	10.02	10.71	11.47	8.04
	27.00	11.41	10.48	9.83	11.25	11.28	10.74	11.47	11.01	8.52	10.02	11.28	11.47
	28.00	10.21	10.70	10.61	10.64	10.74	9.81	10.65	10.69	8.52	8.31	10.71	10.64
	29.00	10.70	8.85	10.71	11.01	10.71	10.74	8.29	10.74	8.93	7.19	8.93	10.71
	30.00	8.94	9.83	9.91	8.76	9.90	9.91	9.86	9.81	11.60	8.94	10.72	10.62

	31.00	9.88	8.06	9.83	9.86	8.95	10.70	9.91	9.82	10.70	10.71	8.94	10.71
	1.00	9.83	9.40	9.83	9.82	8.83	9.91	9.83	10.71	9.83	9.83	11.28	8.22
	2.00	9.80	8.33	10.70	10.70	10.74	8.94	9.83	9.82	9.84	9.86	9.83	8.93
	3.00	10.62	8.94	9.82	10.70	10.70	9.83	11.44	11.51	10.71	10.70	10.71	10.85
	4.00	9.86	8.95	10.71	9.90	9.83	10.71	8.94	10.70	9.92	9.83	8.94	8.94
	5.00	9.93	10.71	9.86	9.81	9.83	9.78	10.70	10.70	8.94	11.01	10.71	10.74
	6.00	8.84	13.14	8.57	9.02	8.30	8.94	10.71	9.94	8.94	10.62	8.94	9.83
	7.00	9.83	10.74	8.94	8.98	9.83	9.83	9.02	9.91	9.83	9.81	8.93	9.02
	8.00	9.02	9.82	9.83	9.82	8.94	8.94	8.93	8.94	9.82	10.70	11.67	9.02
	9.00	8.94	9.82	9.86	10.71	9.81	9.91	9.83	8.95	10.97	9.82	10.66	10.70
	10.00	9.83	9.82	9.81	12.57	11.67	10.97	8.94	10.74	8.93	9.83	11.70	12.25
	11.00	9.83	11.62	10.71	10.98	10.74	10.17	10.74	10.97	10.72	10.97	10.73	10.97
	12.00	9.93	11.78	11.68	9.83	10.97	9.82	11.70	11.70	12.57	10.62	10.97	11.43
	13.00	9.83	9.86	10.74	10.71	10.98	9.83	9.85	8.93	10.18	11.43	10.98	10.74
	14.00	11.43	9.82	9.82	10.98	9.82	9.82	9.82	10.71	9.82	10.97	9.82	10.96
	15.00	9.82	9.82	9.82	9.82	10.18	9.86	9.82	9.83	10.98	10.98	9.82	10.98
	16.00	9.82	9.86	9.82	9.86	10.18	9.86	9.82	11.75	9.82	8.93	9.82	9.82
	17.00	9.82	10.73	9.94	9.83	9.82	9.83	9.82	9.86	10.74	9.86	9.82	9.82
	18.00	9.86	11.28	10.18	8.93	9.86	9.82	9.82	9.82	9.91	9.83	9.86	9.86
	19.00	9.82	9.83	9.83	9.82	8.93	9.82	9.82	9.82	8.93	9.82	8.93	9.82
	20.00	9.82	11.62	8.94	10.17	9.86	9.81	9.83	10.74	8.93	9.86	10.66	9.86
	21.00	9.82	11.70	9.82	12.58	9.86	10.10	9.83	11.43	8.33	9.82	8.94	8.93

	22.00	8.93	9.86	9.85	11.67	10.18	8.96	8.93	9.81	9.86	8.94	11.62	9.86
	23.00	8.94	10.73	9.86	8.94	8.96	8.93	8.94	9.83	8.93	9.83	11.70	9.83
	24.00	8.94	11.28	8.98	9.86	11.70	9.86	8.93	11.43	9.03	11.70	8.93	9.86
	25.00	8.96	9.83	9.86	9.83	8.93	9.86	9.85	8.96	9.83	10.97	9.82	11.70
	26.00	9.86	11.62	11.70	10.98	9.83	9.86	9.93	8.93	9.82	11.71	9.85	8.94
	27.00	8.94	11.70	9.86	8.98	9.83	11.34	9.86	9.86	9.83	8.93	8.93	9.86
	28.00	9.83	9.86	9.86	8.94	10.18	10.17	9.85	9.86	8.93	9.86	10.18	8.93
	29.00	8.97	10.18	8.94	9.82	8.99	8.94	11.01	8.97	10.00	8.95	11.43	9.91
	30.00	9.86	11.59	8.97	8.96	9.82	9.82	10.18	9.82	9.93	11.59	8.96	9.82
	31.00	9.86	9.14	9.82	8.97	9.82	11.63	9.82	9.82	11.60	9.82	10.14	9.81
	1.00	8.97	8.97	11.44	10.20	8.97	10.19	9.82	9.86	8.94	9.86	9.86	11.60
	2.00	8.93	9.86	9.82	11.16	8.93	8.96	9.46	10.96	13.39	8.94	9.86	8.96
	3.00	8.60	8.96	8.93	9.86	8.97	8.93	11.62	11.59	13.39	11.59	9.85	10.01
	4.00	10.98	8.96	11.78	11.43	10.18	9.86	10.35	10.18	8.96	9.81	8.93	9.82
	5.00	9.87	8.33	11.14	9.86	8.99	9.86	9.82	9.82	11.43	11.01	10.35	9.83
	6.00	10.74	9.86	8.97	11.79	9.83	9.86	8.99	10.18	10.18	13.41	8.97	9.85
	7.00	8.96	10.13	11.63	8.97	11.62	10.72	11.48	12.50	9.86	8.96	9.82	9.84
	8.00	8.97	8.96	8.96	9.86	8.96	8.94	11.28	9.86	8.96	9.86	9.86	9.86
	9.00	9.86	9.83	9.86	11.80	9.86	9.86	10.20	10.18	8.96	8.96	9.83	9.85
	10.00	8.98	9.86	11.60	8.97	10.73	9.83	9.86	11.00	9.86	10.18	9.21	8.09
	11.00	8.96	9.86	9.86	8.97	8.60	10.20	8.97	9.86	8.96	9.86	8.96	9.86
	12.00	8.97	10.18	11.80	9.55	8.97	8.96	9.86	8.94	9.86	8.96	9.86	9.87

	13.00	9.86	10.20	8.96	9.83	10.20	8.95	8.94	8.96	10.89	9.84	9.05	8.11
	14.00	8.97	8.97	8.96	9.86	8.94	9.86	9.85	10.19	11.00	8.96	8.97	9.86
	15.00	10.01	10.18	11.46	9.86	8.97	9.38	8.97	10.20	10.00	9.38	11.80	8.96
	16.00	9.94	9.86	11.43	9.86	8.97	8.97	8.97	10.73	9.39	9.83	8.97	9.86
	17.00	9.14	9.02	9.40	9.86	9.86	9.86	9.86	9.86	9.05	9.86	9.86	9.86
	18.00	11.01	8.97	8.94	9.86	8.97	8.96	9.39	9.38	9.86	13.41	10.18	9.86
	19.00	10.99	10.18	9.86	10.18	9.86	9.86	8.97	8.94	10.18	10.20	8.97	11.72
	20.00	10.36	8.93	9.86	8.97	9.86	8.97	9.94	9.86	8.94	9.38	9.86	9.86
	21.00	8.83	10.18	11.82	9.94	9.86	8.97	9.86	10.20	10.18	9.86	10.10	9.86
	22.00	11.42	8.97	9.91	10.20	10.18	9.86	10.18	10.18	9.86	8.97	8.95	10.18
	23.00	11.55	8.93	8.33	11.70	11.43	11.80	9.40	9.83	9.84	9.86	10.20	9.86
	24.00	10.89	9.94	10.18	11.43	10.16	8.96	8.97	8.97	8.97	10.18	8.96	11.00
	25.00	10.32	9.86	10.19	9.91	9.86	8.96	10.18	9.86	8.96	10.18	9.86	9.36
	26.00	11.01	9.82	8.97	9.86	8.97	9.86	8.97	11.34	10.18	10.18	9.86	10.18
	27.00	11.17	9.86	8.33	11.01	9.83	10.98	9.86	9.39	9.84	8.95	9.83	11.71
	28.00	9.86	9.86	8.96	10.18	10.18	10.18	10.18	11.79	9.86	11.80	10.77	10.18
	29.00	11.16	10.73	11.01	10.99	9.86	9.06	8.94	8.97	11.00	10.18	9.86	11.44
	30.00	8.94	8.99	8.33	10.16	9.86	10.18	9.86	9.86	8.73	9.86	10.18	9.94
	31.00	9.86	10.10	11.01	9.02	10.20	9.38	10.18	10.18	9.38	11.63	10.20	10.98
	1.00	9.83	9.87	10.73	9.84	10.18	9.84	10.18	10.20	9.86	11.25	10.18	10.20
	2.00	9.86	9.86	8.33	9.91	10.81	8.94	10.18	10.18	8.91	8.83	9.86	9.86
	3.00	9.86	10.74	8.87	8.11	9.86	10.18	11.34	9.86	8.94	10.19	10.20	11.43

	4.00	9.86	9.86	8.87	11.32	11.34	9.86	10.18	9.39	9.86	9.94	9.94	9.86
	5.00	11.00	10.18	11.01	9.86	8.97	9.86	11.34	9.86	9.86	9.86	10.18	9.86
	6.00	11.43	9.86	11.01	9.86	8.95	10.19	8.94	11.94	9.86	8.96	10.98	10.18
	7.00	10.89	9.86	11.01	9.86	9.86	11.52	8.96	9.86	8.94	10.18	11.64	9.86
	8.00	9.95	9.86	8.33	8.97	9.83	11.34	9.87	9.86	9.86	9.86	8.94	10.19
	9.00	9.95	9.86	9.83	9.86	9.86	9.86	9.86	10.19	9.86	9.86	9.86	9.95
	10.00	9.86	9.83	10.74	10.18	10.20	9.86	9.86	9.86	9.23	10.74	8.97	10.74
	11.00	10.74	10.98	8.92	9.86	9.86	9.86	11.43	9.86	9.83	8.99	8.09	9.39
	12.00	10.74	8.97	8.97	10.74	9.94	9.85	9.86	10.81	10.18	9.86	11.58	10.18
	13.00	11.00	11.34	9.86	11.34	9.86	9.82	10.74	10.20	9.86	10.18	9.00	9.86
	14.00	10.74	10.98	8.96	8.94	9.86	9.86	8.94	8.97	10.18	8.97	11.34	9.83
	15.00	9.95	9.86	9.83	10.98	9.86	11.43	8.96	11.34	11.43	11.26	10.18	11.59
	16.00	11.14	9.86	10.74	11.26	11.34	10.18	9.86	9.86	11.25	9.86	11.43	11.43
	17.00	11.00	11.59	9.86	11.16	9.86	9.86	10.74	9.86	10.35	9.86	10.74	11.34
	18.00	9.85	11.16	8.94	10.74	9.86	9.86	9.86	10.74	10.19	9.86	10.18	9.86
	19.00	10.19	11.43	10.72	10.71	9.86	10.18	10.18	11.00	10.18	9.86	9.86	9.86
	20.00	9.94	9.86	10.76	10.18	9.87	10.19	10.18	11.63	9.83	9.86	11.80	9.86
	21.00	11.00	10.74	11.43	11.00	10.18	10.18	11.34	9.87	10.98	9.86	10.74	10.74
	22.00	9.94	9.86	9.86	9.86	10.18	9.83	10.18	9.86	9.86	9.86	9.86	9.86
	23.00	10.74		11.25	9.86	10.18	9.86	10.18	10.19	9.86	9.86	9.86	10.74
	24.00	10.36		9.91	8.25	10.74	9.91	10.20	13.41	10.74	10.20	9.38	9.86
	25.00	9.54		9.86	10.74	9.86	10.74	10.74	11.00	10.98	10.81	10.74	10.74

	26.00	9.94		9.86	10.74	9.86	10.74	9.86	10.18	11.00	10.18	10.74	10.74
	27.00	11.00		9.86		9.86		10.74	10.74		9.86		10.74
	28.00	10.19		11.34		8.22		9.83	10.74		11.79		9.86
	29.00	10.90		11.00		10.18		11.16	10.74		9.87		10.74
	30.00	11.00		10.18		9.86		11.63	10.98		10.74		9.86
	31.00	10.74		9.83		9.93		11.34	9.86		10.71		10.74
mean		10.15	10.06	10.08	10.17	10.02	9.98	10.05	10.18	10.06	10.18	10.13	10.07
median		9.94	9.91	9.88	9.91	9.88	9.86	9.86	9.94	9.92	9.94	9.94	9.91
s.divation		0.75	0.82	0.82	0.80	0.75	0.66	0.77	0.83	0.87	0.83	0.80	1.08
g		0.94	0.95	0.93	0.89	0.93	0.92	0.91	0.90	0.91	0.94	0.91	0.94
c		11.45	11.35	11.3	11.5	11.3	11.3	11.3	11.5	11.3	11.5	11.4	11.4
a=sd		0.75	0.82	0.82	0.80	0.75	0.66	0.77	0.83	0.87	0.83	0.80	1.08
k		16.92	15.17	15.23	15.81	16.64	19.09	16.37	15.14	14.29	15.23	15.65	11.30
Vave		10.15	10.06	10.08	10.17	10.02	9.98	10.05	10.18	10.06	10.18	10.13	10.07
using k=2													

Table E 1: The wind speed of Bahir Dar at the height of 78 meter

F. The Impedance Computation of Ghion and Bata Feeders

Ghion Feeder Impedance Computation																	
	hc	ab	ac	bc	Ω/km	f	$imag(Zaa)$	$imag(Zbb)$	$imag(Zcc)$	Zab	Zac	Zbc	$imag(zm) = 1/3(zab + zac + abc)$	$imag(zs) = 1/3(zaa + zbb + zcc)$	$imag(zf) = zs - zm$	$R(ohm)$	$X(ohm)$
1	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.095	0.0915	0.0488	0.0491	0.0519	0.0499	0.0952	0.0453	0.576	0.0845
2	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.095	0.0915	0.0488	0.0491	0.0519	0.0499	0.0952	0.0453	0.0645	0.0095
3	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.095	0.0915	0.0488	0.0491	0.0519	0.0499	0.0952	0.0453	0.1305	0.0191
4	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.095	0.0915	0.0488	0.0491	0.0519	0.0499	0.0952	0.0453	0.2644	0.0388
5	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.095	0.0915	0.0488	0.0491	0.0519	0.0499	0.0952	0.0453	0.178	0.0261
6	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.095	0.0915	0.0488	0.0491	0.0519	0.0499	0.0952	0.0453	0.0262	0.0038
7	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.095	0.0915	0.0488	0.0491	0.0519	0.0499	0.0952	0.0453	0.141	0.0207
8	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1105	0.013
9	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.2488	0.0292
10	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.0983	0.0115
11	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.5189	0.0609
12	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1325	0.0155
13	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1932	0.0227
14	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.2742	0.0322
15	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.5461	0.0641

16	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1278	0.015
17	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.118	0.0138
18	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1996	0.0234
19	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1007	0.0118
20	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.199	0.0234
21	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1041	0.0122
22	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.2308	0.0271
23	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.4576	0.0537
24	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1036	0.0122
25	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.2999	0.0352
26	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.2129	0.025
27	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.2221	0.0261
28	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.0706	0.0083
29	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1237	0.0145
30	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1254	0.0147
31	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.125	0.0147
32	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.2221	0.0261
33	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1319	0.0155
34	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1176	0.1141	0.0488	0.0491	0.0519	0.0499	0.1178	0.0679	0.1435	0.0168
Bata Feeder Impedance Computation																	
1	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.2245	0.0263	0.05	1.0000	0.0454	0.5504	0.0811
2	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.0487	0.0522	0.05	0.0955	0.0454	0.1317	0.0194
3	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.0487	0.0522	0.05	0.0955	0.0454	0.0706	0.0104
4	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.0487	0.0522	0.05	0.0955	0.0454	0.0352	0.0052
5	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.0487	0.0522	0.05	0.0955	0.0454	0.0728	0.0107
6	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.0487	0.0522	0.05	0.0955	0.0454	0.1916	0.0282
7	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.0487	0.0522	0.05	0.0955	0.0454	0.1675	0.0247

8	0.0089	0.0006	0.0012	0.0005	0.3085	50	0.0991	0.0958	0.0915	0.0492	0.0487	0.0522	0.05	0.0955	0.0454	0.0441	0.0065
9	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1944	0.0229
10	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.4819	0.0567
11	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.5172	0.0609
12	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.2783	0.0327
13	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1718	0.0202
14	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.376	0.0443
15	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1221	0.0144
16	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.155	0.0182
17	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1874	0.0221
18	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.2326	0.0274
19	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.5166	0.0608
20	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1816	0.0214
21	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1886	0.0222
22	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1527	0.018
23	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.0775	0.0091
24	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1446	0.017
25	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1215	0.0143
26	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1816	0.0214
27	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1088	0.0128
28	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.07	0.0082
29	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1591	0.0187
30	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.2488	0.0293
31	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1909	0.0225
32	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.1897	0.0223
33	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.184	0.0216
34	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.114	0.0134

35	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.14	0.0165
36	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.2193	0.0258
37	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.0526	0.0062
38	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.2418	0.0285
39	0.0089	0.0006	0.0012	0.0005	0.5785	50	0.1218	0.1185	0.1141	0.0492	0.0487	0.0522	0.05	0.1181	0.0681	0.4206	0.0495

Table F 1: The impedance calculation sheet of Ghion and Bata feeders