JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

GRADUATE PROGRAM OF ELECTRICAL POWER ENGINEERING

DISTRIBUTION SYSTEM EXPANSION PLANNING STUDY WITH DISTRIBUTED GENERATION (DG): - CASE STUDY OF NEKEMTE DISTRIBUTION SYSTEM

BY

LULU EJETA

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MSc. THESIS

ON

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Declaration

I declare that this thesis is my original work, the work described in this thesis has not been previously presented for fulfillment of a degree in this or any other university and all sources and materials used for this thesis have been fully acknowledged.

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The thesis entitled, Distribution system expansion planning study with distributed generation case study of Nekemte distribution system submitted by Lulu Ejeta to Jimma University in partial fulfillments for the degree of master in Electrical Power Engineering is here by recommended for final evaluation and examination.

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Abstract

In today's power system, distributed generation is a new solution for meeting electrical demand growth while also meeting operational and technological constraints. Distribution system expansion planning with DG is the best expansion strategies to fulfill the predicted load requirements and to satisfy the operational and technical constraints. The major economical and technical benefits of DG integrated to distribution system are power loss reduction, reduction of complications in expansion planning of distribution network and improving the voltage profile. This thesis focuses on the expansion planning of Nekemte substation with DG. The bus voltage sensitivity analysis method is used for the proper location of DG that to be integrated into the distribution grid network. Peak load demand forecasting is a prerequisite for distribution expansion planning since it predicts demand for the future period. In this thesis, peak load demand forecasting for Nekemte substation distribution system is predicted for the period of 2020 – 2030. The peak load demand forecasting is carried out using least square load demand forecasting techniques.

All the compulsory data are collected and distribution system network has been modeled using DigSilent power factory software. To reduce the total power loss of the distribution system network, DG is integrated to distribution system network at proper location with proper capacity. The DG's location and sizing were determined using an analytical approach and load flow analysis. It is shown that the outgoing feeder no-2 and no-3 have the least voltage sensitivity index 0.1379 and 0.1163 respectively and are selected as best location for DG installation. Micro-turbine is chosen as DG from the other DGs in this thesis work based on the availability of the resource and the cost factor. The maximum DG power capacity for feeder no-2 found to be 2.70MW and for feeder no-3 is found to be 3.75MW in MV feeder bus. The result of simulation after integration of DG reveals that active and reactive power loss is reduced to 0.80MW and 2.02MVar with the total loss reduction of 56.76% and 58.18% respectively. Hence, this result shows that even if the load demand increases 8.97% in each year the DG units are able to meet the demand requirements until year-6. After this year the substation should be upgraded to satisfy the load demand.

Key words: - Distribution system expansion planning, DG size, DG location, load demand forecasting, power loss reduction.

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List of Abbreviations and Acronyms

ARIMA	Autoregressive Integrated Moving Average
BVSI	Bus Voltage Sensitivity Index
CHP	Combined Heat Power
DER	Distributed Energy Resources
DG	Distributed Generation
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
FDLF	Fast Decoupled Load Flow
IEEE	Institute of Electrical and Electronics Engineers
LTC	Load taps changing transformers
LV	Low Voltage
MV	Medium Voltage
NDS	Nekemte Distribution System
NR	Newton Raphson
PF	Power Factor
PL	Power Loss
PLR	Power Loss Reduction
PV	Photovoltaic
TL	Technical Losses

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Electric power is generated, transmitted, and distributed by power systems components from generation centers to consumers. Generation units, transmission and sub-transmission networks, consumption centers, system safety devices, and control equipment are all common components of a power system. Although they may often be directly linked to transmission networks, the key components of distribution networks are fed by one or more sub-transmission networks. Distribution substations use transformers to reduce the voltage level from high to low voltage [1].

Most distribution system networks are run in a radial fashion, regardless of their topology, which can be either meshed or radial, since it is the cheapest and easiest approach from the planning, construction, and system security perspectives. Traditionally, these networks have been built with a large operating range, allowing them to be managed passively, resulting in more cost-effective management. However, distribution network investment is several times more expensive than transmission grid investment, demonstrating the economic importance of distribution system planning. Furthermore, the available investment plan must not only be economically oriented, but also meet a number of designs, part, layout, and performance requirements and guidelines.

Distribution companies are responsible for the management and planning of distribution networks from a centralized perspective, ensuring that the increasing demand is met with quality and standards in a safe manner. As a result, planning models are used to arrive at the best investment strategy at the lowest cost while also meeting protection and quality criteria. Traditionally, these planning models have been used to make decisions about branch, substation, and transformer reinforcement and construction. However, distribution generation (DG) is gaining popularity, owing to its various operational and planning advantages and renewable energy's impetus necessitates the incorporation of this form of generation in distribution planning models. This new environment, in which DG plays a role, necessitates improvements in the way distribution systems are managed and designed.

Electric power generation within distribution networks or on the customer side of the network is referred to as DG. Renewable energy eliminates pollution and helps to prevent the building of new transmission lines and massive power plants, which is good for the environment. DG units can also boost power quality and reliability by lowering voltage profile, reducing line losses, and reducing network congestion [2]. DGs also have the ability to improve generation rivalry, resulting in improved service and lower energy costs. Another incentive for the penetration of renewable energy-based DG sources is feed in tariffs paid by regulators to achieve their goals of meeting electricity demand with clean.

DG is made up of small-scale power plants near demand centers. Wind turbines, fuel cells, photovoltaic (PV) plants, micro gas turbines, internal combustion engines, and energy storage devices such as batteries are currently used for DG. The use of DG has a number of benefits in terms of system planning and operation, including reduced energy losses, voltage profile regulation, improved power quality, increased system efficiency, reduced network expansion, and lower C_{O2} emissions.

Power flows, voltage profiles, system performance, and safety devices can all be affected by the presence of DG. As a result, the transition to DG in historically passive distribution networks is dependent on a number of factors, including the form, scale, and position of generation units; the types of control equipment; and the characteristics of feeders and loads.

Currently, in Ethiopia the load demand is increasing from year to year rapidly. The existing distribution sytem network has line losses and interruption problems due to the distribution sytem feeders overloading problems. When there is a distarbunce in 33kV or 15kV distribution system network line bus voltage instability, power loss will be occoured. This causes to interruption of power. These problems can be overcomed by installing the distributed generation units to a selected distribution system feeder bus.

This thesis presents a methodology to investigate and simulate the operation of a radial distribution system with suitable placement of distributed generation units to satisfy the load increment and reduce the distribution system power losses. A systematic scheme that can identify the appropriate locations for installing distributed generation resources in distribution system will be presented. The proposed method uses the DigSilent software for power system simulation purpose. The Nekemte substation system, which consists of a 33kV and 15kV outgoing feeder network in Nekemte city, western region district of Oromia, Ethiopia, is the subject of a case study of radial distribution system investigation and simulation.

1.2 Statement of the Problem

The power system's primary goal is to provide a sufficient electrical supply to its customers while also meeting rising demand. The main issue confronting Ethiopian electric power utilities today, including the Nekemte town distribution system, is that power demand is rapidly growing while supply growth is constrained by economic, environmental, and other societal concerns.

Nekemte town is one of the rapidly growing town and a preferred location for most of the factories, big commercial institutions and tourism. In the near future, Nekemte town area will have load growth in respect with the growth seen in housing development, industrial sectors and commercial buildings. Increased load induces a reduction in voltage profile and an increase in power losses. As a result, more detailed justifications of new system facilities and improvements in electricity production and usage are needed. With that demand and a growing reliance on electricity supplies, it's more important than ever to meet the demand while minimizing power loss. These factors are motivating distribution system planning to determine expansion strategies to serve the load growth. Moreover, using DG technologies have made them feasible and an attractive option for the planning of the system.

From various possible benefits of DG, the most significant ones are environmental sustainability, reduced need of constructing new transmission lines and large power plants, improvement in voltage profile and reduced line losses. Therefore, in this thesis DG was connected to existing system to solve the above stated problems.

1.3 Motivation

Ethiopia's government is currently putting forward a concerted effort to elevate the country's economic status from that of a least developed country to that of a middle-income country. Among the many facets of this initiative, one of the most prominent economic dimensions is the expansion and strengthening of the electric power supply market.

Since Nekemte is one of the country's largest towns and the preferred location for the majority of factories, commercial establishments, and tourism, a significant portion of the electric power supply is directed to the region. Nekemte has also served as the load core for Ethiopia's electric power grid as a result of this. But electric powers demands are increasing from day-to-day with demands for higher reliability of electric supply in this town are constantly increasing. These days, the electric power consumption is increasing quickly. This shows that the energy demand and the supply energy is not in a balanced situation because of the rapid increment of the demand. It is important to reduce power losses in order to meet the growing demand. So, my motivation is to satisfy the demand increment and minimize the electrical energy wastage due to distribution system line losses in the Nekemte distribution system. In fact, planning the distribution system expansion with distributed system is the best solution to meet the load growth, improve the voltage profile and decrease the power loss across the lines.

1.4 Objective of the Study

1.4.1 General Objective

The main goal of this thesis is to study on distribution system expansion planning with distributed generation system fulfills the predicted load requirement and improves the distribution system power losses for Nekemte distribution system.

1.4.2 Specific Objectives

- ❖ Determine the coming ten years of Nekemte substation load demand using extrapolation least-square forecasting method.
- ❖ Identifying the source availability and select /choose type of distributed generation (DG) based on the source availability.
- ❖ Size and select distributed generation in network using voltage sensitivities index analytical method.
- ❖ Modeling the existing distribution system with determined size of distributed generation.
- ❖ Compare the power loss results after and before the placement of distributed generation in distribution network.

1.5 Significance of the Study

Nowadays, the demands for electricity are increasing from time to time. Increasing of these electric demands causes distribution system line losses, economic disadvantage, environmental impact and reduced power reliability. This issue can currently be solved by combining distributed generation with the distribution system. Distributed generation (DG) is a new power system choice for meeting rising electrical demand.

1.6 Scope of the Study

In the case of the Nekemte distribution system substation, the scope of the research begins with a study and analysis of distribution system expansion planning with acceptable location and scale of distributed generation. In this thesis, DG resources are used to reduce the power losses so that insuring the customer load requirements. The results were explained using simulation on Power factory DigSilent software.

1.7 Methodology

The methods and activities have been under taken in this study are:

1st. Literature Review

A number of articles, journals and papers on distribution system expansion planning with distributed generation and other related works have been reviewed.

2nd. Site Selection

Nekemte substation is selected as case study area where there is power loss problems and demand growth from time to time.

3rd. Data Collection

- ❖ Five years (2015-2019) peak load demand data has been collected from Nekemte substation.
- ❖ Data required such as feeder length, number and rating of transformer, medium voltage line data, and number of consumer data has been collected from existing system and districts.

- Other important information and data of the case study distribution substation have been collected from Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU).
- The collected data has been used to clearly analyze the existing structure of Nekemte substation.

4th. System Data Analysis and Modeling

- The load demand forecasting is performed using least-square method and future load demand of the substation distribution system is calculated.
- The distribution system is represented using single line diagram.
- Sizing and sitting of DG was performed by using the analytical method with help of load flow analysis.
- The Nekemte distribution system modeled (integrated) with DG is analyzed and discussed.
- To see the effect of distributed generation resources, DigSilent Power factory software is used.

The system has been designed and simulated using latest Electrical software, DigSilent software.

1.8 Outline of the Thesis

This thesis is organized into six chapters.

Chapter two discuss a literature review on distribution system expansion planning with distributed generation and has some background and explanation of distributed generation also the difference between traditional and new concept of power system. The definition of distributed generation, classification of distributed generation and their application and different distributed generation technologies used for distributed generation are described in this chapter. Chapter three presents distributed generation and distribution system plannig issues. In this chapter different types of load forecasting techniques, distribution system expansion planning issues and methods used for suitable place and size of distributed generation are discussed. The data collection and interpretation of the Nekemte distribution system, as well as the forecasting of peak demand for the Nekemte distribution system, are presented in Chapter 4. Chapter five describes the result and discussion to illustrate the integration of distributed generation in to the system such that voltage profile improvement and energy loss minimization. Lastly, conclusions and recommendations are drawn in chapter six.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Literature Review

Majid Nayeripour and Saeed Hasanvand, 2016 [3] have done a paper in the title optimal expansion planning of distribution system capacity with respect to distributed generations. In this paper mathematical expression for expansion cost is derived clearly. This paper proposes a new method for solving single and multi-objective distribution expansion planning problems, combining the DG and traditional methods. To get the best location of DG, binary particle swarm optimization is suggested. This paper shows that DG has the capability of increase the voltage profile and minimizes the loss so that satisfy the load demand requirements. In this paper the idea is good but it doesn't show the future load demand and growth rate of the demand.

Mohd Nabil Bin Muhtazaruddin and Nurul Aini Bani, 2017 [4] have used Artificial Bee Colony (ABC) for DG and capacitor coordination, location and size in order to solve the distribution sytem power loss and network reconfiguration. In this paper the distribution system loss minimization is selected as the main target in the ABC optimization problem formulation. The implementation of loss minimization for the optimum position of DG and capacitor was tested with a 33-bus test system and simulated with Matlab programming in this paper. However, a disadvantage of this method is that it uses a combination of DG, capacitor, and network reconfiguration to assess only a positive impact on total power losses minimization and voltage profile improvement; the negative effects on the system were not investigated in this paper.

B. Srinivasa Rao, 2011 [5] has also discussed sizing of DG unit to reduce losses in radial distribution. This paper has tried to present an approach to the optimal location of DG based on the sensitivity of total system active power power loss with help of fuzzy logic control. A set of rules for determining the location of DG units in the distribution system, as well as voltage and power loss reduction indices for distribution system nodes are created in this paper. This paper used the software MATLAB/Simulink to examine the effects of DG integration into a distribution system at a suitable location. Even though, the idea is used to minimize the loss with

DG but it chooses the fuzzy logic control only for DG location the size of DG is done analytically.

Subramanya Sarma. S. and Dr. V. Madhusudhan, 2018 [6] concerns on the reliability constrained planning of distribution system under high penteration of stochastic DG units was verified. In this paper, generating probabilistic generation load model, the best location of DG across the feeder was identified and also the cost of distributed generation installation was analysed very well. An advantage of this model is that the model is capable of taking the cost of distributed generation installation into account. Distributed generation is used to improve the reliability of distribution system so that satisfy the demand growth. The proposed approach is tested on radial distribution system with four main feeders. For different distributed generation integration across the feeder bus, the researchers tried to show that integrating of the distributed resources to distribution system improves reliability of distribution system. Its drawback is it doesn't include the optimal placement and sizing of DG rather than locating the DG across all the buses and compares the corresponding values.

Salem Elsaiah, 2015 [**7**] this research concerns on a method for achieving reliability improvement and minimization of line losses in a given distribution system. In order to achieve these two objectives simultinously he has used the distributed generation (DG). In this paper, modeling of distributed system to the distribution system investigates its effects on the reliability and reduction on the power system, significantly to plan the distribution system.

Rui Li and Wei Wang, 2017 [8], this paper suggested the use of a genetic algorithm to determine the best location for distributed generation in a distribution system in order to minimize loss and improve the distribution voltage profile in the planning horizon for optimum planning of a modern distribution system with distributed resources. The method can identify the bus in wich the the distributed generation is located. The genetic algorithm starts with a population that is generated at random. The effectiveness of each person in the population is assessed using a fitness function that takes into account the real power losses in the system. Preliminary investigations show that this approach is successful in minimizing transmission line losses, improving the voltage profile, increasing reliability, and locating distributed generation planning to meet load growth. But still there no clear forecasted future demands of the distribution sytem and a vast deviation of voltage.

Gopiya Naik. S, 2012 [9], suggested that a method for optimal expansion planning of distribution system capacity with distributed generations. This paper has attempted to identify a suitable location for these distributed resources, and distributed generation is a new choice in the power system for meeting the growing electrical demand. The binary parctcle swarm optimization method is projected for suitable size and location of distributed resources. The effectivenes of the proposed work is analyzed using IEEE 32-bus test system. The proposed method identifies appriopriate size of distributed resources, on suitable line at suitable bus location.

Generaly, from [3-9] it is possible to say in one way, the above distribution system expansion planning with distributed resources includes (1) all the distribution parameters are not controlled. (2) The forecasted demand of the system is not clearly known. (3) Uses the evolutionary optimization techniquies and in some cases analytical methods. The proposed design on Digsilent software model to improve distribution sytem loss and the voltage profile so that satisfy the load demand growth using distributed generation resources avoids the above discussed issues.

2.2 Traditional Concept of Power System

Traditionally, the way in which the power is generated; transmitted and distributed is different from the recent one. To generate and supply electricity most of power systems take under consideration the following things [10].

- ❖ Electricity is generated in large power plants that are typically located near the primary energy source but far from the market centers.
- ❖ A vast passive delivery grid, which includes high voltage (HV), medium voltage (MV), and low voltage (LV) networks, delivers electricity to consumers.
- ❖ These distribution networks are made to function in a radial pattern. Power is only delivered in one direction, from higher voltage levels to customers along the radial feeders.
- ❖ There are three steps in this phase that must be completed before the power reaches the final user. Generation, transmission, and distribution are the three phases.

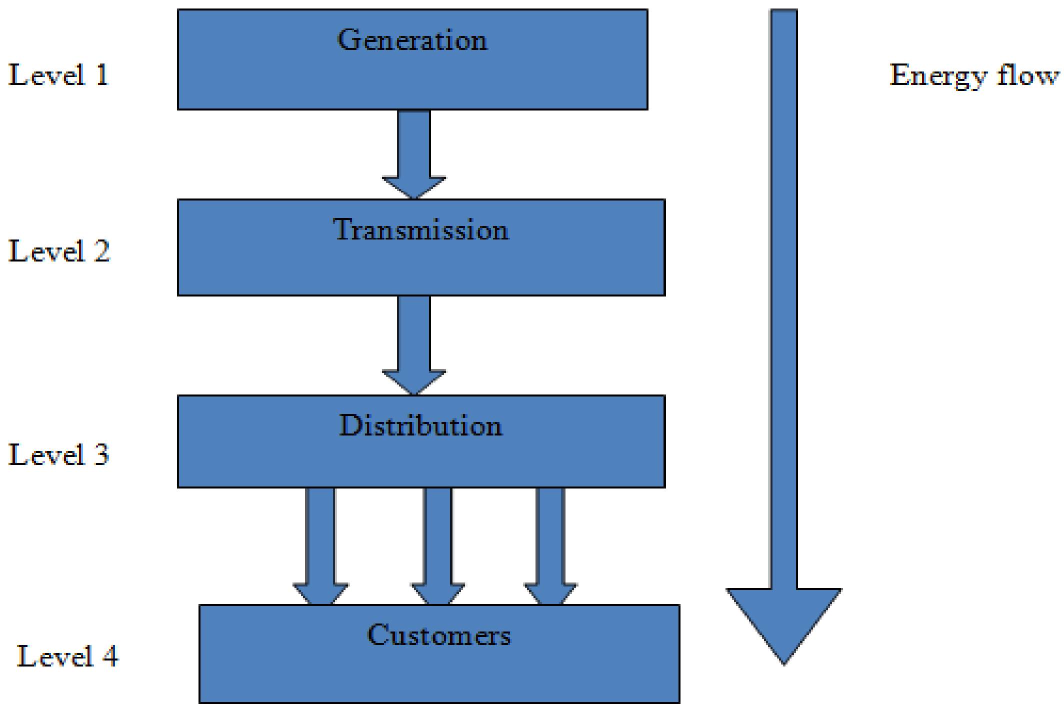

Figure 2.1: Traditional concept of the electrical energy supply [10]

To get around the economics of size and environmental issues, electricity is produced in the first stage (generation) by large generation plants that are located in non-populated areas away from loads. The transmission system is completed in the second stage with the help of different equipment, which varies depending on the type of transmission system, such as transformers, overhead transmission lines, and underground cables. The delivery stage, which is closest to the consumers, is the final stage. It serves as a link between the utility system and the end users. Since the final power quality is dependent on its reliability, the distribution system is the most critical component of the power system [10].

The demand for electricity is steadily growing over time. As a result, in order to satisfy the demand, electricity production must increase. Traditional power systems are dealing with this increase by adding new support systems at the level-1 level, but transmission and distribution level additions are less common.

2.3 New Concept of Power Systems

Technological advancements, environmental policies, and the expansion of the financial and electrical markets are all fostering new conditions in the electricity generation sector today. This new technology allows for the generation of electricity in small plants. Furthermore, as the use of renewable energy sources grows in order to reduce the environmental effect of power generation, new electrical energy supply schemes are developed and implemented.

In this new conception, the generation is not exclusive to generation level. As a result, centralized generation meets some of the energy demand, while distributed generation meets the rest. Electricity will be produced closer to the customer's location. The diagram illustration for new concept of power sytem opration is given bow.

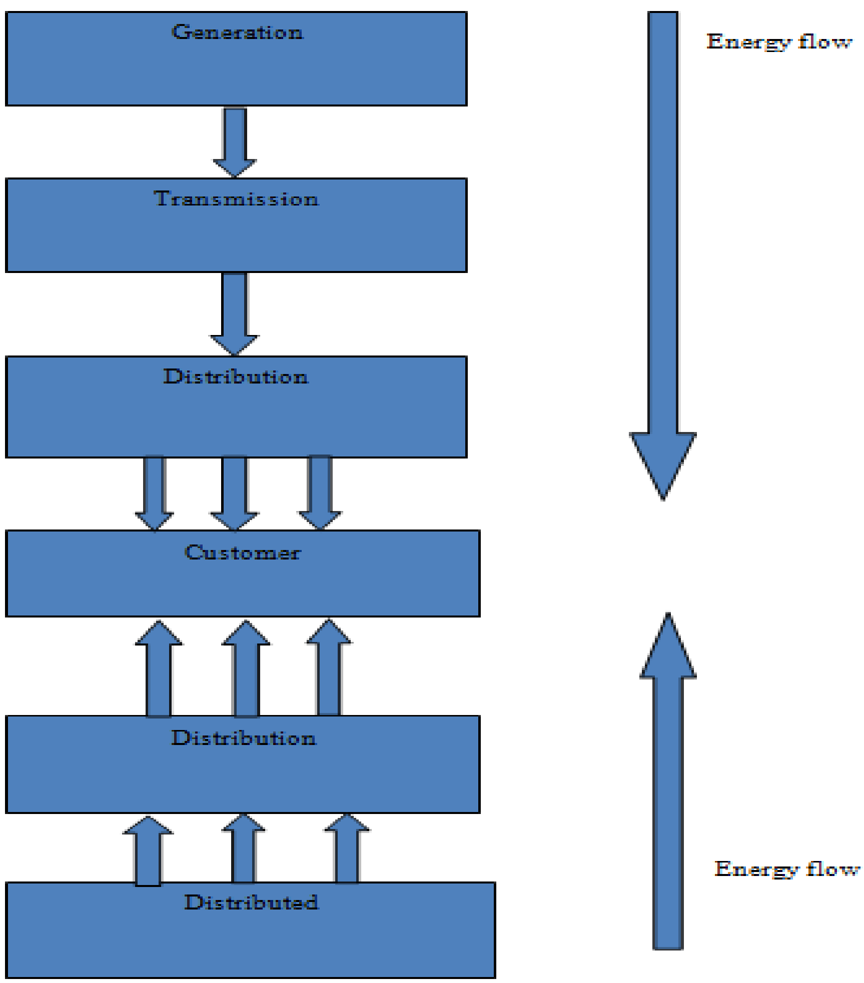

Figure 2.2: The new concept of the electrical energy supply [10]

2.4 The Necessity for Power System Planning

Power system planning is the associated with planning of generation, transmission and distribution systems under energy and economic considerations [11]. The key goal of power system planning is to come up with a low-cost strategy for long-term expansion of generation, transmission, and distribution systems that will meet the load forecast while adhering to a set of technical and economic constraints.

Power system engineering and planning necessitate a comprehensive approach that takes into account the investigation's financial and time constraints, as well as all technological and economic dimensions for the study of complex problem concepts [11]. Planning of power systems is initiated by:

- Customers' requests for higher-load supply or the connection of new production plants in industry.
- Demand for more short circuit power to meet power quality specifications at the connection point.
- Construction of large buildings, such as shopping centers, office buildings or department stores.
- New residential areas are being planned.
- General increase in demand for electricity.

The planning of the power system is based on a reliable load forecast that takes into account the above-mentioned developments in the power system. The following are the objective constraints of power system planning:

- Topologies of systems must be determined and justified.
- Schemes for substations and the equipment's key parameters.
- The economic criterion
- Security
- Reliability measures

Power system planning is basically a prediction of how the system could evolve over time, based on some assumptions and judgments about future load economical and environmental constraints [12].

The acceptable level of reliability of the power system mainly requires additional generation capacity to achieve the expected increase in future electrical requirements. However, in many developing countries with sparsely populated regions, there is a trade-off between meeting quick demand growth by investing in additional generating capacity for isolated systems and building transmission networks to link these systems and move power between their load centers in the event of emergencies or power shortages. As a result, in the power system planning process, reliability and cost constraints are important factors [12].

The recurring process of studying and deciding what facilities and procedures should be given to meet and facilitate acceptable future electricity demands is known as power system planning. As designed, the electric power system should meet or complement societal objectives. These involve providing power to all potential consumers at the lowest possible cost, causing the least amount of environmental pollution possible, maintaining high standards of safety and reliability, and so on. Technically and financially feasible plans are needed [13].

2.5 Planning of Modern Distribution System with Distributed Generation

In the existing power dstribution sytems there is a unidirectinal power flow from distribution substation to end users due to most of the distribution systems are passive networks (radial). Upgrading the distribution system is mostly carried out with the help of additional network components such as transformers, protective devices and transmission lines for meeting the load growth. The integration of DG units has been as one of the attractive options for distribution system due to the incentives and environmental considerations. Distribution system with DG unit’s demands for dedicated operational strategies, since the DG units located near the load centers can possibly change the direction of power flows and consequently modify system operations. It is very important to allocate DG units in distribution networks with comprehensive technical and economic considerations to avoid the overall degradation of system performance.

Since the conventional planning process would not account for variable generation, the industry's first reaction was to simply exclude it from capacity planning. The modern planning process begins with the forecasting of load energy rise, which is immediately followed by the forecasting of peak load. The capacity of generation and transmission is then designed to match the predicted peak load. During device operation, renewable generation is assumed to be possible, and the production of committed thermal units is decreased to allow for the intake of energy from renewable sources. As a result of this sub-optimal system operation, thermal units typically operate below their rated power point, resulting in lower performance, higher emissions, and higher operating costs [14].

The integration of distributed generation (DG) into the distribution system brings conspicuous technical and economic benefits to the grid [15]. In this paper, an analytical technique is used to decide the appropriate size and placement of DGs in a distribution system in order to reduce distribution system power loss and increase voltage profile.

2.6 Planning of Distribution System under Load Growth

In Ethiopia demand for electricity growth from time to time, this becomes a serious problem in the country, to satisfy the demand electricity with reliable and high quality. Distribution system expansion is a must do work by utilities to improve their system voltage profile, reduce power loss and to satisfy their customers.

Gregorio Munoz Delgado presented a paper that discusses the deterministic mullet stage expansion planning problems of distribution systems where investments in the distribution system network or distributed generations are taken into account simultaneously. As a result, the best expansion strategy for the candidates' assets defines the best alternatives, site, and installation time. The resulting optimization problem is cast as a mixed-integer linear program [1].

The use of nonlinear formulations in a multi-objective optimization algorithm for multi-stage distribution expansion planning in the presence of DGs is investigated in [16]. The multistage expansion planning's objective functions include cost minimization, energy not distributed (END), active power losses, and a voltage stability index based on short circuit capacity (SCC). For this multi-objective modified distribution expansion planning optimization, a modified PSO algorithm is developed and used. A new mutation approach is used in the proposed updated PSO algorithm to increase global searching capacity and restrain DG reliability.

Similarly, to capacitor size, line characteristics, DG size and position, and adjusting the distribution transformer tap setting will help maintain the bus voltage within the normal range and minimize line loss [17]. Such reductions in line loss at peak load will minimize the need to invest in equipment with higher power ratings.

According to the papers cited above, DGs can reduce line loss by reducing line power flow and improve reliability by supplying isolated loads after an outage, in addition to supporting annual load rise. As a result, the most important factor affecting the expansion of a distribution system is load growth.

2.7 Definition of Distributed Generation Resources (DGs)

Distributed generation, decentralized generation, dispersed generation, and embedded generation are all terms used today to describe small scale generating units that are located in the distribution network or on the customer side. For a variety of reasons, this method of power generation is now popular. Some of those factors are, global warming, an alternative for fossil fuel and change in the power system network topology [18].

DG has two general definitions with refrence to sources. According to the first definition given above, DG refers to the energy source that production capacity is limited. Although this definition is correct in some cases, fails in comprehensiveness. But the second definition of DG sources, with the direct ability of the connections to the distribution network and to the consumer, offers a comprehensive definition. In this context, these sources are directly connected to the distribution network or the consumer who must be supplied [19].

In general, Distributed generations are small generating units that are either directly connected to the distribution network or placed at customer locations [20]. The capacity of DG units that can be connected to the grid is determined by the distribution system's capacity and voltage level designed for the particular distribution system. The method of connecting distributed generation to the electricity distribution network varies depending on the size of the generation that needs to be connected and the technology that will be used.

When modeling distribution resources for a distribution system, the DG can be used as a PV and PQ model in the distribution system. The PV model is a DG that delivers power at a fixed terminal voltage, while the PQ model is a DG that delivers power regardless of node voltage.

2.8 Classification of Distributed Generation Resources (DGs)

Distributed generation resources are classified based on different criteria. Among these, the main criteria for dsitribution resources are size (capacity), locaction, voltage level, type and application (technology used).

Classification of distrbuted generation resources based on the capacity or output power rating is shown in the figure 2.3 below.

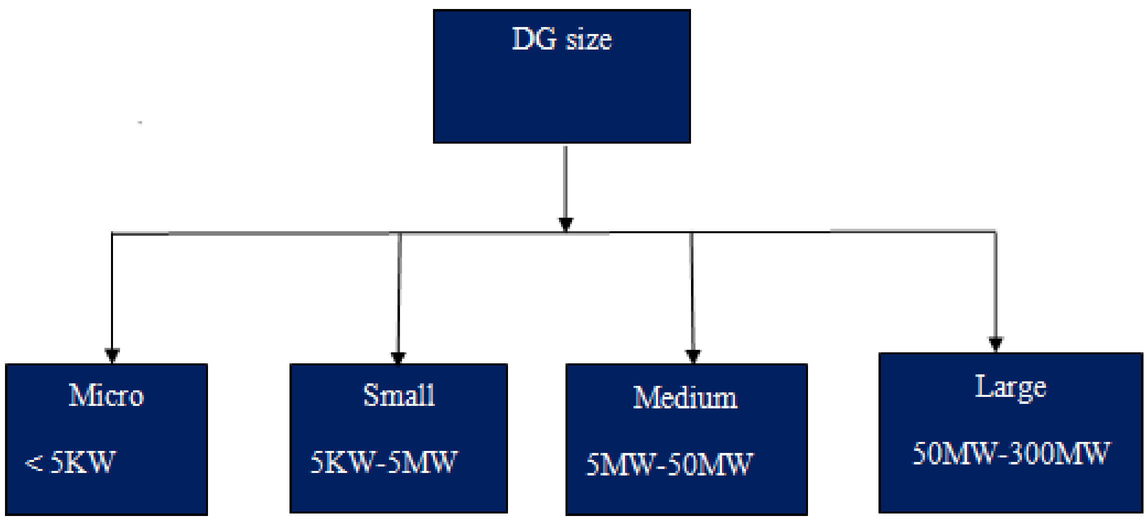

Figure 2.3: Typical size of DG units

The type of technology used in power generation is another criterion for categorizing distributed generation resources. There are two types of distributed generation (DG) technologies: traditional and renewable. As seen in the table below, this is also the key factor that divides distributed generation capital into two categories.

Table 2.1: Classification of DG based on the technology

Conventional DG	Renewable DG
Combined cycle Combustion turbine Micro-turbine Fuel cell Internal combustion engines	Solar Wind Geothermal Ocean

Distributed generation can be divided into two categories depending on the generating method: inverter-based DG and rotating unit DG. Inverters are typically used after the generation process in DG systems because the induced voltage can be in either DC or AC form, but it must be changed to the nominal voltage and frequency. Therefore, it has to be converted first to DC and then back to AC with the nominal parameters through the rectifier [21].

2.9 Distributed Generation Applications and Technologies

Distributed generation technologies can be categorized into conventional and renewable DG technologies. The conventional technologies such as fossil fuel-based generators have been widely deployed in distribution system as backup generation or cogeneration without having significant interaction with distribution networks. In recent years, the development of technology in different fossil-fuel based DG technologies and distribution system automation have made as one of the attractive options for distribution system reinforcement. On the other hand, the renewable DG technologies such as wind turbine generator, solar, hydropower and geothermal are also seen to be increasingly employed in distribution networks due to environmental concerns. Fossil fuel-based DG technologies, capable of power output control; the power generation by renewable DG technologies is non-controllable. The power output of renewable DG impacted by the availability of energy sources, such as water, wind and solar radiation. These things are an important factor for selecting potential sites DG at required plans.

Table 2.2: DG technologies and their advantages and disadvantages

DG Technology	Type of Technology	Advantages and disadvantages DG Technology
Conventional DG Units	Fossil fuel-based generators (diesel /coal /gas / combined heat and power)	**Advantages:** Readily avaliable with continous production Controllable and dispatchable Reliatively low capital investment **Disadvantages:** High operation and maintenance cost High emissions and noise pollution
	Clean feul based DG units (biomass/Fuel cells/Micro-turbines)	**Advantages:** Readily avaliable with continuous production; less emissions Possible to expert reactive power to grid **Disadvantages:** High fuel cost High capital investiment
Renewable DG units	Wind turbine-based DG units	**Advantages:** No emissions and no fuel cost Low operation and maitenance cost Possible to expert reactive power to grid **Disadvantages:** Intermittent and low-capacity power generation Not siutable for all location
	Solar (PV) based DG units	**Advantages:** No emissions; No fuel cost; No noise impact Possible to expert reactive power to grid for network support **Disadvantages:** Low efficiency; requires large area and High capital investiment

Some of the current DG technologies, as well as technologies that are commonly used in DG applications, such as photovoltaic systems, wind turbines, fuel cells, micro-turbines, synchronous and induction generators, are discussed in this chapter.

2.9.1 Photovoltaic Systems

A photovoltaic system is a device that converts sunlight into electricity. Semiconductive materials are used in the construction of solar cells in this system, which when exposed to sunlight convert photons' self-contained energy into electricity. The cells are arranged in a fixed or moving array to keep track of the sun and produce the maximum amount of power [21].

Photovoltaics (PV) (from the Greek "photo" meaning "light" and "voltaic" meaning "electricity") is the direct conversion of sunlight into an electrical potential (photovoltage) that can be used to generate electricity. The photo voltaic effect is the electrical potential developed between two dissimilar materials when their common junction is illuminated with radiation of photons. As a result, the photovoltaic cell converts light to electricity directly [22]. As a result, the photovoltaic cell transforms light into electricity directly [22]. Photovoltaic refers to a substance or device that can transform the energy present in photons of light into an electrical voltage and current [24]. The photovoltaic effect is thus the mechanism by which an electric potential difference, or voltage, is generated in a substance exposed to light (electromagnetic radiation), resulting in the flow of electric current. Figure 2.4 shows a photovoltaic panel.

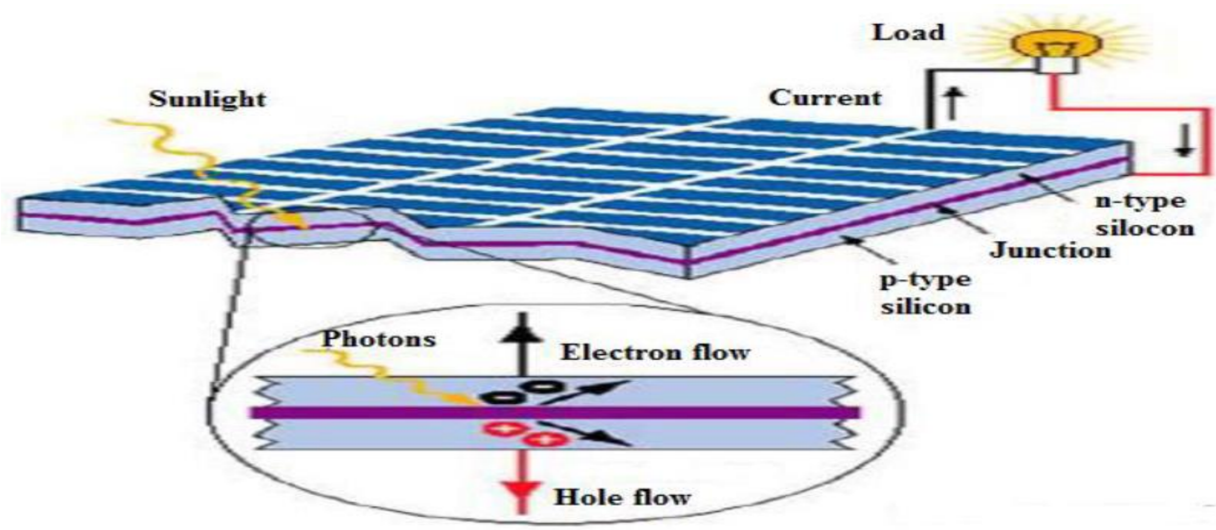

Figure 2.4: A photovoltaic panel [24]

This process is similar to the photoelectric effect, but differs in that in the photoelectric effect, electrons are ejected from the material surface when exposed to high-frequency (energy) light, whereas in the photovoltaic effect, electrons are generated and transferred across a material junctionjunction (e.g., PN junction in a photo-diode) resulting in the buildup of a voltage between two electrodes and the flow of direct current electricity. In other words, photons from the sun provide the energy for a solar cell. In a photovoltaic material, a photon with a short enough wavelength and high enough energy will cause an electron to break free from the atom that holds it. Those electrons can be swept toward a metallic contact and emerge as an electric current if a nearby electric field is created.

The direct generation of electrical energy in the form of current and voltage from electromagnetic (i.e., light, including infrared, visible, and ultraviolet) energy is known as photovoltaic energy conversion. For the most widely used silicon solar cells, a solar cell (PV cell) is a wide area semiconductor diode that consists of a p-n junction formed by impurity addition (doping) into the semiconductor crystal, which consists of four covalent bonds to the neighboring atoms [22].

The solar cell is the most essential component of a PV power system. It's usually a few square inches in size and generates around one watt of power. Several cells are connected in series and parallel circuits on a panel (module) with a surface area of several square feet to achieve high power. A solar array, also known as a panel, is a set of several modules that are electrically connected in series-parallel configurations to produce the necessary current and voltage.

In general, these systems are environmentally friendly, emitting no pollutants, are simple to operate, and do not require any other fuel than solar light. On the other hand, they need wide spaces and have a high initial cost [21].

2.9.2 Wind Turbines

The wind turbine operates by extracting kinetic energy from the wind as it passes through the rotor. An induction or synchronous generator is attached to the wind turbine shaft. The output voltage is then stepped up to utility grid standard using a transformer [23].

Wind energy is dependent on the sun's energy in an indirect way. The key cause of the difference between the net outgoing radiation at high latitudes and the net incoming radiation at low latitudes is that only a small portion of the solar radiation obtained by the earth is converted into kinetic energy. The location and structure of the resulting winds are influenced by temperature gradients, the earth's rotation, and geographic features. The kinetic energy of moving air must be transformed to usable energy in order to use wind energy. As a result, the economics of using wind for electricity generation are highly dependent on local wind conditions and wind turbines' ability to extract energy efficiently over a broad range of normal wind speeds. The availability of wind in a given location affects the production of electricity from wind energy [24].

Figure 2.5 shows schematic operation diagram of a wind turbine. Since the wind is a highly variable source that cannot be processed, it must be treated as such. The generator system in the most popular system produces an AC output voltage that is proportional to the wind speed. Since wind speed varies, the voltage produced must be converted to DC and then back to AC using inverters. Fixed-speed wind turbines, on the other hand, are directly linked to the grid.

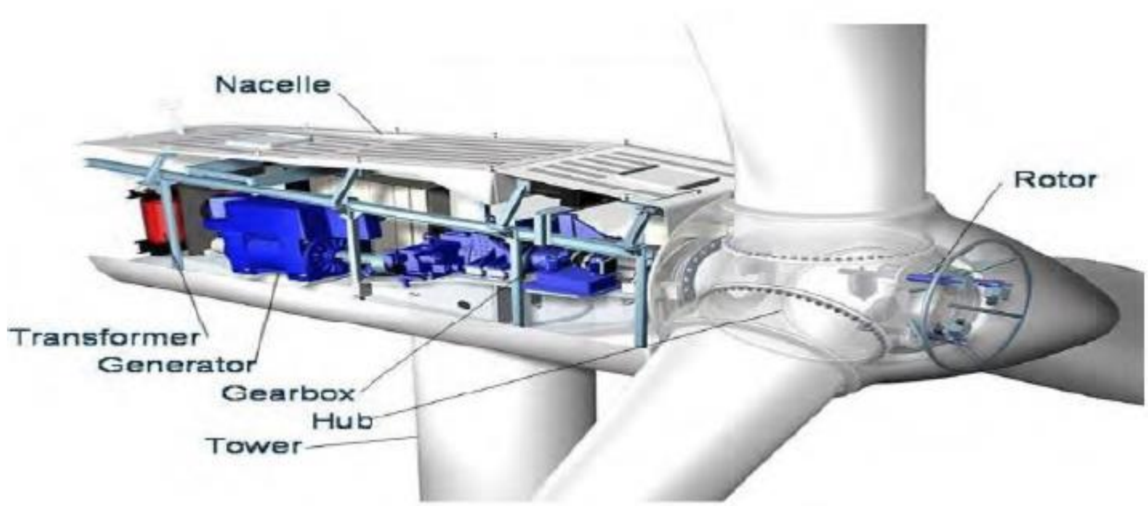

Figure 2.6: Schematic operation diagram of a wind turbine [25]

Unlike windmills, which are used to perform tasks such as water pumping and grain grinding, wind turbines transform wind energy into electricity [25].

2.9.3 Fuel Cells

Fuel cells are extremely effective and emit very few pollutants. A fuel cell works similarly to a battery. The activity of a fuel cell is similar to that of a battery that is constantly charged with a high-hydrogen-content fuel gas; this is the charge of the fuel cell in combination with air, which provides the necessary oxygen for the chemical reaction [26]. Figure 4.2 shows schematic diagram of a fuel cell.

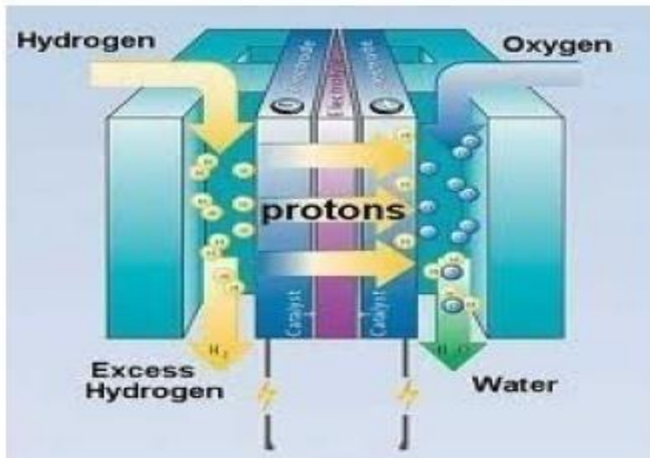

Figure 2.7: Schematic diagram of a fuel cell [26]

It generates electricity by electrochemically mixing hydrogen and oxygen without combustion. The fuel cell, on the other hand, is fed with fuel and an oxidant on a continuous basis, while the battery is a storage system for energy that must be recharged after it has been used up. Pure water is the end result of the electrochemical reaction, which produces electricity and heat without using a flame. The fuel cell generates an induced DC voltage by combining hydrogen and oxygen with the aid of an ion conducting electrolyte. Inverters convert DC voltage to AC voltage, which is then transmitted to the grid.

2.9.4 Micro-Turbines

A micro-turbine is a device that converts thermal energy into mechanical energy by using the flow of a gas. The combustible, normally gas, is mixed with air pumped by the compressor in the combustor chamber. This substance causes the turbine to spin, triggering the generator and compressor at the same time. The compressor and turbine are mounted above the same shaft as the electric generator in the most popular configuration [27]. Figure 2.4 illustrates schematic diagram of a micro-turbine.

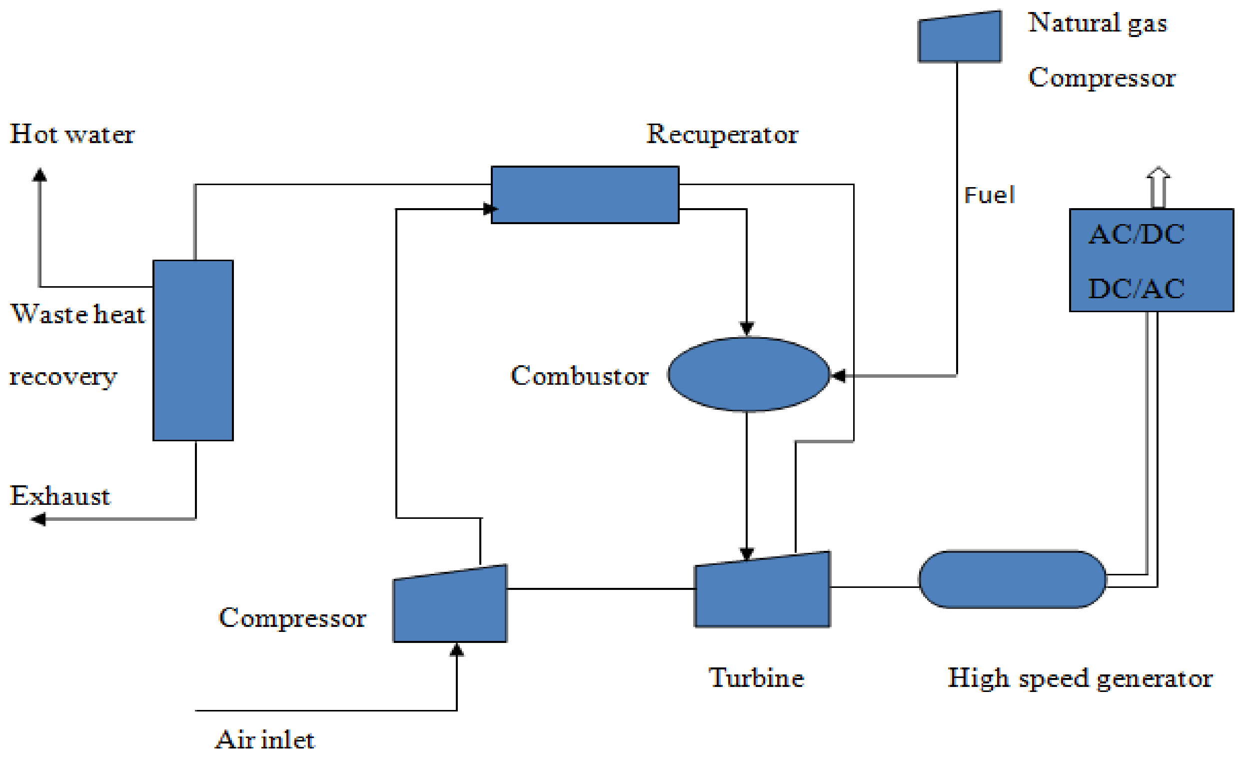

Figure 2.8: Schematic diagram of a micro-turbine [27]

Micro-turbine output voltage cannot be directly connected to the power grid or utility; instead, it must be converted to DC and then back to AC. Using a micro-turbine has its own set of benefits and drawbacks. The main benefit of micro-turbines is their clean operation, which results in low emissions and high efficiency. The high maintenance costs and lack of experience in this field, on the other hand, are its disadvantages.

2.9.5 Synchronous and Induction Generators

Synchronous and induction machines are both electrical machines. These devices transform mechanical energy to electrical energy, which is then transmitted to the network or loads. As the shaft of an induction generator rotates faster than the synchronous frequency powered by a prime mover such as a turbine or motor, it generates electrical power. The rotor flux direction, as well as the direction of the active currents, are modified, allowing the system to power the load or network to which it is connected. With an electronic controller, the induction generator's power factor is dependent on the load, and its speed can be allowed to vary with the wind speed. The cost and efficiency of such a system are usually superior to those of synchronous generators [28].

Synchronous generators run at a fixed synchronous speed and are thus constant speed generators, according to their basic characteristics. The synchronous generator, in comparison to the induction generator, which operates with a lagging power factor, has a variable power factor characteristic and is thus suitable for power factor correction applications. A generator connected to a very large or infinite bus electrical system will have little or no effect on its frequency and voltage, as well as on its rotor speed.

The induction generators require reactive power from the mains to create the magnetic field. As a result, the synchronous machine's operation is usually impossible without the three phase mains. Due to this reason, reactive sources such as capacitor banks would be required at the respective locations, allowing the generator and load to access reactive power. As a result, induction generators are difficult to use as a backup generation facility, such as during an islanding operation [28].

CHAPTER THREE

DISTRIBUTED GENERATION INTEGRATION ISSUES AND PLANNING OF DISTRIBUTION SYSTEM NETWORKS

3.1 Introduction

This chapter covers the distributed generation integration issues and planning of distribution networks such as proper placement, sizing methodology of DG and different methods of peak load demand forecasting techniques. To decrease system losses and satisfy the load demand requirements, DGs are allocated and sized in this chapter as part of the integrated planning. The overviews of some of the distribution system peak load demand forecasting techniques are included in this topic.

3.2 Distribution System Expansion Planning with DG

Planning on the distribution system network may be classified as reinforcement planning and expansion planning. Reinforcement planning is the planning strategy that improves the power losses and the voltage profile level in the network without considering new DG units. Expansion planning is the planning strategy that improves the power losses and the voltage perofiles level in the initial network taking new DG units into considerations. In this thesis the planning strategy used is the second one; wich is the expansion planning strategy. The primary role of distribution network expansion planning is to provide new loads with electrical energy, but it also involves the connection of DG units. The aim of distribution network expansion is typically to reduce the costs of installing and operating new substations, cables, and overhead lines. The distribution network expansion planning can be enforced by using network analysis software such as ETAP and DigSilent power factory where the aim is to form the network in advance and then checks its voltage, current and power parameters of the distribution networks.

DG can be used to handle load growth and provide relief for overloaded components in addition to expanding existing substations, constructing new transmission lines, and building new substations. A key problem in distribution system planning is the positioning and sizing of compensating units to utility networks, such as when DG is used to perform network reconfiguration. The incorrect placement of DG can result in increased device losses, resulting in an increase in cost. DG can be used to accommodate new load growth and provide relief to the delivery system's overloaded components. The strategies for achieving the task of distribution system planning at the distribution network are specifically proposed in this study.

One of the most important activities of the distribution system to deal with rising electric power demand is expansion planning. Distribution system expansion planning consists of defining facilities to be installed (reinforced) so that the system serves as the forecasted demand. Distribution system expansion planning has traditionally been accomplished in one of two ways:

- ❖ The static approach, this takes only one planning horizon into account when determining the position, type, and capacity of new equipment to be added to the system. Alternatively, all expansion conditions are decided within a single planning phase.
- ❖ Multistage approach, which determines not only the most appropriate location, type, and capacity of investments, but also the most appropriate times to carry out such investments, so that the system can still assimilate the continuing growth of demand in an optimal way. In a short, this strategy entails expanding the scheme in steps, one after the other.

Today, in power system distributed generation (DG) is selected as a new option for expansion planning of distribution sytem. Thus, currently distributed generations (DG) are implemented as possible solution in distribution system expansion planning to minimize the loss of distribution system, improve voltage profile and satisfy the load requirement.

3.3 DG Placement and Sizing Issue

DG placement in distribution systems is one of the most recent and impressive strategies for loss reduction in distribution systems. Since DG units produce electricity on-site to meet customer demand, proper size and placement of DG units can dramatically reduce power losses in distribution systems [29].

The benefit of distributed generation when connected to distribution system depends on the suitable place and size of distributed generation. Thus, the distributed generations (DGs) are only beneficial if their installations are carried out according to the appropriate plans. This demonstrates that if the capacity and location of DGs are not properly defined, the network parameters are not improved [30]. As a result, determining the capability and position of these tools are two of the most critical aspects of DG plans.

The integration (installing) of distributed generation (DG) into the distribution system brings conspicuous technical and economic benefits to the grid. Technical benefits of introducing DGs in the distribution system can be accrued categorically through the reduction in line losses and emissions, improving the voltage profile, reducing the power loss, decreasing the requirements of installing new transmission lines, and deferring the necessity of improving the capacity of substations [31]. However, the installation of DGs at arbitrary locations may result in degraded voltage profiles and increased system losses. As a result, DG unit sizing and placement should be carefully designed and calculated [32].

The incorrect size and position (placement) of DG will increase system losses, resulting in a cost increase. If it is located in a suitable location, DG can be used to handle new load growth and provide relief for overloaded components [33].

Active power losses occur when active and reactive power are transferred via overhead lines, underground cables, and transformers. Putting generation close to the consumers, as DG does, may increase or decrease losses. It is dependent on the position and size of the DG power, as well as the load correlations. If both load and generation are located at the same feeder, a small amount of DG is likely to minimize losses in pure load networks. The losses from segregated feeders are still increasing [34].

The installation of distributed generators on distribution networks has the ability to minimize total system losses. As a result, if distributed generators are properly positioned and sized, they may play a critical role in reducing losses and improving voltage profile, thereby increasing the reliability and security of distribution systems [35].

However, the location and sizing of distributed resources (DG) are very important for distribution networks for additional benefits such as loss reduction and satisfy load demand requirements, there is no clear guidelines and restriction for both location and size of distributed generation for distribution networks.

Here, for location of distributed generation units in the distribution networks there are no clear restrictions. The only limitation of of DG location arises from electrical requirements. This is depending on the DG operation if it is utility owned or customer owned. When the DG is located at the customer's site, the utility has no control over its position as it is customer-owned. If the DG is operated by a utility, its location is determined by a variety of electrical factors, including:

- Reducing system losses
- Providing the required additional load demand
- Improving system voltage profile and augmenting substations capacities
- DG units have to be placed on feeders that do not impact the existing protective device co-ordinations and sytem ratings.

There are no widely agreed criteria for deciding the size and number of DG units to be installed in distribution networks. Furthermore, there are no specific guidelines for deciding the size and number of DG units to be installed in the network; however, some factors can be guiding the selection of DG unit size selection. Those factors are:

i. It is necessary to use DG units with a total capacity of 20-50 percent of the total feeder load demand to improve the system voltage profile and minimize power losses. While more DG capacity can be used to reduce the substation loading.
ii. The DG unit size can affect system protection coordination schemes and devices as it affects the value of the short circuit current during a fault. As a result, the safety systems, fuses, re-closers, and relays settings should be re-adjusted / upgraded as the DG size increases.

3.4 Demand and Peak Load

The rate at which electricity is consumed is represented by electricity demand, which is calculated in kilowatts (KW). Energy consumption, on the other hand, is measured in kilowatt-hours (KWH) and measures the total amount of electricity used for a specific time span. As a result, demand is defined as the average load value over a given time period, or demand interval. Demand can be measured on any interval such as seconds, one minute, day, etc.

The average value of power during the demand interval is found by dividing the kWh accumulated during the interval by the number of hours in the interval. During the interval, the peak and minimum consumption rates can vary significantly from this average. The overall demand estimated over a measurement period is known as peak demand, or peak load. This value is frequently used as a capacity target in this study. Therefore, the peak demand is the maximum amount of power the system must deliver.

3.5 Demand Forecasting Techniques

To plan the distribution system, it is so essential to develop a demand forecasting technique that is suitable to the aim of the forecast. There are different type forecasting techniques, but the techinques can be selected based on the forecasting objectives. In other words, the type of demand forecast technique adopted should fall in line with the requirements of the study.

Demand forecasting strategies can also be divided into groups depending on the amount of mathematical work that goes into the forecasting model. The methods are divided into two categories: quantitative and qualitative methods [36]. The qualitative forecasting approaches are subjective in nature and are focused on judgments, thoughts, instincts, feelings, or personal experiences. These types of load forecasting methods do not rely on any rigorous mathematical computations and are mostly used by the planners to forecast accuratly. Quantitative forecasting approaches are objective in nature and are focused on statistical models. They relay heavily on mathematical computations.

However, there are different methods of load forecasting techniques; the basic categories are parametric and artificial intelligence methods. The parametric load forecasting techniques can be grouped into time series (extrapolation-based demand forecasting), econometric, end-user and hybrid econometric and end-user load demand forecasting techniques. The artificial intelligence can be devided into fuzzy logic, artificial neural networks and support vector regression. In general, the main parametric type demand forecasting techniques that are widely used are listed below:

- End-user demand forecasting method
- Econometric demand forecasting method
- Extrapolation based demand forecasting method

- ❖ Hybrid Econometric and End-user based demand forecasting method

A general idea of each of main load demand forecasting methods is detaily intruduced in the sub-sections below.

3.5.1 End-User Demand Forecast Method

The end-user approach directly measures energy use by evaluating a broad range of data about end users, including applications, consumer use, age, house sizes, and so on. The prediction is focused on statistical knowledge about customers as well as change dynamics [36].

The end-user method measures energy demand by adding up all of the kWh used by all of the electrical appliances in the home. Since the data needed for this forecast includes: forecast year, number of residential customers, residential housing stock or commercial buildings, industrial process data, major appliances, and kWh usage per appliance, it is most easily applicable to the residential sector. Simple accounting procedures enumerate the end uses and add the electricity usage for each end use for its components are the most basic type of this model.

This method is primarily concerned with the numerous applications of electricity in the residential, commercial, and industrial sectors. These models work on the assumption that electricity demand is generated from consumer demand for light, cooling, heating, and refrigeration, among other things. As a consequence, end-use models describe energy demand as a feature of the market's number of applications [36].

In an ideal world, this method is extremely accurate, particularly for greenfield developments and residential demand forecasts. Load density-based forecasting is an extension of end-user demand forecasting, in which the maximum load in each region is determined by the surface area occupied by each customer type and the power density associated with that consumer type. This is particularly useful to distribution planning. End-user forecasts often take into account changes in industries and agriculture, where demand trends can be identified. However, since it is sensitive to the quantity and quality of end-use data, the distribution of equipment age is essential for specific types of appliances in this process. Most of the time, this prediction needs more knowledge about customers and their equipment than historical data [37].

The energy consumptions are predicted using this tool. If we want to calculate the load, we need the load factor for each section and various types of energy consumptions, and then we can calculate the load in each section using the load factor [38]. The drawback of end-use analysis is that most models presume a constant relationship between electricity and end-use, i.e., electricity per-appliance.

3.5.2 Econometric Demand Forecast Method

The econometric method measures the relationship between energy consumption and the factors that affect it. For forecasting electricity demand, this method combines economic theory and statistical techniques. The relationships are estimated by the least square method or time series methods, extrapolation. One of the options in this framework is to aggregate the econometric method, which involves calculating consumption in various sectors such as residential, commercial, and industrial as a function of weather, fiscal, and other variables, and then assembling estimates using recent historical data. Integration of the econometric approach in to the end-use approach introduces behavioral components in to the end-use equations [39].

It calculates energy demand by factoring in independent variables including population, employment, income, weather, appliance ownership, and interest rates. Estimated equations that link electricity demand to external factors are known as econometric models. End-use models use data on kWh usage by type of equipment or operation, whereas econometric models use data over time. Econometric models are among the most complex forms of energy forecasting. They are used in a number of service environments, including residential, industrial, and commercial.

This type of model, like the time series model, uses historical regularities to forecast the future, but it seeks to go beyond time series models in describing why patterns occur. As a result, the econometric approach is based on the relationships between energy consumption or peak demand and a number of economic demographic variables. Econometric models assume that the dependent variable (either energy or power) has explicit causal relationships with other economic, technical, or demographic variables. Econometric modeling would be preferred to time series analysis. Even if both methods were equally accurate at forecasting demand changes, the econometric model would be more useful because it might aid in understanding why demand changes were happening. Knowing these causes can help to plan to meet future needs.

The econometric approach has its own range of benefits and drawbacks. The benefit of econometrics is that it offers extensive details on future levels of electricity demand, such as why future electricity demand is projected to grow and how electricity demand is influenced by all of the different factors.

One disadvantage of econometric forecasting is that, in order for an econometric forecast to be reliable, fluctuations in electricity must remain constant in the forecast period as they were previously. This assertion, known as constant elasticity, can be difficult to explain, particularly when large increases in electricity rates make consumers more vulnerable to them.

3.5.3 Hybrid Econometric and End-User based Demand Forecast Method

Another form of energy modeling is the hybrid econometric and end-user approach, which forecasts energy demand by combining end-use structure with econometric estimation. Forecast years, the number of customers, independent variables to estimate housing and appliance stocks, kWh consumption per appliance, and industrial process information are all required for this system. Hybrid models were specifically produced for the industrial and residential markets. To generate parameter values and input data, these models employ econometric methods.

The process for forecasting using a hybrid end-use and econometric approach starts with the development of model specifications, both for the core end-user model and the econometric equations used to estimate input values. The estimation of the econometric equations is the next step. The third step is to put together all of the data for the end-use model, with the exception of the econometric estimates. The fourth step is to create econometric forecast values, which entails forecasting exogenous variable values and simulating econometric equations for forecast years. The fifth step is actually making the forecast.

3.5.4 Extrapolation Forecast Method (Time-Series Method)

The extrapolation technique predicts energy demand based on data patterns and trends. This approach examines historical data trends in order to forecast the future based on the underlying patterns found in the data. The researcher uses statistical extrapolation of load demands based on historical data for the load demand being predicted hourly loads, peaks, or energy sales by using extrapolation techniques. Extrapolation methods, in general, look at historical patterns in energy and power demand over time and extrapolate them into the future. This means that in time series (extrapolation) forecasting, it is widely believed that variables that influenced demand in the past will continue to influence demand in the future.

Time series (extrapolation) method often contains the following main characteristics:

Trend: Data indicates a gradual rise or decrease over time. The phrase "trend" refers to long-term average growth that can be interpreted as an average rise in a time series.

Seasonality: In a short to intermediate time period, data shows upward and downward swings. Because of consuming patterns at various times of the year, there could be periodic, repeated changes in time-series.

Cycles: Over a long period of time, the data show upward and downward swings. It's a cyclic variable with similar properties to a sine wave in that it has approximately the same beginning and end values over a given period of time. Variations of this form can be seen over a 24-hour cycle, a weekly period, an annual period, or even longer.

Auto-regression: There is variation wich is seen in given period of time. This variation may be seen over 24 hours period, aweekly, or annualy. There may be depandance between those succeessive values. This interdependency is known as auto-regression.

Random variations: Variation in the data that is inconsistent and variable over time, with no discernible trend.

In general the time series method uses historical data as the basis of estimating future outcomes. To estimate the future outcomes historical data should be analyzed. This method uses certain techniques to analysis data, among them the commonly used analyzing techniques are:

- ❖ Exponential smoothing
- ❖ ARIMA (autoregressive integrated moving average)
- ❖ Moving average
- ❖ Autoregressive techniques;
- ❖ Simple regression
- ❖ Extrapolation
- ❖ Linear prediction and

- ❖ Trend estimation

3.6 Distribution System Load Growth

Due to the rapid development of industrial and commercial loads, the growth in feeder load has been increasing every year. This distribution load growth rate is not constant in each year, shows that in each year the load increases rapidily. The rise in feeder load may be the result of new loads being added to the feeder or gradual changes to existing loads. When the load exceeds the capacity of the feeder, it is either restricted by voltage regulation or by thermal constraints. The feeder can accept the loads only when the voltage constraint is satisfied.

Increase in load demand system experiences

- ❖ Increased power loss
- ❖ Increased load factor
- ❖ Increased cost of feeder energy loss
- ❖ An increase in the cost of supplied energy
- ❖ Voltage deviation in the system

Additional feeders or substations have been needed to meet the loads requirements. But it is practically difficult due to the economic constraints. Moreover, the feeder has been designed on a long-term basis and the peak demand may exist only for a few hours. Due to these reasons, the placement of DG can extend the life of the existing feeder for few years without need of additional feeders or substations. This chapter deals about placement of DG in radial distribution system (RDS) to meet the incremental load and reducing the system power loss.

From the above Nekemte distribution substation peak demand load forecasted the followings are taken under considration. However, the load growth increases rapidly, in this thesis the following things are assumed:

- ❖ The load growth rate is 8.97% per-year.
- ❖ The DG is connected to across the selected bus.

3.7 Methodology for Suitable Location and Size of DG

The distributed generation resources (DGs) are allocated in suitable way to make the function of existing distribution system better. The allocation of DG problem consists of three important steps. Via Selection of Load flow analysis technique, finding suitable location and selection of the appropriate size of DG. In case of allocation DG and sizing for distribution system certain electrical parameters of distribution system such as substation capacity, voltage drop, and line currents should be under consideration.

In each plan year, the total power delivered by the substation over the outgoing distribution feeders from that bus does not exceed the capacity of the substation. This implies that the power outgoing from distribution system must be with in the substation capacity limit. Hence, the ratted current of the lines and transformer rating should not be exceeded.

Substation Capacity

The transformer rating must not be exceeded. The total amount of generation connected, minus the lowest load, must not exceed the higher voltage transformer's rating. If there is already any generation, it must be subtracted from the sum. The result is the remaining capacity available below that station. When two parallel transformers are used, the capacity is determined using the smaller transformer's rating plus the lowest load. The constriant is officially expressed as equation 3.1.

$$P_{TX} < P_{TrafoCap} \quad 3.1$$

Where P_{TX} refers to power flow through the transmission substation transformer and $P_{TrafoCap}$ refers to the rating of that transformer.

Rated Current of the Lines

It is important just to put the rated current of the lines should not be exceeded. This is given by equation 3.2.

$$I_i < I_{rated} \quad 3.2$$

Where I_{rated} is the maximum valued current for the line between each generator and its corresponding bus, and I_i is the current flowing from generator I to bus i. The rated current of a line can be directly converted into a rated active power for that line under normal voltage and power factor conditions.

Voltage Drop Constraints

As DG is connected to a network section, it changes the active and reactive flows, which affects the voltage drop along the lines. It has been demonstrated that DG causes a major voltage rise at the ends of long lines, high-impedance lines. When there is low demand and high generation, the voltage rises, allowing a large amount of power to pass through lightly loaded lines with high impedance. Equation 3.3 gives the voltage at the generator from the circuit below.

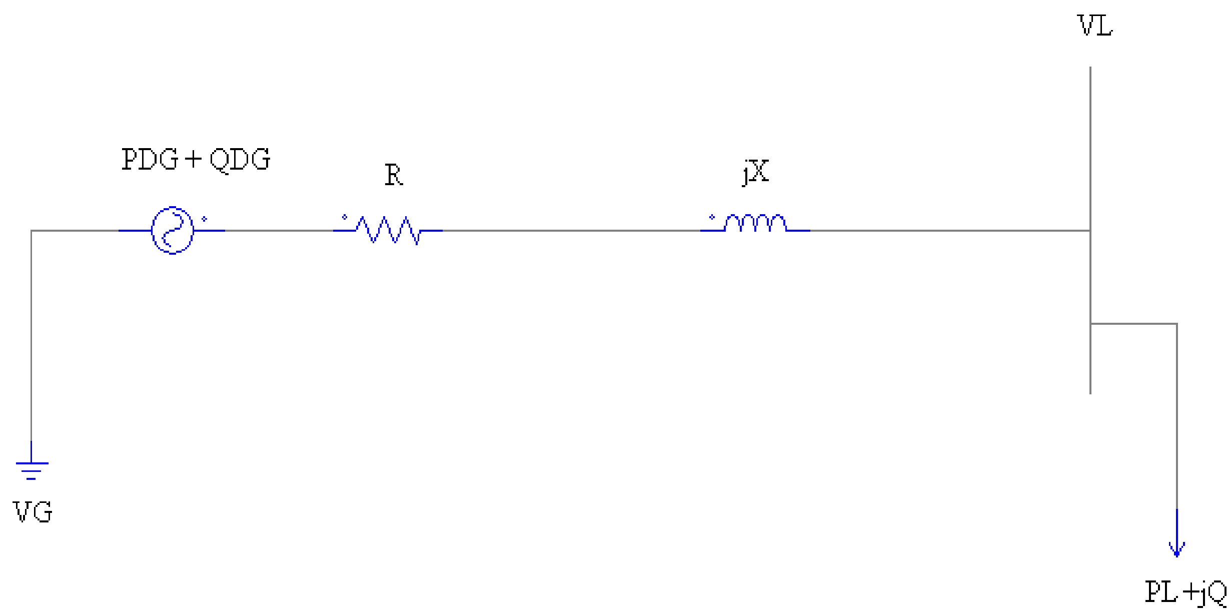

Figure 3.1: Loaded lines with high impendece

Hence, the generator voltage is:

$$V_G = V_L + \frac{R_{PL} + X_{QL}}{V_L} + j\frac{X_{PL} - R_{QL}}{V_L} \quad 3.3$$

Where Z=R+jX is the impedance of the line, P_L and Q_L are active and reactive power at the bus and V_G and V_L are the voltages at the generator and bus respectively. As a consequence, the generator voltage would be the load/bus voltage plus a value relevant to the line's impedance and the power flowing through it. The voltage increases proportionally to the size of the impedance and power flow. Since the resistive elements of distribution network lines are higher than those of other lines, increased active power flows on the distribution network have a major effect on the voltage level. As shown in equation 3.4, the voltage must be held within standard limits at each bus.

$$V_{mini} < V_i < V_{maxi} \qquad 3.4$$

Where $V_{min\ i}$ and $V_{max\ i}$ refer to the minimum and maximum voltage limits at the i^{th} bus. At each bus, the relationship between voltage and power injections is calculated. The voltage rises as more megawatts are applied to each bus. At each bus, increasing levels of generation are introduced incrementally, and a load flow analysis is performed to establish a voltage verses active power characteristic.

3.7.1 Radial Distribution System Load Flow Analysis

Load flow studies are critical for planning and designing future power system expansion. It is one of the most relevant methods for both planning and operation stages of power systems analysis [40].

Finding all of the node voltages is the first step in the distribution load (power) flow. It is possible to compute current, power flows, system losses, and other steady-state quantities directly from these voltages. As a consequence, the principle of power flow analysis is used as a fundamental method in the power system to evaluate values such as active and reactive power losses, voltage magnitudes, and phase angles at each bus.

On the other hand, load flow studies are performed on power systems to understand the nature of the installed network. This understanding gives the knowledge of the installed generation systems, loads connected, losses incurred, and also the flexibility of the system to allow future load connections. So, load flow or power flow analysis is an essential part of any power system.

For power flow analysis, traditional methods such as the Gauss Seidel method (GS), Newton Raphson method (NR), and Fast-Decoupled methods were previously used. However, these approaches were found to be unsuccessful in the distribution side due to a variety of factors, including distribution systems with radial networks, polyphase systems, unbalanced operating conditions, continuously variable load, and a large number of nodes and branches. For these purposes, a power flow analysis was performed on the radial distribution bus system using an efficient method known as backward or forward (FW/BW) sweep analysis. FW/BW analysis has much lesser time of operation than other approaches. When compared to other analyses in active and reactive power losses, the FW/BW sweep approach will have good results [41].

Due to the unique characteristics of distribution networks, such as radial structure, high R/X ratio, and unbalanced loads, traditional NR and Gauss Seidel (GS) methods can become inefficient in the analysis of distribution systems [42]. As a result of these characteristics, power flow calculation in distribution systems is different and more complex to study than in transmission systems. There are several approaches for analyzing balanced and unbalanced radial distribution networks, which can be classified into two groups. The first form of method is created by modifying existing methods like the NR and GS methods. The second set of methods, on the other hand, is based on backward and forward sweep processes based on Kirchhoff's laws [43].

In general, load flow analysis is a core component of a power system, and it is used to determine voltage, current, actual power, reactive power, losses, and power factor. It can also be used to verify adequate voltage profiles under various operating conditions, such as heavily loaded and lightly loaded systems. For a given power system network, with known loads and some set of specifications or restrictions on power generation and voltages, load flow analysis solves for unknown bus voltage and unspesified generation, and finally from complex power flow in the network components. A load flow analysis can be used to determine the total distribution system losses as well as individual component losses. At various buses, it provides real and reactive power. The algebric number of powers injected at all buses can be used to measure total distribution network losses.

The bus voltage profiles, active power flows, reactive power flows, and distribution line losses on all lines and transformers of the Nekemte distribution system network were determined using load flow analysis in this study. The software used in carrying out this analysis was Digsilent power factory.

3.7.2 Distribution System Power Losses

Losses are a significant concern in the distribution system because the lost energy must be compensated, and network components are heated by losses, which can shorten their lifespan.

Furthermore, energy for active power losses has a monetary value and must be generated. As a result, losses should be kept to a minimum [44].

Electrical power losses in distribution systems are caused by a number of factors, including the amount of power lost by transmission and distribution lines, transformers, capacitors, and insulators [45]. The Power losses contain real power loss and reactive power loss. Real power loss is caused by line resistance, while reactive power loss is caused by reactive components. Real power loss tends to attract the utilities' attention because it limits the efficiency of transmitting electricity to customers. Reactive power loss, on the other hand, is unquestionably important. This is due to the fact that reactive power flow in the system needs to be maintained at a certain amount for sufficient voltage level. Consequently, reactive power makes it possible to transfer real power through transmission and distribution lines to customers.

Generally, distribution of electrical power and energy must be done at minimum distribution network losses. Losses in the distribution network are typically split into two categories: technological and non-technical losses. This demonstrates that technical and non-technical losses can occur during the process of supplying electricity to consumers via electrical distribution. The technical losses (TL) are composed of both variable and fixed losses. Depending on the power distributed across the network, variable losses (load losses) are proportional to the square of the current. They are commonly known as copper losses, occur mostly in lines, cables, and copper sections of transformers. As long as the transformer is energized, fixed losses (no load losses) occur primarily in the transformer cores and manifest themselves as heat and noise. These losses are constant regardless of the amount of power transmitted through the transformer and can be decreased by using high-quality raw materials in the core, such as special steel or amorphous iron core.

Non-technical (NTL) compromise units are delivered and consumed but are not registered as a sale for various reasons. Metering errors, wrong meter installation, billing errors, illegal energy abstraction, and unread meters are all blamed. Because of their high precision, the use of meters would aid in the reduction of these losses.

The distribution system is part of power system wich is nearest to the consumers. This illustrates that the distribution network is the final stage of the power system, which is completed by customers. Consumers and utilities are both affected by issues in the distribution network. One of these issues is voltage drop, which must be minimized in order to maintain voltages at load points within acceptable limits. When using lateral radial feeders over long distances or feeding large loads, the voltage drop problem may occur. As a consequence, the solution to this problem becomes critical, requiring that the voltage at various nodes of the system be controlled. The voltage control actually refers to the control of reactive power.

Thus, losses are significant consideration when designing and planning the distribution system. It is difficult to eliminate network losses; thus, losses are unavoidable on any network. However, depending on the network's design, the amount can vary significantly. The network is being used in a different way with more variable and bidirectional power flows since the introduction of distributed generation. The level of losses is inextricably related to power flows. Losses are proportional to the square of the current, which means that doubling the current quadruples the losses. As a consequence, DG allocation and the resulting altered power flows can have a significant impact on losses and have an opportunity to improve them.

Ethiopian distribution systems including Nekemte distribution systems are radial type. As compared to a high voltage transmission system, the power loss in the radial distribution system is considerably higher due to lower voltage and hence high current, resulting in an increase in the cost of power and a poor voltage profile along the distribution feeder.

In the distribution system the resistance value is large compared to the reactance value. Hence, the active power loss is taken under consideration during connection (installation) of distributed generation to the distribution system.

There are a variety of methods for loss reduction in the distribution system, including:

- ❖ Feeder reconfiguration
- ❖ Capacitor placement
- ❖ Conductor grading
- ❖ DG placement

All of these methods involve passive elements, except for DG placement. Both DG unit placement and capacitor reduce power loss and improve the voltage profile significantly, but the placement of DG reduces the loss more as compared to the capacitor placement. In this thesis the DG unit is selected used to reduce the distribution system power loss, improves the voltage profile and fulfills the load requirements.

3.7.3 Suitable Location of DG Using Voltage Sensitivity Index (VSI)

The location of DG is chosen as the one that gives the best power loss minimization. In order to limit solution space to a few buses, the voltage sensitive busses are first identified by penetrating DG with 50 percent of the total feeder load capacity on each bus at a time and then calculating the voltage sensitivity index (VSI) using equation 3.5. When DG is connected at bus i, VSI for bus i is defined as:

$$VSIi = \sqrt{\frac{\sum_{q=1}^{n}(V_{nominal} - V_q)^2}{n}} \quad 3.5$$

Where V_q is voltage at q^{th} bus and n is the number of buses. Here $V_{nominal}$ is taken as 1.0 P.u. The bus with least VSI will be picked as the best location for the DG placement.

3.7.4 Appropriate Sizing of DG at Suitable Location

The suitable bus for locaction of DG is obtained by the voltage index using load flow analysis. The DG size inserted at the suitable is determined analytically with the mentioned procedure below. The size which gives the minimum complex power loss is the best size of DG to be placed at the best location.

The distribution system under taken in this study is radial distribution system. The total actual power losses of a radial distribution system can be calculated by adding the values of all power losses at each of the network's n nodes. The power loss reduction as loss saving based on total real power loss in radial distribution system as:

$$P_{loss} = \sum_{i=1}^{n}(I_i^2 R_i) \quad 3.6$$

Where Ii denotes each branch's current magnitude and Ri denotes the resistance of the i^{th} branch. The current Ii is measured using the Newton-Raphson method and load flow. This is the loss without DG in equation 3.6. The active current generated by a single DG at bus m is represented by I_{DG}, and the new active current I_{new} of the i^{th} branch is given by:

$$I_{inew} = I_i - I_{DG}J_i \quad 3.7$$

Where J is 1 if branch i has DG connected to its bus and is zero if no DG connection to the bus. When DG is placed in agiven bus there is a new power loss. This power loss is the loss with DG. The new power loss with penetration of the DG into the network is given by:

$$P_{loss-new} = \sum_{i=1}^{n}(I_{inew})^2 R_i \quad 3.8$$

Now, substituting equation 3.7 in to equation 3.8.

$$P_{loss-new} = \sum_{i=1}^{n}(I_i - I_{DG} J_i)^2 R_i \quad 3.9$$

Equition 3.9 can be written as:

$$P_{loss-new} = \sum_{i=1}^{n}(I_i{}^2 R_i - 2I_i J_i I_{DG} R_i + J_i I_{DG}^2 R_i \quad 3.10$$

Where Ji =1 for a feeder with DG or else Ji = 0

For single source network all the power is supplied by the source but with the appropriate placement of DG there is going to be reduction in power loss. The difference between the power loss with and without DG is used to calculate this reduction in power loss. Hence, the power loss reduction (P_{LR}) value for bus i is obtained by subtracting the power loss with DG and power loss without DG, subtracting 3.10 from 3.6 as:

$$P_{LRi} = P_{loss-new} - P_{loss} \quad 3.11$$

Where P_{LR} is the power loss reduction, $P_{Losses-new}$ is the power loss with DG placement at buses i and P_{Loss} is the power loss with out DG placement at given bus.

$$P_{LRi} = \sum_{i=1}^{n}(I_i{}^2 R_i - 2I_i J_i I_{DG} R_i + J_i I_{DG}^2 R_i) - \sum_{i=1}^{n}(I_i{}^2) R_i \quad 3.12$$

$$P_{LRi} = \sum_{i=1}^{n}(-2J_i I_i I_{DG} + J_i I_{DG}^2) R_i \quad 3.13$$

The bus with the highest Power Loss Reduction (P_{LR}) value is chosen as the best location for DG. The goal is to position the DG in such a way that it reduces losses to the greatest extent possible. Equation 3.14 is differentiated with respect to I_{DG} and equated to zero to obtain the DG current that will result in the greatest loss reduction.

$$\frac{dP_{LRi}}{dI_{DG}} = \frac{\sum_{i=1}^{n}(-2J_i I_i I_{DG} + J_i I_{DG}^2) R_i}{dI_{DG}} = 0 \quad 3.14$$

Hence the DG current that gives maximum power loss reduction (P_{LR}) value given by equation 3.15 below.

$$I_{DGi} = \frac{\sum_{i=1}^{n} J_i I_i R_i}{\sum_{i=1}^{n} R_i} \qquad 3.15$$

The most important thing is to locate the DG in such a way that it eliminates loss to the greatest extent possible. Since the DG units are individually placed, the process is repeated for all buses in order to achieve the maximum power loss reduction value. Assuming that the voltage does not change significantly as the DG units are connected, the DG power size that can be generated is:

$$P_{DGi} = I_{DGi} V_i \, Pf \qquad 3.16$$

Where V_i is the voltage magnitude of the bus i and the DG size from equation 3.16 should be located at bus i for maximum power loss reduction.

The following steps are being taken to decide the best size of DG:

Step 1: Run the base case load flow.

Step 2: Determine the voltage index at each node by penetrating 50% of the feeder load DG value at each node using equation 3.5, and then rank the sensitivities of all nodes in ascending order to form a priority list.

Step 3: Select the bus that has the lowest priority.

Step 4: Determine the capacity of DG by using equation 3.15 and 3.16.

Step 5: Place the DG capacity found in step 4 at selected buses, one atime and observes total power loss.

Step 6: Keep the DG size that results in the least amount of loss.

Step 7: Compare the loss with the previous solution. If loss is less than previous solution, store this new solution and discard previous solution.

Step 8: Repeat Step 5 to Step 7 for all buses in the priority list.

Step 9: End

CHAPTER FOUR

DISTRIBUTION SYSTEM DATA COLLECTION AND ANALYSIS

4.1 Description of the Study Area

Nekemte is a separate woreda and market town in western Ethiopia. This town is located in the East Wollega zone of the Oromia region; it has a latitude and longitude of 9°5′N 36°33′E and an elevation of 2,088m and 354km away from Addis Abeba, capital city of Ethiopia. The rainy season lasts from late May to early September, with annual rainfall ranging from 1,500 to 2,200 mm. The town's average annual temperature ranges from 14 to 26 degrees celsius. The population of Nekemte was 210,688 in 2012, according to the central statistical agency. By 1960 E.C., a branch of the Ethiopian Electric Light and Power Authority had begun to provide electricity to the town.

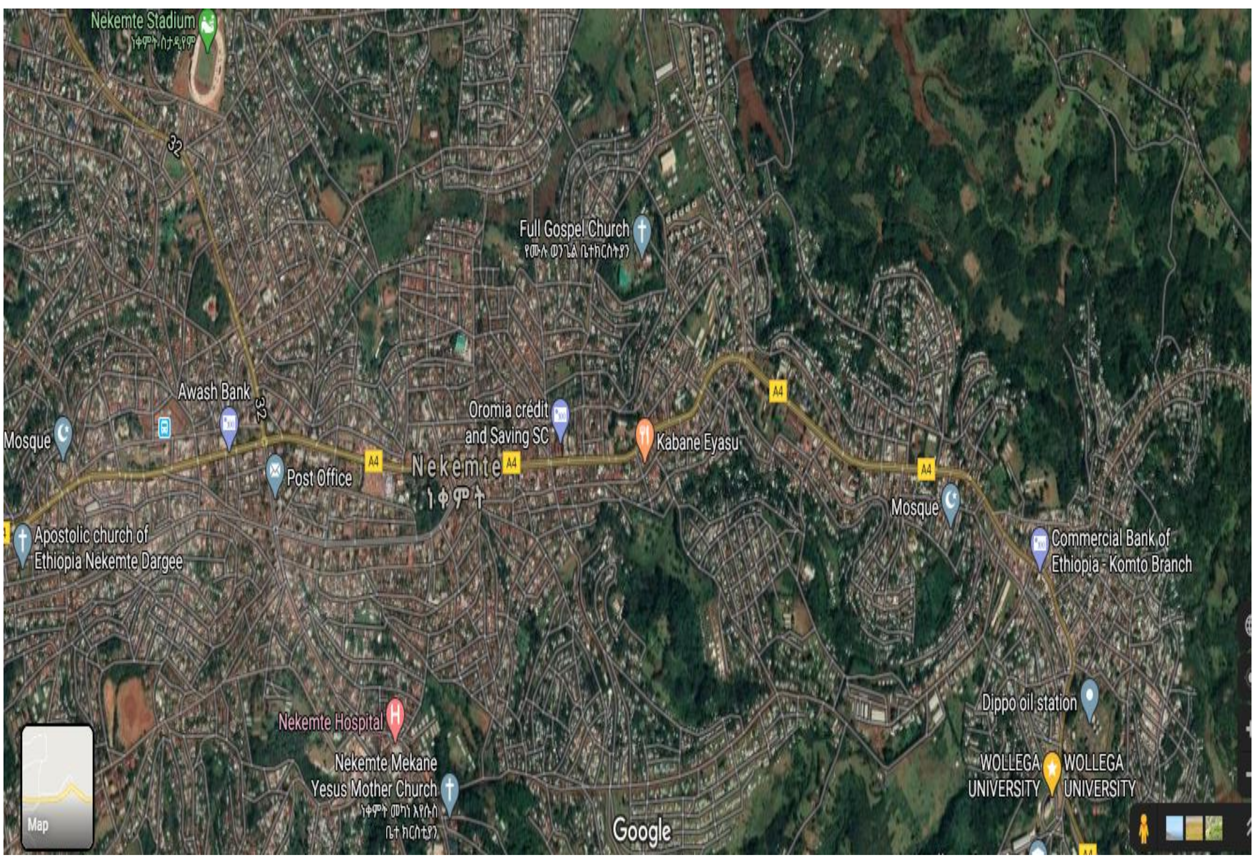

Figure 4.1: Geographical map of Nekemte town

4.2 Over View of Nekemte Substation

The Nekemte distribution substation is currently arranged in radial arrangement. The control and protection systems are also included, in the control room there are old type oil circuit breakers which are shown in Figure 4.3 and the control room is not well equipped and, however there are some of recorded data, most of data collections and communications are done manually. Figure 4.2 and 4.3 are taken during site visit and data collection at Nekemte substation and shows the transformers bus bars and control room.

Figure 4.2: The general view of Nekemte substation taken during site visit

Nekemte substation has its own control room. The general over view of the control room wich is taken during data collection and substation visit is shown in figure 4.3 below.

Figure 4.3: Oil circuit breakers and control room of Nekemte substation

4.3 Peak Demand Forecasting for Nekemte Distribution Substation Network

The Nekemte distribution system peak load demand is forecasted using the earlier recorded data as input. Hence the substation peak demand data recorded in the past is used to estimate the future peak demand of the substation. For this study the peak demand load history of Nekemte town distribution system substation in the years of 2015 to 2019 G.C is used. The five years actual peak load is collected from the western district of transmission substation, maintenance and operation office. The least-square load forecasting method is used in this research. This method was used for the reasons of lack of necessary data that will use as input for other types of load forecasting method. This methodology predicts future power demand by assuming the factors that influanced demand in the past will continue to do so in the same way in the future. Historical peak load demand of Nekemte distribution network is shown in Table 4.1 below. These values are then used as input to forecast for the coming ten years using extrapolation least square forecasting method.

Table 4.1: Historical peak load data from 2015-2019 G.C

Year	2015	2016	2017	2018	2019
Peak load (MW)	16.24	17.29	18.53	20.57	22.88
Peak load (MVA)	19.11	20.34	21.80	24.20	26.91

The study of the behavior of a time series or a method in the past and its mathematical modeling such that future behavior can be extrapolated from it is known as trend or regression analysis.

The least squares equation that relates the peak load with the year is

$$Y = \alpha + \beta X \qquad 4.1$$

This model is used based on the relationship between the dependent variable Y which is the peak load of the year and independent variable X which is the year as shown in equation 4.1. This is the equation of a straight-line which intercepts y-axes at α with a slope of β

The principle of regression theory is used to forecast the coming ten years peak load demand. Hence, this theory is used to forecast the load for the coming ten years by using the results in

Table 4.1 as a previous data. Its principle is that any function Y=f(x) can be fitted to a set of points (X_1, Y_1), (X_2, Y_2) so as to minimize the sum of errors squared at each point.
This implies that:

$$\sum_{i=1}^{n}\{Y_i - f(x)\}^2 n_i = \text{minimum} \qquad 4.2$$

The regression theory principle is used to predict peak load demand for the next ten years. As a result, using the results in Table 4.1 as previous data, this theory is used to forecast the load for the next ten years. Its general concept is that any function Y=f(x) can be fitted to a set of points (X_1, Y_1), (X_2, Y_2) in such a way that the sum of errors squared at each point is minimized.

$$\varepsilon^2 = \sum_{i=1}^{n}[Y_i - (\alpha + \beta X_i)]^2 n_i = 1 = \text{minimum} \qquad 4.3$$

Making partial differentiation the above equation 4.3 with respect to the regression's coefficients (α nd β) is made and the equations set to zero to obtain the minimum error criterion.

$$\frac{\partial(\sum_{i=1}^{n}[Y_i - (\alpha + \beta X_i)]^2 \ n_i)}{\partial\alpha} = 0 \qquad 4.4$$

$$\frac{\partial(\sum_{i=1}^{n}[Y_i - (\alpha + \beta X_i)]^2 \ n_i)}{\partial\beta} = 0 \qquad 4.5$$

The differentiation of those two equations above with respect to the regression coefficient gives us a set of simultaneous equations in terms of α and β :

$$N\alpha + \beta \sum X_i = \sum Y_i \qquad 4.6$$

$$\alpha\sum X_i + \beta \sum {X_i}^2 = \sum X_i Y_i \qquad 4.7$$

The input data that is expressed in the above Table 4.1 should be analyzed in order to obtain the forecasted peak load demand data.

Table 4.2: The analysis of all input historical data

Year	Peak demand (MW)	X_i	$P_{Di} = \frac{\text{Peak demand}}{\text{N}}$	$Y_i = \ln P_{Di}$	X_iY_i	X_i^2
2015	16.24	-2	1.624	0.4848	-0.9696	4
2016	17.29	-1	1.729	0.5475	-0.5475	1
2017	18.53	0	1.853	0.6168	0	0
2018	20.57	1	2.057	0.7212	0.7212	1
2019	22.88	2	2.288	0.8276	1.6552	4
		$\sum X_i = 0$		$\sum Y_i =$ 3.1979	$\sum X_iY_i =$ 0.8593	$\sum X_i^2 =$ 10

Here, in the analyzing the input data, N is the number of years to be forecasted wich is ten. In order to get the value regression coefficients of α and β, the following simultaneous equation is used.

$$N\alpha + \beta \sum X_i = \sum Y_i \tag{4.8}$$

$$\alpha \sum X_i + \beta \sum X_i^2 = \sum X_iY_i \tag{4.9}$$

Substituting the values from Table 4.2

$$5\alpha + \beta * 0 = 3.1979 \tag{4.10}$$

$$\alpha * 0 + \beta * 10 = 0.8593 \tag{4.11}$$

Solving the equation 4.10 and 4.11 simultaneously, the regression coefficient values are given in Table below.

Table 4.3: Calculated regression coefficients

α	β
0.63950	0.08593

The values in Table 4.2 are used to determine the load of the selected area up to 2030 G.C. The forecasting is then done using equation 4.12 and 4.13 shown below by considering 2017 as a reference year.

$$Y_i = \alpha + \beta X_i \quad 4.12$$

$$P_n = 10e^{Y_i} \quad 4.13$$

By using the equation 4.12 and 4.13 the respective forecasted load is calculated. From Table 4.1 the starting year 2018 acts as 1 value of X and the last year 2019 will be the X value of 2.

For 2018 the forecasted load is calculated as:

$$Y_i = \alpha + \beta X_1 \quad 4.14$$

$$P_1 = 10e^{Y_1} \quad 4.15$$

Substituting the regression coefficient values

$$Y_1 = 0.6395 + 0.08593 * 1 \quad 4.16$$

$$Y_1 = 0.7254 \quad 4.17$$

Substituting the values of Y_1 in equation 4.15

$$P_1 = 10e^{0.7254} = 20.65 \quad 4.18$$

For 2019 the forecasted load calculated as:

$$Y_2 = \alpha + \beta X_2 \quad 4.19$$

$$P_2 = 10e^{Y_2} \quad 4.20$$

Substituting the regression coefficient values

$$Y_2 = 0.6395 + 0.08593 * 2 = 0.8113 \quad 4.21$$

$$P_2 = 10e^{0.8113} = 22.50 \quad 4.22$$

For 2020 the forecasted load is calculted as

$$Y_3 = 0.13547 + 0.10762 * 3 = 0.8972 \quad 4.23$$

$$P_3 = 10e^{0.8972} = 24.51 \tag{4.24}$$

Similarly, the forecasted peak load demand from 2020 to 2030 G.C is calculated and given in the Table 4.4 below. The forecasting is done by considering 2017 year as a reference year. The values of forecasted peak load demand are shown in the table below. In general, this power demand forecasted at Nekemte distribution system substation after 10 years is tabulated as follows.

Table 4.4: Power demand forecasted for Nekemte distribution network from 2020 – 2030 G.C

Year	Forecasted demand in (MW)	Forecasted demand (MVA)
2020	24.51	28.83
2021	26.73	31.45
2022	29.19	34.34
2023	31.74	37.34
2024	34.59	40.69
2025	37.69	44.34
2026	41.08	48.33
2027	44.76	52.65
2028	48.78	57.39
2029	53.16	62.54
2030	57.93	68.15

A computer program wich corresponds to the above equation is formulated on Matlab m-file to forecast the peak load demand of the distribution system is given in Appendix-B. As it is seen from the forecasted peak load demand of the distribution system substation in the Table 4.4; after ten years ahead the peak load demand of Nekemte town distribution system substation will be approximatly 57.93MW of active power and 68.15MVA by considering power factor of 0.85 and the overall demand ahead for ten years wil be aproximated as shown in the table. Since the maximum capacity of the present distribution system substation is 34.85MW; extra 23.08MW is looked-for to customers after ten years. Accordingly, in order to avoid the shortage of power due to capacity of the present distribution system; in the coming year's expansion of the present distribution system should be needed by the substation. The Nekemte distribution network is integrated to the distributed generation by considering the maximum load of the substation in each year. Therefore, planning and operation of Nekemte substation will be integrated with different DG by consideration of the maximum load of the substation.

4.3 Basic Nekemte Distribution Systems Data

The Ethiopian Electric Power (EEP) is a service provider of electric power in the country. Nekemte substation has been supplied from the national grid which is tapped from Fincha'a and Dedessa substation. The substation supplies electric power to Nekemte town and the nearby areas and it receives power via 132kV power lines from power plants Fincha'a & Dedessa in synchronized mode. The 132kV is stepped down and distributed by 15kVand 33kV feeders. Also, there is 132kV outgoing line from Nekemte substation wich is connected to Bedelle substation. The substation consists of seven outgoing feeders. The nominal voltages of the four feeders are 15 kV and the remaining three feeders are 33kV.

The incoming line from the Bako substation which is called Fincha'a tap carrying 132kV and Dedessa is the input of the substation. Inside this substation there are two power transformers to convert the 132kV to 33kV and 15kV distribution voltage levels. The major rating data for the substation main transformers are shown in the Table 4.5 below.

Table 4.5: Power transformer at the substation

Name of transformers	Type	MVA	HV/MV/LV
Transformer 1	2 winding	25	132 kV/15kV
Transformer 2	2 winding	16	132kV/33kV

Presently, Nekemte substation has four feeders of 15kV and three feeders of 33kV lines which supply power to 15/0.4kV and 33/0.4kV transformers which feed different consumers such as residential, commercial and industrial. The average power factor of the entire distribution system is 0.85. Table 4.6 lists the main feeder's name, transformer numbers, ratings, customer connected numbers, and remarks for low voltage outgoing feeders. The substation provides electricity to a variety of user loads, including residential, commercial, and industrial. The detail information for the Nekemte distribution transformer data collected from EEU shown at Appendex-D, provides the voltage, MVA ratings and location of the distribution transformers.

Table 4.6: Feeder's name, number of customers, number of transformers and ratings of the low voltge transformers of each feeder.

Substation Feeder name	Transformer voltage level (kV)	Rating of transformer (KVA)	No. of transformer	No. of customers	Remarks
K01	15/0.4	25	7		Arjo Awuraja
		50	5		
		100	11		
		200	2		
		315	4		
Sum		**29 (3185KVA)**		4602	
K02	15/0.4	25	11		Baka Jama
		50	3		
		100	14		
		200	7		
		315	13		
		630	2		
Sum		**50 (8580KVA)**		9607	
K04	15/0.4	25	15		Hospital
		50	8		
		100	14		
		200	18		
		315	12		
		630	2		
		800	1		
		1200	1		
		1250	1		

Sum		**72 (14065KVA)**		12400	
K06	15/0.4	25	3		Wollega University
		50	3		
		100	4		
		200	4		
		315	10		
		630	2		
		800	1		
		1250	1		
Sum		**28 (7885KVA)**		8781	
L13	33/0.4	25	9		Nunu
		50	8		
		100	14		
		200	13		
		315	1		
		800	1		
Sum		**46 (5740KVA)**		7806	
L14	33/0.4	25	11		Boneya
		50	13		
		100	6		
		200	11		
		315	11		
		400	1		
		630	2		
Sum		**55 (8850KVA)**		9748	
L15	33/0.4	25	7		Gida
		50	14		
		100	11		
		200	3		
Sum		**35 (2575KVA)**		4250	

4.3.1 Basic Line Data

Table 4.7: Basic data of Nekemte substation feeders

Supplying substation	Feeder line	Voltage level	Number of Transformer
Nekemte substation	Line 1 (K01)	15 kV	29
	Line 2 (K02)	15 kV	50
	Line 3 (K04)	15 kV	72
	Line 4 (K06)	15 kV	28
	Line 5 (L13)	33 kV	46
	Line 6 (L14)	33 kV	55
	Line 7 (L15)	33 kV	35

4.3.2 Line Parameters of Nekemte Substation Feeders

Table 4. 8: Line parameters of Nekemte substation feeders

Code of conductor	R (Ω/km)	X (Ω/km)	I_{sc} (kA)	I_{rated} (KA)	Type of conductor
AAC25	1.179	0.379	2.1	0.145	OH Bare
AAC50	0.578	0.36	4.3	0.225	OH Bare
AAC95	0.307	0.34	8.1	0.340	OH Bare
AAAC150	0.183	0.34	8.4	0.385	OH bare

Where,

R: Positive sequence resistance of conductor (Ω/km) I_{sc} (kA): short circuit capability and

X: positive sequence reactance of conductor (Ω/km) I_{Rated} (kA): thermal limit

4.3.3 Load Data of Nekemte Substation

The peak load demand data, average load demand, minimum load demand and the number of custumers of each feeder is summurized in as shown in the following Table 4.9.

Table 4.9: Number of costumers, minimum, average and peak load data of each feeder.

Feeder name	Number of customers	Minimum load (MW)	Average load (MW)	Maximum load (MW)
Arjo Awuraja (k01)	4602	1.30	1.50	1.808
Baka Jama (k02)	9607	3.20	3.23	3.810
Hospital (k04)	12400	2.76	4.52	4.872
Wollega University (k06)	8781	2.30	2.75	3.452
Nunu (L13)	7806	1.50	2.75	3.452
Boneya (L14)	9748	2.89	3.50	3.830
Gida (L15)	4250	0.57	1.20	1.670
Total	57,194	14.52	19.45	22.51

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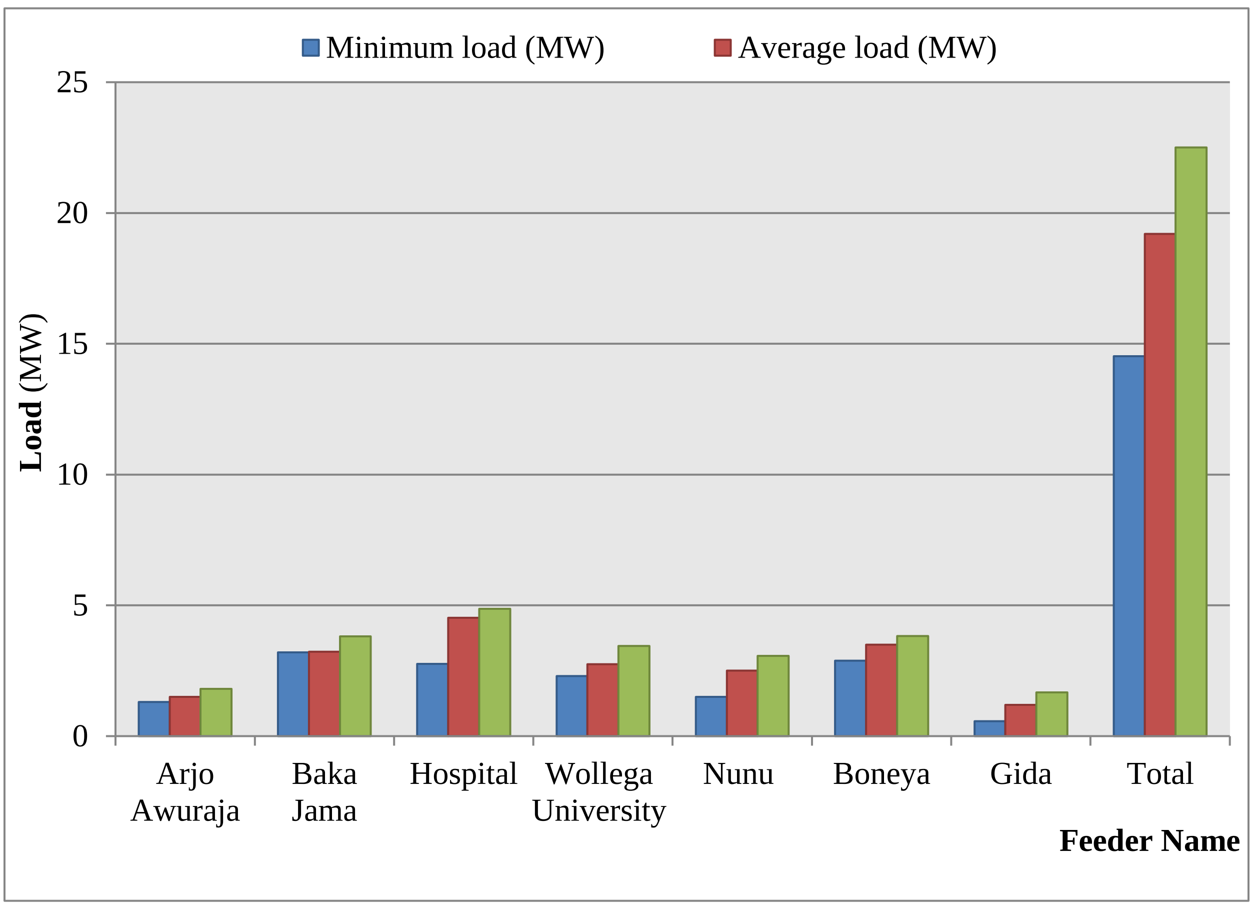


Figure 4.4: Average and peak demand of each feeder

The total numbers of customers corresponding each distribution substation feeder's as well as the distribution substation total number of customers represented in the figure below.

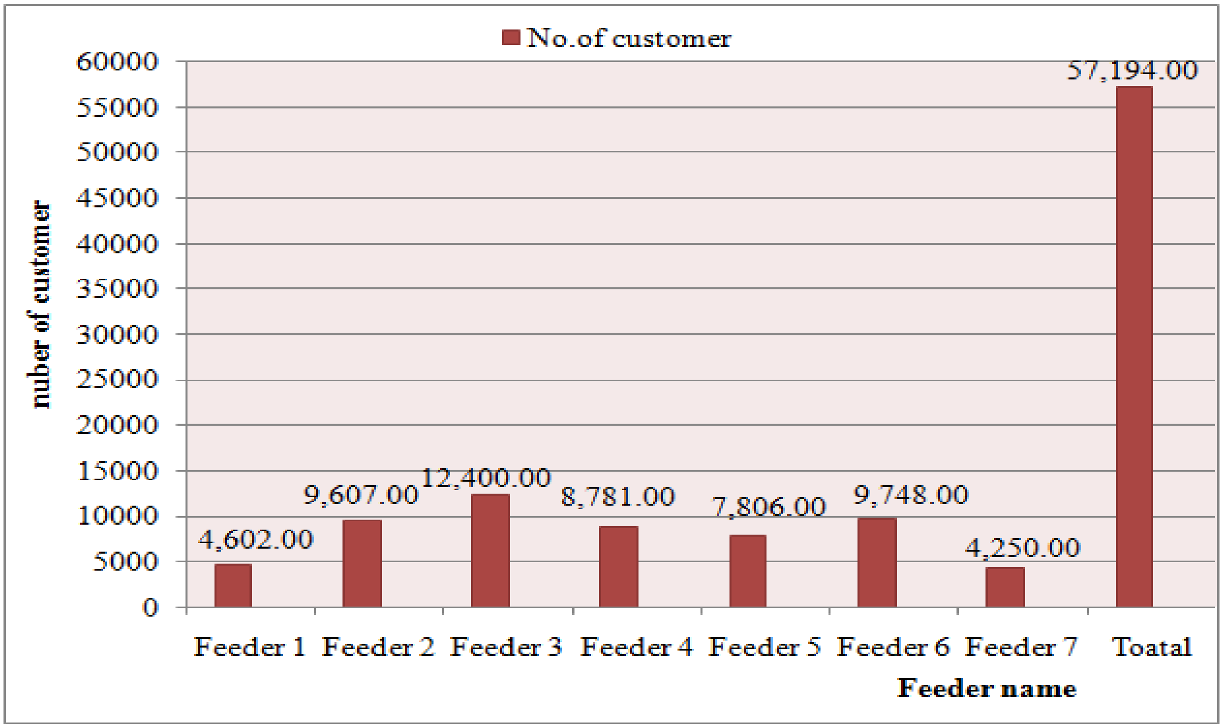


Figure 4.5: Number of distribution network feeder's customers

The forecasted peak load demand of the substation that is analyzed in section 4.3 is summarized in the given figure below.

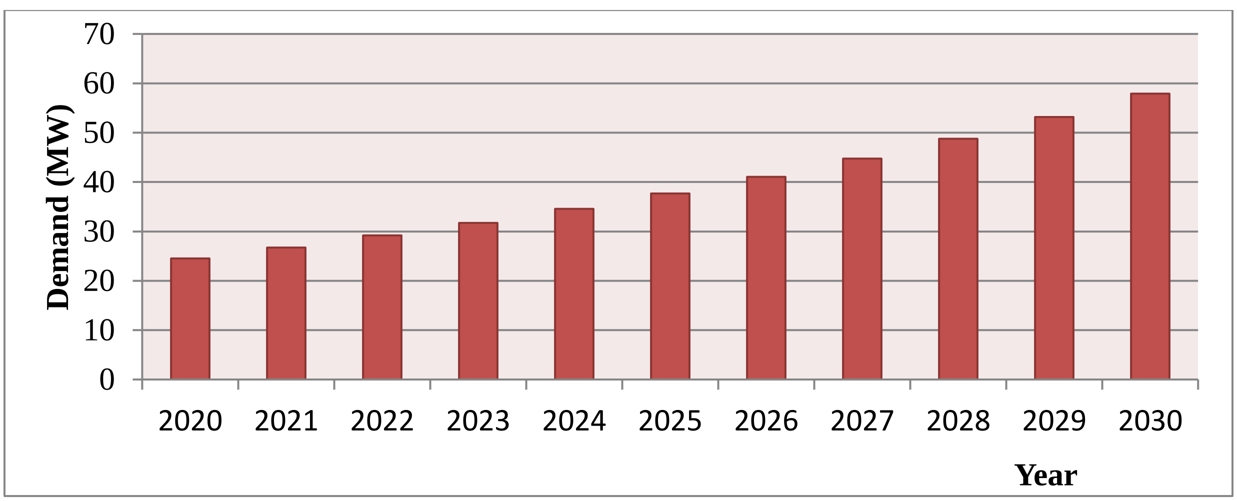


Figure 4.6: Peak load demand of the substation

4.4 Description of Nekemte Distribution substation Network

In this study, in the operation of real distribution system with connection of distributed generation, acase study based on the distribution system around the Nekemte town in western Ethiopia has been performed. The study has done by a power flow analysis of the 33kV, 15kV and 0.4kV network wich has been maintained by the distribution system network operator and with the integration of ditributed generation to the 15kV medium voltage bus of the distribution network.

The Nekemte substation has two main transformers and seven outgoing feeders. The two main transformers have the capacity of 16MV and 25MV for 33kV and 15kV voltage level respectively. There are three 132/33 kV transformer stations and four 132/15kV transformer stations out going feeders and also other is 132kv line wich is given to Bedelle substation. This study only focuses at the 132/15kV transformer, which is fed by four 15kV outgoing feeders, as well as 315 low voltage distribution transformers with a total capacity of 50.88MVA. The system serves mostly residential. The customers can either be on the main distribution line or the 1-phase lateral. The circuit is feed by 15kV and 33kV substation termed as distributor. Each distributor lateral is handled as if it were a single load point. The load points are connected to the main distribution line, and these loads are often called load points. The 33 and 15kV system consists of over head and underground transmission lines and cables, but 0.4 kV systems are considered a load connected point.

The Nekemte distribution substation supplies 57194 customers. The utility owns the distribution lines at 33, 15 and 0.4kV levels. The grid is connected to the bus bar through the 132/33kV and 132/15kV transformers, but it can be connected to the Bedelle substation wich is neighboring substation system through three 132 kV lines.

The distribution system planning is the the first step in the any power system problem is the development of a single-line diagram of the interconnected power system, from wich computer solution is obtained. The one-line diagram of the case study network, Nekemte distribution system network, was thus drawn on the Digsilent power factory software 15.1.7 for this study. All the organized data were then fed to the one-line diagram of the network. Figure 4.7 illustrates a general one-line diagram of the 33 and 15kV grid, including the 132 kV in feed. The 15 kV network is operated as radials, with a total capacity of 25 MVA supplied to four 15 kV outgoing feeders through a 132/15 kV transformer.

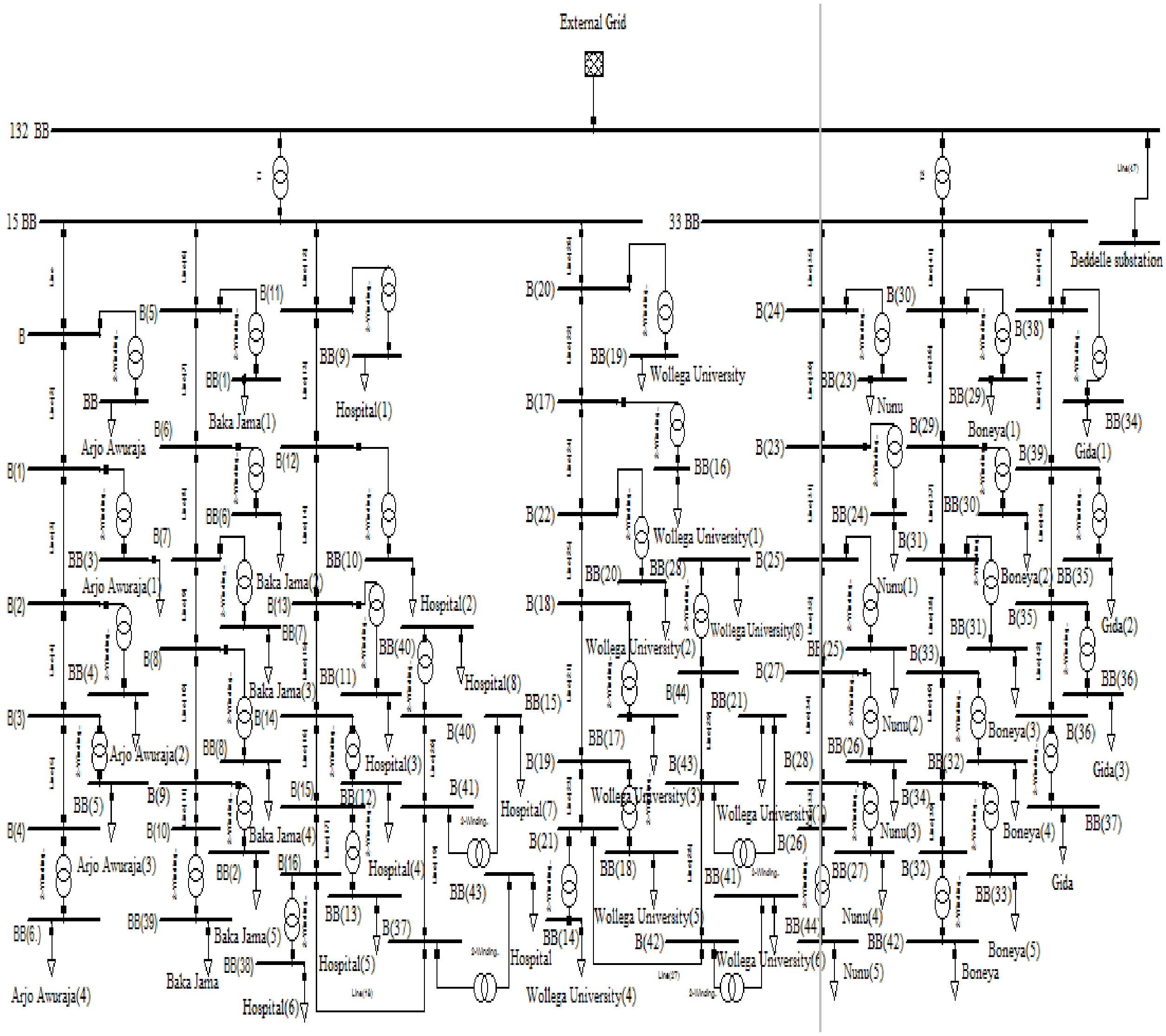


Figure 4.7: Representation of overall Nekemte distribution system

4.5 Distribution Test System

The distribution sytem is modaled with DigSilent software as shown in figure 4.8. There is one 132kV main bus bar that corresponds to substation transformers as it was represented in the figure 4.7, which is connected to 132kV transformers through four 15kV feeders and to 132/33kV transformers through three 33kV feeders. The 15kV feeders have the power supply transformer capacity of 25MVA and the 33kV feeders have 16MVA transformer capacity.

This shows that 15kV network is operated as radial and the total capacity of 132/15kV transformers is 25MVA supply to four out going feeders. Also, the 33kV network is operated as radial with a capacity of 132/33kV transformer is 16MVA supply to three out going feeders. Detail represantation of Nekemte distribution system one-line diagram for 15kV and 33kV is given in figure 4.8 below.

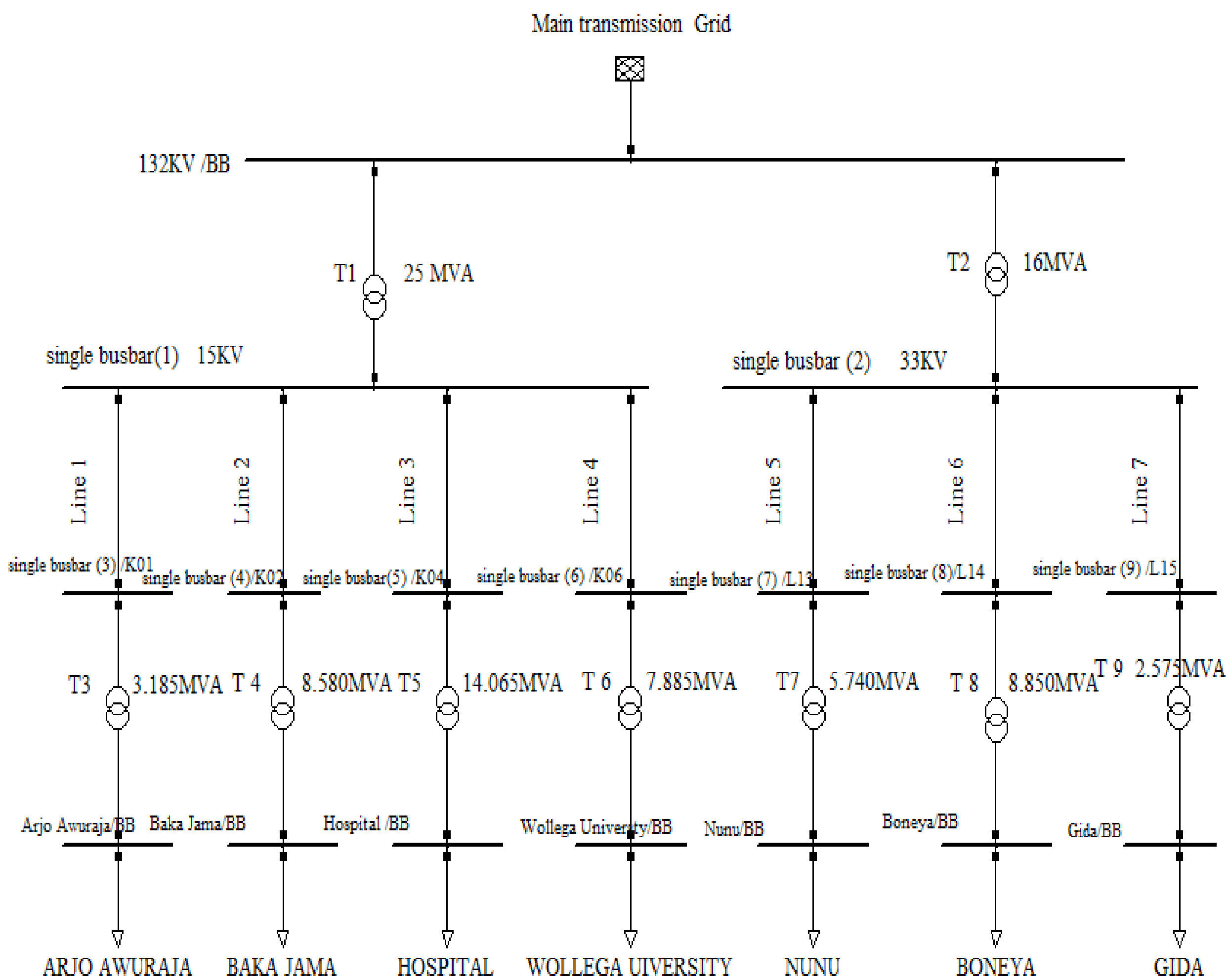


Figure 4. 8: One-line diagram of Nekemte distribution system

CHAPTER FIVE

SIMULATION RESULTS AND DISCUSSION

5.1 Introduction

This chapter begins with the selection and sizing of the appropriate DG technology for a specific location, followed by a power loss simulation of the current substation with and without DG. Also, the analysis of the obtained result is presented in the corresponding simulation. This section covers the selection of specific DG technology, as well as sizing and location, power loss analysis with DigSilent software, and improvements with DG technology.

5.2 DG Technology Selections

As mentioned in chapter two, there are various technologies or resources for distributed generation. Among these resources, the application of a particular DG technology to a specific area is determined by the potential availability of resources, environmental suitability, and DG technology cost. Different geographical regions have different renewable and nonrenewable resources. The availability as wll as the capacity of distributed resources is different from place to place. For instance, the solar energy availability varies from place to place and also the wind energy resources vary due to the difference in wind speed of different areas.

The solar energy and wind energy resources are freely available. The costs of these resources are low as compared to other distributed resources of fuel cell. However, their costs are low, they are not freely available in all places with the required potential, and this shows that their availability varies from one area to another area and their potentil is not equal in all places.

DG technologies vary in terms of the positive and negative effects they have on the environment. One of the effects is the amount of C_O, C_{O2}, and other gases released into the atmosphere. The emissions levels and costs of various DG technologies are shown in the table below. Cost of each technology is another factor that affects the selection of distributed generation for a given area. The type of different distributed generation technology including their emission and cost level is shown in Table 5.1.

Table 5.1: Description of emission and cost levels of different distributed generation

DG technology	Emission	Cost
PV	No	Moderate
Feul cell	Low	High
Wind turbine	No harmfull emissions	Moderate
Micro-turbine	Low	Moderate
Diesel generator	High emissions	Low

Even though, the PV systems and wind turbines are free energy sources with low cost and low emission level their potentials are low in Nekemte town. So, it is not comfortable to implement them in Nekemte substation. Depending on the factors mentioned above distributed generation resources (DGs) are selected. Based on these factors, the DG technologies selected in this thesis are Micro-turbine. This DG technology selected in this thesis owing to their low emission level and average limited cost.

Because of their versatility in connection methods, their ability to be stacked in parallel to serve larger loads, their ability to provide stable and reliable power, and their low emissions level, micro-turbines are used in DG applications. This makes the micro-turbine comfortable to be used as the distributed resources; however, it exhausts heat if it does not well suited to be used.

The distributed generators (DG) selected for this study case was a synchronous generator which are available in DigSilent power factory software 15.1.7. The type of distributed generations (DGs) used is constant power factor model and the loads are general type loads types as constant impendence and do not contribute to fault level.

DigSilent power factory software is one of power system software that is used for DG connection to the distribution system. There are recently a wide variaties of software applications that can be modaled DG. However, DigSilent software was chosen for this study because it is simple to use, contains blocks to model the most common power system components, and is suitable for radial distribution networks. It also has the capability of simulating the components in a steady state and transient events. The equipments used for DG connection from the Power factory software are, lines, breakers, transformers, busbars, DG, external grid, loads and so on.

5.3 Modeling of Distribution System

The single line diagram of distribution system network which is modeled by DigSilent software is shown in figure 5.1. The distribution network is formed by seven radial feeders, namely Feeder-1 (Arjo Awuraja), Feeder-2 (Baka Jama), Feeder-3 (Hospital), Feeder-4 (Wollega University), Feeder-5 (Nunu), Feeder-6 (Boneya) and Feeder-7 (Gida) of 15kV and 33kV Nekemte distribution system in Nekemte town, wich is owned by Ethiopian Electric Utility (EEU).

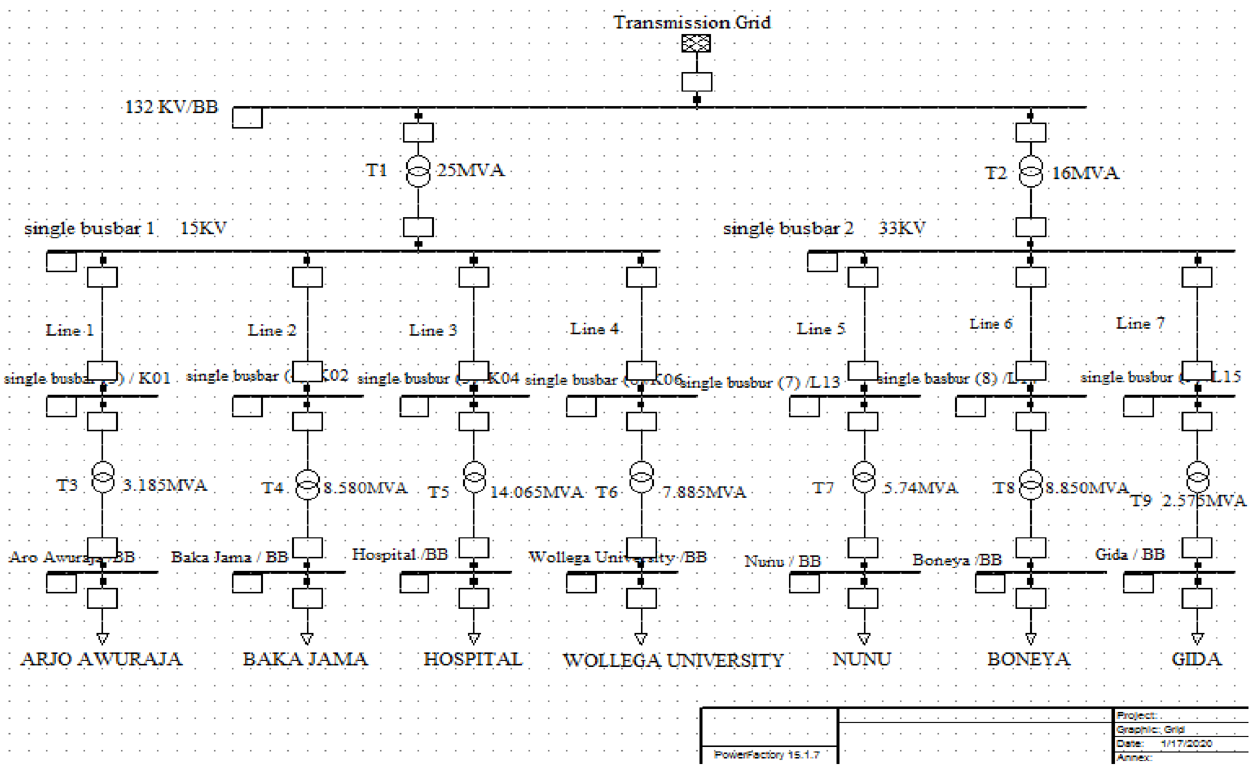


Figure 5.1: DigSilent model of Nekemte distribution substation

The load flow analysis of the 33kV, 15kV and 0.4kV distribution network is performed under this based on the data collected from the distribution network operator. By connecting 50% of the selected distributed generation to the 15kV of each feeder bus, voltage sensitivity index (VSI) of each bus is calculated.

Voltage Sensitivity Index (VSI) gives the voltage sensitivity of all the nodes of the network with respect to the nominal voltage. The bus corresponding to the minimum VSI value when DG is inserted at the same bus is the appropriate location of DG in the distribution system.

Table 5.2: Base case bus voltages for 15kV feeders test system

Bus number	Bus 1	Bus 2	Bus 3	Bus 4
Bus Voltages (P.U)	0.861	0.849	0.781	0.905

By using the equation 3.5, the VSI for all the 15KV buses are calculated and shown in Table 5.3 blow.

Table 5.3: Variation of VSI with DG placement

Bus number	Bus 1	Bus 2	Bus 3	Bus 4
VSI	0.1444	**0.1379**	**0.1163**	0.1474

From the bus voltage sensitivity index calculated above Table 5.3 the best location for placing DG will be Bus3 and Bus2 respectively as they have least VSI. In the medium voltage 15kV bus feeders DG to be placed on bus2 and bus3 due to least of VSI from Table 5.3 calculated with the formula in equation 3.5 in the section 3.7.3.

After getting the appropriate DG location, from equation 3.15 and 3.16 we get I_{DG2} and I_{DG3} is 0.2114 and 0.2941kA respectively. The corresponding their size is 2.70MW and 3.75MW by considering 0.85 power factor of the distributed generation. As a result, by applying equation 3.15 and 3.16, the maximum DG that should be installed at bus 2 and 3 are determined and the power loss before DG integration and after DG integration is compared as shown in section below.

5.4 Distribution System Simulation Using DigSilent

The simulation studies carried out in this section is under two different conditions. Case I considers the load flow analysis without integration of DG while in case II load flow analysis with integration of DG is carried out. Here, the DG is integrated in MV of 15kV feeder's bus.

5.4.1 Case I: Distribution System Load Load Flow before the Integration of DG

In this case, the Nekemte distribution system is used without any change to the existing system and by using data collected from Nekemte distribution system for load flow analysis.

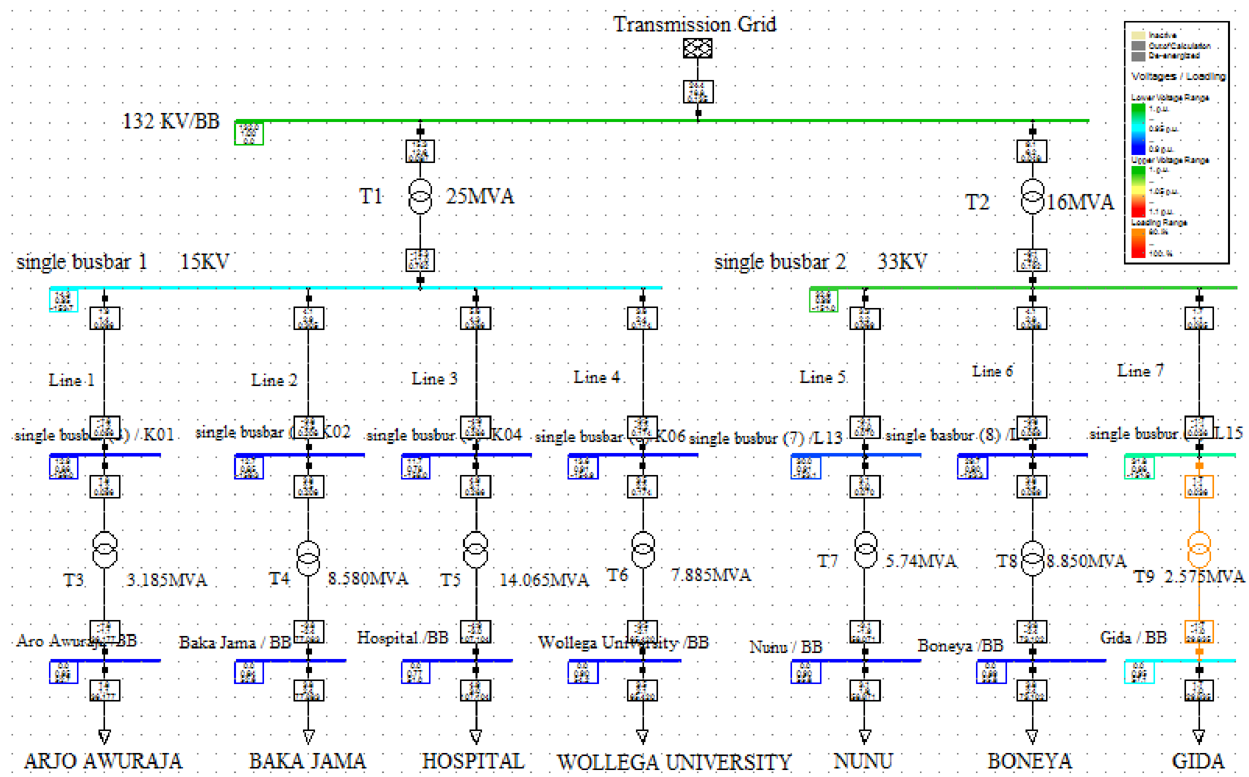
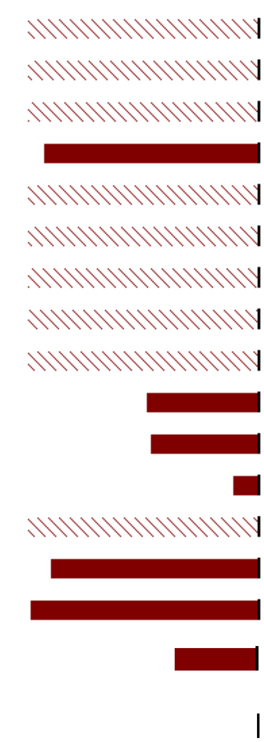


Figure 5.2: A radial distribution system without integrating DG

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.04	0.00	0.00	22.51	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	13.95	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.94	-0.00	-0.00	0.00
							-8.64	0.35	0.35	0.00
						33.00 kV	-8.57	-0.00	-0.00	0.00
							-5.31	0.22	0.22	0.00
15.00	0.00	0.00	0.00	0.00	0.00			1.36	1.36	0.00
	0.00	0.00	0.00	0.00	0.00			1.99	2.00	-0.01
						0.04 kV	13.94	-0.00	-0.00	0.00
							9.00	0.35	0.35	0.00
						132.00 kV	-15.30	-0.00	-0.00	0.00
							-10.98	1.57	1.57	0.00
33.00	0.00	0.00	0.00	0.00	0.00			0.50	0.50	0.00
	0.00	0.00	0.00	0.00	0.00			0.48	0.75	-0.27
						0.04 kV	8.57	-0.00	-0.00	0.00
							5.53	0.22	0.22	0.00
						132.00 kV	-9.06	-0.00	-0.00	0.00
							-6.01	0.23	0.23	0.00
132.00	0.00	0.00	0.00	0.00	24.36			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	18.78			0.00	0.00	0.00
						15.00 kV	15.30	-0.00	-0.00	0.00
							12.55	1.57	1.57	0.00
						33.00 kV	9.06	-0.00	-0.00	0.00
							6.23	0.23	0.23	0.00
Total:	0.00	0.00	22.51	0.00	24.36		0.00	1.85	1.85	0.00
	0.00	0.00	13.95	0.00	18.78		0.00	4.83	5.12	-0.28

Total System Summary						Study Case: Study Case			Annex: / 7
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\123\15 kv and 33 kv\Network Model\Network Data\Grid									
	0.00	0.00	22.51	0.00	24.36	0.00	1.85	1.85	0.00
	0.00	0.00	13.95	0.00	18.78	0.00	4.83	5.12	-0.28
Total:									
	0.00	0.00	22.51	0.00	24.36		1.85	1.85	0.00
	0.00	0.00	13.95	0.00	18.78		4.83	5.12	-0.28

Figure 5.3: Power loss simulation result without DG



Grid: Grid System Stage: Grid	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Study Case: Study Case / Annex: / 4
single busbar (3) / K01	15.00	0.861	12.92	-155.96	
single busbar (4) /K02	15.00	0.849	12.74	-156.29	
single busbur (5) /K04	15.00	0.781	11.72	-158.01	
single busbar (6)/K06	15.00	0.905	13.58	-154.88	
Baka Jama / BB	0.04	0.839	0.03	52.64	
Hospital /BB	0.04	0.773	0.03	51.00	
Wollega University /BB	0.04	0.896	0.04	54.19	
Nunu / BB	0.04	0.897	0.04	55.82	
Boneya /BB	0.04	0.890	0.04	55.78	
Gida / BB	0.04	0.951	0.04	57.15	
single busbar 1 15KV	15.00	0.952	14.28	-153.69	
single busbar 2 33KV	33.00	0.988	32.62	-150.99	
Aro Awuraja /BB	0.04	0.849	0.03	52.71	
single busbur (7) /L13	33.00	0.908	29.97	-153.05	
single basbur (8) /L14	33.00	0.899	29.66	-153.29	
single busbur (9) /L15	33.00	0.963	31.79	-151.64	
132 KV/BB	132.00	1.000	132.00	0.00	

Figure 5.4: Base case voltage profile simulation result

The output of the simulation is as indicated in figure 5.3 and 5.4 above. Based on this base case simulation it can be observed that system power losses are significantly very large. Hence, this shows that the existing substation has power loss problems.

5.4.2 Case II: Distribution System Load Load Flow after Integration of DG

In this case study, the proposed method was applied to a 15kV bus radial distribution system by installing DG at least voltage sensitivity index of outgoing feeders which are selected in the above Table 5.3. All the 15kV buses of the feeders are considered as candidate buses in the tests. Now, a 6.45MW DG is connected to the selected two least voltage sensitivity feeders. Installing the DG at 15kV buses with a size of 6.45MW in order to improve power loss. The power loss minimization after installing of DG is shown in figure 5.5.

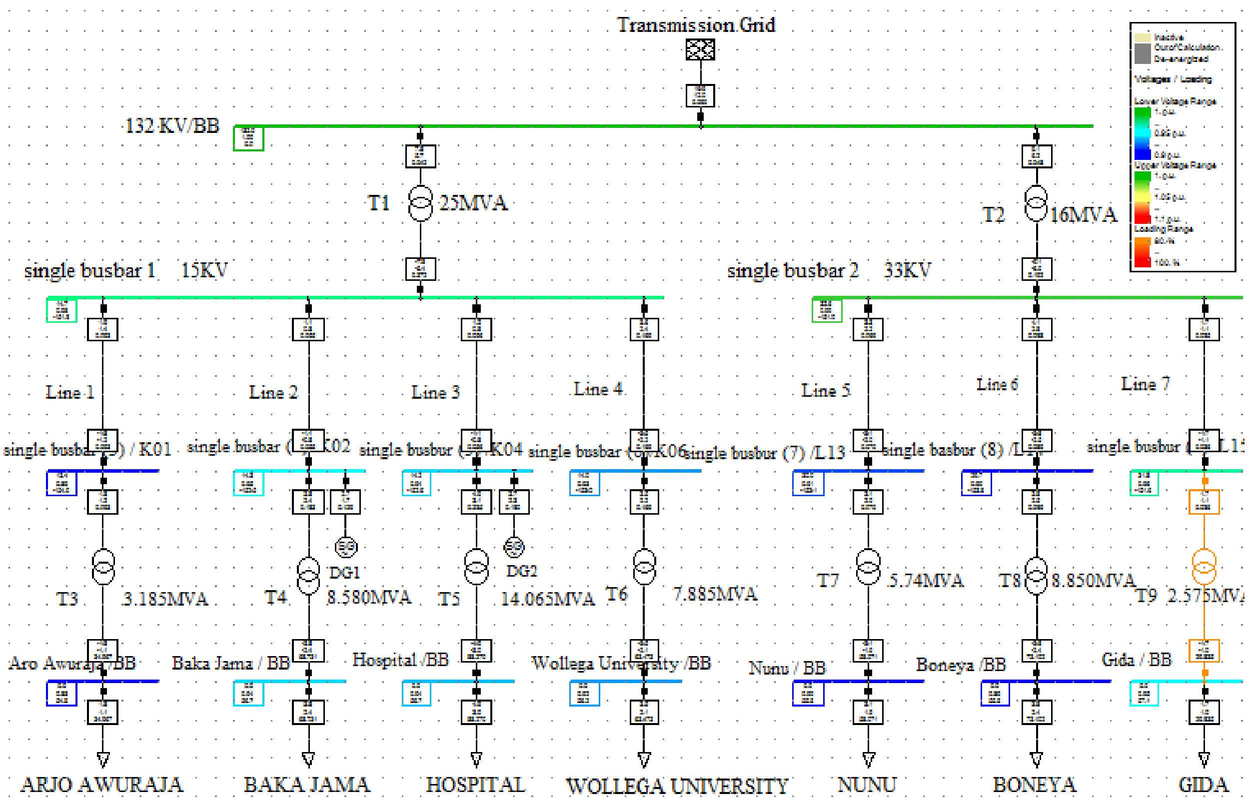


Figure 5.5: A radial distribution system with integrating DG

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.04	0.00	0.00	22.51	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	13.95	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.94	-0.00	-0.00	0.00
							-8.64	0.29	0.29	0.00
						33.00 kV	-8.57	-0.00	-0.00	0.00
							-5.31	0.22	0.22	0.00
15.00	6.45	0.00	0.00	0.00	0.00			0.30	0.30	0.00
	4.00	0.00	0.00	0.00	0.00			0.43	0.44	-0.01
						0.04 kV	13.94	-0.00	-0.00	0.00
							8.93	0.29	0.29	0.00
						132.00 kV	-7.79	-0.00	-0.00	0.00
							-5.36	0.37	0.37	0.00
33.00	0.00	0.00	0.00	0.00	0.00			0.50	0.50	0.00
	0.00	0.00	0.00	0.00	0.00			0.48	0.75	-0.27
						0.04 kV	8.57	-0.00	-0.00	0.00
							5.53	0.22	0.22	0.00
						132.00 kV	-9.06	-0.00	-0.00	0.00
							-6.01	0.23	0.23	0.00
132.00	0.00	0.00	0.00	0.00	16.86			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	11.97			0.00	0.00	0.00
						15.00 kV	7.79	-0.00	-0.00	0.00
							5.74	0.37	0.37	0.00
						33.00 kV	9.06	-0.00	-0.00	0.00
							6.23	0.23	0.23	0.00
Total:	6.45	0.00	22.51	0.00	16.86		0.00	0.80	0.80	0.00
	4.00	0.00	13.95	0.00	11.97		0.00	2.02	2.30	-0.28

Total System Summary | Study Case: Study Case | Annex: / 7

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\123\15 kv and 33 kv\Network Model\Network Data\Grid									
	6.45	0.00	22.51	0.00	16.86	0.00	0.80	0.80	0.00
	4.00	0.00	13.95	0.00	11.97	0.00	2.02	2.30	-0.28
Total:									
	6.45	0.00	22.51	0.00	16.86		0.80	0.80	0.00
	4.00	0.00	13.95	0.00	11.97		2.02	2.30	-0.28

Figure 5.6: Power loss simulation result after integration of DG

As we have seen DigSilent simulation test results, this paper presents the suitable location of distributed generataion (DG) based on the improving the system power loss of Nekemte distribution system.

For the smallest possible actual power loss, the DG power factor is set to 0.85, which is equal to the combined device load demand power factor. The appropriate size of DG and suitable location bus obtained by the proposed method are 2.70MW and 3.75MW and 2 and 3 respectively. With appropriate DG at the appropriate location, the total system real power loss was found to be 0.80MW, resulting in a net percentage real power loss reduction of 56.76. The real power loss in case I, as well as the real power loss and corresponding DG capacity required at bus 2 and 3 in case II, are shown in Table 5.4. The results obtained by the proposed method (technique) are summarized in the Table 5.4.

Table 5.4: Comparison of power losses in different two cases

Case I	No generation at the buses	Power loss (MW)
	P_{DGi} = 0	1.85
Case II	Generation at buses (MW)	Power loss (MW)
	P_{DG2} = 2.70	0.80
	P_{DG3} = 3.75	
	Total = 6.45	

Generally, the power loss before DG integration is 1.85MW. Hence, by applying equation 3.15 and 3.16 the maximum DG that should be installed at bus 2 and 3 are determined and the power loss before and after DG integration were compared as shown in the Table 5.4. From this we can observe that with the best location and DG capacity, the power loss has been highly decreased. For this distribution system a total power of 6.45MW DG capacity is installed. The power loss also decreased from 1.85MW to 0.80MW which is about 56.76% compared to the power loss without DG integration. Also, the reactive power loss is decreased from 4.83MVar to 2.02MVar which is about 58.18% compared to the reactive power loss without DG integration. The power generation at case II is obtained by applying equation 3.15 and 3.16.

Here, the load flow of Nekemte distribution system is analyzed by installing the 6.45MW DG and keeping the same data used for load flow analysis as of the base case to observe how installing DG will improve the power losses of distribution system. From the the forecasted load demand in section 4.3 in Table 4.4 and the installed DG capacity, it is shown that however the load demand increases rapidily in each year, the DG units are able to meet the demand requirements untill year-6. This shows that the substation should be upgraded in order to draw power from the substation at year-7. Then after, the supply power had drawn from the substation increases significantly.

The following observations can be summarized from load flow analysis

- If the DG unit is located at the distribution substation, regardless of the required DG capacity, the power losses will not be improved.
- The best improvements are obtained when the DG is put on the appropriate feeder bus.

CHAPTER SIX

CONCLUSION, RECOMMENDATION AND FUTURE WORK

6.1 CONCLUSION

This thesis investigates the proper DG location and size to meet the load demand increment and reducing the power loss for Nekemte substation distribution network. In the proposed methodology general set of steps is used which can be applied for any number of DGs, but in this study only two DGs is presented. The minimum losses obtained only with the proper sized DG; otherwise, the losses can exceed the values obtained without DG. The Nekemte substation distribution system peak load demand is collected for five years and forecasting is conducted for the the future ten years. Least-square technique is used to obtain future ten years load demand.

On the Nekemte distribution network, the methodology was implemented and tested. The modeling and simulation were carried out using DigSilent power factory 15.1.7 simultion package software. The analytical method, voltage sensitivity index with load flow analysis is used to determine the appropriate location and size of DG for distribution system network. Here, bus 2 and bus 3 are the selected as the best place to integrate DG based on the bus voltage sensitivity index (BVSI) with the capacity of 6.45MW on both feeders. The simulation result showed that suitable location of DG present at the best benefit on power loss minimization. The numerical results for the Nekemte distribution system network have been presented with and without DG and the comparative analysis was made. At the suitable location and maximum size of DG the real power loss is decreased to 0.80MW and the reactive power loss is reduced to 2.02MVar which is 56.76% and 58.18% in percentage respectively. Installing 6.45MW on Nekemte distribution system the active and reactive power loss is decreased and shown that however the load demand increases rapidly in each year the DG units are able to meet the demand requirements untill year-6.

Generally, this study shows that minimizing distribution system losses by integrating of DG with appropriate location and size to the distribution system network and is advantageous in terms of balancing demand and supply inorder to satisfy the load demand increment. Hence, both the location and the capacity of DG must be taken into consideration in order to create the appropriateness and fairness for both distribution network and DG.

6.2 RECOMMENDATION

The electrical energy consumption of Ethiopia is increasing rapidly from year to year. The existing distribution system network of EEU will be incapable to handle the increasing demand efficiently. Thus, the EEU, the individual utility company of the country should have to apply the concept of DG integration to distribution network in order to reduce losses and improve the voltage profile so that satisfy the growing load demand.

The most critical aspect of this thesis work was data collection, and the majority of the necessary data was collected manually. I recommended EEU, particularly Ethiopian electric utility Nekemte district office. There should be an organized, ordered, structured and computerized data base system to collect all necessary data of power system elements with their detail information.

6.3 FUTURE WORK

This section presents the possibilities of extension of this thesis paper in the future.

In this thesis, load forecasting is done considering least square method. It is suggested to carry out load forecasting affected by other method such as demand forecasting techniques based on soft computing methods and comparing these results. Further, distribution system expansion planning may be carried out using those load demand forecast methods.

This research work only conducted the 15kV distribution system line feeders, future work uses some analysis to minimize the losses and improve voltage profile of the 33kV line feeders of the substation.

The costs of integrating distributed generation and impact of distributed generation on the distribution system are not assessed in this thesis. Thus, future works should include the cost analysis of system integrating distributed generation to distribution system and distributed generation impacts on distribution system in detail.

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APPENDICES

Appendix - A: Line current parameters of medium voltage feeders

Line	Line current (kA)
Line 1	0.1
Line 2	0.21
Line 3	0.29
Line 4	0.17
Line 5	0.07
Line 6	0.09
Line 7	0.04

Appendix - B: Peak load demand forecasting result using mat lab

```
fprintf('\nDemand Forecast\n');

fprintf('\nEnter an array of demand values in the form:\n');

fprintf('\t[yr1 ld1; yr2 ld2; yr3 ld3; yr4 ld4; yr5 ld5]\n');

past_dem = input('\nEnter year/demand values: ');

sizepd = size(past_dem);

% get the # of past years of data and the # of cols in the array

np = sizepd(1); cols = sizepd(2);

% get the number of years to predict

nf = input('\nEnter the number of year to predict: ');

ntotal = np + nf;

% obtain the least-square terms to estimate the ld growth value g

% y = ab^x must be transformed to ln(y) = ln(a) + x*ln(b)

Y = log(past_dem(:,2))'; X = 0:np - 1;
```

```
sumx2 = (X - mean(X))*(X - mean(X))';

sumxy = (Y - mean(Y))*(X - mean(X))';

% get the coeffs of the transformed data A = ln(b) and B = ln(a)

A = sumxy/sumx2; B = mean(Y) - A*mean(X);

% solve for the initial value, Po and g

Po = exp(B);

g = exp(A) - 1;

fprintf('\n\tRate of growth =%2.2f%%\n\n', g*100);

fprintf('\tYEAR\tACTUAL\t\tFORECAST\n');

% calculate the estimated values

est_dem = 0;

for i = 1:ntotal

n = i - 1;

% year = first year + n

est_dem(i, 1) = past_dem(1, 1) + n;

% load growth equation

est_dem(i, 2) = Po*(1+g)^n;

if i < np;

fprintf('\t%4d\t%6.2f\t\t%6.2f\n', est_dem(i,1),past_dem(i,2),est_dem(i,2));

else

fprintf('\t%4d\t-\t\t\t%6.2f\n', est_dem(i,1),est_dem(i,2));

end

end

plot(past_dem(:,1),past_dem(:,2), 'k-s', est_dem(:,1), est_dem(:,2), 'k-+');
```

xlabel('Year'); ylabel('Demand'); legend('Actual', 'Forecast');

Demand Forecast

Enter an array of demand values in the form:

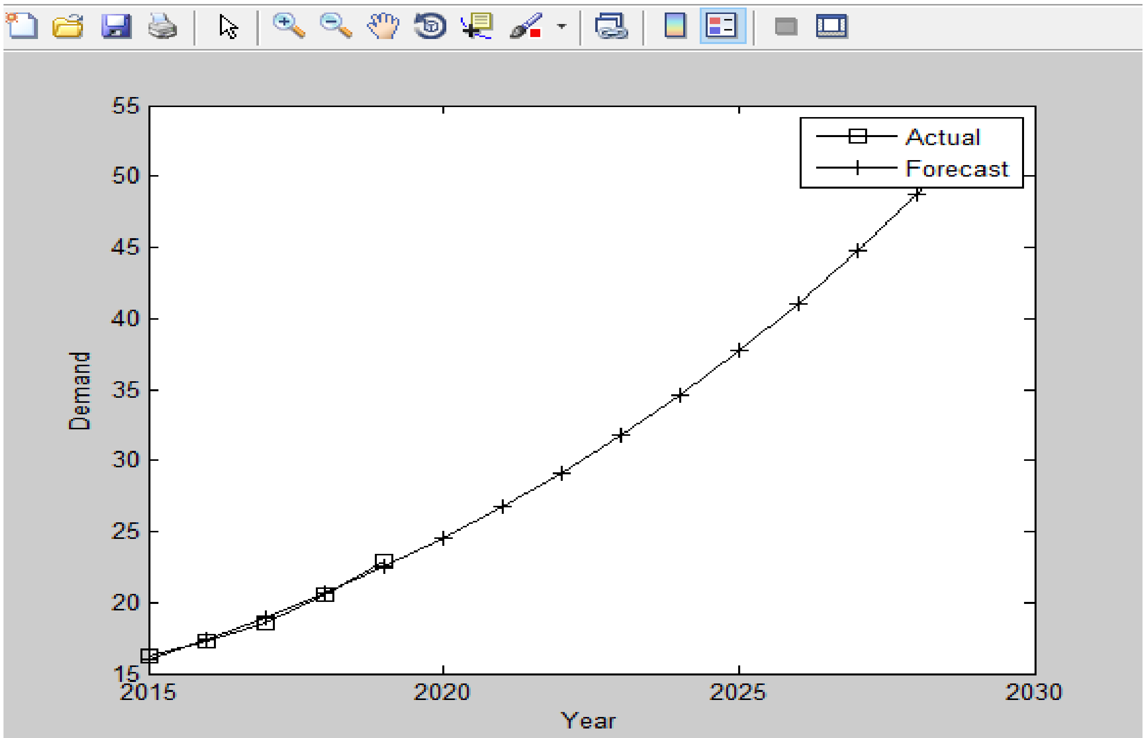
[yr1 ld1; yr2 ld2; yr3 ld3; yr4 ld4; yr5 ld5]

Enter year/demand values: **[2015 16.244; 2016 17.29; 2017 18.53; 2018 20.576; 2019 22.88]**

Enter the number of years to predict: **10**

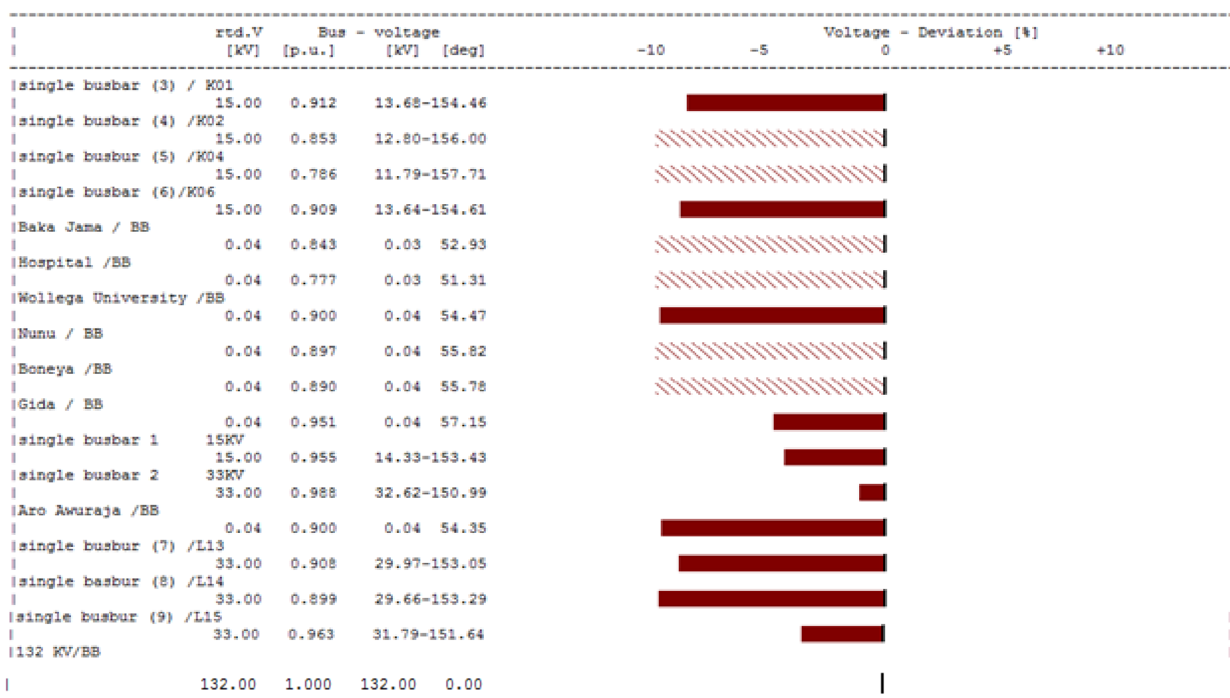
Rate of growth =8.97%

YEAR	ACTUAL	FORECAST
2015	**16.24**	**15.97**
2016	**17.29**	**17.40**
2017	**18.53**	**18.96**
2018	**20.58**	**20.66**
2019	**-**	**22.51**
2020	**-**	**24.53**
2021	**-**	**26.73**
2022	**-**	**29.13**
2023	**-**	**31.75**
2024	**-**	**34.59**
2025	**-**	**37.70**
2026	**-**	**41.08**
2027	**-**	**44.76**
2028	**-**	**48.78**
2029	**-**	**53.16**



Appendix - C: Simulation result when 50% feeder load DG is connected to each 15KV bus

C1: Voltage profile simulation result when 50% feeder load DG connected at bus one 15kV



	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
single busbar (3) / K01	15.00	0.912	13.68	-154.46
single busbar (4) /K02	15.00	0.853	12.80	-156.00
single busbur (5) /K04	15.00	0.786	11.79	-157.71
single busbar (6)/K06	15.00	0.909	13.64	-154.61
Baka Jama / BB	0.04	0.843	0.03	52.93
Hospital /BB	0.04	0.777	0.03	51.31
Wollega University /BB	0.04	0.900	0.04	54.47
Nunu / BB	0.04	0.897	0.04	55.82
Boneya /BB	0.04	0.890	0.04	55.78
Gida / BB	0.04	0.951	0.04	57.15
single busbar 1 15KV	15.00	0.955	14.33	-153.43
single busbar 2 33KV	33.00	0.988	32.62	-150.99
Aro Awuraja /BB	0.04	0.900	0.04	54.35
single busbur (7) /L13	33.00	0.908	29.97	-153.05
single basbur (8) /L14	33.00	0.899	29.66	-153.29
single busbur (9) /L15	33.00	0.963	31.79	-151.64
132 KV/BB	132.00	1.000	132.00	0.00

C2: Power loss simulation result when 50%feeder load DG connected at bus one 15kV

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.04	0.00	0.00	22.51	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	13.95	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.94	-0.00	-0.00	0.00
							-8.64	0.34	0.34	0.00
						33.00 kV	-8.57	-0.00	-0.00	0.00
							-5.31	0.22	0.22	0.00
15.00	0.90	0.00	0.00	0.00	0.00			1.24	1.24	0.00
	0.56	0.00	0.00	0.00	0.00			1.81	1.82	-0.01
						0.04 kV	13.94	-0.00	-0.00	0.00
							8.98	0.34	0.34	0.00
						132.00 kV	-14.27	-0.00	-0.00	0.00
							-10.24	1.35	1.35	0.00
33.00	0.00	0.00	0.00	0.00	0.00			0.50	0.50	0.00
	0.00	0.00	0.00	0.00	0.00			0.48	0.75	-0.27
						0.04 kV	8.57	-0.00	-0.00	0.00
							5.53	0.22	0.22	0.00
						132.00 kV	-9.06	-0.00	-0.00	0.00
							-6.01	0.23	0.23	0.00
132.00	0.00	0.00	0.00	0.00	23.34			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	17.82			0.00	0.00	0.00
						15.00 kV	14.27	-0.00	-0.00	0.00
							11.59	1.35	1.35	0.00
						33.00 kV	9.06	-0.00	-0.00	0.00
							6.23	0.23	0.23	0.00
Total:	0.90	0.00	22.51	0.00	23.34		0.00	1.73	1.73	0.00
	0.56	0.00	13.95	0.00	17.82		0.00	4.43	4.72	-0.28

C3: Voltage profile simulation result when 50% feeder load DG connected at bus two15kV

Grid: Grid | System Stage: Grid | Study Case: Study Case | Annex: / 4

Bus	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
single busbar (3) / K01	15.00	0.870	13.05	-155.37
single busbar (4) /K02	15.00	0.911	13.67	-154.31
single busbur (5) /K04	15.00	0.791	11.87	-157.37
single busbar (6)/K06	15.00	0.913	13.70	-154.31
Baka Jama / BB	0.04	0.902	0.04	54.76
Hospital /BB	0.04	0.783	0.03	51.67
Wollega University /BB	0.04	0.904	0.04	54.78
Nunu / BB	0.04	0.897	0.04	55.82
Boneya /BB	0.04	0.890	0.04	55.78
Gida / BB	0.04	0.951	0.04	57.15
single busbar 1 15KV	15.00	0.959	14.39	-153.13
single busbar 2 33KV	33.00	0.988	32.62	-150.99
Aro Awuraja /BB	0.04	0.857	0.03	53.32
single busbur (7) /L13	33.00	0.908	29.97	-153.05
single basbur (8) /L14	33.00	0.899	29.66	-153.29
single busbur (9) /L15	33.00	0.963	31.79	-151.64
132 KV/BB	132.00	1.000	132.00	0.00

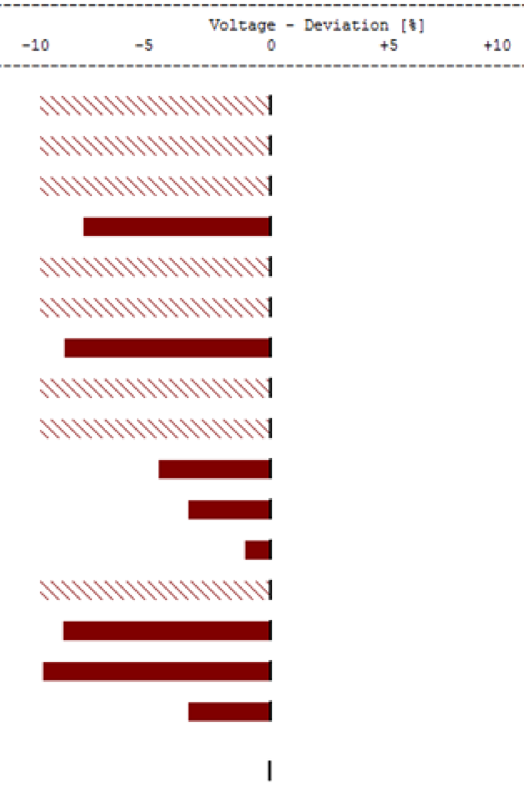
Voltage - Deviation [%]: -10, -5, 0, +5, +10

C4: Power loss simulation result when 50% feeder load DG connected at bus two 15kV

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.04	0.00	0.00	22.51	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	13.95	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.94	-0.00	-0.00	0.00
							-8.64	0.34	0.34	0.00
						33.00 kV	-8.57	-0.00	-0.00	0.00
							-5.31	0.22	0.22	0.00
15.00	1.90	0.00	0.00	0.00	0.00			1.07	1.07	0.00
	1.18	0.00	0.00	0.00	0.00			1.57	1.58	-0.01
						0.04 kV	13.94	-0.00	-0.00	0.00
							8.98	0.34	0.34	0.00
						132.00 kV	-13.11	-0.00	-0.00	0.00
							-9.37	1.13	1.13	0.00
33.00	0.00	0.00	0.00	0.00	0.00			0.50	0.50	0.00
	0.00	0.00	0.00	0.00	0.00			0.48	0.75	-0.27
						0.04 kV	8.57	-0.00	-0.00	0.00
							5.53	0.22	0.22	0.00
						132.00 kV	-9.06	-0.00	-0.00	0.00
							-6.01	0.23	0.23	0.00
132.00	0.00	0.00	0.00	0.00	22.17			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	16.73			0.00	0.00	0.00
						15.00 kV	13.11	-0.00	-0.00	0.00
							10.50	1.13	1.13	0.00
						33.00 kV	9.06	-0.00	-0.00	0.00
							6.23	0.23	0.23	0.00
Total:	1.90	0.00	22.51	0.00	22.17		0.00	1.57	1.57	0.00
	1.18	0.00	13.95	0.00	16.73		0.00	3.96	4.24	-0.28

C5: Voltage profile simulation when 50% f eeder load DG connected at bus three 15kV

Bus	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
single busbar (3) / K01	15.00	0.874	13.12	-155.13
single busbar (4) /K02	15.00	0.863	12.94	-155.44
single busbur (5) /K04	15.00	0.888	13.32	-154.76
single busbar (6)/K06	15.00	0.917	13.76	-154.08
Baka Jama / BB	0.04	0.853	0.03	53.52
Hospital /BB	0.04	0.881	0.04	54.48
Wollega University /BB	0.04	0.908	0.04	55.02
Nunu / BB	0.04	0.897	0.04	55.82
Boneya /BB	0.04	0.890	0.04	55.78
Gida / BB	0.04	0.951	0.04	57.15
single busbar 1 15KV	15.00	0.963	14.45	-152.91
single busbar 2 33KV	33.00	0.988	32.62	-150.99
Aro Awuraja /BB	0.04	0.862	0.03	53.58
single busbur (7) /L13	33.00	0.908	29.97	-153.05
single basbur (8) /L14	33.00	0.899	29.66	-153.29
single busbur (9) /L15	33.00	0.963	31.79	-151.64
132 KV/BB	132.00	1.000	132.00	0.00



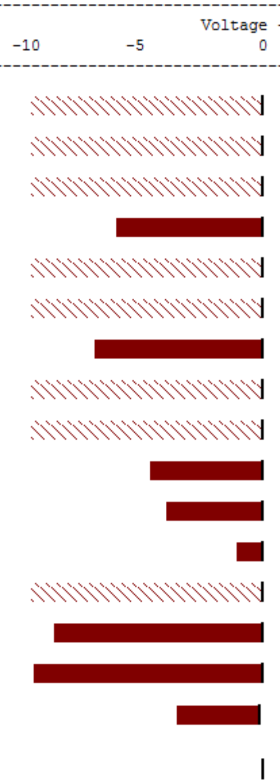
C6: Power loss simulation result when 50% feeder load DG connected at bus three 15kV

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.04	0.00	0.00	22.51	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	13.95	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.94	-0.00	-0.00	0.00
							-8.64	0.32	0.32	0.00
						33.00 kV	-8.57	-0.00	-0.00	0.00
							-5.31	0.22	0.22	0.00
15.00	2.44	0.00	0.00	0.00	0.00			0.73	0.73	0.00
	1.51	0.00	0.00	0.00	0.00			1.06	1.07	-0.01
						0.04 kV	13.94	-0.00	-0.00	0.00
							8.96	0.32	0.32	0.00
						132.00 kV	-12.23	-0.00	-0.00	0.00
							-8.51	0.96	0.96	0.00
33.00	0.00	0.00	0.00	0.00	0.00			0.50	0.50	0.00
	0.00	0.00	0.00	0.00	0.00			0.48	0.75	-0.27
						0.04 kV	8.57	-0.00	-0.00	0.00
							5.53	0.22	0.22	0.00
						132.00 kV	-9.06	-0.00	-0.00	0.00
							-6.01	0.23	0.23	0.00
132.00	0.00	0.00	0.00	0.00	21.29			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	15.70			0.00	0.00	0.00
						15.00 kV	12.23	-0.00	-0.00	0.00
							9.47	0.96	0.96	0.00
						33.00 kV	9.06	-0.00	-0.00	0.00
							6.23	0.23	0.23	0.00
Total:	2.44	0.00	22.51	0.00	21.29		0.00	1.22	1.22	0.00
	1.51	0.00	13.95	0.00	15.70		0.00	3.26	3.54	-0.28

C7: Voltage profile simulation result when 50%feeder load DG connected at bus four 15kV

Grid: Grid   System Stage: Grid   Study Case: Study Case   Annex: / 4

Bus	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
single busbar (3) / K01	15.00	0.868	13.02	-155.46
single busbar (4) /K02	15.00	0.856	12.84	-155.78
single busbur (5) /K04	15.00	0.789	11.83	-157.48
single busbar (6)/K06	15.00	0.935	14.03	-153.78
Baka Jama / BB	0.04	0.846	0.03	53.16
Hospital /BB	0.04	0.781	0.03	51.56
Wollega University /BB	0.04	0.926	0.04	55.35
Nunu / BB	0.04	0.897	0.04	55.82
Boneya /BB	0.04	0.890	0.04	55.78
Gida / BB	0.04	0.951	0.04	57.15
single busbar 1 15KV	15.00	0.958	14.37	-153.22
single busbar 2 33KV	33.00	0.988	32.62	-150.99
Aro Awuraja /BB	0.04	0.856	0.03	53.22
single busbur (7) /L13	33.00	0.908	29.97	-153.05
single basbur (8) /L14	33.00	0.899	29.66	-153.29
single busbur (9) /L15	33.00	0.963	31.79	-151.64
132 KV/BB	132.00	1.000	132.00	0.00



C8: Power loss simulation result when 50% feeder load DG connected at bus four 15kV

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.04	0.00	0.00	22.51	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	13.95	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.94	-0.00	-0.00	0.00
							-8.64	0.34	0.34	0.00
						33.00 kV	-8.57	-0.00	-0.00	0.00
							-5.31	0.22	0.22	0.00
15.00	1.73	0.00	0.00	0.00	0.00			1.23	1.23	0.00
	1.07	0.00	0.00	0.00	0.00			1.81	1.82	-0.01
						0.04 kV	13.94	-0.00	-0.00	0.00
							8.98	0.34	0.34	0.00
						132.00 kV	-13.45	-0.00	-0.00	0.00
							-9.73	1.20	1.20	0.00
33.00	0.00	0.00	0.00	0.00	0.00			0.50	0.50	0.00
	0.00	0.00	0.00	0.00	0.00			0.48	0.75	-0.27
						0.04 kV	8.57	-0.00	-0.00	0.00
							5.53	0.22	0.22	0.00
						132.00 kV	-9.06	-0.00	-0.00	0.00
							-6.01	0.23	0.23	0.00
132.00	0.00	0.00	0.00	0.00	22.51			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	17.16			0.00	0.00	0.00
						15.00 kV	13.45	-0.00	-0.00	0.00
							10.93	1.20	1.20	0.00
						33.00 kV	9.06	-0.00	-0.00	0.00
							6.23	0.23	0.23	0.00
Total:	1.73	0.00	22.51	0.00	22.51		0.00	1.73	1.73	0.00
	1.07	0.00	13.95	0.00	17.16		0.00	4.28	4.56	-0.28

Appendix- D: Detail information of Nekemte substation distribution transformers

D1: Arjo Awuraja feeder's distribution transformers

NO	Voltage level	Distribution transformer code	Distribution transformers located place	Rating of distribution transformers
1	15	DT-020636	Efrem Tele	25
2	15	DT-020634	Gatama ato Tolemariyam Jibat floor mill	50
3	15	DT-020633	Arjo hospital	315
4	15	DT-020632	Jemo giros	100
5	15	DT-020631	Jamogros tele	25
6	15	DT-020630	Arjo best water industry	315
7	15	DT-020629	Arjo technical college	100
8	15	DT-020628	Arjo infront of education	315
9	15	DT-020627	Dashen bank	100

10	15	DT-020626	Arjo infront of post office	315
11	15	DT-020625	Arjo bari water supply	50
12	15	DT-020205	Near to Jimma arjo wereda adimenstration	100
13	15	DT-020204	Arjo town st. george cherch	200
14	15	DT-020203	Arjo tele	50
15	15	DT-020202	Ine tele network	25
16	15	DT-020201	Jemata town	100
17	15	DT-020200	Bedho village	50
18	15	DT-020199	Bedho village	100
19	15	DT-020198	Bedho	100
20	15	DT-020197	Gatama near to tele	25
21	15	DT-020196	Gatama Infront of Tele network	200
22	15	DT-020195	Getema infront of OEB	100
23	15	DT-020194	Getema tele	25
24	15	DT-020193	Getema town st jorj. cherch	100
25	15	DT-020192	Kewisa school	50
26	15	DT-020191	Jarso gute catolic	100
27	15	DT-020190	Tarari tele network	25
28	15	DT-020189	Jirata village water supply	25
29	15	DT-020188	Sorga mekeneyesus cherch	100

D2: Baka Jama feeder's distribution transformers

No	Volatge level	Distribution transformer code	Distribution transformers Located place	Rating of Distribution transformer
1	15	DT-020079	Nekemte referal Hospital	630
2	15	DT020082	Diga Water supply treatment	100
3	15	DT-020081	Nekemte ner Muluwengel church	100
4	15	DT-020080	Cheleleki makane yesus church	100

5	15	DT-020078	Abba tayita dandiwan oromiya	100
6	15	DT-020077	Wacha 2ndry shool tele tower trafo	315
7	15	DT-020076	Wacha 2ndry shool	25
8	15	DT-020075	04 keble chereka dabo bet	200
9	15	DT-020074	Infront of Guto Gidda woreda	100
10	15	DT-020073	Infront of st. mary orthodox church	315
11	15	DT-020072	Behind of st. mary orthodox church	315
12	15	DT-020071	Dambal	25
13	15	DT-020070	Dacha shibo trafo	100
14	15	DT-020068	Dacha shibo tele tower trafo	25
15	15	DT-020067	Dacha shibo oromia Radio tower	630
16	15	DT-020066	Near to kumsa moroda palace	25
17	15	DT-020065	01 kebele Vision clinic	100
18	15	DT-020064	Goma fabrica tele tower	25
19	15	DT-020063	Wollega University Engineering work shop (Goma fabrica)	100
20	15	DT-020062	Kumsa Moroda condominium	315
21	15	DT-020061	Goergis safar ECX trafo	50
22	15	DT-020060	Georgis safar	100
24	15	DT-020059	Nekemte 7 kilo trafo	200
25	15	DT-020058	Ambessa gibbi tele trafo	25
26	15	DT-020057	Nekemte7 kilo	50
27	15	DT-020056	Nekemte CSC trafo	315
28	15	DT-020055	Shalom hotel	315
29	15	DT-020054	Ijo hotel	200
30	15	DT-020053	Nekemte District coopirative Bank	315
31	15	DT-020052	Nekemte Adarash	200
32	15	DT-020051	Behind of nek csc	315
33	15	DT-020050	Dandi boru college	315
34	15	DT-020049	Main market tele tower	25

35	15	DT-020048	Nekemte health center	315
36	15	DT-020047	Bake jama astadader	200
37	15	DT-020046	Nekemte gaba kamisa	315
38	15	DT-020045	Nekemte gaba kamisa	200
39	15	DT-020044	TTC tele tower	25
40	15	DT-020043	TTC Collage	315
41	15	DT-020042	Fayinera tele	25
42	15	DT-020041	Infront of bake jama mosqoue	100
43	15	DT-020040	Nekemtetele store arround Baka Jama	25
44	15	DT-020039	Infront of Madanialem church	50
45	15	DT-020038	Oromia seed micro interprise trafo	200
46	15	DT-020037	Sorga tele tower	25
47	15	DT-020036	Sorga Ato Jregna Kelecher	315
48	15	DT-020035	Behind of Ato Jiregna kelecher	100
49	15	DT-020034	Sorga near to ECX	100
50	15	DT-020033	Sorga trafo	100

D3: Hospital feeder's distribution transformers

NO	Voltage level	Distribution transformer code	Distribution transformers located place	Rating of distribution transformers
1	15	DT-020020	Tinfa wollega university Water supply	100
2	15	DT-020085	Gaarii kebele	50
3	15	DT-020084	Komto EBC trafo	50
4	15	DT-020083	Komto tele tower trafo	25
5	15	DT-020019	Tinfa ketema	100
6	15	DT-020018	Boqe tele tower trafo	25
7	15	DT-020016	Gulit safar 07 keble	200
8	15	DT-020015	Gidel gibu	200

9	15	DT-020014	Gulit safar	315
10	15	DT-020007	Hadiya Water supply	315
11	15	DT-020017	High shcool	200
12	15	DT-020006	Dipo	100
13	15	DT-020005	Dipo tele tower trafo	25
14	15	DT-020004	Dalo 2ndry school tele tower trafo	25
15	15	DT-020003	Infront of Ethiopian road Authorities	315
16	15	DT-020002	Condominiuem	200
17	15	DT-020001	Nekemte Fana FM trafo	50
18	15	DT-020000	Wajjira sanyii filaatama	200
19	15	DT-019999	Infront of Nekemte Town Water supply treatment	200
20	15	DT-019998	Burqa gaarii tele tower trafo	25
21	15	DT-019997	Behind of pepsi public service trafo	200
22	15	DT-020013	Nekemte Hospital tele tower trafo	25
23	15	DT-020012	Nekemte Hospital public trafo	100
24	15	DT-020011	Dalo trafo	50
25	15	DT-020010	Liz safar trafo	100
26	15	DT-020009	Near to Dalo Makane yesus church tele tower trafo	25
27	15	DT-020008	OBN Tower trafo Behind of Wollega University	50
28	15	DT-019996	Behined of pepsi tele tower trafo	25
29	15	DT-019995	Afar mirimir	200
30	15	DT-019994	Jitu condominium	1250
31	15	DT-019993	Infront of madanit fund tele tower trafo	25
32	15	DT-019992	Infront of madanit fund	100
33	15	DT-019991	Madanit fund	200
34	15	DT-019990	Wacha mikael teale tower trafo	25
35	15	DT-019989	Calalki bono safar trafo	200

36	15	DT-019988	Infront of ASK elementry school tele tower trafo	25
37	15	DT-019987	Hostel safar	200
38	15	DT-019984	Jitu wollega unversty trafo	315
39	15	DT-019986	Int. Oromia live stock and nitrogen Nekemt office	100
40	15	DT-019985	Oromia agriculture and resource berio	200
41	15	DT-019983	Doro irbata	50
42	15	DT-019982	Preparatory school tele trafo	25
43	15	DT-019981	Shalom international hotel	200
44	15	DT-019980	Board centre sefer	630
45	15	DT-019979	Infront of New Generation college	200
46	15	DT-019978	Infront of Walda arara charch	315
47	15	DT-019977	Riftvaly University	100
48	15	DT-019976	Deninet	50
49	15	DT-019975	Infront of Farmland hotel	50
50	15	DT-019974	Behind wegagen hotel	315
51	15	DT-019973	Infront of wegagen hotel	315
52	15	DT-019972	Behind Nekemt district CBE office	100
53	15	DT-019971	Behind Nekemt district CBE office	100
54	15	DT-019970	Behind of Desalegn hotel	100
55	15	DT-019968	EBC Nekemt office	25
56	15	DT-019968	Tele reginal office	315
57	15	DT-019967	Around Tele customer service office	100
58	15	DT-019966	Nato deninet	315
59	15	DT-019965	Near to board shell oil	200
60	15	DT-019964	Nib irbata	200
61	15	DT-019963	Lagarde damma tele tower	25
62	15	DT-019962	Nekemt senodes	100
63	15	DT-019961	Nurse shool	100

64	15	DT-019960	Infront of Jato isir bet	315
65	15	DT-019959	Darge kebele office	1200
66	15	DT-019958	Katolic kidanmhert school	200
67	15	DT-019956	Darge technique collegetele twor	25
68	15	DT-019955	Darge technic coolege	315
69	15	DT-019954	Darge tecnic college	630
70	15	DT-019954	Mitiku and Wagari blocket mamirecha	200
71	15	DT-019953	Nekemt biretabiret	315
72	15	DT-019952	Nekemt biretabiret fabirika	800

D4: Wollega University feeder's distribution transformers

NO	Voltage level	Distribution transformer code	Distribution transformers located place	Rating of distribution transformers
1	15	DT-020086	Wollega University condominiuem	315
2	15	DT-020032	Woolega University near to main registerar	315
3	15	DT-020031	Wollega University near to mell dorm	315
4	15	DT-020030	Wollega University infront of nursing schools	800
5	15	DT-020029	Wollega University near to west product	315
6	15	DT-020028	Wollega University near to student cafe	315
7	15	DT-020027	Wollega University near to flormill	315
8	15	DT-020026	Wollega University Behind of female's dorm	315
9	15	DT-020025	Wollega University infront of student lounge No -1	200
10	15	DT-020024	Wollega University near to female's dorm	315
11	15	DT-020023	Wollega University near to language school	630

12	15	DT-020022	Wollega University near to register	50
13	15	DT-020021	Wollega University near to register tele tower trafo	25
14	15	DT-019910	Near to FBI Trafo	200
15	15	DT-019916	Wollega University FB tele tower	25
16	15	DT-019915	Wollega University HO student dorm	630
17	15	DT-019914	Wollega University student lounge 2	315
18	15	DT-019913	Wallaga University student dorm	1250
19	15	DT-019912	Wollega University FBE student cafe trafo	100
20	15	DT-019911	Wollega University ouditrum	315
21	15	DT-019909	Tele trafo	50
22	15	DT-019908	Burka jato trafo	200
23	15	DT-019907	Addis safar trafo	100
24	15	DT-019905	Darge tele tower	50
25	15	DT-019904	Infront of nek phisical rehabilitation center	100
26	15	DT-019903	Infront of nek pole production	200
27	15	DT-019902	Infront of nek pole production	100
28	15	DT-019901	Behind of nek pole production	25

D5: Nunu feeder's distribution transformers

NO	Voltage level	Distribution transformer code	Distribution transformers located place	Rating of distribution transformers
1	33	DT-020187	Killo	200
2	33	DT-020186	Killo	200
3	33	DT-020185	Gossene	100
4	33	DT-020184	Kaso town	50
5	33	DT-020183	Kaso Town	100
6	33	DT-020184	Kaso tele network	25

7	33	DT-020181	Adere town centre	200
8	33	DT-020180	Adere town Around tele	200
9	33	DT-020179	Adem town tele	25
10	33	DT-020178	Bidiru Tele	25
11	33	DT-020134	Bidiru around market	100
12	33	DT-020176	Bocholo/wama	100
13	33	DT-020175	Dirre	50
14	33	DT-020174	Korbu seka	50
15	33	DT-020173	Nunu kumba haro water supply	50
16	33	DT-020172	Nunukumba Around st. michael	100
17	33	DT-020171	Nunu near comercal bank	200
18	33	DT-020170	Nunu kumba Around tele	315
19	33	DT-020169	Nunu kumba tele	25
20	33	DT-020168	Nunu kumba /Aroud Market/	200
21	33	DT-020167	Kabba	100
22	33	DT-020166	Nunu kumba stadium	50
23	33	DT-020164	Dilla koye tele	25
24	33	DT-020164	Amuru botoro village	50
25	33	DT-020163	Wayu warke	200
26	33	DT-020162	Negeso	100
27	33	DT-020161	Abote town	100
28	33	DT-020160	Arjo Awraja araga bato tele	25
29	33	DT-020159	Arjo Awraja /chaina camp/	200
30	33	DT-020158	2009	100
31	33	DT-020157	Gatama water pump	50
32	33	DT-020156	Bandera tele network	25
33	33	DT-020155	Bandira town center	100
34	33	DT-020154	Bandira Town interance	200
35	33	DT-020151	Diga fododo no two	800
36	33	DT-020153	Kewisa sheno	200

37	33	DT-020152	Diga fododo	100
38	33	DT-020150	Demeksa kebele	200
39	33	DT-020149	Demekisa	200
40	33	DT-020148	Diga telecom tower	25
41	33	DT-020147	Diga town	100
42	33	DT-020146	Diga interance	100
43	33	DT-020145	Chanco water station	200
44	33	DT-020144	Digga fododo	100
45	33	DT-020143	Abono	25
46	33	DT-020142	Megenteya	50

D6: Boneya feeder's distribution transformers

NO	Voltage level	Distribution transformer code	Distribution transformer located place	Rating of distribution transformers
1	33	DT-020105	Arbi gebiya	315
2	33	DT-020105	Aribi gave Conchita primary school	100
3	33	DT-020103	Gute tele	25
4	33	DT-020102	Gute bonbo	50
5	33	DT-020101	Boneya city	100
6	33	DT-020100	Boneya tele	25
7	33	DT-020099	Boney health centre	50
8	33	DT-020098	Gute town	200
9	33	DT-020097	Gute concentrate pole factory	200
10	33	DT-020096	Gute concentrate pole factory	200
11	33	DT-020095	Gute concentrate pole factory	200
12	33	DT-020094	China camp	50
13	33	DT-020093	In the Gibe sides factory compound	315
14	33	DT-020092	Aria Jawe health centre	50

C8: Gida feeder's distribution transformers

NO	Voltage level	Distribution transformer code	Distribution transformers located place	Rating of distribution transformer
1	33	DT-020152	Kenaf trafo	50
2	33	DT-020148	24 ketema tele tower trafo	25
3	33	DT-020147	24 ketema trafo	100
4	33	DT-020144	Haro fola tele tower trafo	25
5	33	DT-020143	Haro fola Primary school	50
6	33	DT-020581	Balo Bareda village	50
7	33	DT-020580	Balo Bareda	50
8	33	DT-020579	Miliki Aretagn	50
9	33	DT-020578	Milke (3)	50
10	33	DT-020577	Sosetgn	50
11	33	DT-020576	Mojo village	50
12	33	DT-020575	Made jalela	50
13	33	DT-020574	Boke sefer	50
14	33	DT-020573	Medela sefer	50
15	33	DT-020572	Anger Arategh	100
16	33	DT-020146	Tsige ketema trafo	100
17	33	DT-020145	Tsige tele tower trafo	25
18	33	DT-020571	Anger central	200
19	33	DT-020570	Aanger central	100
20	33	DT-020569	Anger Andegh	100
21	33	DT-020568	Wollo sefer	100
22	33	DT-020567	Ewude gebiya village	50
23	33	DT-020566	Ewude gebiya tele network	25
24	33	DT-020565	Ewude gebiya village	100
25	33	DT-020564	Galo (Hadiya village)	50
26	33	DT-020563	Galo village FTC	50

27	33	DT-020562	Adami village	100
28	33	DT-020561	Jemata city tele network	25
29	33	DT-020560	Jemata city	200
30	33	DT-020559	Jemata city	100
31	33	DT-020558	Jemata (Goderu)	25
32	33	DT-020557	Sasiga Tele Network	25
33	33	DT-020556	Sasiga city preparatory school	100
34	33	DT-020555	Sasiga	100
35	33	DT-020554	Sasiga city	200