ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

INTEGRATION OF DISTRIBUTED GENERATION WITH DISRIBUTION NETWORK EXPANSION PLANNING

(CASE STUDY: ADWA DISTRIBUTION SUBSTATION)

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

BY:

GEBREKRSTOS ABRAHA

ADVISOR: Dr. GETACHEW BEKELE

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APPROVAL BY BOARD OF EXAMINERS

Dr. Getachew Bekele	___________________
Chairman Department of Graduate Committee	Signature
Dr. Getachew Bekele	___________________
Advisor	Signature
Mr. Dawit Habtu	___________________
Internal Examiner	Signature
Prof. N.P. Singh	___________________
External Examiner	Signature

DECLARATION

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

Gebrekrstos Abraha ______________

Name Signature

Place: Addis Ababa

Date of Submission: January, 2020

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

Dr. Getachew Bekele ________________

Advisor's Name Signature

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ABSTRACT

Expansion planning of a distribution network answers to be mounted the services, so that the distribution network fulfills the predicted load requirement to satisfy all operational and technical constraints. Integration of distributed generations (DG) which have economical and technical benefits such as reduction in losses, improving voltage profile, reduction line loading and provides good voltage stability.

This thesis mainly investigates expansion planning of Adwa distribution substation with analytical voltage sensitivity index methods to facilitate the integration of distributed generation DG into the distribution network. The results of DG are presented to determine the appropriate places and the capacity to make the distribution network highly reliable service. The feeder was selected due to its lowest voltage sensitivity index from the other feeders and due to its highest power interruption when it is compared with other outgoing feeder for the one year recorded data. In addition, the outgoing feeder KO1 at bus 50 have the least tail end nodal voltage sensitivity index of 0.002210 when it is compared with the other bus. Appropriate places are selected for the DG and their ratings are determined due to the principle of minimum system power loss. The power capacity of DG for feeder KO_1 is found to be 12.70 MW and 3.30 MW as a reserve at bus 50 and the capacity of DG increases with demand growth at each year.

The peak load demand forecasting for ten years for Adwa distribution substation is carried out using least squares extrapolation technique. The peak power demand reaches 75.31MW after 10 year and the load growth it increases by 7.07 present at each year. Moreover, due to presence of DG placement in the distribution network, it implements and coordinates eleven fast protection relays based on magnitude of the fault current and fault tripping time in the line. In order to reduce the impact of DG on the protection device when the capacity of DG highly increase with demand it upgrades the margin of both current and time interval of the relay.

Finally, the voltage profile, voltage stability and power loss of Adwa distribution substation are compared with and without DG integration to meet the current demands as well as when the DG capacity increases to supply the increasing future demand. It is found that without DG integration, the voltage profile lies within a limit of 0.866 – 1.0 p.u while the DG integration provides an improved voltage profile within 0.974 – 1.0 p.u. It is further observed that DG integration provides an improved voltage stability and reduces the active and reactive power loss by 94.67% and 95.59%, respectively as compared to those without DG integration. Furthermore, when the DG capacity increases with increasing demand, it has positive technical benefits such as voltage profile improvement, reduction in active and reactive power losses as well as line loading. The simulation results further demonstrate successful implementation and coordination of fast protection relays. Also, the fast protection relays are successfully upgraded when the capacity of DG increases with increasing demand.

Key words: Distribution network expansion planning, Distributed generation, coordination of relays.

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LIST OF ABBREVIATIONS

AAC	All Aluminum Conductor
ACO	Ant Colony Algorithm
AI	Artificial Intelligence
DER	Distributed Energy Resources
DE	Differential Evolution
DG	Distributed Generation
DNO	Distribution Network Operator
DigSILENT	Digital Simulation of Electrical Network
DSEP	Distribution System Expansion Planning
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
GA	Genetic Algorithm
HV	High Voltage
kWh	kilo Watt hour
IPP	Independent Power Producers
LL	Line to line fault
LLL	Double line to line fault
L-G	Line to ground fault
LL-G	Double line to ground fault
LLL-G	Three line to ground fault
LV	Low Voltage
MVA	Mega Volt Ampere
MVAR	Mega Volt Ampere Reactive
MW	Mega Watt
MV	Medium Voltage
NASA	National Aeronautics and aerospace administration
OPF	Optimal power flow
OL	Over Load
OP	Operational
p.u.	Per Unit
PCC	Point of Common Coupling
POC	Point of Connection

PS	Plug Setting
PSM	Plug Setting Multiplier
PV	Photo Voltaic
PSO	Particle Swarm Optimization
PL	Power Losses
PV	Photovoltaic
R/X	Resistance to reactance ratio
SC	Short Circuit
TD	Time Dial
TSM	Time Setting Multiplier
TEN	Tail End Node
TENVDI	Tail End Node Voltage Deviation Index
UF	under Frequency
VR	Voltage Regulators
WDG	with Distributed Generator
WODG	With Out Distributed Generator
WIDG&L	With increasing DG and Load

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Continuous economic growth and fulfillment of high standards in human life depends on reliable and affordable access to electricity. To answer these issues electricity is generated, transmitted and delivered. Utilities are continuously planning the expansion of their existing electrical networks in order to meet the load growth and to properly supply their consumers with efficient and reliable power supply. An important phenomenon in this regard for further future electric power generation is distributed generation DG, which is also known as embedded generational, Dispersed generation or decentralized generation. Distributed generation (DG) may come from a variety of source and technologies. Distributed Generations (DGs) from renewable sources, like wind, solar (PV) and biomass are often called as Green energy. In addition to this, DG includes micro turbines, gas turbines, diesel engines, fuel cells, starling engines and internal combustion reciprocating engines [1].

In a heavily loaded distribution network, the load current drawn from the source would extremely increase. So this may lead to increase in voltage drop and system losses. The performance of distribution system becomes ineffective due to the reduction in voltage magnitude and increase in distribution network losses. Therefore, changing environment of power systems design and operation has required the need to consider active distribution network by incorporating distributed generator (DG) unit [2].

Nowadays electricity networks are in the era of major transition from stable passive distribution networks with unidirectional electricity transmission to active distribution networks with bidirectional electricity transmission. Distribution networks without any DG units are passive since the electrical power is supplied from the grid system to the customers in the distribution networks. It becomes active when DG units are integrated to the distribution system, so it leads to bidirectional power flows in the networks [3].

The amount of energy loss in an active distribution system in transmitting electricity is less as compared to the passive distribution network, because the electricity is generated nearest to the load center, perhaps even in the same building. The Active distribution network has several advantages like reduced line losses, voltage profile improvement, reduced emission of pollutants, increased overall efficiency of the distribution network, reduce line loading, improved power quality of the network and relieved transmission and distribution congestion. Hence, utilities and distribution companies need tools for proper planning and expansion of *active distribution networks.*

In this thesis, a voltage sensitivity index method is used to determine the appropriate location of DG, and the proper capacity for DG placement is identified by load flow analysis with an injection of DG at each bus with corresponding capacity found at each bus by considering total power loss reduction and voltage profile improvement. The load flow analysis of the sample network is simulated on the DigSILENT Power Factory 15.1.7 software package. The DG is measured to be located in the primary distribution system and the intention of this integration of DG placement is to reduce the total power losses, to reduce line loading, improve the voltage profile and to increase the voltage stability of the distribution network.

1.2. Statement of the Problem

Electricity is generated, transmitted and delivered in order to meet the predicted load requirement and to satisfying all operational and technical constraints. The distribution system is very extensive and it has high resistance to inductance (R/X) ratio. In addition to this, distribution feeders which transfer power from distribution substation to the customer side is overloaded beyond their carrying capacity. Overloaded distribution feeders that travels long distances have large power losses and high voltage drop problems and also poor voltage stability due to load variations time to time. The equipment used by utility and customers are designed to operate at a certain voltage rating. If they operate below that rating, they will draw large current and they have dangerous effect on the life of the connected equipment of the customer.

Among that Adwa distribution substation have seven outgoing distribution feeders and this distribution feeder’s supply for different cities and villages, which have domestic, commercials, industrial and agricultural loads. In the Adwa distribution feeders have a number of problems which is motivated in order to study on integration of DG with distribution network expansion planning to determine expansion strategies in order to serve the load growth and to provide the customers with acceptable service. The factors which have motivated me to do this thesis work are need of constructing new distribution feeder, constructing new power plants, expansion of substations, lower voltage profile, high line losses and poor voltage stability.

This thesis addresses the problems of voltage profile and stability, power loss as well as line loading of the distribution network to meet the future load demand by integrating of DG. In addition, it also investigates the role of DG integration in the distribution system planning for sustainable and emission free energy supply.

1.3. Objectives of the Thesis

General objective

The general objective of the thesis is to integrate distributed generation (DG) with distribution network expansion planning to fulfill the predicted load requirement and to satisfy all operational and technical constraints of the case study.

Specific objectives:

- To forecast the peak load demand of Adwa distribution substation for the coming 10 years.
- To develop a model of integrating of DG to the distribution network using DigSILENT Power Factory 15.1.7 software.
- To carry out simulation studies using the above model and to examine the performance of the integrated system.
- To analysis the contribution of renewable energy by integrating wind energy and photo voltaic (PV) solar energy to the case study existing distribution feeder.
- To investigates the line loading by integrating DG to the distribution feeder.
- To review need of constructing new large power plants, transmission lines and substation expansion.
- To determine the appropriate capacity and placement of DGs by considering uncertainty using sensitivities index analytical method.
- To examine the impacts of integrating DG in the case study of distribution network especially in terms of system voltage profiles, line loading, voltage stability and energy losses with the help of DigSILENT Power Factory 15.1.7 simulation software.
- To analyze the impact of the DG on protection device by implementing and coordinating fast protection relay and also by grading the fast protection relay when the capacity of DG increase with load demand in the selected feeder.

- To draw conclusions based on above analysis and to suggest appropriate recommendation for Ethiopian Electric Utility and Ethiopian Electric Power.

1.4. Scope and Limitation

The scope and limitation of the thesis is as follows:

- The scope of this thesis is starting from studying and analyzing of Distribution network expansion planning with Distributed Generation in Case of Adwa substation. So in this Thesis, DG resources are used to increase power capacity, to improved system constraints and also to investigate impact on the protection device from distribution substation to distribution transformers. The results are explained using DigSILENT Power Factory 15.1.7 simulation software.
- DG technologies have been limited to Synchronous Generator which is standard models available in DigSILENT Power Factory 15.1.7 without considering their detail design due to time limitation because DG output power have affected due to environmental variations and due to different nonlinear components.

1.5. Methodology

The methodology of this thesis starts from the problem identification and reading helpful literatures. The problem identification is the first step towards solving the site problem. And the study goes through a literature survey on integration of distribution network expansion planning with Distributed Generation and come up with ideas for mitigating the problems.

Site Selection

Adwa substation is selected as a case study area where interruption problems are highly pronounced and overloaded due to load growth from time to time. It also has enough resources and space at that site like wind and solar energy in order to integrate the DG to distribution network expansion planning.

Data Collection

Data of this thesis work has been conducted using the following methods.

- Start from intensive literature reading about network expansion planning and DG resources
- Site visit and observations
- Technical data collection from the site office
- Gather relevant data from the Adwa EEU and checked the data collected
- Data has been collected from the following offices in order to analysis existing structure Adwa substation.
  - ✓ Data's on EEU
  - ✓ Data's on planning and design of EEU

Data Analysis and Modelling

- To see the effect of load growth of Adwa substation using Mat lab/Simulink.
- To integrating the DG with distribution network expansion planning is analyses and discussed in detail.
- To see the effect of DG on the distribution network, DigSILENT Power Factory 15.1.7 simulation software is used.

1.6. Organization of the Thesis

This thesis work is organized as follows, Chapter one deals with a brief introduction of the thesis background, problem statement, objective of the thesis, scope and limitation, description of methodology and techniques used in this thesis. Chapter two gives details theoretical background and review of different literatures related to my title. Chapter three describes integration issues of DG in distribution networks expansion planning by considering the presence of DG to the distribution network. Chapter four covers modeling and simulation of the case study distribution network in parallel with discussion of the results found. And the last chapter gives conclusion and recommendation as well as the further work expected to be done in the future is organized.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1. Introduction

The majority of power systems topology is taken for arranged as a radial system, which means power flow from source to load or from generation to consumers. However, with the presence of distributed generation technology, this paradigm has changed and the power source is not only from centralized sources but also from another source such as distributed generation, thus power flow from the central source to the distributed generation or vice versa.

This chapter focused on review of different literatures related to the integration of DG with modern distribution network expansion planning and their impacts of DG integration on a distribution system in order to compare and contrast the legacy distribution network with the active distribution network. Furthermore, the critical review of the distributed generation concepts and technology, their environmental impacts and the contribution of DG technology to modernize the old distribution network which is involved under this chapter.

2.2. Need of Power System Planning

The objective of power system planning is to determine a minimum cost strategy for long range expansion of the generation, transmission and distribution systems adequate to supply the load forecast within a set of technical and economic constraints [4]. In addition to this, power system planning is to determination and justification of system topologies, schemes for substations and the main parameters of equipment considering the criteria of economy, security, and reliability.

Power system engineering and power system planning require a systematic approach, which has to take into account the financial and time restrictions of the investigations as well as to cope with all the technical and economic aspects for the analysis of complex problem definitions [5].

- Demand from customers for supply of higher load, or connection of new production plants in industry.

- Demand for higher short circuit power to cover requirements of power quality at the connection point (point of common coupling).
- Construction of large buildings, such as shopping centers, office buildings or department stores.
- Planning of industrial areas or extension of production processes in industry with requirement of additional power.
- Planning of new residential areas.
- General increase in electricity demand.

Power system planning is based on a consistent load forecast which takes into account the developments in the power system mentioned above. The load increase of households, commercial and industrial customers is affected by the overall economic development of the country [6]. Defining the objective function representing the section of the power system, constraints that capture operating conditions that selected section is subjected to have to be defined. The constraints may capture the following:

- Voltage criteria
- Reliability and security of supply
- Thermal loading of overhead cables
- Power loss minimization
- Reserve capacities in the case of substations
- Use of standardized equipment e.g. substations and cables must be selected from standard substation sizes and conductors.

2.3. Distributed Generation Concept and Technology

Distributed generation is not a new concept because originally, all energy was produced and consumed at or near the process that required it [7]. As cited in this literature a fireplace, wood stove, and candle are all forms of "distributed" small scale, demand sited energy. So is a concise watch, alarm clock, or car battery. However, the key to today's energy revolution involves turning the old centralized generation system (from large power plants hundreds or thousands of miles away to a "heat engine" in the building) towards the generation of electrical energy near the load center to gain several technical and economic benefits.

2.3.1. Concept of Distributed Generation

In general Distributed generation (DG) is small scale electric power generators that produce electricity near to customer's side. In addition, to this DG are not limited to synchronous generators, solar photovoltaic, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, and wind turbines [4]. Distributed Generation (DG) generates electricity from the many small energy sources and it defines as site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy, [8].

Conventional power stations, such as coal fired, and nuclear powered plants, as well as hydroelectric dams and large scale solar power stations, are centralized and often require electricity to be transmitted over long distances. Electricity is generated at the generation side and it delivered to the customers using a large passive distribution infrastructure, which involves high voltage (HV), medium voltage (MV) and low voltage (LV) networks. In these system, networks are designed to operate radially. The power flows only in one direction from generation to distribution customers situated along the radial feeders.

Definition of Distributed Generation

Distributed Generation is a concept of small scale electric power generation that is operated and installed near to the customer's site and used to support the increased energy demand. Usually, it is connected via power electronic converter or other power electronic devices to the distribution system [7]. There is not a common international definition of DG as the concept involves many technologies and applications. Different terms and definitions are used different literature related to DG works in different journals. For example, Anglo-American countries often use the term 'embedded generation', North-American countries use the term 'dispersed generation', and Europe and parts of Asia, uses the term 'decentralized generation' [9].

The definitions of DG which are defined as in terms of capacities of the DG units generating at the site of connection is given her [9].

- The electric power research institute defined DG as generation from a few kilowatts up to 50MW,
- According to the Gas Research Institute, DG is in between 25KW and 25MW,
- Preston and Rastler defined as 'ranging the size from a few kilowatts to over 100 MW',
- Cardell defined DG as generation between 500KW and 1MW,

➢ The international conference on Large High Voltage Electric Systems (CIGRE) defined DG as ‘smaller than 50-100MW.

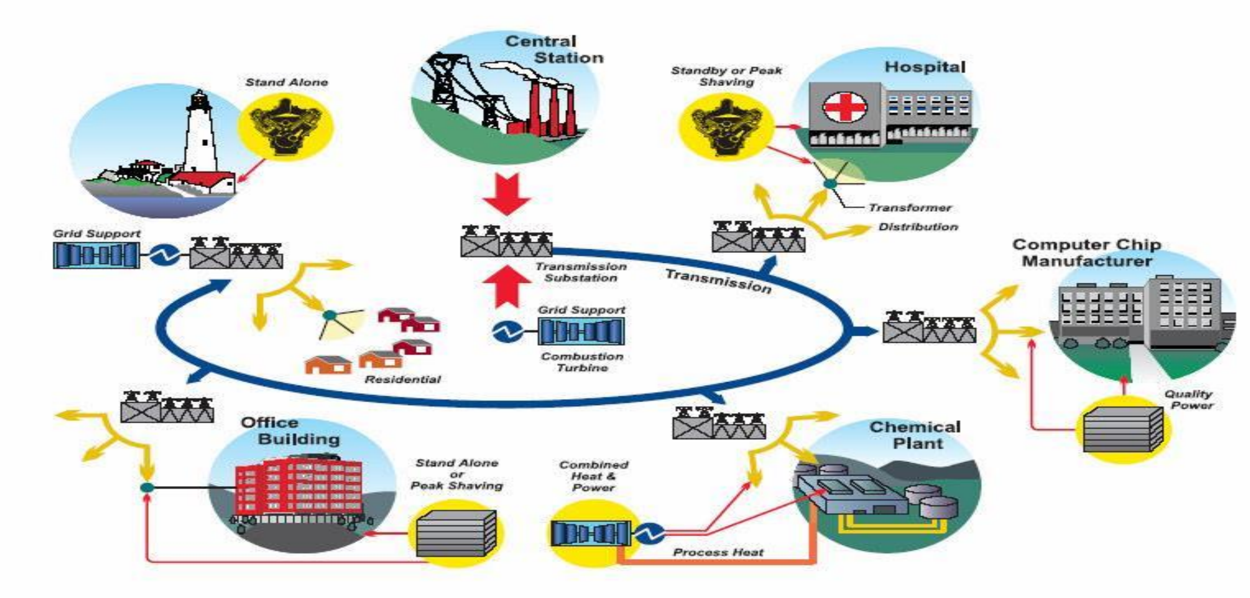

Figure: 2. 1 Summary of DG applications [10]

However, this definition is not essential and there is no universal agreements on the distributed generation definition. The main objective of distributed generation is transferring the electricity from point of generation side to the point of consumer side. Therefore in this thesis, the following definition is used [10].

Distributed generation is considered as the installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer site of the meter in order to provide a source of active electric power which is small enough compared with the centralized power plants.

The motivation for using this definition is that the connection of generation units to the distribution network is done traditionally by the industry. The central idea of distributed generation, is to integrate the generation close to the load center, hence on the distribution network or on the customer.

Classification of Distributed Generation

DGs can be classified based on different criteria. Among these, the two main criteria for DGs classifications based on capacity or output power rating and the type of technology involved in the power generation. The classifications of DGs based on capacity or output power rating is as shown in Table 2.1.

Table 2. 1 Classification of DG based on power rating.

DG Classification	Output Power Range
Micro Distributed Generation	1W – 5kW
Small Distributed Generation	5kW – 5MW
Medium Distributed Generation	5MW – 50MW
Large Distributed Generation	50MW – 300MW

Another basis for classification of DGs is the type of technology involved in the power generation. Therefore, distributed generation technologies can be categorized as renewable and non-renewable as depicted in Table 2.2.

Table 2. 2 Classification of DG based on technology.

Renewables DG	Non-renewables DG
Solar Wind Geothermal and Ocean	Internal Combustion Engines (ICE) Combined Cycle Combustion Turbine Micro turbine Fuel Cell

Distributed generation technologies could also be grouped according to their dispatch ability namely renewable and non-renewable [10]. This is because one of the primary elements in a distributed generation management system is the dispatch strategy: the aspect of control strategy that pertains to the sources and destinations of energy flows. The key difference between the two categories is the controllability of electric power. The non-renewable resources, in general, have the energy stored, and could therefore be called upon at any given time to produce power. This implies that nonrenewable units such as conventional generator sets, fuel cells, and micro turbines, can be controlled by a central intelligence and relied on to generate according to the needs of the power system. The renewable resources, on the other hand, inherently do not have any control of the input energy for later use when needed. This means that renewable technologies generate not as a function of power system needs, but rather as a function of intermittent availability of their energy source. From the foregoing it can adduced that while renewable DG technologies are dispatch able resources. Hydroelectric, biomass and geothermal are dispatch able resources, whereas, wind, solar and tidal waves would be classified as non-dispatch able resources most or common renewable energy systems are non- dispatch able.

Different authors still classify DG as inverter based DG and rotating machine DG [11]. Inverters are used in DG systems after the generation, the generated voltage may be the form be in DC or AC, but it is required to be changed to the nominal voltage and frequency. Therefore, it has to be change first to DC and then convert to AC with the nominal parameters through the rectifier.

2.3.2. Distributed Generation Technology

The liberalization of electricity markets and environmental policy has increased the use of distributed generation units for a range of applications, such as standalone, peak load shaving and remote applications. These units can be classified into two different categories [12]:

1. Distributed generation based generation, including micro turbines, photovoltaic, fuel cells, wind turbines and biomass.
2. Distributed generation based storage, including flywheels, battery, super capacitor and superconducting coil system.

All of these technologies are currently being used and are gaining popularity. Some of the different types of distributed generation are discussed in the subsequent section.

2.3.2.1. Photovoltaic Systems

Photovoltaic (PV), “photo” meaning “light” and “voltaic” referring to electricity which is the direct conversion of sunlight into an electrical potential (a photo voltage) that can be used to provide electric power. The photo voltaic effect is the electrical potential difference between two semiconductor materials when their common junction is illuminated with radiation of photons. The photo voltaic cell, thus, converts light directly into electricity [10]. A material or device that is capable of converting the energy contained in photons of light into an electrical voltage and current is said to be photovoltaic [8]. Therefore, the photo voltaic effect is the process by which an electric potential difference (voltage) is created in a material exposed to light (electromagnetic radiation), which then leads to the flow of electric current. This process is directly related to the photo electric effect, but distinct from it in that in the case of the photo electric effect electrons are ejected from the material surface upon being exposed to high enough frequency (energy) light, whereas in the photo voltaic effect the generated electrons are transferred across a material junction (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, the energy supply for a solar cell is photons coming from the sun. A photon which very have short wavelength and high enough energy can cause an electron in a photovoltaic material to break free of the atom that holds it. If a nearby electric field is provided those electrons can be swept toward a metallic contact where they can convert to electric current.

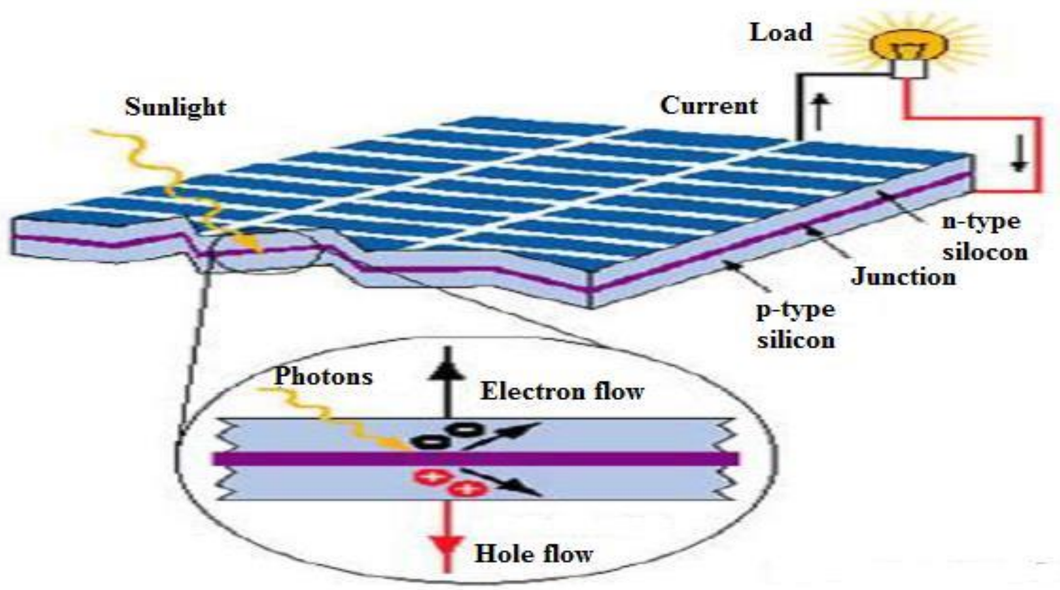

Figure: 2. 2 Schematic diagram of a photovoltaic system

Photovoltaic energy conversion is a direct conversion from electrical energy in the form of current and voltage from electromagnetic (i.e., light, including infrared, visible, and ultraviolet) energy. A solar cell (PV cell) is a large-area semiconductor diode (Figure 2.3 a). It consists of a *p-n* junction created by an impurity addition (doping) into the semiconductor crystal (consisting of four covalent bonds to the neighboring atoms for the most commonly used silicon solar cells) [10]. The solar cell explained above is the basic things of the PV power system. Typically, it is a few square inches in capacity and on production about one watt. For obtaining high power, numerous such cells are connected in series and parallel circuits on a panel (module) area of several square feet (Figure 2.3 b). The solar array is defined as a group of several modules electrically connected in series and parallel combinations to generate the as you want of current and voltage. Figure 2.3 (c) shows the actual construction of a module in a frame that can be mounted on a structure.

As stated below, the basic elements of a PV system are the modules that are usually series parallel connected and is usually called a PV string. But several components are needed to construct a grid connected PV system to perform the power generation and conversion functions.

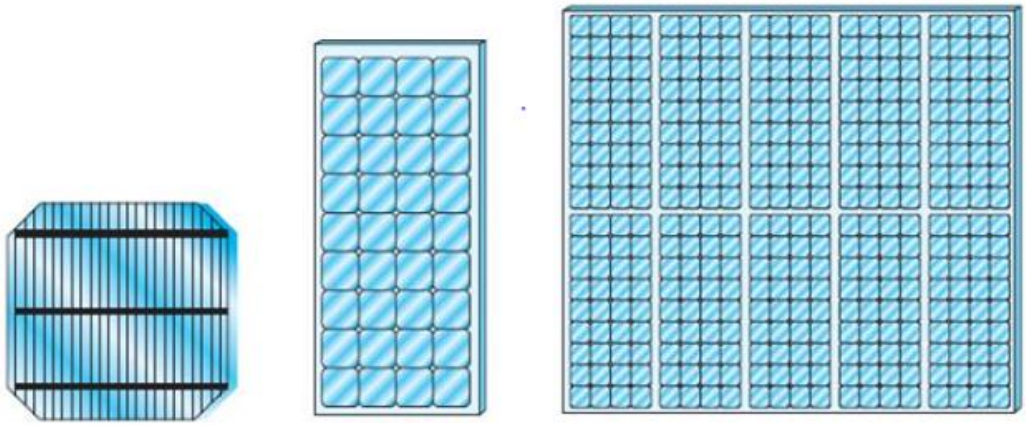

Figure: 2. 3 Distinction between cells, modules, and arrays

If the voltage of the PV string is always higher than the peak voltage of the grid the PV converter does not require a step-up stage [10]. In this case higher efficiency can be obtained because a single stage full-bridge converter can be used. Otherwise, a DC-DC boost converter or a transformer must be added for voltage amplification but it reduces efficiency. However, energy storage devices can be included in order to store the energy produced in case of grid support connection [8]. A three-phase inverter performs the power conversion of the array output power into AC power suitable for injection into the grid. Pulse width modulation control is one of the techniques used to shape the magnitude and phase of the inverter output voltage.

2.3.2.2. Wind Turbine

Wind energy relies, indirectly, on the energy of the sun. A small proportion of the solar radiation received by the Earth is converted into kinetic energy, the main cause of which is the imbalance between the net outgoing radiation at high latitudes and the net incoming radiation at low latitudes [10]. The Earth's rotation, geographic features and temperature gradients affect the location and nature of the resulting winds [8]. The use of wind energy requires that the kinetic energy of moving air be converted to useful energy. As a result, the economics of using wind for electricity supply are highly sensitive to local wind conditions and the ability of wind turbines to reliably extract energy over a wide range of typical wind speeds. Over recent years, there have been dramatic improvements in wind energy technologies, and wind turbine generation has developed rapidly as a competitive and effective source of distributed generation. Wind energy can be exploited in many parts of the world, but is the most cost-effective in windy climates, where average wind speeds exceed 6.5 m/s [10].

The wind farm is composed of several wind turbines which have basic electrical components: an aerodynamic rotor, a mechanical transmission system, an electric generator, a control system, limited reactive power compensation and a step-up transformer as shown in Figure: 2.4.

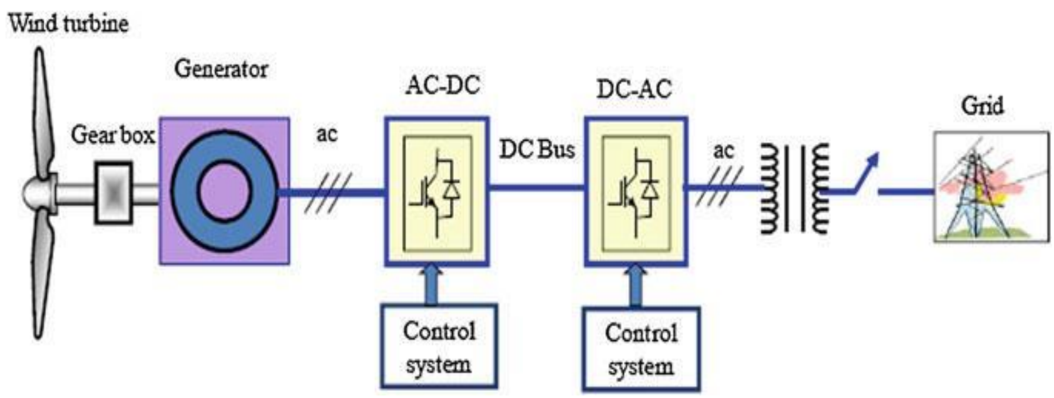

Figure: 2. 4 Grid Connected wind Energy system

The generator is used for converting the mechanical power obtained from the wind turbine to electrical power. A wind turbine comprises rotor/blades for conversion of wind energy into rotational shaft energy, a nacelle with drive train that contains the generator and gear box, a tower that supports the rotor and drive train and the necessary electric equipment for connection to the grid. The majority of wind turbines offered today is of the three bladed upwind horizontal axis type and installations intended to connect at the PCC at medium or high voltage of the network [9].

In consideration of speed wind energy systems are either fixed or variable while the coupling between the mechanical and electrical parts could be with or without a gear-box. Nowadays, induction generators are widely used in wind turbine and a variable speed generator is the preferred option in newer wind turbine installations [9].

2.3.2.3. Fuel Cells

Fuel Cells (FC) are classified as non-traditional generators. They are electrochemical devices that convert chemical energy from a fuel directly into electrical energy by combining oxygen, as an oxidant, and hydrogen, as a fuel, without combustion [12]. The hydrogen is usually procured from a fossil fuel "natural gas" while air is used as a source of oxygen. The result of this electrochemical process is high-current/low-voltage DC power. To connect the fuel cell to the grid, a DC/AC converter and filter system current are used to convert the output to AC power. Water (H2O) and heat are by-products of the process. This heat, which often exceeds 1,000 0F, converts the water to steam, which can then be used to perform other work. Regardless of the auxiliary systems, FCs have no moving parts and no combustion, making them silent devices.

2.3.2.4. Micro-turbines

Micro-turbines (MT) are small electricity generators that burn fuel such as natural gas, propane, and fuel oil to create a high-speed rotation that is transferred to an electrical generator via a main shaft. MT consists of three basic components: a compressor, a turbine generator, and recuperates [13, 14]. In present energy markets, MT generators are the most improved and most attractive devices in distributed power generation equipment. Their capacity ranges from 20 kW to 500 kW and their efficiency is more than 80% when the CHP application is used in the system. Also, the NOx emissions of MT are very low compared to large-scale turbines.

2.3.2.5. Induction and Synchronous Generators

Induction and synchronous generators are electrical machines which convert mechanical energy into electrical energy then dispatched to the network or loads. Induction generators produce electrical power when their shaft is rotated faster than the synchronous frequency driven by a certain prime mover (turbine, engine). The flux direction in the rotor is changed as well as the direction of the active currents, allowing the machine to provide power to the load or network to which it is connected. The power factor of the induction generator is load dependent and with an electronic controller its speed can be allowed to vary with the speed of the wind. The cost and performance of such a system is generally more attractive than the alternative systems using a synchronous generator [15].

The induction generator needs reactive power to build up the magnetic field, taking it from the mains. Therefore, the operation of the asynchronous machine is normally not possible without the corresponding three-phase mains. In that case, reactive sources such as capacitor banks would be required, making the reactive power for the generator and the load accessible at the respective locations. Hence, induction generators cannot be easily used as a backup generation unit, for instance during islanded operation [15].

The synchronous generator operates at a specific synchronous speed and hence is a constant- speed generator. In contrast with the induction generator, whose operation involves a lagging power factor, the synchronous generator has variable power factor characteristic and therefore is suitable for power factor correction applications. A generator connected to a very large (infinite bus) electrical system will have little or no effect on its frequency and voltage, as well as, its rotor speed and terminal voltage will be governed by the grid.

Normally, a change in the field excitation will cause a change in the operating power factor, whilst a change in mechanical power input will change the corresponding electrical power output. Thus, when a synchronous generator operates on infinite bus bars, over-excitation will cause the generator to provide power at lagging power factor and during under-excitation the generator will deliver power at leading power factor. Thus, synchronous generator is a source or sink of reactive power. Nowadays, synchronous generators are also employed in distribution generator systems, in thermal, hydro, or wind power plants. Normally, they do not take part in the system frequency control as they are operated as constant power sources when they are connected in low voltage level. These generators can be of different ratings starting from kW range up to few MW ratings.

2.4. Expansion Planning of Distribution Networks with Integrating DG

The current existing distribution network are seen to be passive networks units due to the unidirectional power flow from distribution substation to end users. Usually, distribution network upgrade is carried out with the aid of additional network components such as transformers, protective devices and transmission lines for meeting the load growth. The integration of DG has been as one of the attractive options for distribution system due to the incentives and environmental considerations. Distribution network with DG 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.

A different methods are used in order to determine the proper DG locations and sizes. And understand that while DG addition is the most appropriate alternative, it could become a cost effective solution, with the right DG size, place and distribution capital deferral credit [7]. For placing DG under load uncertainty is proposed where minimization of economic cost (including investment, operation cost of DG units and cost of losses), technical risks (including risks of voltage and loading constraints violation) and economic risks (due to the uncertainty in the electricity price) are considered [16].

The economic planning of a reliable distribution network that satisfies the annual load growth for the planning period is a significant issue for distribution network companies striving to survive in the competitive electricity market [17]. For this purpose, installation of new substations or upgrading the substation capacity is required. DG is an alternative approach to such upgrades that has attracted engineers' attention in recent years. In addition to supporting the annual load growth, DGs can decrease the line loss by reducing the line's power flow, it improve the voltage profiles, reduced line loading and it increases voltage stability.

DG based planning method is presented in to minimize the line loss in a planning area. In addition to DGs, capacitors can postpone the need to upgrade the HV/MV transformer required due to the load growth. [18, 19, 20, 21] The capacitors are used commonly for minimizing the line loss and improving the voltage profile by reducing the reactive component of the feeder current [22, 23]. In [24], a dynamic programming method is used for solving the reactive power and voltage control. The capacitors and the main transformer tap changer are dispatched to minimize the line loss and to improve the voltage profile. A similar procedure is implemented in [25, 26] using the GA. A mechanism for optimal voltage support is proposed in [26], which introduces a procedure to optimize voltage regulator (VRs) in addition to capacitors and the main transformer tap. It is observed that including VRs can decrease the total cost by 3.6%. In the presence of nonlinear loads [27] introduce a capacity or planning to minimize the line loss.
Similar to the capacitor size, the line characteristics, DG size and location, and adjusting the distribution transformer tap setting can assist to keep the bus voltage within the standard level and to reduce the line loss [25]. Such reductions of the line loss at peak load level can reduce the need for investment in equipment of a greater power rating.

Improving the voltage profile, minimizing the line loss, reduction of line loading and increasing voltage stability is used to supporting the load growth are the main objective in the planning of a distribution network. Since DG improve the voltage profile and line loss and also DGs increase system voltage stability so this elements can help the HV/MV transformers for supporting the load growth, so DGs should be planned simultaneously to have a low cost planning. This highlights a need for a method to consider this integrated planning method as implemented in this thesis.

2.5. Impact of DG Integration on Distribution Network

The operation of distribution network originally radial and designed to operate without any generation on the distribution network, and power flow is unidirectional. The introduction of DG in distribution network can significantly impact the power flow and voltage conditions at both customers and utility equipment. These impacts can be manifested as having positive or negative influence, depending on the DG features and distribution network expansion planning and operation characteristics [28, 29, 30, 31]

Generally, impacts of penetration of DG to the distribution network can be classified into three main categories, namely technical, environmental and commercial and regulatory impacts [29].

2.5.1. Technical Impact of DG

There are some technical impacts of DG to the distribution network, among that on power loss, voltage regulation and on protection device coordination the main technical impacts.

Impact of DG integration on Power Losses

One of the major impacts of distributed generation is on the power losses in a feeder. Locating the DG units is an important criterion that has to be analyzed to be able to achieve a better reliability of the system with reduced losses. Locating of DG units to minimize losses is similar to locating capacitor banks to reduce losses. The main difference between both situations is that DG may contribute with active power and reactive power (P and Q). On the other hand, capacitor banks only contribute with reactive power flow (Q). Mainly, generators in the system operate with a power factor range between 0.85 lagging and unity, but the presence of inverters and synchronous generators provides a contribution to reactive power compensation (leading current).

The optimum capacity and location of DG can be obtained using load flow analysis software, which is able to investigate the suitable capacity and location of DG within the system in order to reduce the losses. For instance, if feeders have high losses, adding a small capacity DGs will show an important positive effect on the losses and have a great benefit to the system. On the other hand, if larger units are added, they must be installed considering the feeder capacity boundaries [32]. For example, the feeder capacity may be limited as overhead lines and cables have thermal characteristic that cannot be exceeded.

Most DG units are owned by the customers. The grid operators cannot decide the locations of the DG units. Normally, it is assumed that losses decrease when generation takes place closer to the load site. However, as it was mentioned, local increase in power flow in low voltage cables may have undesired consequences due to thermal characteristics [30].

Impact of DG integration on Voltage profile

Radial distribution systems regulate the voltage by the aid of load tap changing transformers (LTC) at substations, additionally by line regulators on distribution feeders and shunt capacitors on feeders or along the line. Voltage regulation is based on one way power flow where regulators are equipped with line drop compensation.

The connection of DG results in changes in voltage profile along a feeder by changing the direction and magnitude of real and reactive power flows. Nevertheless, DG impact on voltage regulation can be positive or negative depending on distribution system and distributed generator characteristics as well as DG location and capacity [30].

The installation of DG units along the power distribution feeders may cause overvoltage due to too much injection of active and reactive power. For instance, a small DG system sharing a common distribution transformer with several loads may raise the voltage on the secondary side, which is sufficient to cause high voltage at these customers [31]. This can happen if the location of the distribution transformer is at a point on the feeder where the primary voltage is near or above the fixed limits.

Impact of DG Integration on protection device

The presence of DG in a network disturbs the short circuit levels of the network. It creates an increase in the fault currents when compared to normal conditions at which no DG is connected in the network [30, 31]. The influence of DG to faults depends on some factors such as the generating capacity of the DG, the distance of the DG from the fault location, number of DG installed in one bus as well as in different bus and the type of DG. This could affect the protection device in the distribution network and safety of the distribution system. The fault contribution from a single small DG is not large, even so, there will be an increase in the fault current. In the case of many small units, or few large units, the short circuit levels can be altered enough to cause miss coordination between protective devices, like fuses or relays. This could affect the reliability and security of the distribution arrangement. If the DG is located between the utility substation and the fault, a decrease in fault current from the utility substation may be observed. This reduction needs to be examined for minimum tripping or coordination problems. On the other hand, if the DG source (or combined DG sources) is strong compared to the utility substation source, it may have a noteworthy impact on the fault current coming from the utility substation. This may cause fail to trip, consecutive tripping, or coordination problems [32].

The nature of the DG also disturbs the short circuit levels. The highest paying DG to faults is the *synchronous generator*. During the first few cycles its contribution is equal to the induction generator and self-excited synchronous generator, while after the first few rounds the synchronous generator is the most fault current contributing DG type. The DG type that contributes the least quantity of fault current is the inverter interfaced DG type, in some inverter types the fault contribution continues for less than one cycle. Even though a few cycles are a short time, it may be extensive enough to influence fuse breaker coordination and breaker duties in some bags [14].

Impact of DG Integration on Voltage Stability

Voltage stability refers to the capability of a power system to maintain steady state voltage at all buses in the system after being exposed to a disturbance. Voltage stability is classified into steady state and dynamic involving minor and huge disturbances respectively. It is also classified into steady state and transient voltage instability, according to the time range of the occurrence of the singularities. Voltage stability worries stable load action, and acceptable voltage stages all over the system buses. A power system is said to have go in a state of voltage variability when a disturbance causes a progressive and uncontrollable decline in voltage [33].

Under dangerous loading conditions in convinced industrial areas, radial distribution system experiences unexpected voltage collapse due to low value of voltage stability index at most of its nodes . Voltage constancy analysis often needs examination of lots of system states and many contingency situations. For this reason the method based on steady state analysis is more possible, and it can also provide worldwide insight of the voltage reactive power problems.

In general, the inability of the system to supply the required demand leads to voltage instability (Voltage collapse) [33]. Integration of DG renders a group of advantages, such as, economic, environmental and technical. The location and size of DG has the main consequence on voltage constancy of the system. Due to considerable costs, the DGs must be allocated suitably with optimal capacity to improve the system performance such as to reduce the system loss, improve the voltage profile while maintaining the system stability [33]. The problem of DG arrangement has recently received much care by power system researchers. The consequence of DG capacity and location on voltage stability analysis of radial distribution system is examined in this thesis.

2.5.2. Environmental Impact of DG Integration

After so many years of discussions and negotiations about sustainable development, the world‘s climate and its biodiversity are still deteriorating [28]. Environmental issues are prime concern for any countries due to increasing global warming and its negative impact over human being. Due to global warming our weather has changed and it becoming disaster for human life. Often DG technologies are described as more environmental friendly than centralized generation. Keen public awareness of the environmental impacts of electric power generation and efforts to mitigate climate change are crucial to DG renaissance.

Unfortunately some distributed generation technologies could, if fully deployed, significantly contribute to present environmental problems. Therefore, the technologies that can be used for distributed generation cannot be described in general as environmental friendly. But regarding the main current environmental issue, the increased greenhouse effect, all DG technologies lead to significantly lower emissions than coal-based technologies [29]. On the contrary, in the case of the so called “zero emission” generation systems, though direct emission due to combustion is zero, indirect emissions linked to construction, maintenance and dismantling have to be considered. This is the case with nuclear power plants, windmills, photovoltaic generators, hydroelectric power plants and power plants using biomass.

From the fuel utilization point of view, smaller distributed generation plants generally are less efficient than larger central plants of the same type. Only when operating in a CHP mode, they may conserve primary energy compared to the separate generation of electricity and heat in best available technology (BAT)-electric-power plants and high-efficiency boilers [28]

2.5.3. Commercial and Regulatory Impact of DG Integration

Commercial Impact of DG Integration

Active administration of distribution networks can permit noteworthy increases in the amount of DG that can be connected to the present networks. Although the cost related with the process of active distribution networks is still to be recognized, it is expected that the benefits are likely to considerably compensate the cost of its implementation. In order to support the growth of active distribution networks and excerpt consistent benefits associated with relating increased amount of DG, new commercial schedules need to be developed.

Regulatory Impact of DG Integration

In the absenteeism of a clear policy and related regulatory instruments on the conduct of DG, it is very unlikely that this type of generation is going to thrive. The explanations for this are partly past and connected to the way distribution networks have been developed and operated as passive networks. In order to foster the compulsory changes, there is a clear need to grow and articulate suitable policies that care the integration of DG into distribution networks [28].

2.6. Literature Review

This topic explains the detailed literature study on integration of DG to the distribution networks with their impacts related to my problems faced in the distribution substation with respective solutions. The information was gathered from several sources such as books, journals and websites. Each reference used is explained in detail as follows.

- **In Kuri et al M. R. Haghifam, H. Falaghi and O. P. Malik.** [34] Genetic algorithms are used to place the generation to reduce the losses, costs and network interruption and the rating of the generator to maximize. Also Generation is located in single units at individual buses, while disregarding the interdependence of the buses and the network purification that can result improper DG placement.
- **In El-Khattam et. al.** [35] uses a heuristic approach to determine the optimal DG size and site for an investment point of view. Once again short circuit restrictions are not considered and its focus on the objective purpose on optimal asset rather than maximizing renewable energy.

- **Liu, J., Salama** [35] have examined the impact of distributed resources on the transmission network in terms of influence issues.
- **Wang C, Nehrir MH.** [36] Has presented a new approach for finding the location and capacity of distributed generation in distribution network, with multiple generation sources and minimizing power losses and generation costs. The planned method has considered at first place the siting problem by reducing the search space. To this end, a modest and estimated formulation of the mixed integer nonlinear programming has been planned. The results of the planned relaxed mixed integer nonlinear programming have condensed the search space considerably. Regarding to the size problem, a generalization for one generator unit reducing the power loss has been advanced for multiple generators, and has been extended to include the power loss and generation costs, resulting in a system of nonlinear equations. The simulation results have exposed established the good compromise between the efficiency and computational efforts of the proposed method but it ignores the interdependence of the buses and the network purification also that can result improper DG placement.
- **Al Abri RS, El-Saadany EF, Atwa YM.** [37] Has dealt with the problems related to the integration of distributed energy resources (DERs) into the distribution grid. Indeed, as i have earlier illustrated, the large diffusion of DERs in the distribution network, which has not been conceived to support it, are causing numerous technical as well as, in view of the expansion of the energy market, also regulatory problems. But in this paper it is not consider grading to the protection system of the distribution when the distributed generation penetration highly increase.
- **Borges CLT, Falcao DM.** [38] proposed a new index to obtain the optimal location and size of DG unit, in order to reduce losses and enhance voltage stability considering load variations. To resolve this optimization problem, PSO algorithm has been presented and used. To verify the results of the PSO algorithm and this algorithm connected the DG at different buss. Due to this this paper also not consider interdependence of the buses and the network sterilization that gives improper DG placement.
- **Hatziargyriou, N. et al.** [39] proposes an analytical expression to calculate the optimal size and an effective procedure to identify the corresponding optimal place for DG placement for minimalizing the total power losses in primary distribution systems. The analytical expression and the procedure are based on the exact loss formula. The consequence of size and location of DG with respect to loss in the network is also examined in detail. The proposed procedure was tested and authenticated in

three distribution test systems with changing size and difficulty. Results found from the proposed procedure are compared with that of the exhaustive load flows and loss sensitivity process. Results show that the loss sensitivity issue based approach may not principal to the best location for loss reduction. But this paper also objectives to maximize the capacity and in order to reduce line loss, line loading and to improve voltage profile i.e. not consider the impact of increasing DG penetration on the protection devices.

In summary, different researchers have spent much time in explaining the integration of DG with distribution network expansion planning to reduce power loss, to improve voltage profile, to reduce line loading when the demand increase and to maximize the power capacity. For more than one single unit they have been placed a distributed generation at different buses. Placing the DG at different busses could result in improper DG placement due to interdependence of the buses and the network sterilization. They have focused on maximizing the power capacity without considering the impact of power protection devices. However, this thesis work uses voltage sensitivity index analytical method for the appropriate placement and capacity of DG. Assigning DG at the proper capacity and location can improve voltage profile, provide good voltage stability, and reduce power loss and line loading when it increases the load demand. In addition, by implementing fast over current relays and making them to coordinate the impact of over current relay will be reduced and also when the DG capacity increase with demand the over current relay can be upgraded by setting the time interval.

CHAPTER THREE

INTEGRATION ISSUES OF DG IN DISTRIBUTION NETWORK EXPANSION PLANNING

3.1. Introduction

This chapter covers the distributed generation integration with a distribution network expansion planning and the impacts of DG in protection devices, among that demand forecasting techniques, expansion planning with DG, appropriate placement and sizing of DG methodology and impact of DG on the protection device of the distribution network. The protection of distribution system without and with consideration of distributed generation integration (DG) is involved. The overview of some of the distribution system protection devices and how to implement, coordination and grading of the overcurrent protective relays are included in this topic.

3.2. Peak Demand Forecasting Techniques

To cover this eventuality it is essential to develop a demand forecasting technique that is appropriate and suitable to the objectives of the forecast. No technique can be considered incorrect for demand forecasting. The technique adopted will depend on the time frame under consideration, the size of the system and the plant available. In other words, the type of demand forecast technique adopted should fall in line with the requirements of the study. There are four main demand forecasting techniques

- Intuitive based demand forecasting.
- Extrapolation based demand forecast.
- End-user demand forecast.
- Econometric demand forecasting.

A general overview of each of the four main methods is detailed in the sub-sections below.

3.2.1.Intuitive Demand Forecasting Techniques

The term intuitive forecasting can be used to define methods which rely mostly on experience and quick calculations using simple expectations (i.e. the use of the immediate past performance and an assumption that the rates of change will continue unaltered in the future).

The intuitive load forecast should not be entirely reduced, as it is after all in the contextual of reviewers' minds when they appraise other peoples' demand forecasts. In some cases, the lack of available data may make intuitive forecasting the only possible option. The forecast may be appropriate for minor progresses, isolated systems and minor island utilities.

An alternative approach, but still within the intuitive forecasting outline, would be to apply a development factor that is obtained for a country with similar economic faces. Indeed, it may be beneficial to compare load forecasts with the performance of a similar system in another part of the world at a similar stage of development. This will chiefly be the case where (i) there is slight statistical information presented on past loads, such as in new areas of source, (ii) data errors that cannot be simply corrected, or, (iii) it becomes essential to forecast on the results of direct query and demographic and economic figures. Such forecasting is no more than deduction, but the results can be used to cross check on forecasts prepared by more scientific approaches. Where a new system of forecasting is to be ready, it is often cooperative to make a comparison of the intuitive forecasts ready in the past and subsequent performance.

3.2.2.Extrapolation Demand Forecasting Techniques

Extrapolation methods look at past trends in energy and power demand over time and, extend them into the coming. Any time sequence may be rotten into three elements:

- Tendency
- Periodic variation
- Serial dependence (auto-regression)

The Tendency is defined as "the long-term average growing and may be experimental in some way as an average rise in a time series". Superimposed on this may be a seasonal disparity. Periodic in this sense is defined as "a cyclic variable that has unevenly the same beginning and end values for a given dated of time (similar to the properties of a sine wave)". Such disparities may be seen over a 24 hour period, a weekly period, an annual period, or even a longer period. Finally, there may be a addiction between successive values. For instance, if the value in the earlier period was high, the value in the current period may be in height. Such behavior could relate to the random use of batch dispensation equipment. This interdependency is known as auto-regression.

3.2.3.End user Demand Forecasting Techniques

End user demand forecast modeling attractions on many utility forecasting approaches. The individual characteristic of end user demonstrating is the detailed report of how energy is used. Such models usually begin by agreeing uses for which energy is eventually required, such as heating water, cooling buildings and cooking food. The model then defines, via exact equations and secretarial identities, the types of energy-using equipment that businesses and households have, and how much energy is used by each type of equipment to gratify the programmed levels of end use energy needed. A large amount of study data and data are needed by such a model. By summing up the units of equipment times the average energy used by each session of equipment, total energy demand by fuel type is exposed. Multiplying types of equipment by average use standards is just an accounting outline, but even so, it can produce insights into the way energy is used now and in the coming. Optimization end user models are a step outside secretarial end-user models. By agreeing an objective function (such as minimizing cost) and classifying both the unit costs of using energy in the given procedures and the restraints to the system, the secretarial end user model can be transformed into a device that will predict how customers will act (assuming that their objective function is properly specified), given the molds about costs and constraints. End user models are often linked to econometric models.

End user models are often frailest in predicting customers' fuel use choices. With the accessible data, they can easily describe where the energy is presence used and for what purposes but, without a theory to clarify selections, they are limited in their aptitude to predict the future. The ideal end user model (which is rarely achieved) would, for example, not only tell us the usual watts of lighting energy in homes, and how this amount has changed over time, but also what caused households and/or housing operators to make these changes.

End user forecasting can be extremely accurate, particularly for green field growths, and for forecasts of residential demand. A delay of end user demand forecasting is load density based forecasting, in which the extreme load in any area is based upon the surface area engaged by each consumer type and a power density (i.e. watts per square meter) associated with that consumer type. This can be particularly useful for distribution arrangement. End user forecasts also include developments in segments such as industry and agriculture where feasting patterns can be recognized for, say, cement production or water pumping.

3.2.4. Econometric Analysis Demand Forecasting Techniques

This session of model, like the time sequence model (extrapolation), uses past data to predict the future. Econometric analysis however, attempts to go beyond time series models by explanation the causes of the identified trends. Econometric models assume explicit causal relations between the dependent variable (either energy or power) and independent variables (either financial), scientific (e.g. number and type of applications; industrial processes), demographic (e.g. population).

Assuming these relations are true it should then be possible to regulate the past relationships between electrical demand and such, individual income, the price of electricity etc. Future stages of these economic variables are then prediction and used as inputs to govern future levels of consumption. One benefit of econometric forecasting is the ease with which in height and low situation load forecasts can be resultant and the logical basis on which they can be formed. This simply requires variations in the forecast rate of the input variables, e.g. economic development and electricity price. A quicker economic development will produce a higher load forecast whilst the burden of price increases will decrease forecast levels of energy demand. Econometric showing would be preferred to time sequence analysis. Even if both techniques could predict changes in demand with equal accuracy, the econometric model would be more respected since it might help in sympathetic why variations in demand were occurring.

3.3. Distribution System Peak Demand Forecasting

In this thesis extrapolation least square technique is used to forecast for the next coming 10 years. I have collect past peak load request for five year from Adwa distribution system as shown in table 3.1 below. From the principle of regression theory to forecast the load for the coming ten years by using the past peak load demand in table 3.1 data. Its attitude is that any function y = f(x) can be tailored to a set of points (X_1, Y_1), (X_2, Y_2) so to minimize the sum of errors squared at each point, i.e.

$$\sum_{i=1}^{n}\{Y_i - f(x)\}^2 = \text{minimum} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Table 3. 1 Historical peak load data from 2013-2018 G.C

Substation Name	**Year**	**2013/14**	**2014/15**	**2015/16**	**2016/17**	**2017/18**
Adwa	Peak load (MW)	28.5	30.7	33.5	35.5	37.3
	Peak load (MVA)	31.31	33.73	36.81	39.01	40.98

Among the dissimilar typical regression curves used in power arrangement forecasting the simple least square line is used for forecasting the load. So the line y = $a_0 + a_1x$ is close-fitting to the sets of points (X_1, Y_1), (X_2, Y_2) ….. (X_n, Y_n).

$$\varepsilon^2 = \sum_{i=1}^{n}[Y_i - (a_0 + a_1 X_i)]^2 = \text{minimum} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.2)$$

Partial differentiation with respect to the regressions coefficients (a_0 and a_1) is made and the equations set to zero to obtain the minimum error criterion. This gives us a set of simultaneous equations in a_0 and a_1:

$$Na_0 + a_1\sum X_i = \sum Y_i \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.3)$$

$$a_0\sum X_i + a_1\sum X_i^2 = \sum X_i Y_I \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.4)$$

Table 3. 2 All input historical data of the analysis

Year	Peak demand (MW)	X_i	$P_{Di} = \frac{\text{peak Demand}}{10}$	$Y_i = \ln P_{Di}$	$X_i Y_i$	x_i^2
2013/14	28.5	-2	2.85	1.04	-2.094	4
2014/15	30.7	-1	3.07	1.12	-1.12	1
2015/16	**33.5**	**0**	**3.35**	**1.2**	**0**	**0**
2016/17	35.5	1	3.55	1.26	1.26	1
2017/18	37.3	2	3.73	1.32	2.64	4
		$\sum X_i$=0		$\sum Y_i$= 5.94	$\sum X_i Y_i$= 0.686	$\sum X_i^2$=10

a_0	a1
1.188	0.0686

Finally, the values in Table 3-2 are used to regulate the load of the certain area up to 2028G.C. The forecasting is done using equation 3-5 (a) and (b) shown below by considering 2015/16 as a reference year and all the above equations are formulated using Matlab M. file see in **appendix A** in detail.

$$Y=a_0+a_1.x_i \quad \text{……………………………………………………………….. 3.5 (a)}$$

$$P_n=10e^Y \quad \text{……………………………………………………………… 3.5 (b)}$$

Table 3. 3 Power demand forecast for of Adwa sub city from 2018-2028

Year	Forecasted Demand in (MW)	Forecasted Demand in (MVA)
2018/19	40.02	43.97
2019/20	42.94	47.18
2020/21	46.05	50.6
2021/22	49.41	54.29
2022/23	53.0.	58.25
2023/24	56.83	62.45
2024/25	61.01	67.04
2025/26	65.54	72.02
2026/27	70.2	77.14
2027/28	75.31	82.74

From Table 3.3 the power demand at Adwa substation after 10 years will be approximately 75.31MW of active power and 82.74MVA reactive power by seeing a power factor of 0.91 and the load growth at each year increases by 7.07% and also the overall demand after Y-1 years will be approximate as shown in the Table3.3. Therefore the expansion planning of Adwa substation will be combined with DG by attention of the load growth of the substation in each year.

3.4. Integration of DG with Distribution Networks Expansion Planning

When viewed from a total system point of view, a power system typically exhibitions a smooth, unceasing development trend in annual peak load. Local area load development usually occurs only over a few years, from a near zero to a value near to the final ‘saturated’ peak load. Examines are carried out a numerous load growth and associated supply conditions. The operation and planning of distribution systems under such conditions is explored. Long term planning contains principle to grow a policy to meet the utility’s long term power sending needs, usually minimizing cost by bring about an best balance between capital accompaniments and operative cost. It mainly requires that the distribution planner evaluation every alternative, including load forecasts, revenue restraints, and a lot of other factors. However, the long term planning has to encounter the basic restrictions or supplies for the distribution network. In this thesis, the proposed method speeches a solution for long term planning while assembly the proposed constraints of the network.

There are many factors touching DG action such as DG technologies, types, working modes, and others. DGs connected in the distribution network can be owned, operated and measured by either an electric utility or a customer. If DG is utility owned, then its operating cycle is well known as is controlled by the utility. The shape of the DG operating cycle depends on the purpose of its use in the distribution network. For example internal combustion engines, small fuel cell units limited working time units for peak load shaving. Micro-turbines and fuel cells they have partial working time units to share the load with dissimilar functioning cycles and micro-turbines and large fuel cells works on base load power supply. In addition, renewable energy units unnatural by environmental situations such as wind speed and sunlight respectively.

On the other hand, customer owned DG working cycles are not known to the workers unless there is a unit commitment promise between the electric utility and the client, which is not very likely. Thus, small customer kept DG working cycles are considered to be random processes from the point of view of the electric utility. The utility has no regulator over their process. This chance changes the planning and process problem from a deterministic unruly to a non-deterministic one.

Appropriate Capacity and Placement of DG Guidelines

There are no clear guidelines on selecting 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:

- To improve the system voltage profile and reduce power losses, it is sufficient to use DG units of total capacity in the range of 10-50% of the total feeder demand. While more DG capacity can be used to reduce the substation loading.
- For reliability purposes in case of islanding, the DG size must be greater than double the required island load. 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. Therefore, as the DG size increases, the protection devices, fuses, re-closers and relays settings have to be readjusted and/or upgraded.

There are no clear restrictions also on the location of DG units in the distribution network, as there are no geographical limitations as in the case of substations. If the DG is customer owned then the utility has no control on its location because it is placed at the customer's site. If the DG is utility owned then the choice of its location is based on several electrical factors such as:

- Reducing maximum system losses and improving system voltage profile and augmenting substations capacities
- Providing the required additional load demand
- To placed DG units on feeders do not impact the existing protective device coordination and ratings.

3.5. Rapid Load Growth

This thesis presents an approach to obtain the suitable DG capacity that meets a rapid development of system load. An initial set of candidate DGs are designated. DG capacity obligation varies across buses because of the load distribution design, differences in total primary distribution feeder parameters and hence losses in each feeder being different. The situation is to obtain the DG power condition at these selected buses, and also the power condition from the station source while and load demand rises. Therefore, in the Adwa distribution network, it is assumed that

- DG is joined to the buses of the proposed network.
- Peak load demand rises by 7.07% every year over a period of 10 years

In table 3.3, it is shown that while the load demand increases quickly each year, so the required power from DG units rises at each bus in a linear manner with load demand increase. Also the DG units are able to light the demand requirements when the demand is extremely growth the distribution system needs to advancement in order to draw power from the substation with reliable service. Thereafter, the power drawn from the substation rises expressively.

3.6. Methodology for Appropriate capacity and Location of DG

The addition of DG modifies the characteristics of the distribution system. A number of technical restrictions and issues arise which are impacted by the amount of DG that is connected. These issues are: distribution constraints, thermal constraint, voltage rise, capacity of transformer and power loss.

Voltage Drop Constraints: The voltage drop constraints depend on the voltage guideline limits on each year.

Line Transmission Constraints: The maximum power transmission between bus-i and bus-j in every year.

Distribution Substation Capacity Constraint: Every plan year, the total power delivered by the substation over the outward distribution feeders from that bus must be within the substation size limit. The rated current of the lines and the transformer rating must not be surpassed.

Capacity of Transformer

The extent of generation related minus the lowest load must not surpass the transformer rating at the higher voltage. If there is some existing generation then this must be withdrawn from the total. The result is the outstanding size available below that station. In the case of two parallel transformers, the size is taken as the rating of the smaller transformer plus the lowest load. The restriction is expressed formally as in equation (3.6)

$$P_{Tx} < P_{TrafoCap} \quad \text{……………………………………………. (3.6)}$$

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

Thermal Constraint

The rated current of the lines could not be exceeded than the current comes from the generator. It is given by below equation (3.7).

$$I_I < I_i^{rated} \quad \text{……………………………………...……… (3.7)}$$

where I_I is the current flowing from generator i to bus i and I_i^{rated} is the maximum rated current for the line among each generator and its corresponding bus. Under normal voltage and power factor conditions, the rated current of the line can be interpreted directly into a rated active power for that line.

Voltage rise

If DG is related to a network unit, it will modification the active and reactive power flows and therefore change the voltage dropped across the lines. It has been shown that DG mains to an important voltage rise at the end of the long, high impedance lines. A rise in voltage occurs if there is low demand and high generation, which leads to a bulky quantity of power flow along casually loaded lines with high impedance. Losses are a significant thought when designing and planning the distribution system. Losses are unescapable on any network; however, the amount can differ importantly contingent on the design of the network. With the overview of distributed generation, the network is existence used in a different way with more variable and bidirectional power flows. The level of losses is carefully linked to the power flows. Losses are a function of the square of the current, i.e. a repetition in current results in losses being quadrupled. Therefore the provision of DG and the altered power flows that result may have a noteworthy influence on losses and may provide an chance to advance them.

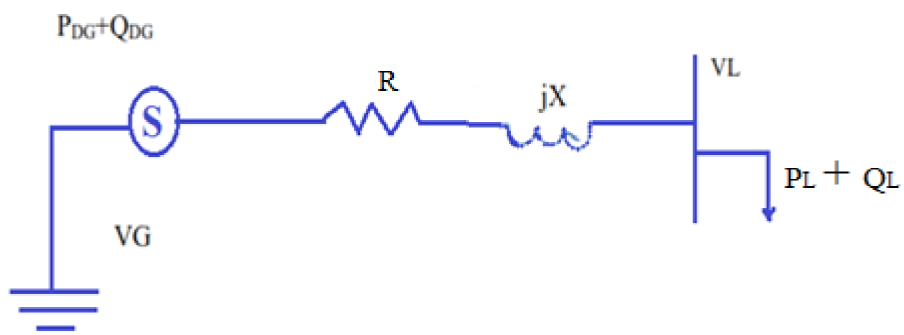

Figure 3. 1 Voltage rise effect

$$VG = VL + \frac{RPL+XQL}{VL} + j\frac{XPL-RQL}{VL} \quad \ldots\ldots 3.8$$

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 correspondingly. Thus it can be seen that the generator voltage will be the load/bus voltage plus some value associated to the impedance of the line and the power flows lengthways that line. It is obvious that the larger impedance and power flow the larger the voltage rise. The improved active power flows on the distribution network have a large influence on the voltage level because the resistive elements of the lines on distribution systems are higher than other lines. The voltage must be retained within standard limits at each bus as given by equation (3.9).

$$V_{mini} < V_i < V_{maxi} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.9)$$

where V_{mini} & V_{maxi} refer to the minimum and maximum voltage limits at the ith bus.

Losses

Losses are significant deliberation when scheming and planning the distribution network. Losses are unescapable on any network; however, the total can differ greatly depending on the design of the network. With the overview of distributed generation, the network is being used in a different way with more variable and bidirectional power flows. The level of losses is carefully related to the power flows. Losses are function of the square of the current, i.e. a doubling in current consequences in losses being quadrupled. Therefore the distribution of DG and the altered power flows that result may have a noteworthy influence on losses and may provide an chance to improve them.

The allocation of DG problem consists of three significant steps. Via Choice of Load flow analysis technique, finding suitable capacity and selection of the suitable location of DG.

3.6.1. Load Flow Analysis

Conventional NR and Gauss-Seidel (GS) methods may become unproductive in the study of distribution systems, due to the unusual features of distribution networks, i.e. radial structure, high R/X ratio and unbalanced loads, etc. These features make the distribution systems power flow calculation different and rather difficult to analyze as related to the transmission systems. Several methods are available to carry out the study of balanced and unbalanced radial distribution systems and can be divided into two classes. The type of methods is applied by proper adjustment of existing methods such as NR and GS methods. On the other hand, based on backward and forward sweep procedures using Kirchhoff's laws.

3.6.2. Appropriate Power Capacity of DG

For determining the best capacity of DG to be located at the best place, for radial distribution system, by considering maximum power reduction. So the total real power losses of the network can be determined by summing all power losses value at each branch of the network with n nodes. The power loss reduction (PLR) as loss saving based on total real power loss in radial distribution scheme as;

$$P_{losses} = \sum_{i=1}^{n}(I_i^2)R_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (3.10)$$

where I_i is the current magnitude of each branch and R is the resistance of the i^{th} branch. The current I_i is resolute by load flow using the Newton-Raphson method. This loss in equation (3.10) is the loss without DG and for single DG placement at bus m, the active current produced by the DG is I_{DG}.Therefore I_i^{new} the new active current of the i^{th} branch is given by.

$$I_i^{new} = I_i + I_{DG}C_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.11)$$

where C is 1 if branch i has DG joined to its bus and is zero if no DG connection to the bus. The new power loss with penetration of the DG into the network is given by:

$$P_{Losses-new=} \sum_{i=1}^{n}(I_i^{new})^2 R_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \quad (3.12)$$

$$P_{Losses-new=} \sum_{i=1}^{n}(I_i^2 R_i + 2I_iC_i\, I_{DG}R_i + C_i\, I_{DG}^2 R_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

The power losses reduction (PLR) which is the objective for placement is resolute by subtracting equation (3.10) from equation (3.13) which is the difference between power losses before DG and after DG connection as expressed below:

$$PLR_i = P_{Losses-new} - P_{Losses} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

$$PLR_i = \sum_{i=1}^{n}(\, 2I_iC_i\, I_{DG} + C_i\, I_{DG}^2)R_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.15)$$

The DG current that gives maximum PLR value can be determined by distinguishing equation (3.15) with respect to I_{DG} and equate to zero as:

$$\frac{dPLR_i}{dI_{DG}} = 2\sum_{i=1}^{n}(\, I_iC_i + I_{DG}C_i\,)R_i = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \quad (3.16)$$

Hence, the current for maximum power loss reduction value is:-

$$I_{DGi} = \frac{\sum_{i=1}^{n} C_i\, I_i R_i}{\sum_{i=1}^{n} R_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.17)$$

The importance is to place the DG at a place that will give extreme loss reduction. This process is repeated for all the buses in order to find the highest power loss discount value as the DG units are singly located. Assuming no noteworthy change in voltage as DG units are connected, the consistent DG size. The DG size from equation (3.18) must be located at bus m for maximum power loss reduction.

$$P_{DGi} = I_{DG} V_i Pf \quad \text{…………………………..………………………………………….. (3.18)}$$

3.6.3. Appropriate Location of DG using TENVDI

In order to limit the solution space to one bus, tail end nodes are first known by viewing the distribution network topology. By penetrating DG at each node at a time, the *Tail End Nodes Voltage Deviation Index (TENVDI)* is calculated using equation (3.19). When DG is connected at bus m, TENVDI for bus m is defined as

$$\text{TENVDI}_m = \sum_{i=1}^{TEN} \frac{(V_{nominal} - V_i)^2}{TEN} \quad \text{……………………………………… (3.19)}$$

where, ‘m’ corresponds to element of tail end node when connected DG at the bus, V_{nominal} is taken as 1.0 P.u V_{i} is voltage at the bus in p.u see in **appendix E** in detail how to find the voltage of at each bus when it connect DG at the buss m from the result of DigSILENT software. To determine the capacity that gives maximum power loss reduction and the location that gives minimum voltage variations of DG, the following steps are taken as follow:

Step 1: Run the distribution load flow using DigSILENT Power Factory 15.1.7 simulation software to determine total active and reactive power losses, branch currents and voltage profile at each bus.

Step 2: calculate the current of DG that gives maximum system losses redaction by keeping the power factor of DG and bus voltage as a constant, after that multiplying the voltage and the current of DG with the power factor to give the appropriate size of DG.

Step 3: Connect the selected capacity of DG value at the respective node and using TENVDI equation find the bus voltage sensitivity indices at the respective node then rank the sensitivities of all nodes in ascending order to form priority list.

Step 4: Select the bus with the lowest priority and place DG at that bus then it gives maximum power losses reduction and less variation of voltage at the buss is taken as appropriate capacity at appropriate location of the distribution feeder.

Step 5: End

3.7. Protection in Distribution System

Integration of the distributed generation to the power system may be made at the usage voltage level, at the utility distribution system level, or at the utility transmission level. Where the connection is made depends on the location and size of the generation plant. Rules will vary slightly by jurisdiction, but are generally similar from one location to another. Connections at the usage level and on the distribution system level are smaller installations and are also known as "distributed generation" because the generation is dispersed and intermingled with the connected loads [40].

If there is a risk of operation as an unintended island, the utility may require additional protective equipment such as communications equipment to facilitate transfer trip or it must to upgrade the protective device. Such means are avoided if possible because of the increase of the system cost, but may be required for the safe operation of the distribution system.

3.7.1.Fuse

A fuse is a short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuit. Fuse is the simplest current interrupting device for protection against excessive currents. Since the invention of first fuse by Edison, several improvements have been made and now-a-days, a variety of fuses are available. Some fuses also incorporate means for extinguishing the arc that appears when the fuse element melts. In general, fuses may be classified into (i) Low voltages fuses (ii) High voltage fuses.

It is a usual practice to provide isolating switches in series with fuses where it is necessary to permit fuses to be replaced or rewired with safety. If such means of isolation are not available, the fuses must be so shielded as to protect the user against accidental contact with the live metal when the fuse carrier is being inserted or removed.

A fuse model, irrespectively of the group to be represented, has to duplicate the following stages [31]: current sensing, arc initiation, arc interruption, current interruption. The melting period, during which temperature rises, begins with the fault and finishes when the fuse melts; during this stage the current flows without limitation. The melting mechanism of a fuse depends on the magnitude and the duration of the current, as well as on the electrical properties of the fuse. This characteristic is shown in the so called time-current curve provided by manufacturers.

3.7.2. Reclosers

A reclosers is a device with the ability to detect phase and phase-to-ground overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to re-energize the line. If the fault that originated the operation still exists, then the reclose will stay open after a preset number of operations, thus isolating the faulted section from the rest of the system. In an overhead distribution network between 75 to 95 per cent of the faults are of a temporary in nature and last, at the most, for a few cycles or seconds. Thus, the reclose, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults. Typically, recloses are designed to have up to three open-close operations and, after these, a final open operation to lock out the sequence. One further closing operation by manual means is usually allowed. The counting mechanisms register operations of the phase or ground-fault units which can also be initiated by externally controlled devices when appropriate communication means are available [31].

The operating time/current characteristic curves of recloses normally incorporate two curves, one fast and one delayed. The first one, known as fast or instantaneous, is mainly used to save lateral fuses under temporary fault conditions. The second curve is known as slow or time -delay, and its main purpose is to delay reclose tripping, and allow fuses to blow under permanent fault conditions [40].

3.7.3. Sectionalizer

A sectionalizer is a device that automatically isolates faulted sections of a distribution circuit once an upstream breaker or recluse has interrupted the fault current and is usually installed downstream of a recluse. Since sectionalizer have no capacity to break fault current, they must be used with a back-up device that has fault current breaking capacity. Sectionalizes count the number of operations of the recluse during fault conditions. After a preselected number of recluse openings, and, sectionalizes opens and isolates the faulty section of line. This permits the recluse to close and re-establish supplies to those areas free of faults. If the fault is temporary, the operating mechanism of sectionalizes is reset [31].

A sectionalizer does not have a current/time operating characteristic, and can be used between two protective devices whose operating curves are very close and where an additional step in coordination is not practicable. Sectionalizers can be used in place of fuses or between a reclosing device and a fuse.

3.7.4. Circuit Breakers Overcurrent Relay

The main characteristics of protective devices presently used by utilities to protect radial distribution systems are presented. A circuit breaker is an automatic interrupting device which is capable of breaking and reclosing a circuit under all possible conditions, and based up on arc extinguishing methods can be classified as (oil, air, SF6,vacuum) circuit breakers [30].

The performance of a breaker during an opening operation is governed by the characteristics of the overcurrent relay. Concerning the relay operating characteristics, overcurrent relays may be classified into three major groups: definite current, definite time, and inverse time.

(i) Definite Current Relay

This type of characteristic makes the relay to operate instantaneously when the current reaches a predetermined value. This feature is shown in Fig. 3.2.

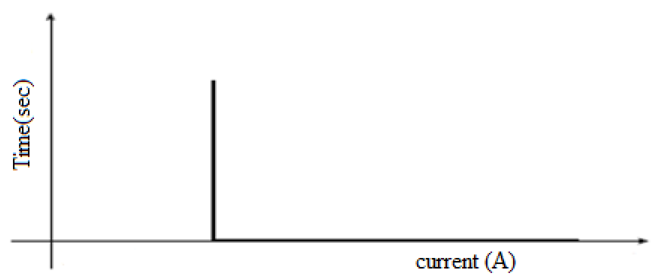

Figure 3. 2 Definite current characteristic of over-current relays

The setting is chosen in such a way that the relay, which is installed at the furthest substation away from the source, will operate for a small current value and the relay operating currents are gradually increased at each substation, moving towards the source. Therefore, the furthest relay from the source operates first disconnecting the load in the neighboring site of the fault [30].

(ii) Definite Time Relay

In this type of relay the setting may be changed to deal with different levels of current by using different operating times. The settings can be attuned in such a way that the relay which is installed at the furthest substation away from the source is tripped in the shortest time, and the remaining relays are tripped in sequence having longer time delays, moving back in the direction of the source [30]. Definite time protection is more selective as the operating time can be set in fixed steps. However, faults close to the source which results in higher currents may be cleared in a relatively long time.

This relay allow setting of two independent parameters, the pickup setting and the time dial setting. The pickup setting define the current value necessary to operate the relay and the time dial sets the exact timing of the relay operation. In Figure 3.3, the characteristic curve of a definite time relay is shown [30].

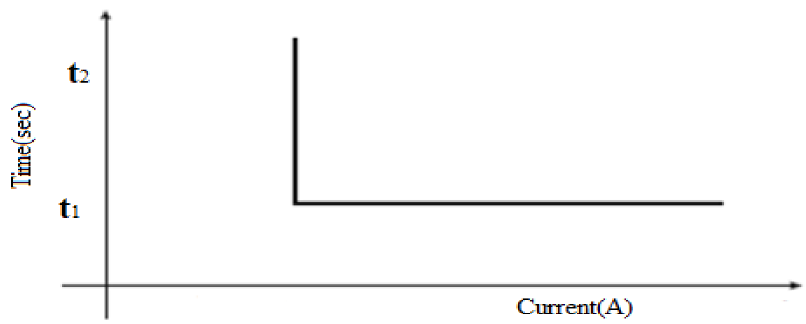

Figure 3. 3 Definite time characteristic of overcurrent relays

(iii) Inverse Time Relays

These relays operate in a time that is inversely proportional to the fault current. Inverse time relays have the advantage of that shorter tripping times can be achieved without risking the protection selectivity. These relays are classified based on their characteristic curves, which define the speed of operation as inverse, very inverse or extremely inverse. Their defining curve shape is shown in Figure 3.4.

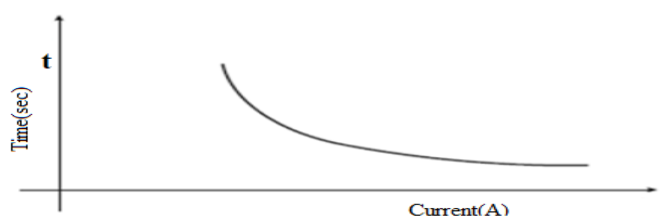

Figure 3. 4 Inverse time/ current characteristic of over-current relays

3.8. Protection of Distribution Network in the Presence of DG

Distribution level protection is created on a time overcurrent project. Such design contains choice of equipment and locations or upgrade, location of equipment, and coordination of devices to clear faults with as slight influence on customers as possible. One of the main imports is to stop further harm to utility equipment. Secondary goals are consistency and power intermission. Distribution protection also there must be edge between protective devices: an upstream device should work for a fault if the downstream protector fails [31].

Although over current protection is humble and works very well with radial networks, it owns several features that have to be accounted for when choosing the appropriate protective devices [15].

- Any distribution protective device has an associated maximum distance (also known as reach) for which the device mechanism. For large distribution networks, in which the lengthiest distance from a load node to the substation can be several lots of kilometers, it is incredible to protect the entire network from the substation. Therefore, numerous protective devices have to be connected along the network.
- A extremely reliable performance of a distribution network can be attained by installing different types of protective devices. The coordination between protective devices is additional significant aspect, and this is chiefly difficult in distribution networks given the amount of dissimilar protective devices (breaker-relay sets, reclosers, fuses, sectionalizers). This coordination is not informal and not always likely. In addition, it can be altered by the attendance of distributed generators.
- There are some transients, such as transformer inrush and cold load unplanned, which can look throughout system energization. The currents associated to these transients can be of the same order that the pickup current of many distribution protective devices. This feature has to be careful when selecting the time-current typical of those devices that can be affected.

DG penetration at the distribution close may have positive and negative influences. For DG to have a positive benefit, it must be at least appropriately synchronized with the system working philosophy and feeder design. The joining of DG unit raises few tests related with protection system. And also when the penetration of DG increase at each year incessantly and the size of DG highly rise on the protection device so you must have set or advancement the protection device.

3.8.1.Islanding due to Presence of DG

Islanding is a major interconnection subject. Islanding is a condition where one or more generators (or group of distributed generators) continues to invigorate a portion of the utility system that has been detached from the main utility system and function separately from the rest of the utility system. Although DG may positively function in island if there is a equilibrium between load and generation, islanded operation is not generally allowed for some major reasons [30].

- The utility wants to restore the outage circuits and this is complex by having islanded generators with utility loads. Since automatic reclosing is generally used to restore power to customers, having islanded generators confuses both automatic and physical switching, which requires harmonizing the generator
- Power quality generally cannot be preserved by the islanded generators within an satisfactory level, and this can result in injury to the customer equipment.
- Personnel security is another reason, since upkeep and reparation crews may reason that there is no voltage when in fact some generation is still active and consecutively in islanded mode.

The formation of an accidental island is a problem for the utility business. Moreover, islanding only can be reinforced if the generator(s) can self-excited and preserve the load in the islanded area. This parting could be due to process of an upstream breaker, fuse, or reflex sectionalizing switch.

The most mutual means to prevent islanding is to use *voltage and frequency relays* on the generator to trip whenever either of these two strictures journey outside a designated window. This form of islanding protection is known as inactive defense. It prevents islanding in most cases because when a segment of the distribution system and one or more generators discrete together, the output of the generator will not competition the load on the island. For synchronous or induction generators, the voltage and frequency will meaning, which will trip the relays in a small time. Typically the relays are set to a close-fitting frequency range of perhaps ±1 Hz or even ±0.5 Hz. Voltage relays have a bit broader window to allow for typical voltage rule excursions on the circuit (±5 to 10% is typical) [30].

3.8.2.Protection Relay due to Presence of DG

The effect of DG in a distribution scheme may influence the fault detection and protection of the circuit breakers in the distribution system. It mainly depends upon the protection, designing and place of DG in a distribution system. Typical likely problem may be protection blinding, understanding tripping and loss of coordination between the protection schemes.

The other influence of the presence of DG in the distribution network is a reduction of influence protective devices. If a large generation unit or numerous small ones are related to the distribution network, the fault current seen by the feeder protection relay may be condensed, which can lead to improper operation for the over current relays. When the DG is fixed in the network (figure 3.5), its influence to the fault current $\mathbf{I_k}$ reduces the current seen by the feeder relay $\mathbf{I_1}$**.** If the unit is larger, the fault current injected will be higher, as well as, if the unit is located near to the grid, higher $\mathbf{I_1}$ will be seen, as the impedance of the line will be lower. Therefore, it can be also decided that the influence increases with the size of the unit and the distance between the feeder and the DG system [41]. This is the disappointment of the protection devices to cover its intended protective distance, as the DG causes a decrease in the compassion of these protection devices, thus declining the distance protected. The relay $\boldsymbol{R_1}$ is set up to refuge the whole line, but the presence of the DG will cause a change in the seeming impedance of the line which causes a miss-estimation of $\boldsymbol{R_1}$. When the fault is at the end of the line the impedance of the line will be advanced and $\boldsymbol{R_1}$ will not be able to intellect the fault due to the less fault current from the grid.

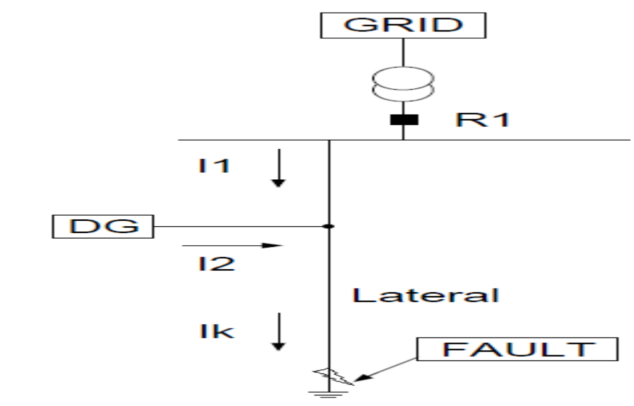

Figure 3. 5 Reduction of reach of protective devices

3.8.3. Mal-trip and Fail-to-trip due to presence of DG

Integration of DG in the radial arrangement causes a amount of problems with the protective device coordination. For example in the outdated system, when using over current protection, it is likely to assume that the fault current only flows in one course, whilst, this is not always true if there are DG fixed in the network. The feeder protective relays are usually modest overcurrent relays and often with an involuntary reclosing relay. With the addition of distributed generation on the feeders, several difficulties can occur: the new generation foundation will increase the available short-circuit current on the power system, reach of present relays may be pretentious, current flow from unforeseen directions may cause miss operation of existing relays and unintended islanding operation may occur [41].

The protection systems can fail to operate in two dissimilar ways: by unnecessarily removing a non-faulted module **(**mal-trip**)**; or by not removing a faulted component **(**fail-to-trip). A mal-trip is the case in which one of the protection devices trips in its place of the other. This elegant occurs due to one protective device noticing the fault while it is outside of its protection region and trips before the required tripping device. In contrast, fail to trip occurs for downstream faults. In this case the fault current is principally formed by the current created from the DG unit. Consequently, the fault current through the over current protection device can be below the location for which it was designed and the protection remnants passive, hence the faulty feeder will not be detached [41].

Reflect the distribution substation shown in Figure 3.6 with the distributed generation DG_1 installed on one of the feeders [41]. For a fault wherever on the distribution feeder, the extra generation provides additional fault current that may result in present equipment on the power system being subjected to faults in excess of their ability to interject. For example, for the fault at location F_1, the fuse must interrupt not only the fault current from the substation bus, but also the extra fault current complete from the DG source. If the fuse had been designated based on the fault current influence from the substation alone, it may be incompetently rated for the total fault current when the DG contribution is included. As a result, it may be necessary to substitute the fuse with a device having higher ratings before allowing the DG to be brought on line. All other apparatus's must be likewise evaluated.

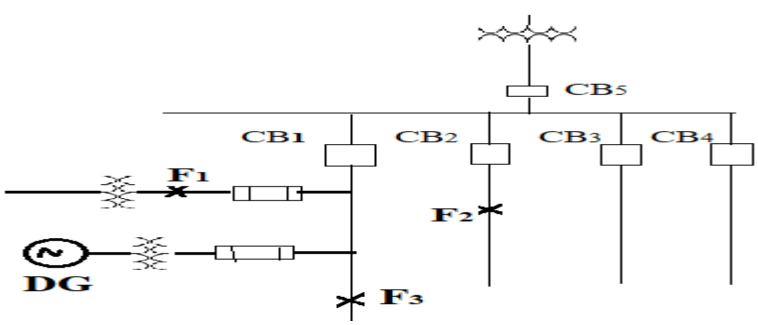

Figure 3. 6 Mal trip and fail to trip

For the fault at location F_2 in Figure 3.6, the generator DG will also donate fault current. In addition to the option of exceeding the fault interrupting capacity of the circuit breakers, the back feedstuff of fault current may result in redundant trip (mal-trip) of the feeder circuit breaker CB_1 if the current influence from DG exceeds the trip location of the feeder overcurrent relays. For a fault at site F_3, the DG will donate fault current, and the infeed from the DG source may consequence in a reduced fault contribution from the substation bus. Thus, the aptitude of the feeder relays to detect this fault may be abridged (protection blinding).

3.9. Coordination of Overcurrent Protection Relay

Transmission and distribution systems are unprotected to overcurrent flow into their basics. In an electric power system, overcurrent or extra current is a situation where a superior than intended electric current exists over a conductor, leading to excessive generation of heat, and the danger of fire or damage to equipment and also for dependability and security of power supply in distribution system, the network must be defend. So overcurrent protection relay is the main protection technique used for distribution feeders. Over current relays are used in the protection of distribution circuits. Overcurrent relay is a detecting relay which operates when the current surpasses a predetermined value. Over current relays use time current features in their processes. It is widely recognized that in radial networks, discrimination of fault protection is attained through time-current coordination of overcurrent relays. This is because for a specific fault, all the relays linked in the radial feeder see the fault current but are made to operate at different times. The coordination is founded on the fact that the relay neighboring to the fault (primary relay) sees the largest fault current than those farther away (backup relays) [41]. Choice of different time current characteristics in the relay settings is the means of realizing coordination.

The coordination of the protective relay is done throughout the process of system design based on the short circuit current level. It is the process of determining the sequence of relay operation for various faults in power system so that the faulted section is cleared in minimum time. For the proper relay coordination it is necessary to determine two crucial relay settings. These are:

- Pickup or plug setting (tap setting)
- Time dial or time multiplier setting

Plug setting (PS) or current setting for each relay is determined by two limits; the minimum and the maximum fault current. The minimum and maximum fault current is determined from load flow study. In the coordination problem of over current relays, the objective is to control the time setting multiplier (TSM) and plug setting multiplier (PSM) of each relay. This least current in the relay coil at which relay starts to work is called Pick-up Current. If the current through the relay coil is less than the pick-up value then relay won't function. On contrary, if the current over the relay coil is more than the Pickup current, relay will function, so that the overall operating time of the primary relays is minimized properly. In order to determine current transformer (CT) ratio, the cable nominal current must be identified. Here the DigSILENT 15.1.7 Power Factory allows 80% of supreme load current (cable rated current) as a cable loading limit. Therefore, this needs a current transformer (CT) whose ratio products 1A secondary current for the maximum load (primary current):

$$\text{current transformer(CT)ratio} = \frac{\text{Cable rating current}*80\%}{\text{Secondary transformer current}} = \frac{N_1}{N_2} \qquad (3.20)$$

where:

N_1 = Primary winding of current transformer

N_2 = Secondary winding of current transformer

The minimum value of current (minimum fault current) for which the relay must operate should be at least 1.5 times pickup, but not very much more [4].

$$I_{pprim} = \frac{I_{fmin\ prim}}{1.5} \qquad (3.21)$$

$$I_{psec} = I_{pprim} * \frac{N_2}{N_1} * PS \qquad (3.22)$$

$$I_{fmaxsec} = I_{fmax} * \frac{N_2}{N_1} \qquad (3.23)$$

$$PSM = \frac{I_{fmaxsec}}{I_{psec}} = \frac{\text{measured second CT current}}{\text{pick current}} \qquad (3.24)$$

where:

I_{pprim} = Primary pick up current

$I_{fminprim}$ = Minimum primary fault current

I_{psec} = Secondary pick up current

$I_{Fmaxsec}$ = Maximum secondary fault current

I_{fmax} = Maximum fault current

Plug Setting Multiplier (PSM) is definite as the ratio of fault current to the pick-up current of the relay. The three approaches used for a correct relay coordination are judgement by time, discrimination by current and discrimination both by current and time. The time setting multiplier (time dial) can be originate as:

$$t = 0.14 \frac{TD}{((PSM)^{0.02} - 1)} \qquad (3.25)$$

$$\mathrm{TD} = \mathrm{t}\frac{((\mathrm{PSM})^{0.02}-1)}{0.14} \quad \ldots\ldots (3.26)$$

where

t = Operation time of the relay

TD = Time dial

3.9.1.Overcurrent Relay Coordination Procedure

Correct overcurrent relay request requires knowledge of the fault current that can flow in each part of the network. Since large scale examinations are normally unviable, system analysis must be used.

The relay settings are first strong-minded to give the shortest operating times at maximum fault levels and then checked to see if operation will also be satisfactory at the minimum fault current predictable. It is always sensible to plot the curves of relays and other defense devices, such as fuses, that are to operate in series, on a common scale. It is usually more suitable to use a scale corresponding to the current expected at the lowest voltage base, or to use the main voltage base. The alternatives are a common MVA base or a separate current scale for each system voltage. The basic rules for precise relay coordination can generally be specified as follows:

RULE #1

Whenever possible, use relays with the same functioning characteristic in series with each other.

RULE #2

Make sure that the relay farthest from the foundation has current settings equal to or less than the relays behind it, that is, that the primary current obligatory to operate the relay in front is always equal to or less than the primary current compulsory to operate the relay behind it.

3.9.2. Principles of Grading Overcurrent Protection Relay

Among the various likely methods used to achieve correct relay organization are those using either time or overcurrent, or a combination of both. The shared aim of all three methods is to give correct discrimination. That is to say, each one must isolate only the faulty unit of the power system network, sendoff the rest of the system undisturbed.

1. **Discrimination by Time**

In this method, an suitable time setting is given to each of the relays regulatory the circuit breakers in a power system to ensure that the breaker adjacent to the fault unlocks first. A simple radial distribution system is shown in Figure 3.7, to illustrate the principle.

Overcurrent protection is provided at B, C, D and E, that is, at the infeed end of each unit of the power system. Each protection unit includes a definite-time delay overcurrent relay in which the process of the current sensitive component simply initiates the time delay element. Providing the setting of the current element is below the fault current value, this component plays no part in the achievement of discrimination. For this reason, the relay is sometimes labeled as a 'self-governing definite-time delay relay', since its working time is for practical purposes independent of the close of overcurrent. It is the time delay element, therefore, which provides the means of taste. The relay at B is set at the straight time delay possible to allow the fuse to setback for a fault at A on the secondary side of the transformer. After the time delay has died, the relay output contact closes to trip the circuit breaker. The relay at C has a time delay setting equal to t_1 seconds, and likewise for the relays at D and E. If a fault occurs at F, the relay at B will operate in t seconds and the following operation of the circuit breaker at B will clear the fault earlier the relays at C, D and E have time to operate. The time intermission t_1 between each relay time setting must be long enough to safeguard that the upstream relays do not function before the circuit breaker at the fault location has tripped and cleared the fault.

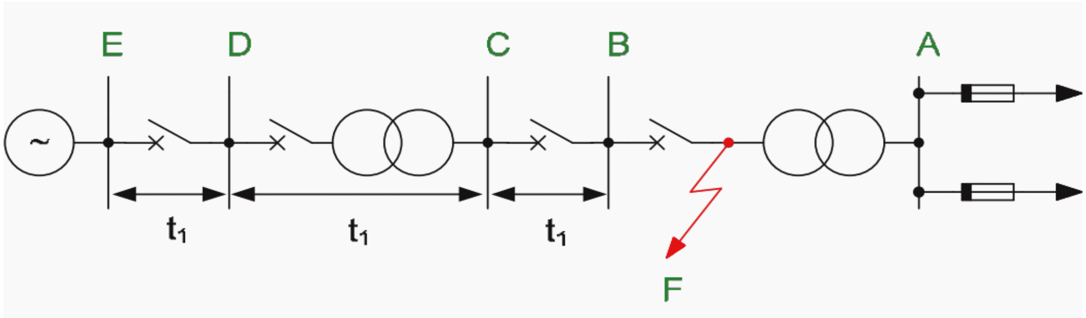

Figure 3. 7 Radial system with time discrimination.

The main disadvantage of this method of taste is that the longest fault clearance time occurs for faults in the section neighboring to the power source, where the fault level is highest.

2. **Discrimination by Current**

Discrimination by current trusts on the fact that the fault current varies with the location of the fault because of the difference in impedance values between the source and the fault. Hence, characteristically, the relays regulatory the various circuit breakers are set to operate at suitably tapered values of current such that only the relay nearest to the fault trips its breaker.

Discrimination by current is not a applied proposition for correct grading between the circuit breakers at C and B. because, the problem changes appreciably when there is important impedance between the two circuit breakers concerned.

3. **Discrimination by both Time and Current**

Each of the two methods labelled above has a fundamental disadvantage. In the case of discrimination by time alone, the disadvantage is due to the fact that the more plain faults are vacant in the longest operating time. On the other hand, discrimination by current can be applied only where there is appreciable impedance between the two circuit breakers concerned.

It is because of the boundaries imposed by the independent use of either time or current grading that the inverse time overcurrent relay characteristic has evolved. With this typical, the time of process is inversely relative to the fault current level and the actual characteristic is a function of both 'time' and 'current' settings.

Characteristics for different settings

For a large disparity in fault current between the two ends of the feeder, faster working times can be attained by the relays nearest to the source, where the fault level is the uppermost. So, by using both functions the disadvantages of coordination by time or current alone are overcome. Variations of current/time tripping features of relays will be discussed in some of the coming practical sections.

CHAPTER FOUR

MODELING, SIMULATION STUDIES AND ANALYSIS OF RESULTS

4.1. Introduction

This chapter covers modeling, simulation studies and analysis of results of Adwa distribution substation using DigSILENT Power Factory 15.1.7 simulation software. The integration of DG with distribution network expansion planning in a radial distribution system with proper sizing and placement is discussed. In addition, it inspects the impact of DG integration on distribution network expansion planning specially on voltage profile, power loss and voltage stability without increment the load and with increment the load. Moreover, due to presence of DG it implements, coordination and grading of fast protection relay when it is increase the capacity of DG has been investigated in detail.

4.2. Modeling of Distribution Network

Adwa substation is located in central zone of Tigray region which is at a distance of 1006 km from Addis Ababa, the capital city of Ethiopia. As defined in the statement problem Adwa substation is selected as a case study area and the substation is connect to the organized system (ICS), Adwa substation has been providing the power from main grid that is an interconnected system. The substation is supplied from two incoming line Tekeze hydropower substation and Adigrat substation with two lines with voltage rate of 132kV. These two 132kV received lines are connected to the single bus bars at Adwa substation and this single bus bar connected to two transformers. Those transformers are three winding transformer with the capacity of 40/20/20 MVA and voltage rating of 132/66/15kV respectively, and those transformer gives to one transformer with voltage rating of 66kV and this transformer step down to 33kV. And also this substation feeds to Aksum substation with 132kV voltage rating directly.

The overall model of the Adwa distribution substation network using DigSILENT Power Factory 15.1.7 software is shown in the figure 4.1. The network is shaped by seven radial feeders, namely KO1, KO2, KO3, KO4 and KO5 with 15 kV voltage rating outgoing feeder and P_1 and p_2 are the other outgoing feeders with 33kV voltage rating. In this substation 202 low voltage distribution transformers are connected with total capacity of 52.705MVA. The distribution system feeders serves mostly residential, commercial, and industrial customers. Each load connected to the main distribution line is also considered as one load point. The study has a power flow analysis of the 33kV, 15 kV and 0.4 kV network.

The substation supplies 48,997 customers and the utility owns the distribution lines at 33, 15 and 0.4 kV levels. The 33kV, and 15 kV system consists of overhead and underground transmission lines and cables, but 0.4 kV systems are considered a load's connected point. In general one-line diagram of the 33kV and 15 kV grid is as shown in the figure 4-1 below.

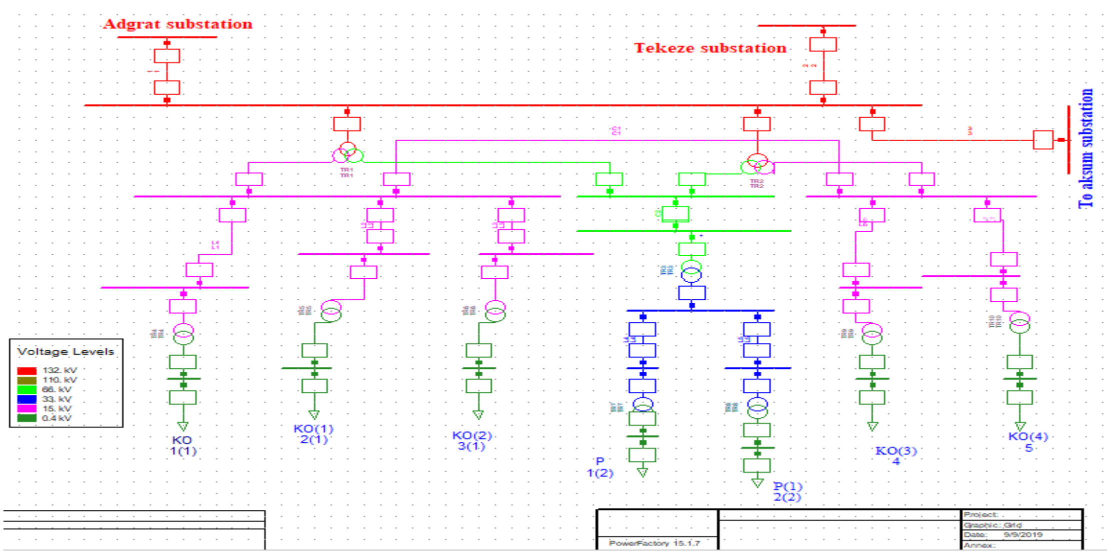

Figure: 4. 1 Single line diagram of Adwa distribution substation using DigSILENT

4.3. Existing Distribution Network Data

All necessary data like the size of the substation, peak load, type of faults, and all interruption data of medium voltage (15kV and 33kV) outgoing feeders are composed from the substation noted data. The table below indicates total number of transformers and their capacity found in Adwa substation as summarized.

Table 4. 1 Transformer data of Adwa substation

Substation	No Transformer	Voltage Level(kV)	Capacity(MVA)
Adwa	2	132/66/15	40/20/20
	1	66/33	9/6

The existing system loadings of all low voltage transformers, number of customers connected to the base system, type and size of each feeders, are tabulated in Table 4.2 and figure 4.2.

Table 4. 2 Existing system data of the outgoing feeder

Outgoing Feeders	**Overhead lines** **type and size**	**Line length in km**	**Voltage level (kV)**	**No of transformer**	**Total Transformer capacity (kVA)**	**Total no. customers**
KO1	AAC 3 X 95	37.12	15	107	24295	24219
KO2	AAC 3 X 95	47.5	15	29	5140	7244
KO3	AAC 3 X 95	6.2	15	14	15350	5833
KO4	AAC 3 X 95	38.8	15	17	525	1627
KO5	AAC 3 X 95	39.7	15	26	6225	5354
P1	AAC 3 X 50	56	33	5	575	1811
P2	AAC 3 X 50	61.8	33	4	800	1909
Total	**………**	**298**	**……..**	**202**	**52705**	**48997**

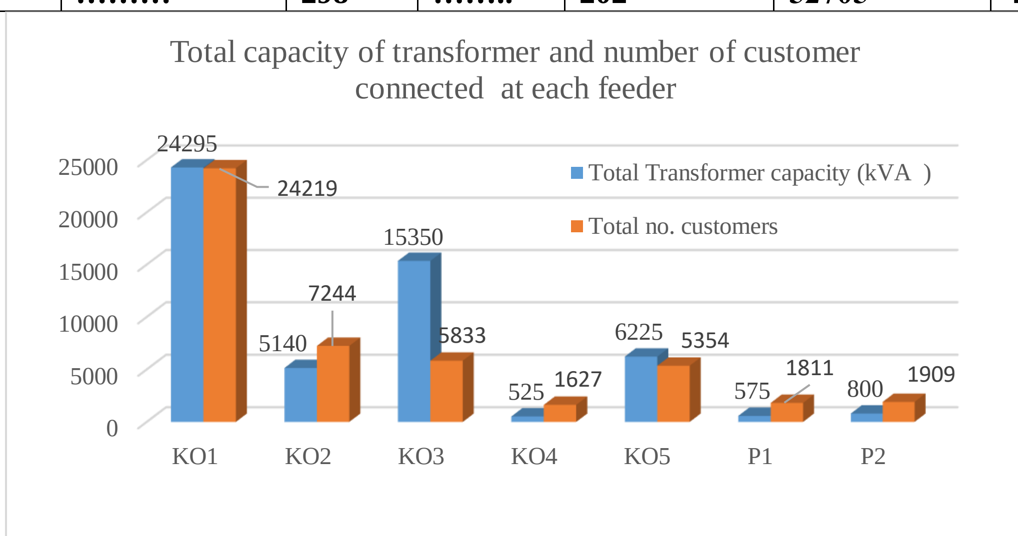

Figure: 4. 2 Total capacity of transformer and number of customer's data of each feeder

4.3.1. Power Interruption Data

An interruption to service is the isolation of an electrical load from the system providing that load, resulting from an abnormality in that system. The irregularity in the system can either be a malfunction of a system component a fault or a system process due to conservation or repair. Interruptions independent from the cause are usually undesired, as they leave energy unserved and customers without service. Most of the time interruptions occur because of the system is reacting to a fault. A fault or short-circuit is defined by IEEE100-1992 as an irregular connection of relatively low impedance, whether made accidentally or intentionally between two points of different potential [42, 14]. Overloading earth fault and short circuits are the major cause of breaks in Adwa distribution system. These major faults are secret into two main categories, those are temporary and permanent faults. Temporary faults account for the majority of faults in distribution systems. Impermanent faults can occur for many details, but may include tree or animal contact and weather as the main donors of this fault. Temporary faults can be simply solved with a little or no intervention from the system itself. Many are self-clearing such as a branch or animal interaction which burn and fall off, conductors slapping together in severe wind or insulation flashover due to pollution and also lightning is also a temporary fault. Lightning arrester failure on the other hand, can become an enduring fault. Other temporary faults are merely cleared once a trip from the substation is delivered. Prompt reclosing de-energizes the line for a short duration of time, which permits the arc or interaction path to disappear, which in turn eliminates the fault path. Once the circuit is de-energized the system resumes normal operation. Permanent faults are those that cannot be resolved with reclosing action and will not self-clear. Equipment fault, cable failure and downed lines or persistent tree contact can all produce also permanent faults [42, 14]. The collected interruption data are abridged for one year representative yearly power interruption with whole frequency and duration interruption as shown below in Tables 4.3 and figure 4.3.

Table 4. 3: Frequency and Duration of Power Interruption in Adwa substation (01/12/2017-30/11/2018)

No	Feeders		TLP		M/V		Total fault		Total interruption	
			F	D	F	D	F	D	F(int/yr)	D(hr/yr)
1	132KV incoming feeders	IF1	27	12:33	….	….	…	..	27	12:33
		IF2	27	12:33	..	….	…	..	27	12:33
2	15KV outgoing feeders	KO1	27	12:33	420	214:21	440	480:39	987	1706:14
		KO2	27	12:33	345	147:49	401	38:10	773	478:39
		KO3	27	12:33	299	108:11	75	310:17	401	158:54
		KO4	27	12:33	98	72:23	102	184:45	227	269:40
		KO5	27	12:33	26	49:14	91	188:24	144	250:11
3	33KV outgoing feeders	P1	27	12:33	38	30:37	71	206:43	136	149:53
		P2	27	12:33	72	92:27	231	1036:3	330	1143:30

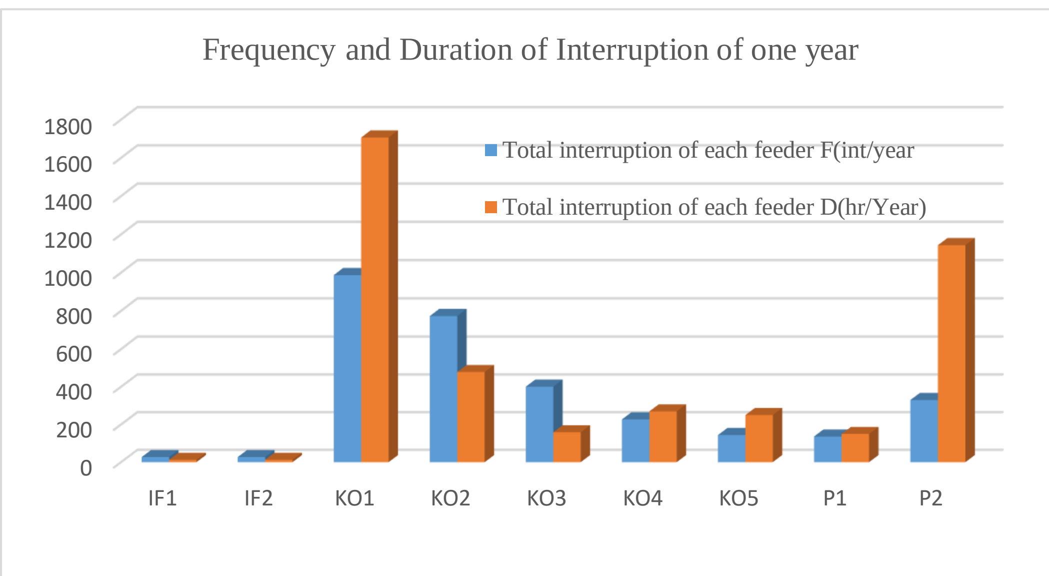

Figure: 4. 3 Frequency and Duration of Interruption for one year

4.3.2.Line Parameters of Distribution Feeders

Table 4. 4 Line parameters of the Feeder

Conductor type and size(mm^2)	R(20^0) (Ω/km)	X (20^0) (Ω/km)	Rated voltage (kV)	I_{Sc} (kA)	I_{Rated} (KA)	Earth fault current (I_e)
AAC95	0.3242	0.417	15	1.8	1.2	0.8

where:

R: Positive sequence resistance of conductor (Ω/km) at 20^0c

X: positive sequence reactance of conductor (Ω/km) at 20^0c

I_{Rated} **(kA)**: Thermal Limit

I_{sc} **(kA)**: short circuit capability

4.3.3. Distributed Generator Energy Source

The solar resource raw data are the average global horizontal radiation obtained from the National Aeronautics and Space Administration (NASA) website. On top of the solar resources data the latitude and longitude of Adwa would be used as an input and the time zone is another parameter to be set. The place is located at latitude: 414.164 N^0, longitude: 38.894 E^0, and elevation 1361m. Similar to the solar source data also the wind speed was taken from NASA website as shown in table 4.5.

Table 4. 5 Solar and wind speed sources of data taken from NASA website

Months	Solar radiation (kWh/m^2)				Wind speed(m/s)
	2015/1	**2016/17**	**2017/18**	**Average**	**2017/18**
January	6.11	5.81	5.63	5.58	4.5
February	6.39	6.11	6.39	6.3	4.5
March	6.85	6.55	6.67	6.63	4.5
April	6.95	7.5	6.67	7.04	4.3
May	7.02	6.5	6.67	6.71	3.6
June	6.91	6.41	5.94	6.42	4.9
July	6.28	5.72	5.28	5.76	5.4
August	5.58	5.48	5.62	6.3	5
September	6.39	6.67	5.84	6.3	4.1
October	6.1	6.42	6.23	6.26	3.1
November	5.71	5.84	6.01	5.82	3.6
December	5.94	5.84	5.84	5.87	4
Average	**6.272**				**4.3**

4.4. Selection of Appropriate Capacity and Location using DigSILENT

The distributed generators is selected for the case study were a synchronous generator which is available in DigSILENT Power Factory 15.1.7 software that can be used in thermal, hydro, solar, or wind power plants. The DG is modelled as a Turbo Series 1 of IEC909/IEC60909 machine type and the excitation system control mode is a constant power factor. Power factor control mode is aimed to maximizing the active power production. Also, it expect the DG from participating in the system frequency control. In consequence, unitary power factor operation is adopted. The loads are general load types modelled as constant impedance and do not contribute to the fault level.

In order to restrict the solution in this thesis work identified the outgoing feeders by entering the data to the distribution network topology in DigSILENT power factory software. The feeder was selected due to its highest power interruption and overloaded. Due to this KO_1 feeder was selected in order to integrate with DG, because the feeder is loaded and more power interruption is accord, when it compare from other outgoing feeder during the one year recorded data. [See in **appendix D** in detail the comparison of loading feeders in DigSILENT power factory software]. Then in order to integrate the DG at appropriate power capacity from the equation (3.17) and (3.18), I_{DG1} gets 0.931kA and its capacity is 12.7 MW and 3.3MW is selected as a reserve by considering 0.91 power factor of the distributed generation. After getting the appropriate DG capacity analytically in order to calculate the appropriate location at appropriate capacity using tail end nodal voltage deviation indexes (TENVDI) first it is must to know the voltage at each buses by penetrating the appropriate capacity of DG [see in **appendix E** in detail] and calculate the total deviation of the voltages of all tail end nodes of the network with respect to the nominal voltage. Then, when DG is inserted at each buss and if the bus gives the lowest value of TENVDI from the other bus feeder value so the appropriate placement of DG is at the lowest variation of TENVDI bus.

Table 4. 6 Variation of TENVDI by penetrating the DG at different bus

Bus no	BB1	BB16	BB19	BB25	BB34	BB43	BB50	BB55	BB70
Variation of TENVDI	0.0026	0.00295	0.00279	0.00232	0.00230	0.00225	0.00121	0.00193	0.00251

In order to be placed DG due to its lowest value of TENVDI from table 4.6 that is calculated using equation 3.19 in the section 3.6.3. Therefore, the lowest variation is at bus 50. After getting the appropriate DG location and capacity analytically, the capacity obtained are connects with the existing load at different bus and gives maximum power flow reduction at the selected bus as shown in figure 4.4, i.e. the penetration of DG at buss 50 it gives maximum power loss reduction when it compare with the other bus in the distribution network.

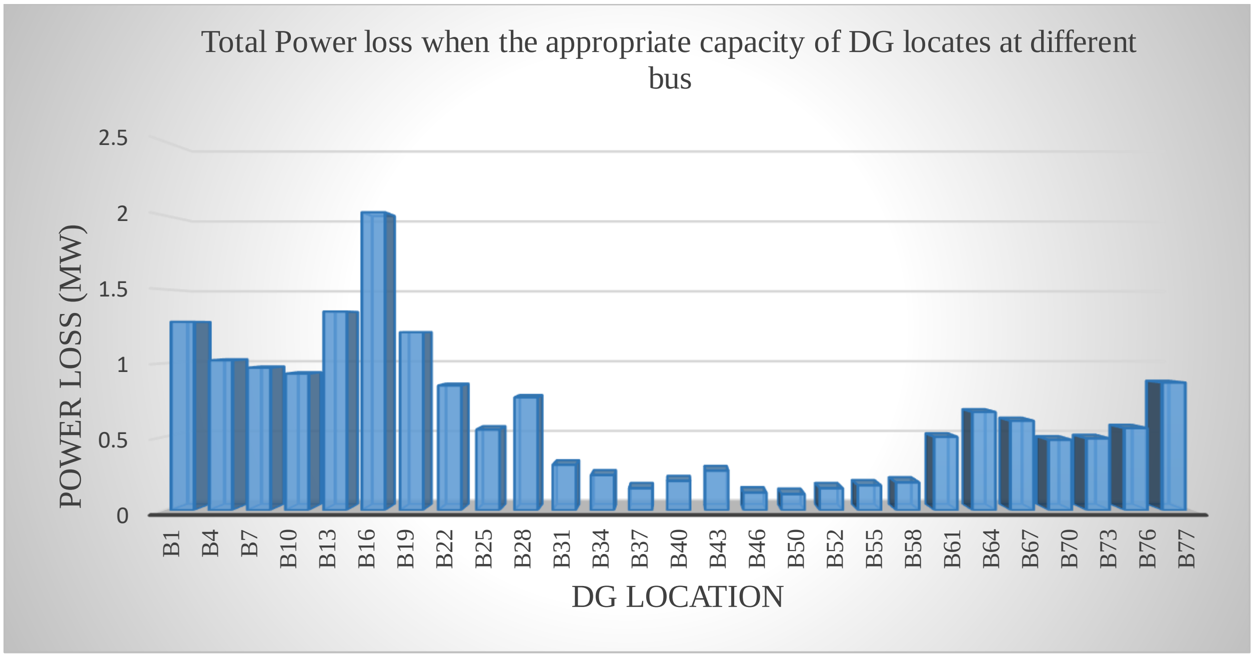

Figure: 4.4 Power loss when the appropriate capacity of DG locates at different bus

4.5. Distribution Network Simulation using DigSILENT

This simulation studies were carried out under three different conditions. Case I consider the load flow analysis without integration of DG (i.e. without change the existing system) while in Case II load flow analysis with an integration of DG is carried out and case III consider the load flow analysis when the capacity of DG increase with demand.

4.5.1. Distribution Network without Integration of DG

In this case, it has been seen the effect of power loss and voltage profile of the Adwa distribution system without any change to the existing system and also it investigates on line loading after one year by entering the forecasted data obtained from Adwa distribution system.

4.5.1.1. Line loading without Integration of DG

Load flow analysis is necessary to obtain how much the voltages, currents, and power (active and reactive) are flowing in the power system network under steady state conditions and also it provides power losses in the system, the voltage profile and the percentage of line loading. To investigate the DG on loading of line segments, after one year load flow analysis is made on case study radial distribution system modeled in DigSILENT Power Factory 15.1.7 software and the simulation result of loading of line segment before the integration of DG unit is over loaded from the next year. It can be seen the result of line loading from DigSILENT Power Factory the lines colored in red indicates that the line segment is overloaded from the next year show in figure 4.5, and the percentage of loading those lines is out of standard (i.e. same of result have above 100%). This range is the default in DigSILENT Power Factory 15.1.7 table 4.7 from the result box of DigSILENT Power Factory 15.1.7 shows for each line segment of the system separately [see in **appendix C1** in detail].

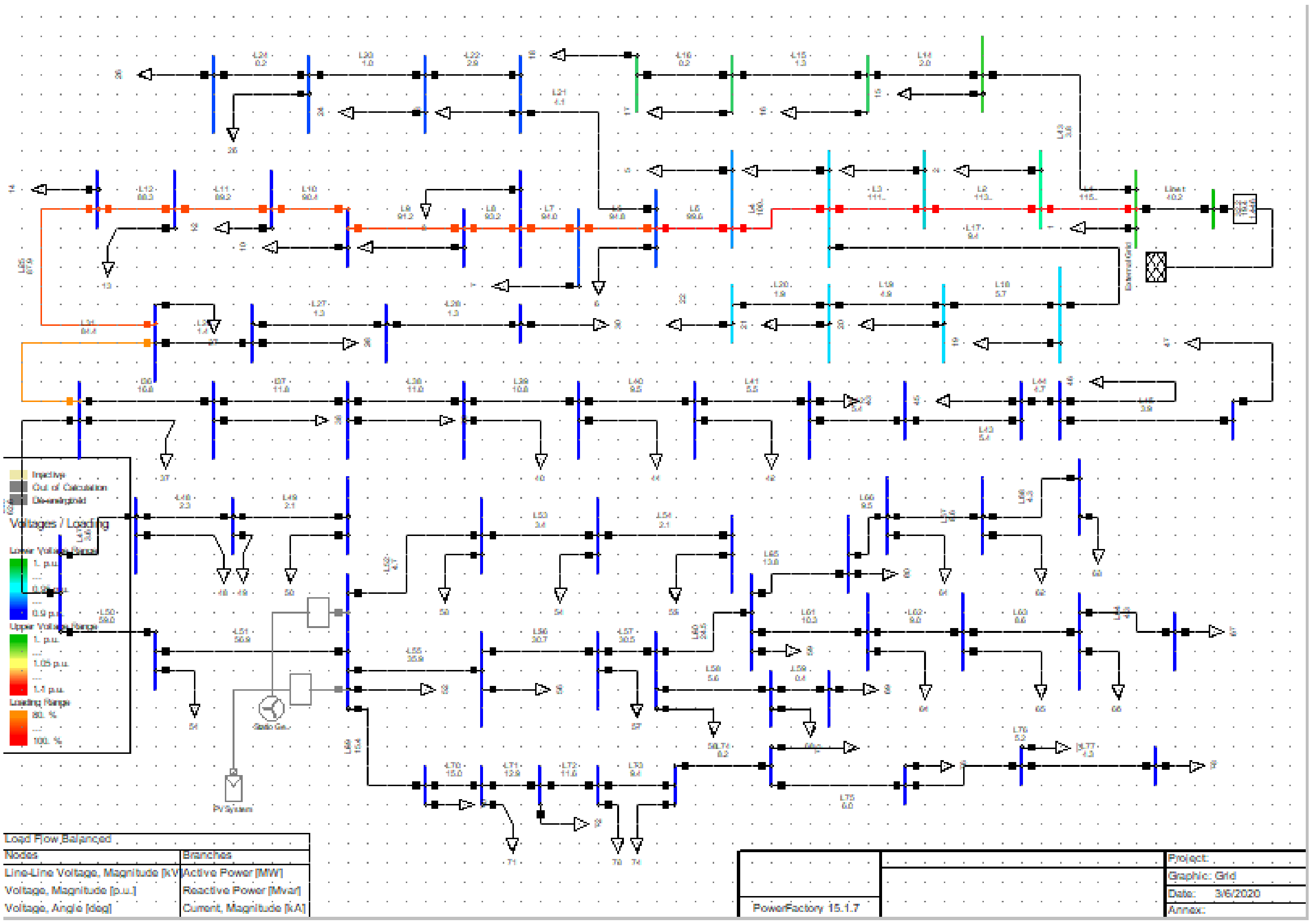

Figure: 4. 5 Line loading without integrating DG (after one year)

Table 4. 7 Percentage of line loading after one year without integrating DG

Line	Line loading % WODG	line	Line loading (%) WODG	Line	Line loading (%) WODG	line	Line loading (%) WODG
L1	114.96	L21	4.06	L41	5.51	L61	10.32
L2	113.14	L22	2.9	L42	5.42	L62	9.33
L3	111.29	L23	0.97	L43	5.42	L63	8.60
L4	99.99	L24	0.19	L44	4.65	L64	4.30
L5	99.61	L25	87.93	L45	3.64	L65	13.76
L6	64.79	L26	1.27	L46	62.63	L66	9.46
L7	94.01	L27	1.27	L47	3.61	L67	8.6
L8	93.22	L28	1.27	L48	2.33	L68	4.3
L9	91.22	L29	0.92	L49	2.12	L69	15.02
L10	90.41	L30	0.89	L50	59.02	L70	12.89
L11	89.18	L31	84.4	L51	56.9	L71	11.89
L12	88.55	L32	4.67	L52	4.71	L72	11.59
L13	3.79	L33	3.24	L53	3.43	L73	9.44
L14	1.99	L34	2.89	L54	2.16	L74	8.16
L15	1.27	L35	2.54	L55	35.89	L75	6.01
L16	0.18	L36	2.11	L56	30.74	L76	5.15
L17	9.4	L37	1.74	L57	30.53	L77	4.29
L18	5.67	L38	10.99	L58	5.58		
L19	4.91	L39	10.78	L59	0.43		
L20	1.89	L40	9.55	L60	24.51		

- WODG – With Out Distributed Generation

4.5.1.2. Total power loss without Integration of DG

In this case, it can be seen that the effect of power loss of the Adwa distribution system without any change to the existing system by entering the data obtained from the Adwa distribution system. During the base case load flow analysis of steady state condition, the total real and reactive power loss is determined as 2.06 MW and 2.95 MVAR respectively as show in figure 4.6 that have from the result of DigSILENT Power Factory 15.1.7 for total power loss without integrating DG.

```
|                |                                                       |   15.1.7    | Date:  8/13/2019           |
-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                  Grid Summary |
-----------------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence           |   Automatic Model Adaptation for Convergence           No    |
|    Automatic Tap Adjust of Transformers          No    |   Max. Acceptable Load Flow Error for                        |
|    Consider Reactive Power Limits                No    |      Nodes                                            1.00 kVA |
|                                                        |      Model Equations                                  0.10 %   |
-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------
| Grid: Grid                 System Stage: Grid          | Study Case: Study Case             | Annex:            / 1  |
-----------------------------------------------------------------------------------------------------------------------
| Grid: Grid                 Summary                                                                                 |
|                                                                                                                     |
| No. of Substations    0         No. of Busbars       73        No. of Terminals      0         No. of Lines          72 |
| No. of 2-w Trfs.      0         No. of 3-w Trfs.     0         No. of syn. Machines  0         No. of asyn.Machines  0  |
| No. of Loads         69         No. of Shunts        0         No. of SVS            0                                 |
|                                                                                                                     |
| Generation          =      0.00  MW          0.00  Mvar       0.00  MVA                                              |
| External Infeed     =     26.08  MW         15.25  Mvar      30.21  MVA                                              |
| Inter Grid Flow     =      0.00  MW          0.00  Mvar                                                              |
| Load P(U)           =     24.02  MW         12.29  Mvar      26.99  MVA                                              |
| Load P(Un)          =     24.03  MW         12.29  Mvar      26.99  MVA                                              |
| Load P(Un-U)        =      0.00  MW          0.00  Mvar                                                              |
| Motor Load          =      0.00  MW          0.00  Mvar       0.00  MVA                                              |
| Grid Losses         =      2.06  MW          2.95  Mvar                                                              |
| Line Charging       =                       -0.03  Mvar                                                              |
| Compensation ind.   =                        0.00  Mvar                                                              |
| Compensation cap.   =                        0.00  Mvar                                                              |
```

Figure: 4. 6 Power loss without DG integration

4.5.1.3. Voltage profile without Integration of DG

The voltage level of the distribution systems of requirement must be kept within a specific range, which is well defined in international standards and its common range is 1 ± 5% p.u. This range is the default in DigSILENT Power Factory 15.1.7 for the steady-state bus voltages. The investigation of the possible effects of DG on the voltage profile along the feeder entails, firstly, ascertaining the feeder voltage profile in the absence of a DG base case scenario. This necessitated the execution of a balanced and positive sequence load flow simulation of the distribution model. The result indicated that before the integration of DG the voltages at all buses were not within permissible limit. So the screenshot of the network model shows the steady state load flow analysis with the voltages at all buses were not acceptable range is shown in figure 4.7 and figure 4.8. The green color indicate that the voltage on that bus is within an allowable range that is above 0.95 p.u. During the base case load flow analysis, the minimum voltage magnitude which occur at bus 57 and 58 had been determined to be 0.866 p.u which is out of a specific range [see in the result of DigSILENT Power Factory 15.1.7 in **appendix B1** in detail].

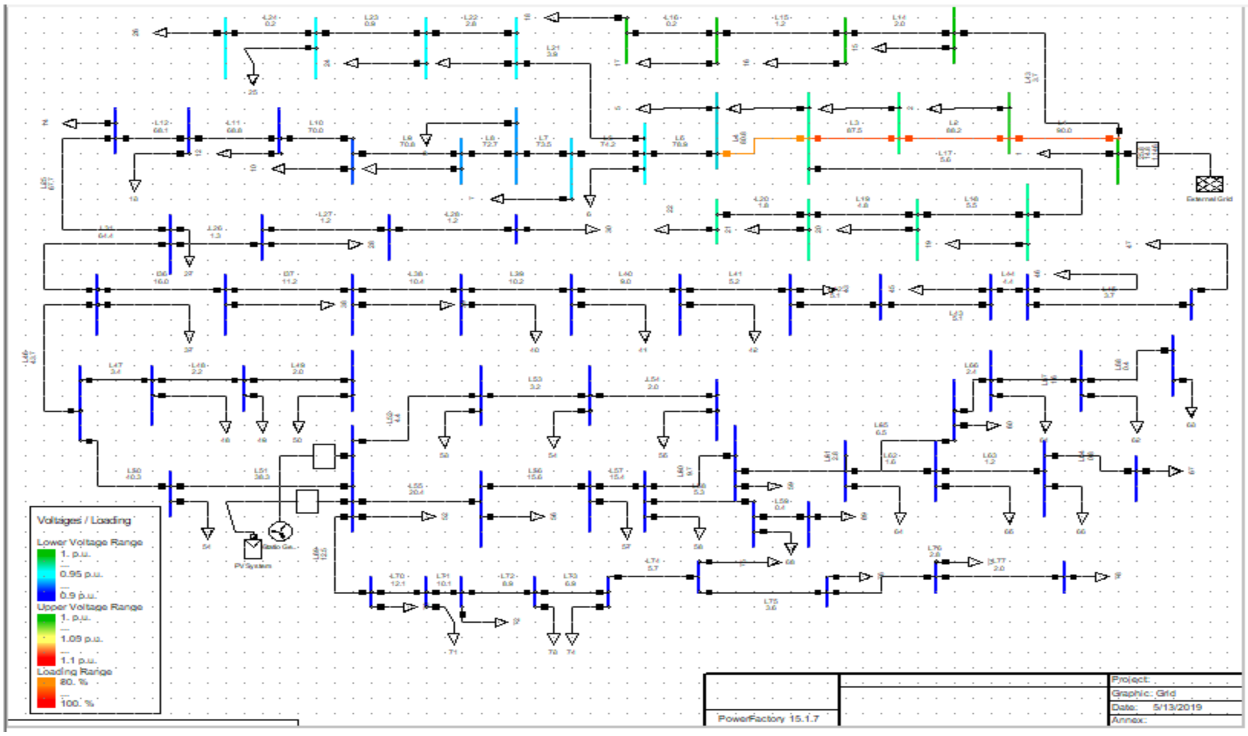

Figure: 4. 7 Voltage profile without DG integration

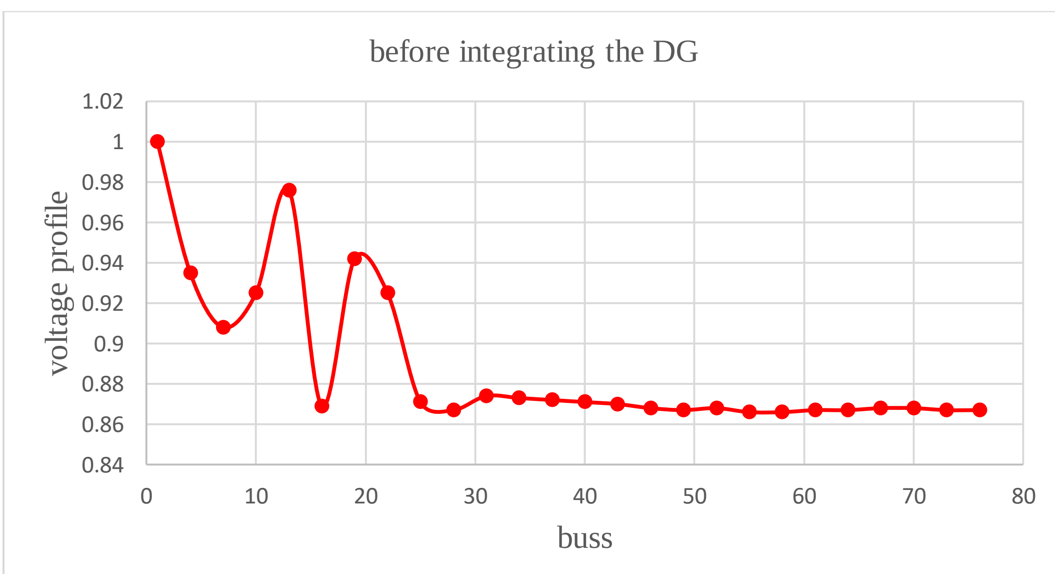

Figure: 4. 8 Voltage profile without integration of DG at each feeder

4.5.2. Integration of DG with Distribution Network

Under this case, it has been seen the effect of power loss, voltage profile of Adwa distribution substation network with integrate of DG at appropriate location with in appropriate capacity to the existing system by entering the data obtained from Adwa distribution system (i.e. without change the load).

The proposed method is 15 kV bus radial distribution system by installing DG at the least voltage sensitivity index of outgoing feeders of KO1 and installing the DG at bus 50 with a size of 12.70 MW and by considering 3.30 MW as a reserve, in order to have maximum power loss reduction and to have acceptable voltage profile. It can be seen that the simulation below shows the power loss is reduced and it improves the voltage profile after installing the DG without change the existing distribution network.

4.5.2.1. Total power loss with integration of DG

In order to reduce the total power losses of the system, the integration of the DG unit at proper size with proper location is significant. Therefore to get the best benefit from DG integration, sizing and siting of distributed generation should be made with a great care otherwise they have negative effect of DG may dominate. Here the appropriate size and location of DG had been determined. The steady state balanced and positive sequence of load flow analysis indicated that the total real and reactive power loss 2.06 and 2.95 which is reduced to 0.11 MW and 0.13 MVAR respectively after the integration of DG units with selected capacity and location by taking into account the appropriate capacity with appropriate location of the DG, see figure 4.10 below the simulation result in DigSILENT Power Factory 15.1.7 software.

```
----------------------------------------------------------------------------------------------------------------------------
|                 |                                                                |   DIgSILENT   | Project:                 |
|                 |                                                                | PowerFactory  |--------------------------|
|                 |                                                                |     15.1.7    | Date:  8/7/2019          |
----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                          Total System Summary |
----------------------------------------------------------------------------------------------------------------------------
|     AC Load Flow, balanced, positive sequence              |   Automatic Model Adaptation for Convergence         No   |
|     Automatic Tap Adjust of Transformers          No       |   Max. Acceptable Load Flow Error for                    |
|     Consider Reactive Power Limits                No       |      Nodes                                   1.00 kVA    |
|                                                            |      Model Equations                         0.10 %     |
----------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------------------------------
| Total System Summary                          | Study Case: Study Case              | Annex:                       / 1 |
----------------------------------------------------------------------------------------------------------------------------
|                                                                                                                          |
| No. of Substations      0        No. of Busbars       73        No. of Terminals      0        No. of Lines          72   |
| No. of 2-w Trfs.        0        No. of 3-w Trfs.     0         No. of syn. Machines  0        No. of asyn.Machines  0    |
| No. of Loads           69        No. of Shunts        0         No. of SVS            0                                   |
|                                                                                                                          |
| Generation            =     16.00  MW          7.29  Mvar      17.58  MVA                                               |
| External Infeed       =      8.14  MW          5.13  Mvar       9.62  MVA                                               |
| Load P(U)             =     24.02  MW         12.29  Mvar      26.99  MVA                                               |
| Load P(Un)            =     24.03  MW         12.29  Mvar      26.99  MVA                                               |
| Load P(Un-U)          =      0.00  MW          0.00  Mvar                                                               |
| Motor Load            =      0.00  MW          0.00  Mvar       0.00  MVA                                               |
| Grid Losses           =      0.11  MW          0.13  Mvar                                                               |
| Line Charging         =                       -0.04  Mvar                                                               |
| Compensation ind.     =                        0.00  Mvar                                                               |
| Compensation cap.     =                        0.00  Mvar                                                               |
|                                                                                                                          |
| Installed Capacity    =      1.28  MW                                                                                   |
| Spinning Reserve      =      0.00  MW                                                                                   |
|                                                                                                                          |
| Total Power Factor:                                                                                                      |
|   Generation          =        0.91  [-]                                                                                |
|   Load/Motor          =  0.89 / 0.00  [-]                                                                               |
```

Figure: 4. 9 Power loss with integration of DG

4.5.2.2. Voltage profile with DG integration

The screenshot of the network model depicting the steady state load flow analysis with the voltages at all buses were within acceptable range is shown in figure 4.11. The green color indicates that the voltage at that bus is within allowable range which is above 0.95 p.u. Figure 4.12 shows that voltage profile of the system resembles graphically after integration of DG. As it is clearly observed from the figure, all the terminal voltages are above 0.95 p.u. During the base case load flow analysis, the minimum voltage magnitude which occur at bus 57 and 58 had been determined to be 0.866 p.u before integrating of DG, then the voltage profile is improved to above 0.973 p.u after integrating the DG by taking the proper capacity with appropriate location [see in **appendix B2** in detail].

Generally, distributed generation (DG) integration on a voltage profile of the radial distribution system is important by taking into account with the appropriate sizing with appropriate location of the DG otherwise, if the capacity of DG increases and if there is no locate at the appropriate place overvoltage may be happen.

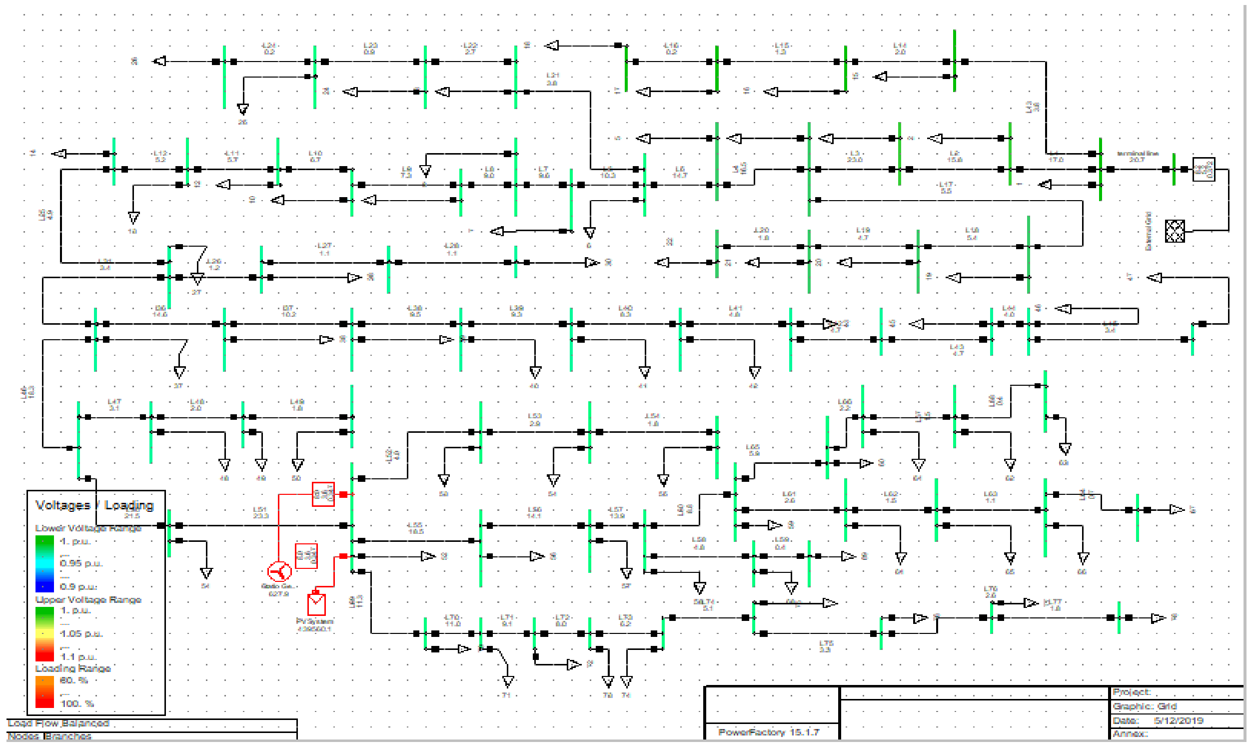

Figure: 4. 10 Voltage profile with integrating of DG

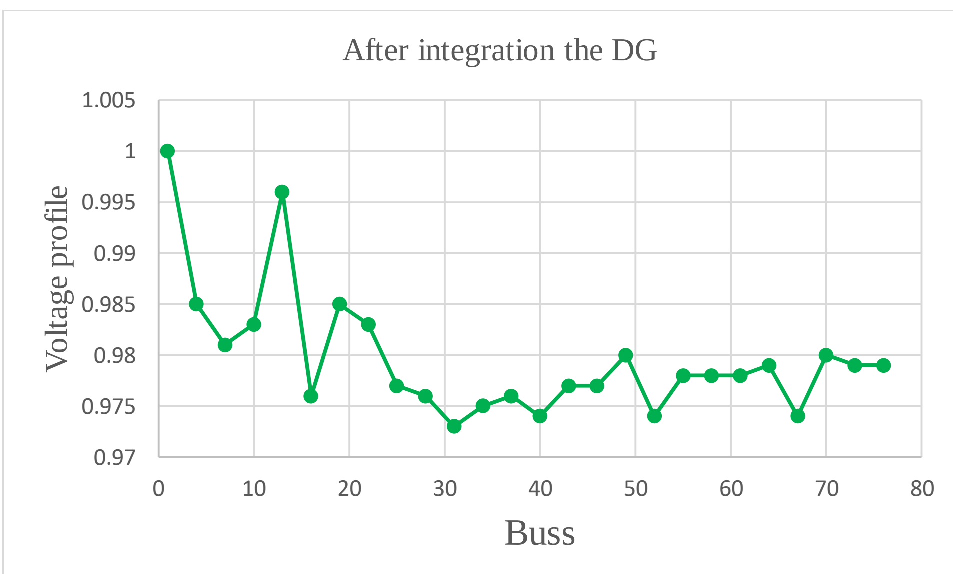

Figure: 4. 11 Voltage profile result with integration of DG

4.5.3.Integration of DG with Distribution Network with Increasing Demand

Expansion planning answers the services to be mounted and reassembled in order to achieve the predicted load requirement and to satisfy all operational and technical constraints in the particular planning horizon while ensuring the power quality standards. So under this case, it can be seen that the effect of power loss, line loading, and voltage profile of the case study distribution network when integrate the DG at appropriate locations with appropriate size to the distribution network and when increasing the penetration of DG and the load at each year increases by 7.07% in order to supply the customer needs.

The proposed method is applied to a 15 kV bus radial distribution network by increasing the penetration of DG by 7.07% at the appropriate location and size, when the distribution network expansion increase gradually. It can be seen that the effect on line loading, voltage profile and power loss on the simulation using DigSILENT Power Factory 15.1.7 software. The result shows it reduces the power loss, it improves the voltage profile and it reduce the line loading after increasing the penetration of DG unit with the load increase.

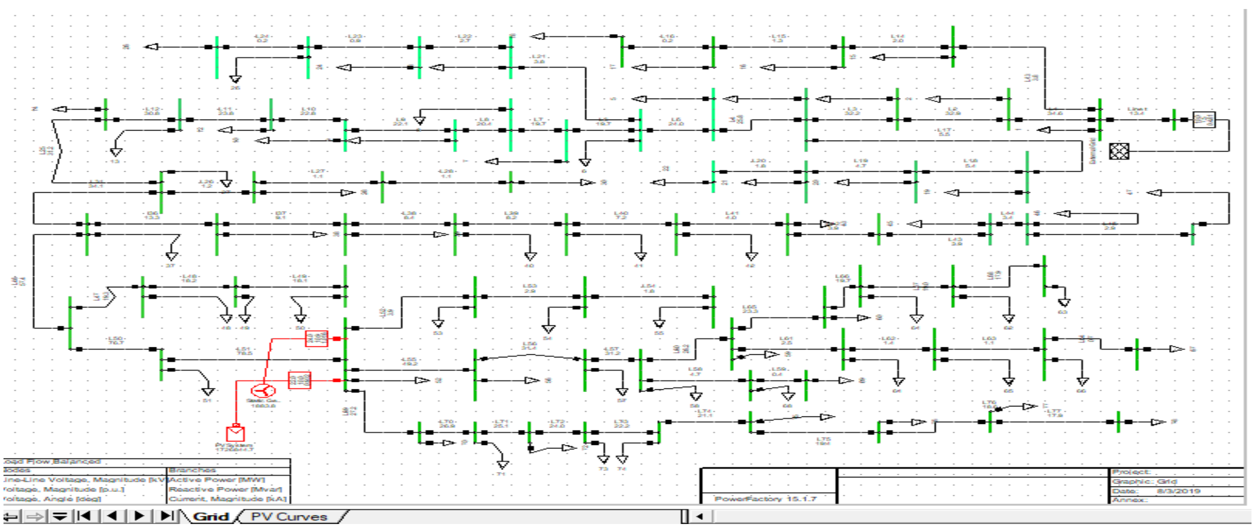

Figure: 4. 12 Integration of DG penetration with distribution network when the load demand increase

4.5.3.1. Line loading with increase load demand

To investigate the integration of DG on line loading after one year (when the load demand increase) load flow analysis is made by modeled in DigSILENT Power Factory 15.1.7 software. The simulation result revealed it reduces the line loading after integrating the DG with increase the load demand. The red color which have seen in the above figure 4.5 and the percentage of line loading is reduced. In general the integration of DG with increasing the load with penetration of DG on line loading segment is important but they have an impact to the distribution system protection due to increase the capacity of DG through the line [see in **appendix C3** in detail].

Table 4. 8 Percentage of line loading after one year with DG integration

Line	Line loading % WIL & DG	line	Line loading % WIL & DG	line	Line loading % WIL& DG	line	Line loading % WIL & DG
L1	36.15	L21	3.83	L41	4.81	L61	8.88
L2	34.37	L22	2.74	L42	4.72	L62	7.77
L3	32.57	L23	0.91	L43	4.72	L63	7.4
L4	21.76	L24	0.18	L44	4.06	L64	3.7
L5	21.43	L25	10.95	L45	3.43	L65	11.84
L6	16.96	L26	1.2	L46	11.8	L66	8.16
L7	16.25	L27	1.11	L47	3.14	L67	7.4
L8	15.54	L28	1.11	L48	2.03	L68	3.7
L9	13.76	L29	0.82	L49	1.85	L69	13.29
L10	13.05	L30	0.77	L50	140.92	L70	12.92
L11	12	L31	8.13	L51	11.76	L71	11.08
L12	11.35	L32	3.27	L52	4.06	L72	9.97
L13	3.76	L33	2.9	L53	2.95	L73	8.12
L14	1.97	L34	2.11	L54	1.84	L74	7.02
L15	1.25	L35	2.1	L55	30.56	L75	5.17
L16	0.18	L36	1.54	L56	26.44	L76	4.43
L17	9.08	L37	0.98	L57	26.25	L77	3.69
L18	5.45	L38	9.58	L58	4.8		
L19	4.72	L39	9.4	L59	0.37		
L20	1.82	L40	8.32	L60	21.05		

- WIL & DG – With Increase load and penetration of Distributed Generation

4.5.3.2. Total power loss with load demand increases

In order to reduce the total power losses of the system, the integration of DG unit at proper capacity at proper location is significant. Here the proper size and place of DG had been determined. The steady state balanced and positive sequence load flow analysis indicated that the total real and reactive power loss is reduced to 0.49 MW and 0.67MVAR respectively from the existing distribution network, after the integration of DG with increasing the load and penetration of DG units as shown in figure 4.13. In general the integrating of DG with increasing the load and penetration of DG on power loss of the distribution system is more important, but it increase the loss when it compared before increasing the load, due to the load increases. Therefore by taking the appropriate capacity and location of the DG in expansion planning is more important and they have maximum power loss reduction.

```
|                  |                                                                     |    15.1.7     | Date:  8/7/2019                 |
-----------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                                   Grid Summary |
-----------------------------------------------------------------------------------------------------------------------------------------
|     AC Load Flow, balanced, positive sequence                  |   Automatic Model Adaptation for Convergence            No          |
|     Automatic Tap Adjust of Transformers              No       |   Max. Acceptable Load Flow Error for                                |
|     Consider Reactive Power Limits                    No       |      Nodes                                              1.00 kVA    |
|                                                                |      Model Equations                                    0.10 %      |
-----------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------
| Grid: Grid                System Stage: Grid           | Study Case: Study Case              | Annex:                          / 1  |
-----------------------------------------------------------------------------------------------------------------------------------------
| Grid: Grid                Summary                                                                                                   |
|                                                                                                                                       |
| No. of Substations      0          No. of Busbars        73         No. of Terminals        0          No. of Lines             72  |
| No. of 2-w Trfs.        0          No. of 3-w Trfs.      0          No. of syn. Machines    0          No. of asyn.Machines     0   |
| No. of Loads            69         No. of Shunts         0          No. of SVS              0                                       |
|                                                                                                                                       |
| Generation            =       46.00  MW          20.96   Mvar       50.55  MVA                                                       |
| External Infeed       =       10.02  MW           7.46   Mvar       12.49  MVA                                                       |
| Inter Grid Flow       =        0.00  MW           0.00   Mvar                                                                        |
| Load P(U)             =       55.53  MW          27.74   Mvar       62.07  MVA                                                       |
| Load P(Un)            =       55.53  MW          27.74   Mvar       62.07  MVA                                                       |
| Load P(Un-U)          =        0.00  MW           0.00   Mvar                                                                        |
| Motor Load            =        0.00  MW           0.00   Mvar        0.00  MVA                                                       |
| Grid Losses           =        0.49  MW           0.67   Mvar                                                                        |
| Line Charging         =                          -0.04   Mvar                                                                        |
| Compensation ind.     =                           0.00   Mvar                                                                        |
| Compensation cap.     =                           0.00   Mvar                                                                        |
|                                                                                                                                       |
| Installed Capacity    =        1.28  MW                                                                                            |
| Spinning Reserve      =        0.00  MW                                                                                            |
|                                                                                                                                       |
| Total Power Factor:                                                                                                                   |
|   Generation          =          0.91   [-]                                                                                        |
|   Load/Motor          =   0.89 / 0.00   [-]                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------|
```

Figure: 4. 13 Total power loss with load demand increases

4.5.3.3. Voltage profile with load demand increases

Figure 4.14 shows that voltage profile of the system resembles graphically after integration of DG and when it increases the load with penetration of DG. As it is clearly observed from the figure below, all the terminal voltages are at the standard range between 0.95p.u. -1.05 p.u. During the base case load flow analysis, the minimum voltage magnitude which occur at bus 57 and 58 had been determined to be 0.866 p.u i.e. it is in the range of 0.866p.u – 1.0 p.u. Then the voltage profile is improved to in the range between 0.973 p.u – 1.0 p.u after integration the DG when increase the load with penetration of DG [see in **appendix B3** in detail].

Generally, distributed generation (DG) integration is important when it increase the load with penetration of DG on a voltage profile of the radial distribution system, but it's important to take the appropriate capacity at appropriate location of the DG in order to have acceptable voltage profile otherwise, if the capacity of DG increases and if there is no locate at the appropriate place it may have overvoltage is happen.

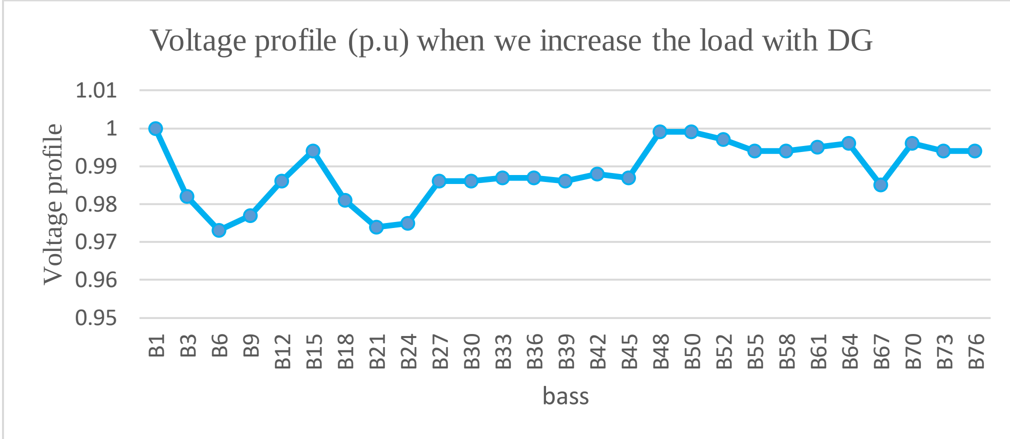

Figure: 4. 14 Voltage profile with load demand increases

4.6. Implementation of Fast Protection Relay

Transmission and distribution systems are exposed to overcurrent flow into their elements. In an electric power system, overcurrent or excess current is a situation where a larger than intended electric current exists through a conductor, leading to excessive generation of heat, and the risk of fire or damage to equipment. In order to protect the system before damaged, you have to implement fast protection.

Integration of DG to the radial distribution network it changes the system operation (the flow of current it changes from unidirectional to bidirectional) and the change in current flow it affects the protection device. Therefore, it is necessary to study the characteristics of the fault to implement fast protection. In addition, it necessary to see the effect of phase to earth and phase to phase fault at each branch of the line then it implement the fast protection device in order to clear the fault based on each line characteristic.

To implement fast protection device using DigSILENT Power Factory 15.1.7 software in to distribution network I have consider different types of short circuit fault. Therefore, to clear those fault earth fault and phase fault element relay is implemented based on each line characteristic. See one by one such like in the figures below.

The two element of earth and phase relay is not trip as shown in the figure 4.15. Because the pick-up current of the relay setting is higher than the steady state current of the line. Therefore, the implementation of fast protection relay is not affected at steady state condition when the DG integrate to the distribution network.

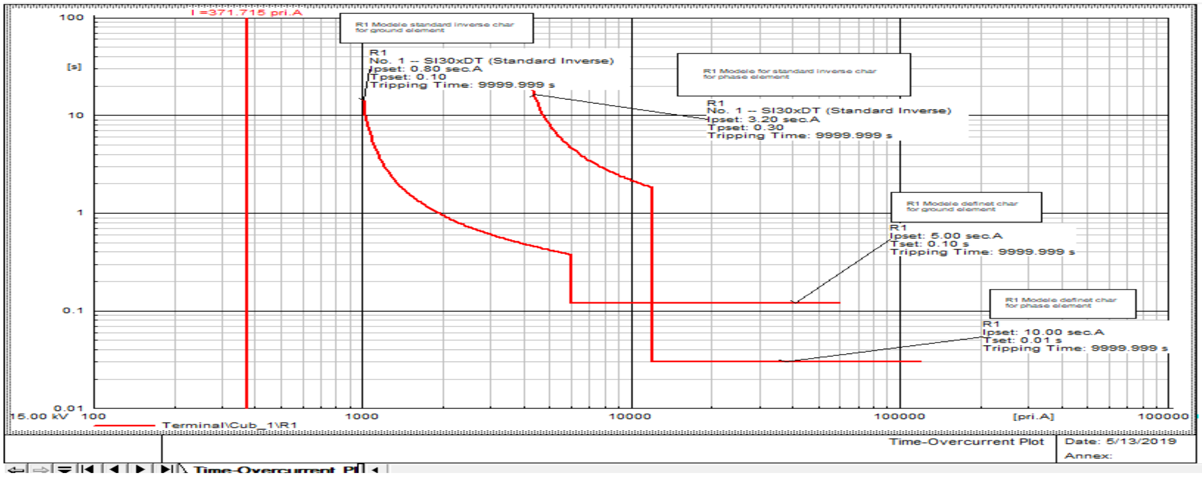

Figure: 4. 15 Operating characteristic of over current **r**elay at normal condition

When there is a phase to phase fault either LLL or LL short circuit fault is happen at any time in the distribution network the only phase relay element is trip in order to clear the short circuit, but earth fault relay element is not trip, because at the system only phase to phase fault is happening, so this relay is tripped the fault as you set the time as well as the fault current. In this figure 4.16 shown below the peak fault current of line to line is 6741.432A pri and the relay trips at 3.710s.

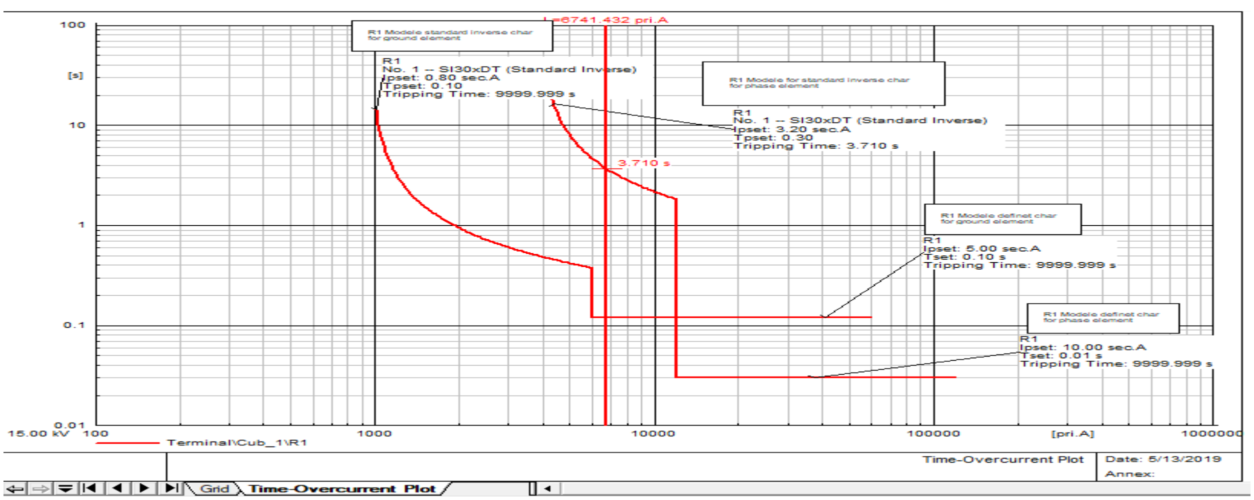

Figure: 4. 16 Phase element relay is trip when LL short circuit is accord

When there is earth fault like L-G short circuit fault happened at any time in the distribution system the earth fault relay element is trip in order to clear the fault. But phase element relay is not trip because at the system it is only phase to ground fault is occurs and this relay trips the fault as you set the time as well as the fault current. In the figure 4.17 shown below the peak fault current of single line to ground is 4000.024 pri A and trips at 0.483s.

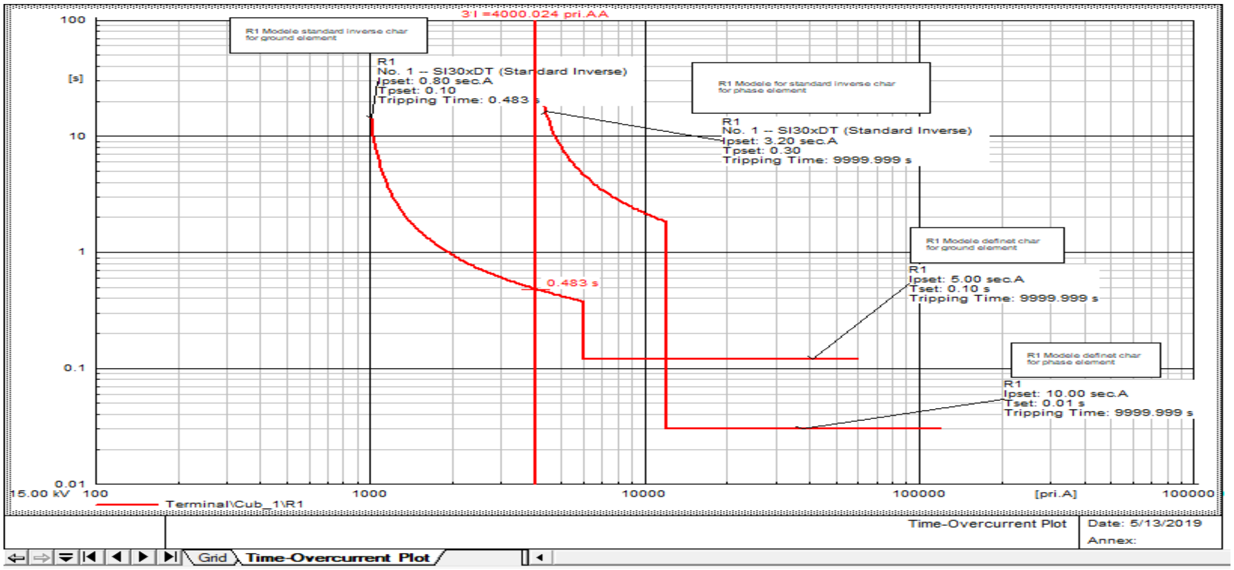

Figure: 4. 17 Ground element relay is trip when L-G short circuit is accord

When both earth and phase fault happened with the same time like LLL-G and LL-G, short circuit fault in distribution system the phase and earth fault relay element is trip in order to clear both type of short circuit. So, this also the relay is trips the fault as you set the time as well as the fault current. In this figure 4.18 shown below the peak fault current between the two line and ground is 2795.505 pri A and the peak current of between the two lines is 6442.335 pri A and the tripping time between the two line is at 4.038s and the tripping time between the two line to the ground is 0.648s.

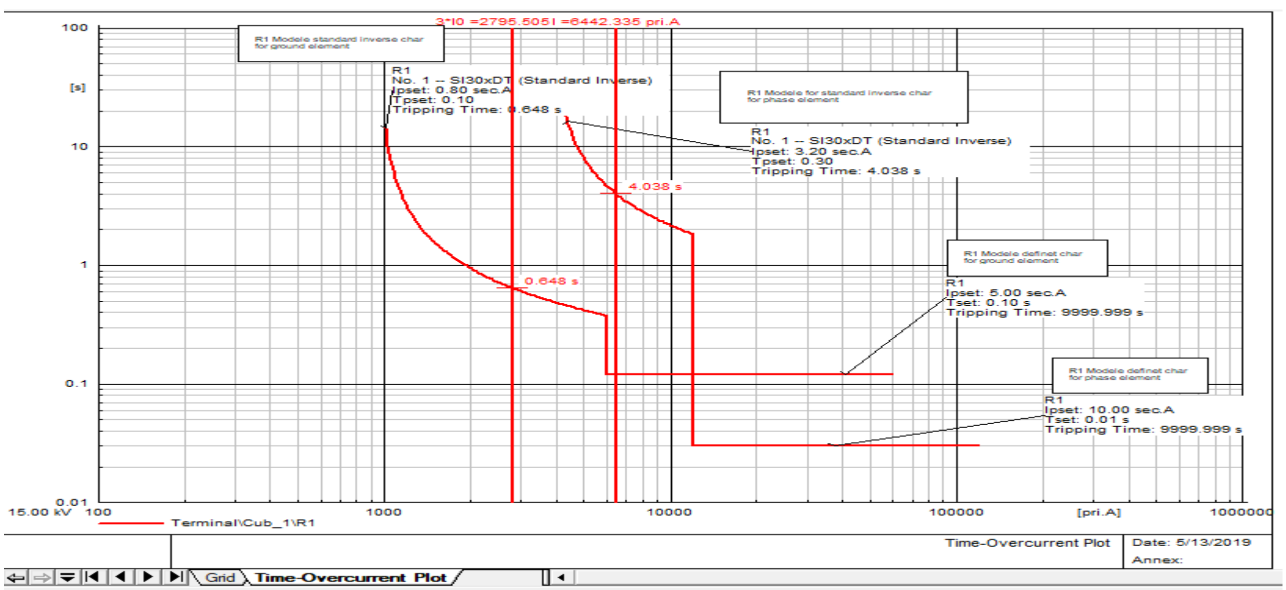

Figure: 4. 18 Phase and ground element relays are trips when LL-G short circuit is happens

General, in this thesis earth fault and phase fault relay element is successfully implemented in the distribution network. Earth fault relay is specifically designed to operate only on faults which involve fault between phase and earth as against a fault not involving earth such as two phase or three phase faults or overload fault due to system overload. The major advantage it offers are as, an overcurrent phase relay operates on over current irrespective of whether the overcurrent is due to any fault its setting has to be more than the normal load current whereas earth fault setting can be kept far low as normal earth current is close to zero, in case of faults involving low impedance there is sufficient current to operate the Earth fault relay.

4.7. Protection Relays Coordination

Investigation on protection issues involving DG is carried out on the industrialized radial system model based on protection coordination. Types of overcurrent protective devices coordination comprise fuse-fuse coordination, fuse-relay coordination and relay-relay coordination. Here, to examine the impact of DG integration on protection coordination of radial distribution network, relay to relay coordination had been selected because the stress is on the feeder although the primary of the substation transformer is ideally protected with a fuse. Also DG protection or its separation methods are above the scope of this thesis.

The aim of this coordination of overcurrent relays is to decrease the influence of DG integration in a radial distribution network, due to increasing load with the penetration of DG in to the distribution network. It is extensively recognized that in radial networks, discrimination of fault protection is achieved through time-current coordination of over-current relays. This is since of particular fault, all the relays related in the radial feeder see the fault current but they are made to operate at different times. The coordination is based on the fact that the relay closest to the fault (primary relay) sees the largest fault current than those beyond away (backup relays). Selection of different time current features in the relay settings is the means of realizing coordination.

On the feeder KO1 Adwa substation has only one relay which is found at the outlet of the feeder with current transformer (CT) ratio 1200A. Due to one relay about the outlet of the substation the fault far away from this relay is less scale and does not sense to clear this fault at a time. So, in this thesis work I am to tray for investigation the impact of DG integration on protection coordination of the protective relay and total eleven relays were added to the utility relay and by changing the protection model. Based on equation 3.19 the current transformer setting has been determined for the eleven instrument transformers. The setting exported from the DigSILENT power factory simulation software is as shown in table 4.10. To ensure the actual of protection on the feeder, eleven GE Alstom KCCG142-1A overcurrent relays with inverse time and definite time over current relay characteristics are chosen from the DigSILENT Power Factory 15.1.7 global library. All relay models perform Inverse Definite Minimum Time (IDMT) and Definite Time (DT) or Instantaneous functions. Assuming Plug Setting (PS) of relay 10 (R_{10}) =100% and time multiplier setting of relay 10 (TD_{10}) = 0.05, the operating time of relay 10 (R_{10}) is determined from equation 3.24 which is found to be 0.0548s. Taking the coordination time interval of 0.2s which is standard the working time of relay 6 (R_6) became 0.2548s. Then the time dial of relay 6 (R_6) is determined from equation 3.25. The procedure is continued in the same way up to the utility relay that is the relay R1 which its operating time was determined to be 1.4749s.

Table 4. 9 Instrument Transformers Setting

Relays	**Location**	**Branch**	**Manufacturer**	**Model**	**CT**	**Slot**	**Ratio[pri. A/ sec.A]**
R_1	Terminal	terminal	Alstom	KCGG142-1A	CT 1	Ct-3p	1200A/1A
					CT 1	Ct-3I0	1200A/1A
R_{10}	BB54	L65	Alstom	KCGG142-1A	CT10	Ct-3p	400A/1A
					CT10	Ct-3I0	400A/1A
R_2	BB1	L1	Alstom	KCGG142-1A	CT 2	Ct-3p	1100A/1A
					CT 2	Ct-3I0	1100A/1A
R_{2-1}	BB1	L13	Alstom	KCGG142-1A	CT2-1	Ct-3p	400A/1A
					CT2-1	Ct-3I0	400A/1A
R_3	BB5	L5	Alstom	KCGG142-1A	CT 3	Ct-3p	1000A/1A
					CT 3	Ct-3I0	1000A/1A
R_4	BB35	l36	Alstom	KCGG142-1A	CT4	Ct-3p	500A/1A
					CT4	Ct-3I0	500A/1A
R5	BB42	L46	Alstom	KCGG142-1A	CT5	Ct-3p	600A/1A
					CT5	Ct-3I0	600A/1A
R_6	BB50	L55	Alstom	KCGG142-1A	CT 6	Ct-3p	500A/1A
					CT 6	Ct-3I0	500A/1A
R_7	BB50	L69	Alstom	KCGG142-1A	CT7	Ct-3p	500A/1A
					CT7	Ct-3I0	500A/1A
R_8	BB50	L52	Alstom	KCGG142-1A	CT8	Ct-3p	500A/1A
					CT8	Ct-3I0	500A/1A
R_9	BB54	L61	Alstom	KCGG142-1A	CT9	Ct-3p	400A/1A
					CT9	Ct-3I0	400A/1A

Table 4. 10 Over Current relay Setting

Relays	Stage (Phase)	Current [pri.A]	Current [sec.A]	Current [p.u.]	Time	Characteristic	Directional
R1	I>/t>	1200.00	1.00	1.00	0.30	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	12000.00	10.00	10.00	0.42	Definite	None
R10	I>/t>	400.00	1.00	1.00	0.05	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	800.00	2.00	2.00	0.42	Definite	None
R2	I>/t>	1100.00	1.00	1.00	0.25	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	11000.00	10.00	10.00	0.42	Definite	None
R2-1	I>/t>	400.00	1.00	1.00	0.10	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	840.00	2.10	2.10	0.42	Definite	None
R3	I>/t>	1000.00	1.00	1.00	0.20	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	5000.00	5.00	5.00	0.40	Definite	None
R4	I>/t>	500.00	1.00	1.00	0.17	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	1750.00	3.50	3.50	0.42	Definite	None
R5	I>/t>	600.00	1.00	1.00	0.17	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	2280.00	3.80	3.80	0.40	Definite	None
R6	I>/t>	500.00	1.00	1.00	0.15	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	1600.00	3.20	3.20	0.42	Definite	None
R7	I>/t>	500.00	1.00	1.00	0.10	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	1350.00	2.70	2.70	0.42	Definite	None
R8	I>/t>	500.00	1.00	1.00	0.08	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	1100.00	2.20	2.20	0.42	Definite	None
R9	I>/t>	400.00	1.00	1.00	0.08	No. 1 -- SI30xDT (Standard Inverse)	None
	I>>/t>>	880.00	2.20	2.20	0.42	Definite	None

In the Figure 4.19 shows below the positive sequence load flow analysis, the network were analyzed with DG integrated, with the location of over current relays which are seen in green color. All the relays are not tripping as expected during steady state condition since the branch currents are below the operation currents of the relays.

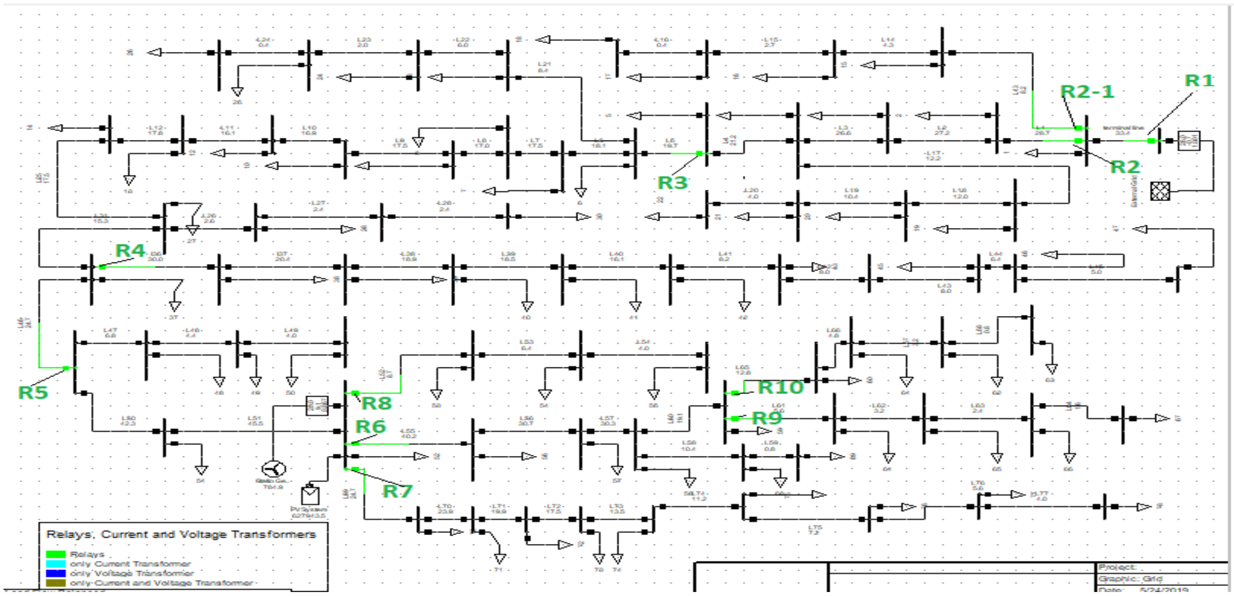

Figure: 4. 19 After DG integration with Protection coordination

However, during DG integration of the reverse power flow is produced without affecting the operation of the relays at steady state condition. In case of faulty condition the integration of DG affects the operation of the relays by causing an increment of fault current. To be noted that if distributed generator (DG) is sized and placed properly the negative impact of DG is not due to increment of fault currents rather the reverse power flow in the network which causes the islanding of DG and all loads downstream of DG. Figure 4.20 shows that the coordination of eleven over current protection in power flow without affecting the operation of the relays at steady state condition.

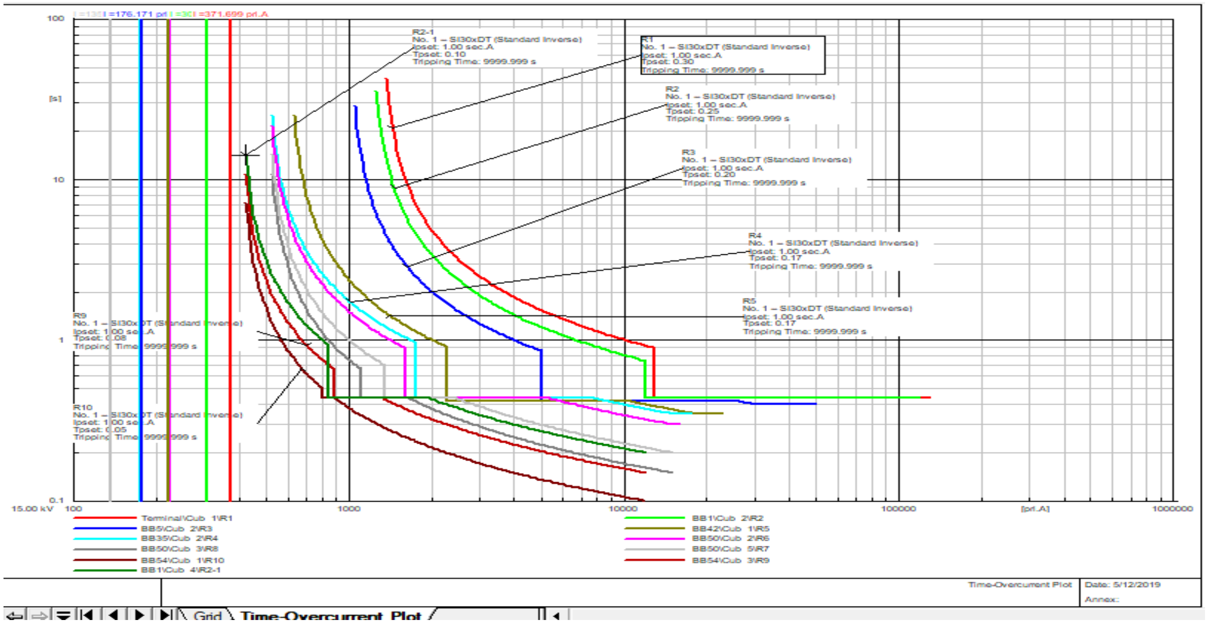

Figure: 4. 20 Coordination of time overcurrent relays at normal condition

In figure 4.21 and 4.22 shown below a three phase fault on bus 8 with DG connected is cleared by R3 in 0.420s. The rest of the relay performs their back up protection according to their sequence of operation for instance R2 clear the fault in 0.775s, R1 in 0.966s if R3 fail to trip and so on.

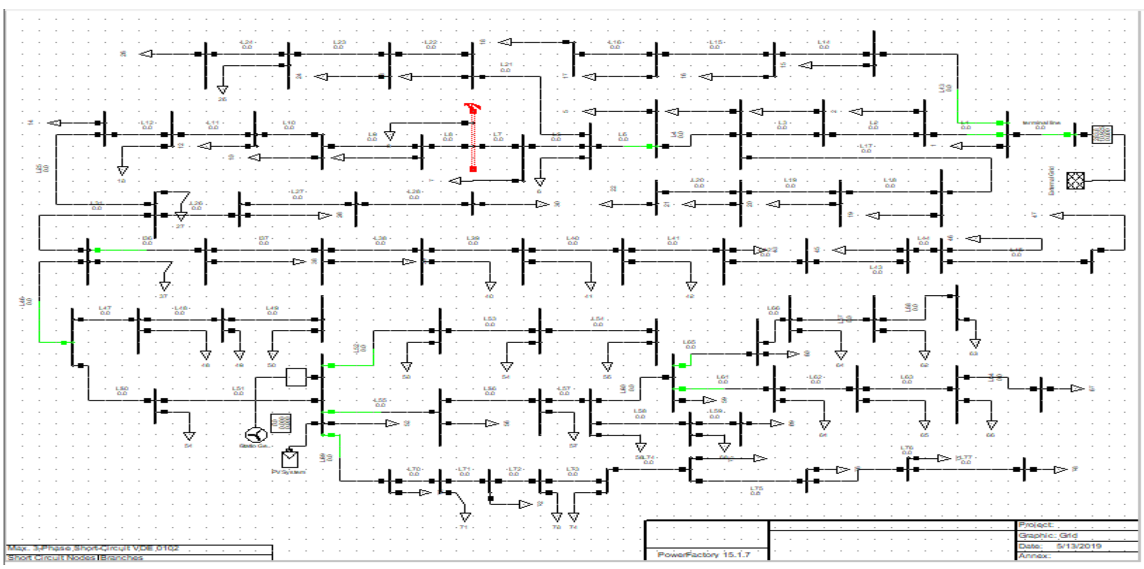

Figure: 4. 21 Coordination of time over current operation of the relays at fault conditions at bus 8.

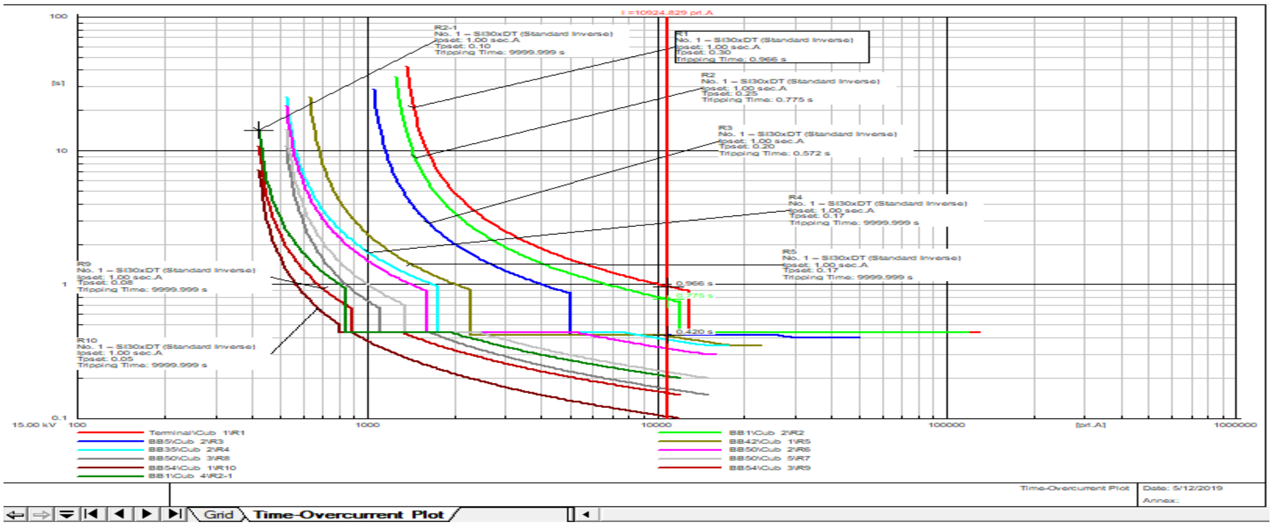

Figure: 4. 22 Protection time over current relay time when 3 phase short circuit is accord at bus 8

At the same distribution network but when the fault is produces far away from the substation at bus 60 the fault level or magnitude is reduced due to increase the impedance of the network, so when the fault is occurred far away from the substation the relay is not sense at a time due to reduce the level of short circuit so it must have to implement or coordinate time over current relay around the fault line.

In figure 4.23 shows below that a three phase fault on bus 60 with DG connected is cleared by R9 in 0.190s. The rest of the relay performs as a backup protection according to their sequence of operation for instance R6, R5, R3, R2 and R1 are connected in sequence i.e (series) respectively and clear the fault 0.416, 0.524, 0.776, 1.063 and 1.370 respectively at a sequence and so on. figure 4.23 and figure 4.24 shows the coordination of eleven over current protection in power flow system protection protect without affecting the operation of the relays at fault conditions at bus 60.

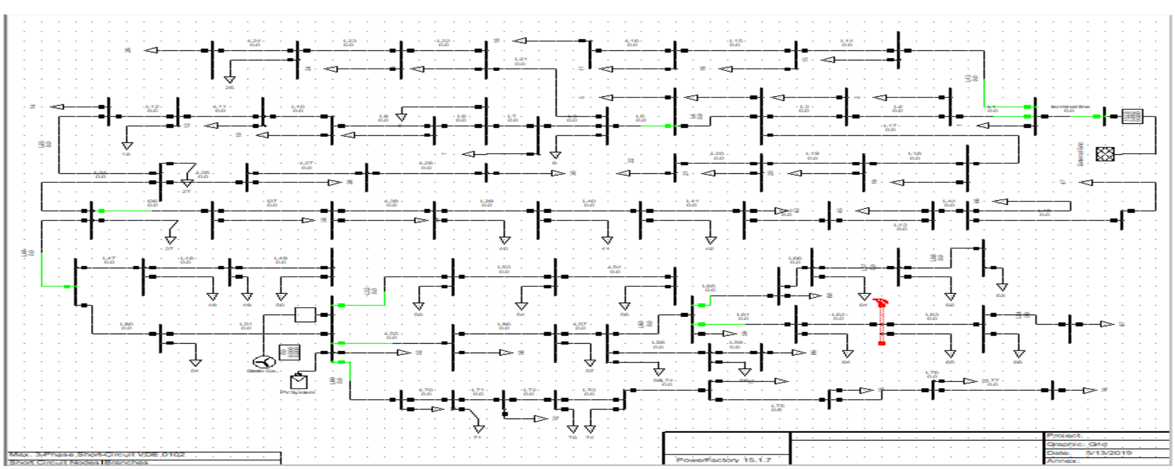

Figure: 4. 23 Coordination time-overcurrent relays when 3 phase short circuit is accord at bus 60

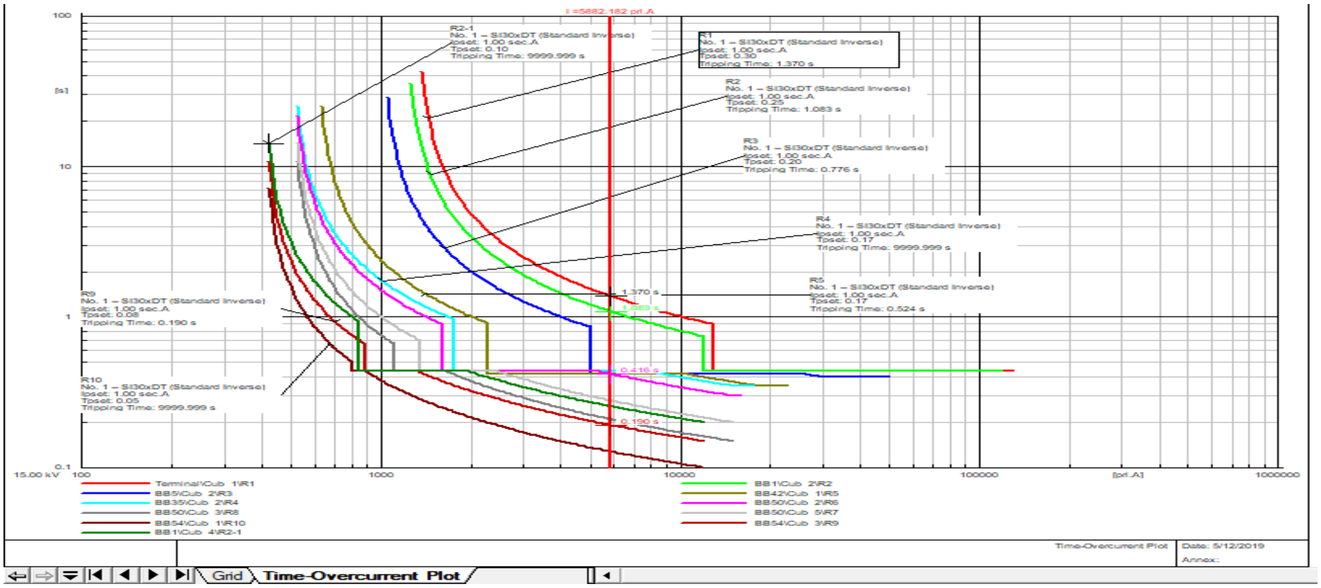

Figure: 4. 24 Protection time over current relay when 3 phase short circuit is accord at bus 60

4.8. Grading of Overcurrent Relays

Among the various possible methods used to achieve correct relay coordination which are using either time or overcurrent, or a combination of both. The common aim of the three methods is to give correct discrimination. Accordingly that everyone must isolate only the faulty section of the power system network, which leaves the rest of the system undisturbed.

Each of the two methods described so far has a fundamental disadvantage in the case of discrimination by time alone, the disadvantage is due to the fact that the more severe faults are cleared in the longest operating time. On the other hand, discrimination by current can be applied only where there is appreciable impedance between the two circuit breakers concerned.

It is because of the limitations imposed by the independent use of either time or current grading that the inverse time overcurrent relay characteristic has evolved. With this characteristic, the time of operation is inversely proportional to the fault current level and the actual characteristic is a function of both 'time' and 'current' settings. Figure 4.25 illustrates the characteristics of eleven relays given different current/time settings in this study. For a large variation in fault current between the eleven ends of the feeder, faster operating times can be achieved by the relays nearest to the source, whereas the fault level is the highest. The disadvantages of grading by time or current alone are overcome.

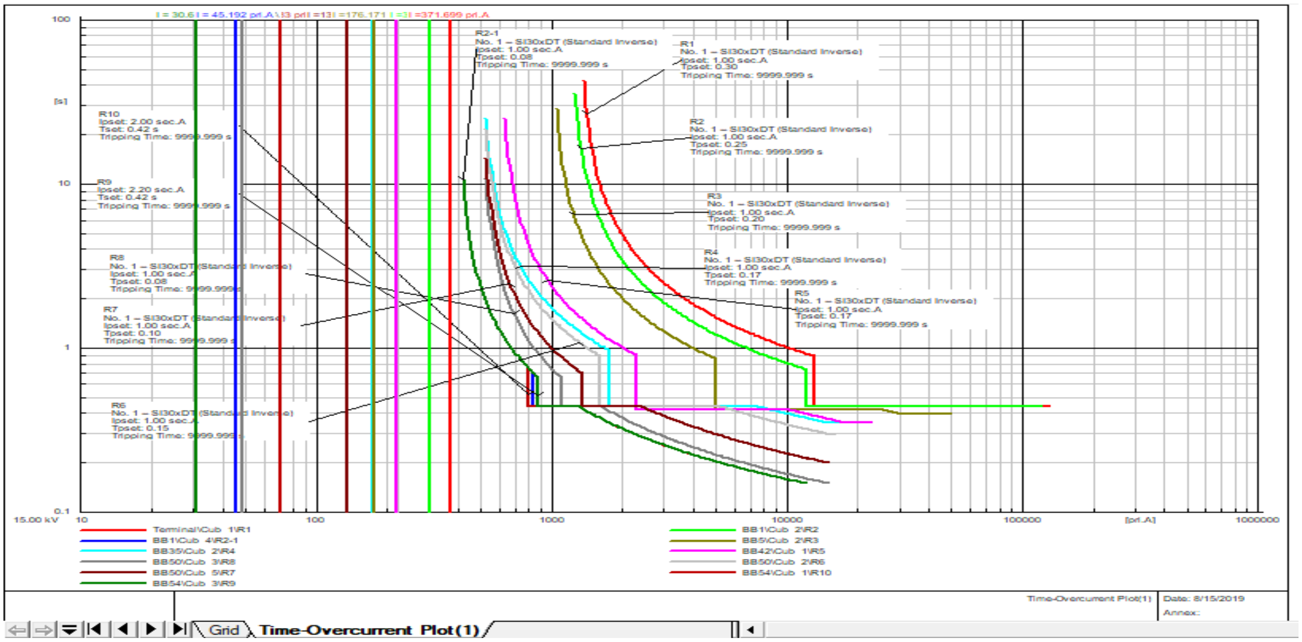

Figure: 4. 25 Coordination of eleven relays at normal condition when the relay is upgraded

The time interval that must be allowed between the operations of eleven adjacent relays in order to achieve correct discrimination between them is called the *grading margin.* If a grading margin is not provided, or is insufficient, more than one relay will operate for a fault, leading to difficulties in determining the location of the fault and unnecessary loss of supply to some consumers. Grading is initially carried out for the maximum fault level at the relaying point under consideration, but a checking is also made that the required grading margin exists for all current levels between relay pickup current and maximum fault level.

In this study the time interval between the operations of eleven adjacent relays before grading the relays in DigSILENT Power Factory 15.1.7 software is performed by selecting ±0.2s grading margin to all relays. But when it increase the penetration of DG with increasing load demand it affects the protection devise as described in chapter three so far. Therefore by increasing the value of margin to all relays by ± 0.3s it decreases the impact of the protection device at the fault condition as shown below in the figure 4.26.

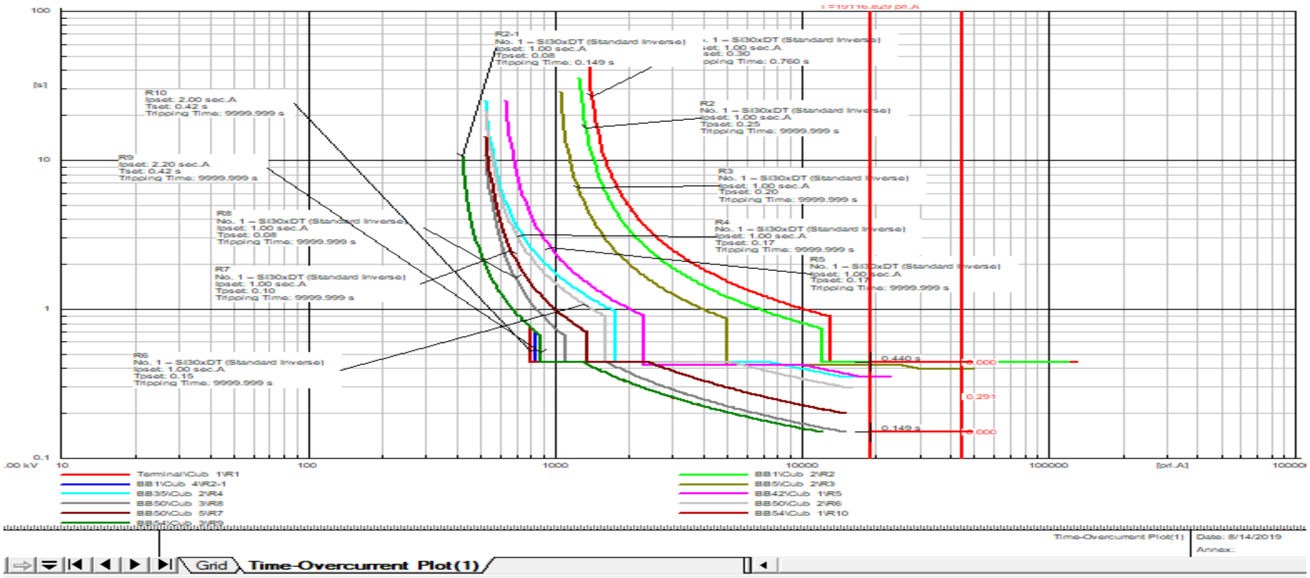

Figure: 4. 26 when there is fault accrued at 15 bus after grading the overcurrent relays

When there is fault accrued at 15 bus the maximum peek fault current is 19116pir A and the tripping time of the R_{2-1} and R_1 relays are 0.149s and 0.760s respectively. So when it increase the load with the penetration of DG capacity which is above the current setting of the protection relay they have an impact on the protection device as it described so far. So when it upgrade the overcurrent relay it protects up to 45kA at the same tripping time. Show the above figures 4.26 to understand the grading margin of the over current.

Generally in a radial system when the number of relay is connected in series as shown in the figure 4.23 above, it is desired that the smallest possible part of the system should be off. So this is conveniently achieved by coordinating and employing time graded protection. The over current system should be adjusted in such a way that the longer relay from the generating station the lesser time of operation.

4.9. Impacts of DG Integration on the expanded System

In this section investigates in order to examine the impact of integration of DG on expansion planning without and with integration of DG and also it investigates when it increasing load with penetration of DG. The load flow study has been performed using the help of DigSILENT Power Factory 15.1.7 software on power loss, voltage profile and voltage stability and also the loading of the line segment compered when the capacity of Dg increases with demand at steady state and transient stability condition on a radial distribution system at the selected capacity and location as follow.

4.9.1.Impact of DG integration on Total Power Losses

During the base case load flow analysis at steady state condition, the total real and reactive power loss was determined as 2.06 MW and 2.95 MVAR respectively. So in order to see the effect of total power losses of the distribution system, the integration of DG unit at appropriate place with appropriate capacity is significant. To get the best benefit from DG integration, sizing and sitting of distributed generation should be made with a great care otherwise the negative impact of DG may dominate.

The steady state balanced and positive sequence load flow analysis indicated that the total real and reactive power loss was reduced to 0.11 MW and 0.13 MVAR respectively after the integration of DG before increase the load and selected capacity. And also the total real and reactive power loss is reduced from the base case to 0.49 MW and 0.67 MVAR respectively, when the load increase with increase the penetration of DG at appropriate placement and location. The comparison of total power loss before and after DG integration is shown in figure 4.27 which depicts a major significant improvement of total power losses reduction. Therefor when it can be seen the effect of DG integration on power loss they have positive impact in the distribution system expansion planning.

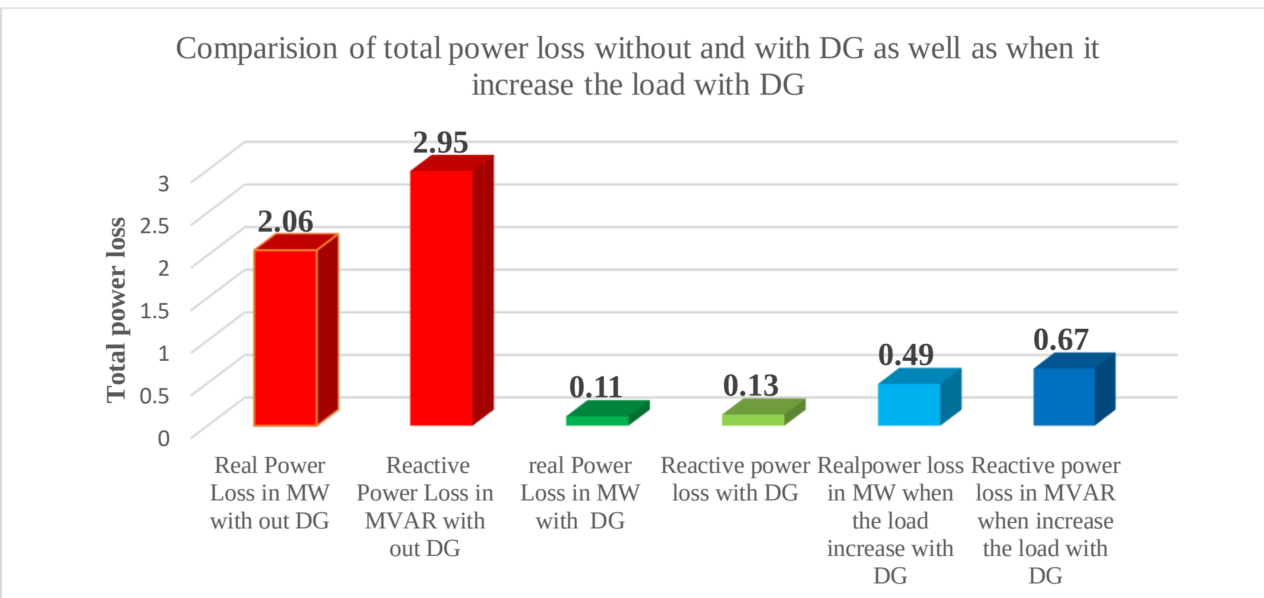

Figure: 4. 27 comparisons of total power loss without and with DG as well as when the load increases

4.9.2.Impact of DG integration on Voltage Profile

In order to clearly indicate the impact of voltage profile of distribution system, the base case voltage profile is compared with the voltage profile of the system after DG integration and with the voltage profile of the system after DG integration with increase the penetration of DG and load of the distribution system. The comparison of voltage profile during base case scenario, after DG integration and after DG integration with increasing load and penetration DG, is shown in figure 4.28 which entail a great improvement of the voltage profile at all buses of the system. The impact of distributed generation (DG) integration on a voltage profile of the radial distribution system is positive by taking into account the appropriate sizing at appropriate location of the DG [see in the **appendixes B** in detail].

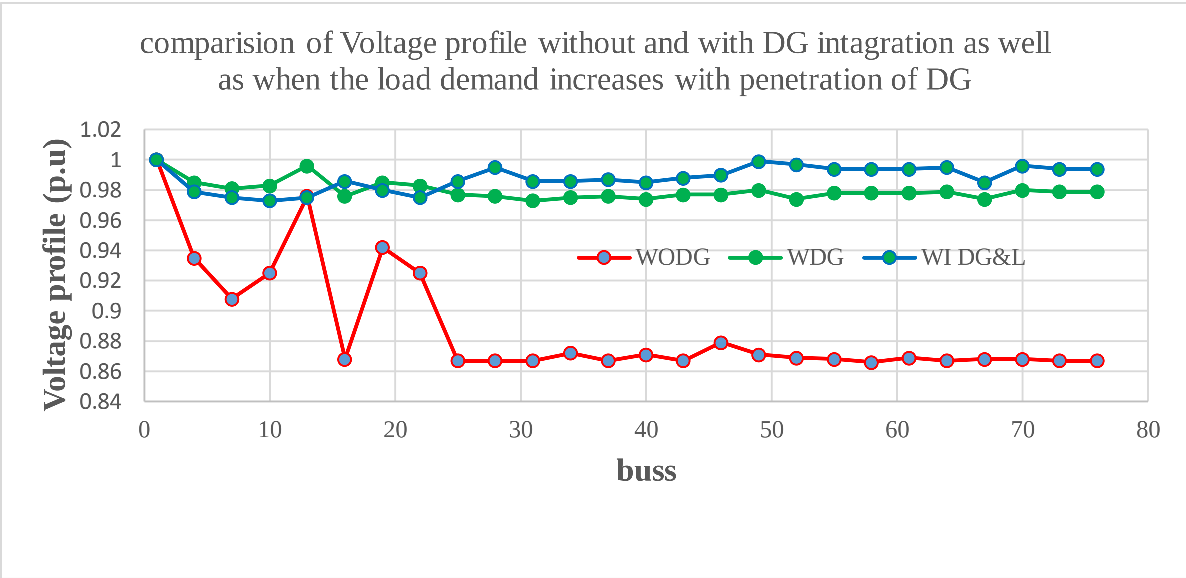

Figure: 4. 28 Comparisons of voltage profiles without and with DG integration as well as when the load demand increases

4.9.3.Impact of DG integration on Line Loading

From the next year the feeder is overloaded due to increase the load demand at each year when it seen the percentage of line loading from the result box of DigSILENT Power Factory 15.1.7 software, so it needs additional distribution network to supply the customer. Therefore, to investigate the impact of DG on line loading after one year without DG and with DG when the load demand increases has made in case study radial distribution system modeled using DigSILENT Power Factory 15.1.7 software simulation. This result revealed the reduction of loading of line segment when the DG increase with demand. The percentage of loading of line have observed from the result box of DigSILENT Power Factory 15.1.7 software. They have significant reduction of line loading when it compared without DG when it see figure 4.29 below. It is established that the impact of DG on line loading when the capacity of DG increase with demand is positive impact in the distribution system expansion planning [see in the **appendixes C]**.

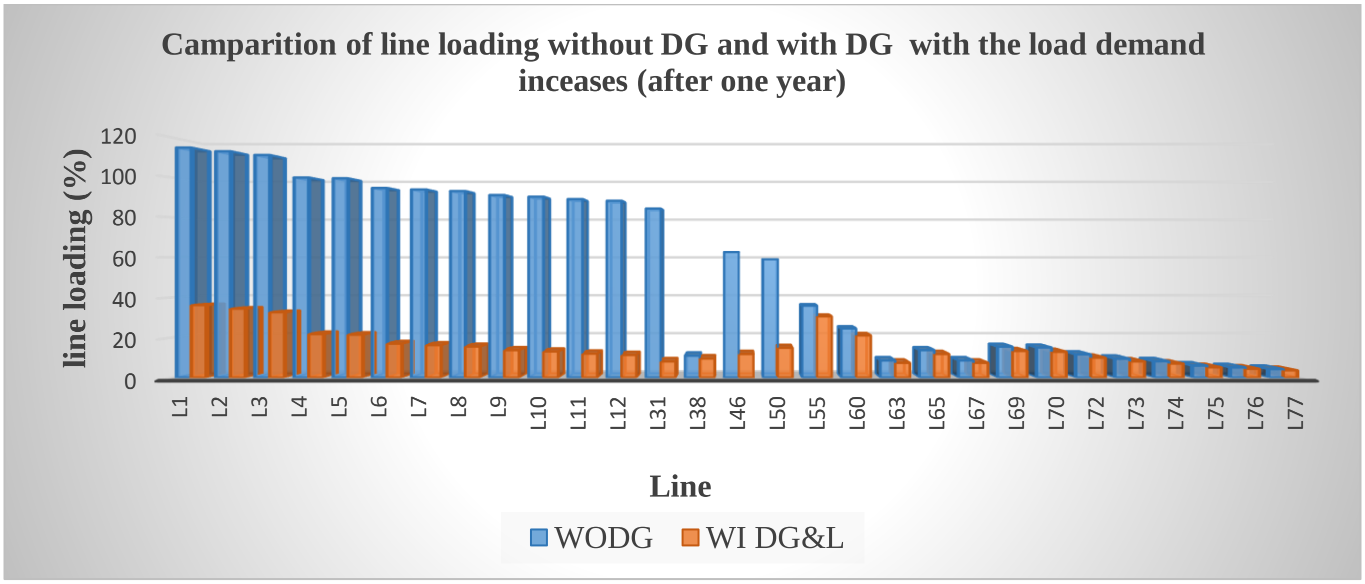

Figure: 4. 29 Comparisons of Line loading without DG and with DG after one year

4.9.4.Impact of DG integration on Voltage Stability

Voltage stability is classified into steady state voltage stability and dynamic voltage stability and it involves small and large disturbances respectively. To be investigated on steady state voltage stability relating to load increase and faults large disturbances is as follow with the help of DigSILENT power factory software.

4.9.4.1. Steady State Voltage Stability

Small disturbance (or small signal) stability pertaining to load increment is studied under steady state conditions. This is because the voltage profile upgrading from DG integration does not implies unlimited loading to avoid the system's failure to sustain the load. In general, the incapability of the system to supply required demand leads to voltage instability (voltage collapse). Voltage stability is usually represented by P-V curve and at the point of voltage collapse the voltage drops rapidly with an increase of the load demand and therefore, the load flow simulation fails to converge outside this limit. P-V curves have been traditionally used as graphical tools for studying voltage stability in electric power systems.

Voltage stability analysis in DigSILENT Power Factory 15.1.7 software is done by selecting the buses and the loads that are of interest, choosing the Execute DSL scripts and the selection of PV-Curve. The resulting graphs are automatically displayed. Prior to voltage stability analysis the loads have unity mounting factors, but DigSILENT Power Factory 15.1.7 performs voltage constancy analysis by gradually increasing the load, while keeping the power factor constant, of the preselected buses until they reach the power transfer limit.

Creation the voltage stability analysis for gradual raise of load, the P-V curve of the developed model without DG is as shown in Figure 4.30 for all the loads down steam of DG which is 4.71425 MW, the maximum or total load before voltage collapse it resolute to be 23.233 MW. Therefore, the loading margin to voltage collapse, for a current operating point, the total increment of load in a specified pattern of load increase which can cause to voltage collapse to became 18.523 MW.

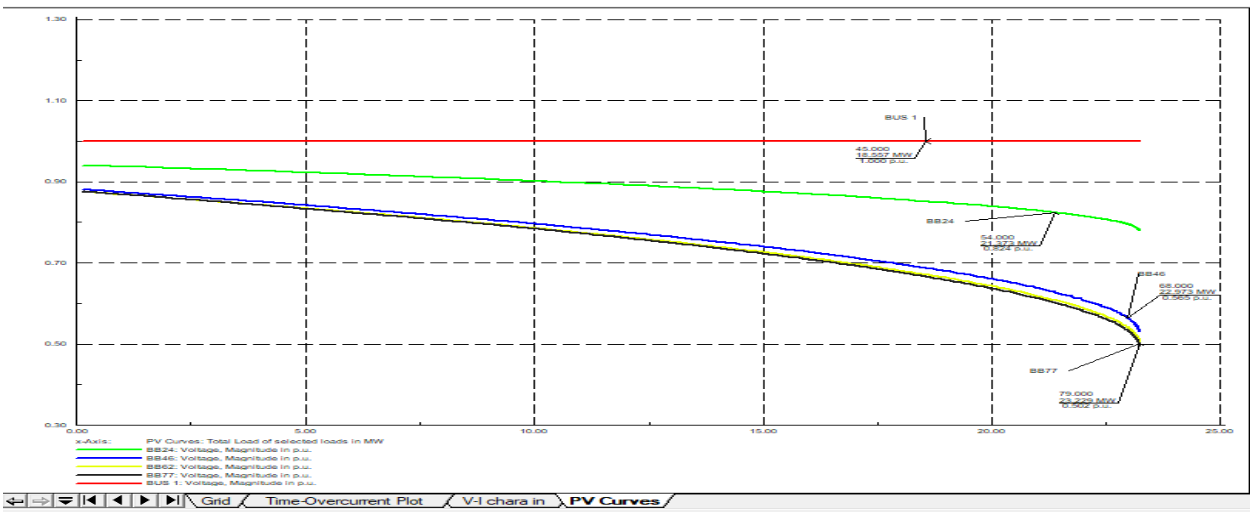

Figure: 4. 30 Voltage stability without DG integration

To examine the impact of DG integration, the voltage stability analysis is made after DG integration and, when the DG injects 16 MW, the p-v curve be came to extreme load of 41.037 MW before voltage collapse as shown in figure 4.31. Now the loading margin of voltage collapse, for a current operating point, the total increment of load in a specified pattern of load increase which could cause a voltage collapse throughout DG injection has been found to be 17.514 MW. This suggests the enhancement of loading margin when DG integrated into distribution system with correct sizing and placement. Finally the overall impact of a DG unit on voltage stability during slow increment of load is positive. This is due to the enhancement of voltage profiles as well as decreased reactive power losses.

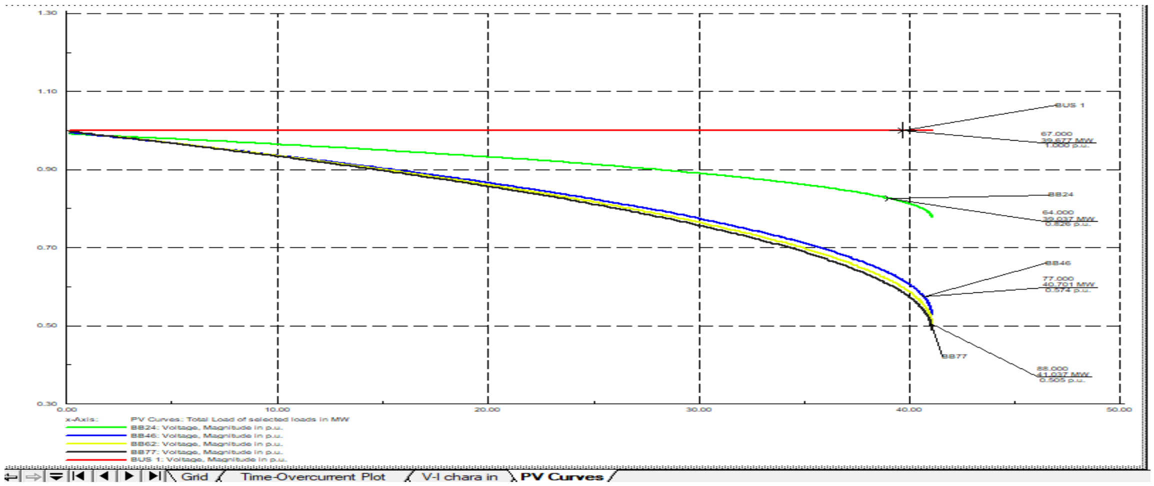

Figure: 4. 31 Voltage stability with DG integration

4.9.4.2. Transient (dynamic) voltage stability

Voltage instability is due to faults is a transient stability problematic which is large disturbance voltage stability deliberate under dynamic conditions. In principle, transient stability problems might occur in distribution networks with DG. The electromagnetic transient (EMT) Simulation of DigSILENT Power Factory 15.1.7 had been utilities in examining single phase to phase, two phase to ground, three phase and three phase to ground short circuits. The electromagnetic transient (EMT) simulation contains the description of variables and events. In this case the variables are phase short circuit currents and their consistent voltages. The short circuit and its clearing time on the selected bus bars are the events.

To examine the transient stability of the advanced model, it considers before fault condition, at fault state as well as after clear the fault for different type of faults such as, three-phase, single phase to ground and two phase to ground short circuits are simulated. In this simulation absolute run time is 0.7s with different type of fault presenting at a different time by considering the impedance of each fault is zero. The figures below shows that investigates of voltage and current wave form during different situations such as, at normal condition, when 3ph fault is follow with there is no protection device, voltage and current wave form during 3ph fault condition and Voltage and current wave form throughout 3ph and LG when the fault is occur at different time and also voltage and current wave form during 3ph, LG and LLG when the fault is accord at different time with protection devices.

This figure 4.32 shows that when the distribution network with DG at normal complaint and it can be seen the wave form of voltage is sinusoidal and the magnitude of short circuit is zero.

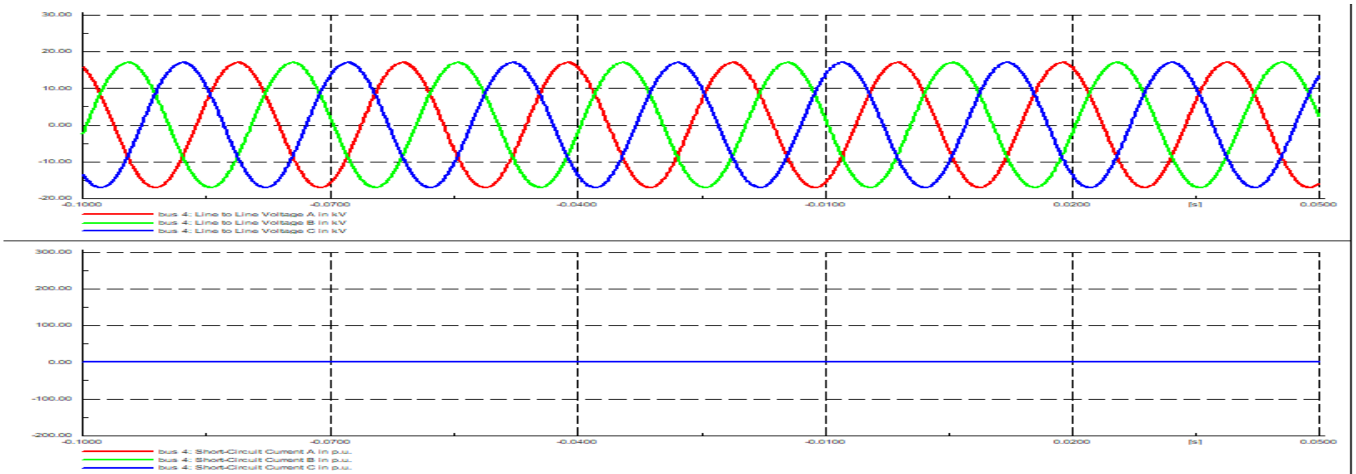

Figure: 4. 32 Voltage and current wave form during normal condition.

The figure 4.33 below shows that voltage and current wave form during 3ph, fault accord and when the distribution network with DG integration have no protection. So, the voltage at the bus comes to zero and the magnitude of fault current continuously unstable after that the distribution system is comes to up normal condition.

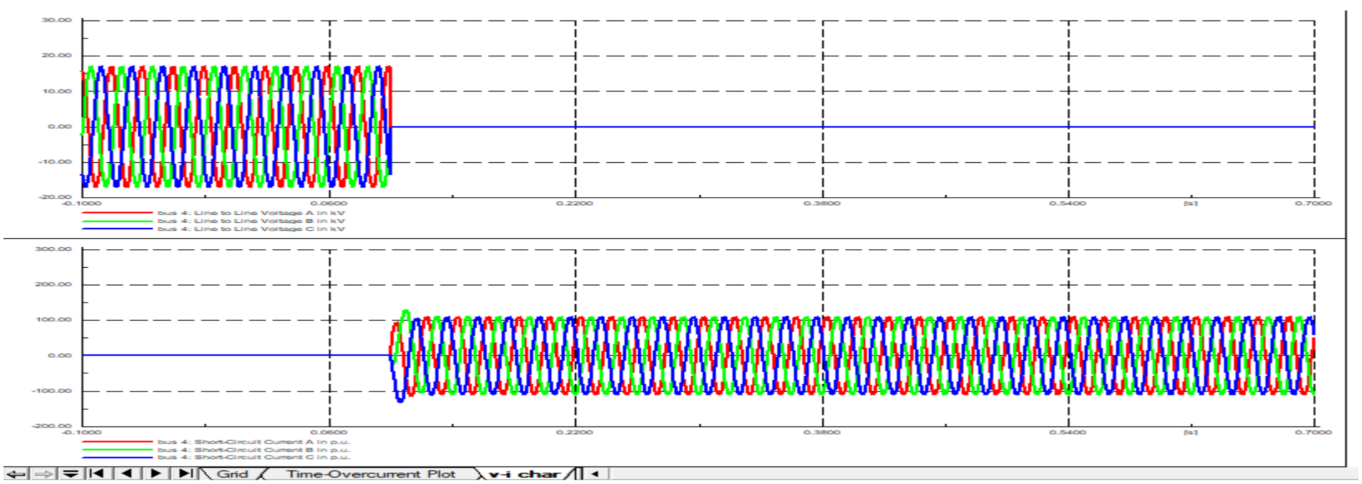

Figure: 4. 33 Voltage and current wave form during 3ph fault occurred when there is no protection

The figure 4.34 shows voltage and current wave form during 3ph, fault accord and when the fault introduced at 0.1s and cleared at 0.2s then the distribution system is comes to stable condition after implement and coordinate the fast overcurrent protection relay.

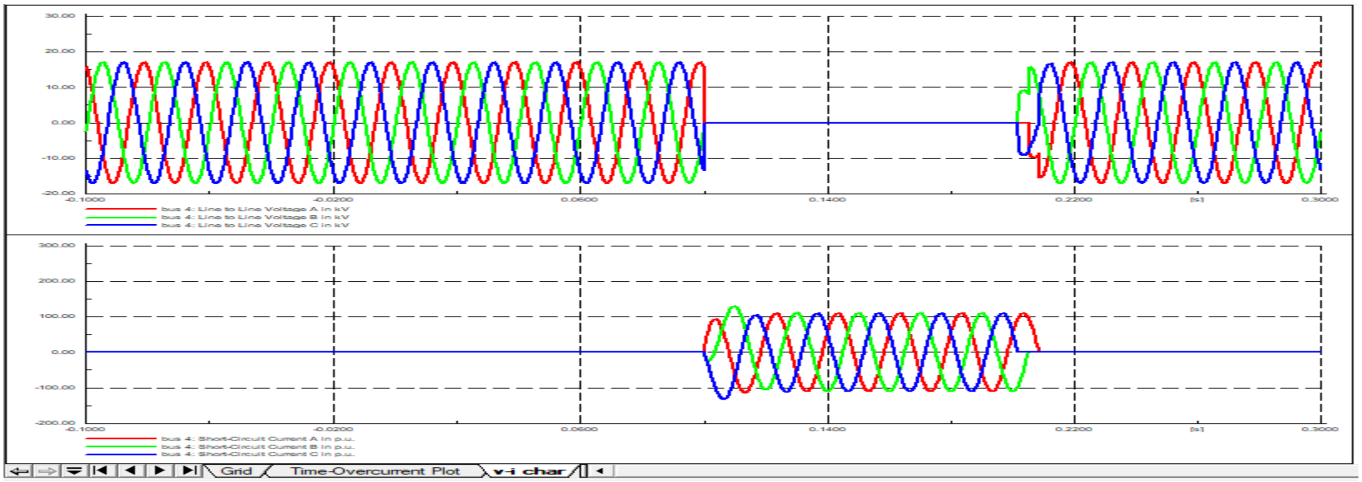

Figure: 4. 34 Voltage and current wave form during 3ph fault

Figure 4.35 shows that voltage and current wave form during 3ph and LG fault accord at different time scenario. The three phase fault introduced at 0.1s and cleared at 0.2s and also the single phase to ground short circuit introduced at 0.3s and cleared at 0.4s, after that the system is stable when you coordinate fast protection relay.

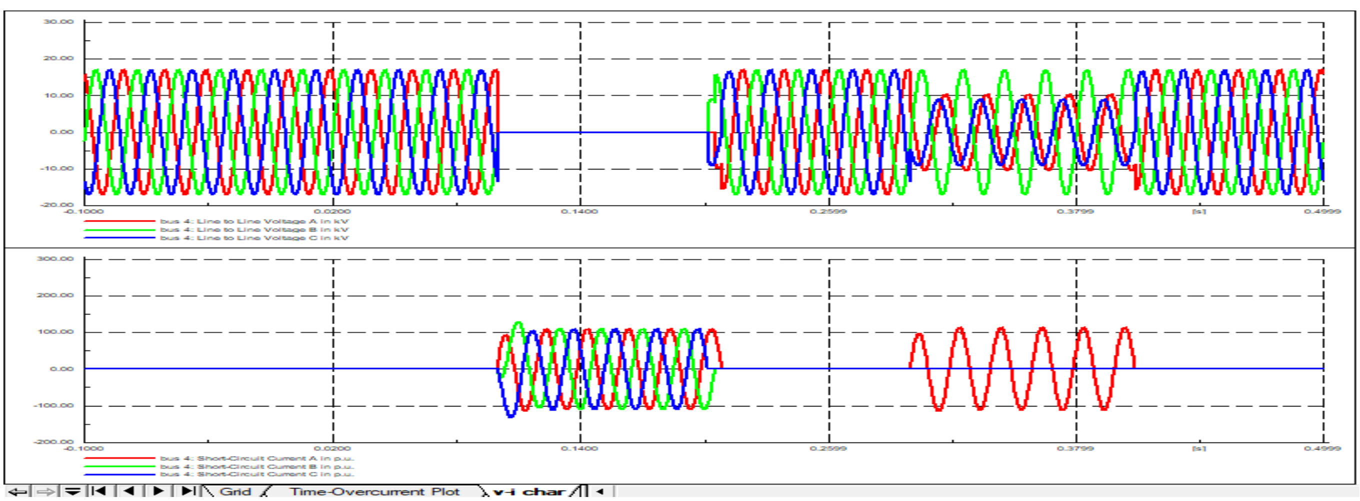

Figure: 4. 35 Voltage and current wave form during 3ph and LG fault at different time

*F*igure 4.36 shows that voltage and current wave form during 3ph, LG and LLG fault accord at different time scenario. The three phase short circuit introduce at 0.1s and cleared at 0.2s, and single phase to ground short circuit introduced at 0.3s and cleared at 0.4s and also the two phase short circuit introduced at 0.5s and cleared at 0.6s. Therefor after that the distribution system is clear the fault it comes to stable condition

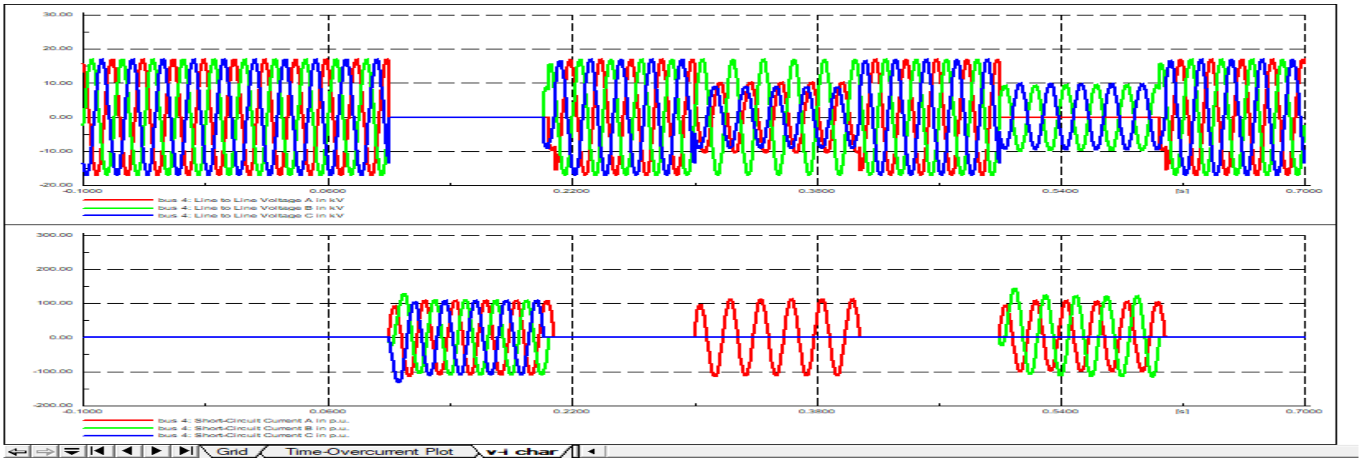

Figure: 4. 36 Voltage and current wave form during 3ph, LG and LLG fault accord at different time

In general the result of the simulation it indicates that the system comes to its original voltage wave form after the clearance the fault with DG injection. Therefore it can be concluded, that the impact of DG on transient stability of the system is positive after implement and coordination the fast overcurrent protection relay by considering its appropriate place with appropriate capacity.

4.10. Cost of the Selected DG

According the International Renewable Energy Agency [43] the costs of renewable energy technologies reached new lows again last year and both solar and wind power have emerged as the most affordable power source for many locations and markets, with cost reductions set to last into the next period. Cost declines across the board in 2018 have reconfirmed the status of renewable power as a highly cost effective energy source.

The basic standard related to the selection of the power system mechanisms in this thesis work is the cost of components, as the main purpose of the work is penetrating the optimum power system configuration that would meet the demand with minimum net present cost and cost of energy. The approximation of the components cost is made based on the current cost available in market.

Initial capital cost of components: It is the total installed cost organized to buying and install the component at the commencement of the project.

Replacement cost: This is the cost required to substitute wear out apparatuses at the end of its life cycle. This cost is different from initial cost of the component, due to the following reasons. At the end of its life cycle not all of the spares of the constituent need to replace, Costs from givers may eliminate or can reduce initial cost, however spare cost may not account travel costs but initial costs do.

Operation and maintenance (O&M) cost: It is the cost accounted for maintenance and operation of the system. The entire scheme mechanisms considered in this thesis has different process and maintenance costs. Miscellaneous O&M costs are considered and also like emission penalties, capacity scarcity penalty and secure process and maintenance costs are include.

4.10.1. Solar PV Size and Cost

According the International Renewable Energy Agency [43] sustained dramatic decline in the cost of electricity from utility scale solar PV continued in 2018, with a fall in the global weighted average of solar PV to USD 0.085/kWh and – 13% lower than for projects commissioned in 2017. This takes the decline between 2010 and 2018 in the global weighted average of solar PV to 77%.

After analyzing different products focusing on the cost provided the following panel is chosen. The reason for choosing the product from the stated business is due to its low cost delivered as long as competence is not a big worry here. The solar panel careful is a 4MW, which is with 4 number of solar module having 250 kW capacity and 4 number of array from a schott Mono-250 Watt Solar Panel Company. The selected panel is mono-crystalline silicon solar cell and factory-made by USA which is known as Item-1202401 model. In this thesis the extra cost and operation and maintenance cost is considered. In this thesis, the installed total cost is taken about $3,306,024. By considering replacement cost and process and maintenance cost of the solar panel is considered 10% and 1% of capital cost respectively.

Table 4. 11 Total capital cost of PV

Life time (yr)	25
Capital cost ($/kWh)	0.085
Capacity of DG (MW)	4
Cost of DG ($)	2,978,400
Replacement cost $ (10% of cost of DG)	297,840
O & M cost $ (1% of cost of DG)	29,784
Total capital cost ($)	3,306,024

4.10.2. Wind Turbine Size and Cost

According the International Renewable Energy Agency [43] the global weighted average of wind projects commissioned in 2018, at USD 0.056/kWh, was 13% lower than in 2017 and 35% lower than in 2010. Costs of electricity wind are now at the lower end of the fossil fuel cost range.

Contingent on the wind speed sources the turbine has to generate large amount of energy to contribute important renewable fraction and this can be performed using single large wind turbine or number of smaller turbines. Quantities of turbines, service time, hub height, Cost of the component, type of electricity produced, cut-in wind speed are the restrictive values to select wind turbine. The selected turbines can generate AC type electricity to content the need of AC load consumer applications. The wind turbine taken for this thesis work is twenty four fuhrlander 0.5 MW AC power rating type to produce 12MW power output. The wind turbine is factory-made by the D-56477 Waigandshain, Germany. In this thesis the wind power installed total cost is taken about $9,831,348. By seeing replacement cost and operation and maintenance cost of the wind turbine is considered about 65% and 2% of capital cost respectively.

Table 4. 12 Total capital cost of wind energy

Life time (yr)	33
Tower height (m)	50
Capital cost ($/kWh)	0.056
Capacity of DG (MW)	12
Cost of DG ($)	5,886,720
Replacement cost $ (65% of cost of DG)	3,826,368
O & M cost $ (2% of cost of DG)	118,260
Total capital cost ($)	9,831,348

4.10.3. Total DG placement result cost analysis

After the resolve of DG location and capacity, cost approximation of the obtained DG size has followed. DG technology also differ in their influence that they impose on the surrounding environment. Hence, to estimate the cost of the DG, the DG technologies selected in this thesis work is wind and photovoltaic due to free emission and it is appropriate to selected site under case study. From table 4.13 the cost of the DG is calculated as follows.

Table 4. 13 Total cost for investment of DG

Total Size of DG (MW)	16
Location of DG	At bus 50
Total cost ($)	13,137,372 $
Total cost in Ethiopian birr by considering current rate 32 (birr)	420,395,904 birr

To calculate the returned cost for the investment of DG is calculate as fellow:

Power loss reduction (PLR) due to the placement of DG is:

PLR =Power loss before DG integrating – power loss after DG integration…………4.1

2.06MW – 0.11MW = 1.95MW

After DG placement total energy saved for one year is:

1.95MW * 24 * 365 = 17,082MWh

According to information from the Ethiopian Electric Utility (EEU), the existing electric power generation, transmission, and distribution costs are, on average, about **$0.09** or in Ethiopian birr 2.88 per kilowatt-hour (kWh), is the current tariff for electricity.

Saving in terms of Ethiopian birr per year is:

$$17{,}082\text{MWh} * 2.88 \left({}^{Birr}/_{kWh}\right) = 49{,}196{,}160 \text{ Birr}$$

The return cost in birr per year for the investment of DG is:

$$ROIC_{DG} = \frac{\text{Total cost of DG instailled}}{\text{Energy saving per year}} \quad \text{.......4.2}$$

where $ROIC_{DG}$ = Return of Investment Cost for DG integration

$$= \frac{420{,}395{,}904 \text{ Birr}}{49{,}196{,}160 \text{ Birr/year}} = \underline{\underline{\mathbf{8.545}}} \text{ year}$$

CHAPTER FIVE

Conclusions, Recommendations and Future Work

5.1. Conclusions

The integration of distributed generation (DG) in the distribution network is gaining momentum, due to their network support capability and modular designs. It is one of the effective and viable planning option for improving the supply quality of the network with ever increasing loads. It is expected that a renewable DG system may play a key role in the future power distribution system for sustainable and emission free energy supply. However, the incorporation of active DG units into conventional passive distribution system is difficulties to distribution system planners due to alterations in existing infrastructure and operational strategies. Moreover, the integration, renewable DG units such as wind and solar photovoltaic based generation system, system planner have to deal with uncertainty in power availability under grid connected and islanded modes of operation.

Generally, in this thesis a methodology for optimal distribution system expansion planning with DG system is developed. Moreover, the distributed generation impact has been investigated with the increasing load and penetration of DG. The analytical method using the voltage sensitivity analysis is implemented and tested on the distribution network using DigSILENT power factory commercial software. In order to reduce line loss, line loading of the distribution network when the load increases, and to enhance all node voltages to within the allowable range distributed generator was integrated into the system. The results are presented by determining the appropriate place at appropriate capacity of DG for this distribution network. Accordingly, TENVDI and maximum active power loss reduction the appropriate location and capacity of DG was found and determined at bus 50 with proper capacity of 12.70 MW with 3.30 MW as a reserve on the feeder of KO1 distribution network. The load demand increment with increment the penetration of DG units to meet the demand requirements for the future was analyzed using extrapolation forecasting technique. As a result the location of DG and its capacity was taken into account to reach an appropriate condition in order to create the stability and fairness for both utility and customer.

With the objective of investigating the impact of DG integration on protection device due to increase the capacity of DG in this radial distribution system case study distribution feeder was identified based on power interruption data and loaded feeder method. Therefore, feeder KO1 of Adwa substation was selected due to loaded feeder and more power interruption occurrence compared to the rest of the feeders. The modelling and simulation of the feeder was carried out using DIgSILENT Power Factory 15.1.7 simulation package. The simulation results before integration the DG indicated that the feeder encountered the total real and reactive power loss of 2.06 MW and 2.95 MVAR, respectively, with major bus voltages were out of acceptable range and also it is over loaded feeder after one year. In order to reduce the total real and reactive power loss and line loading of the system when the demand increases, and also to enhance all node voltages to within allowable range, distributed generator was integrated into the system at appropriate place with appropriate capacity. The cost estimation for the determined DG size was carried out by taking the PV and wind DG type. Consequently, the total cost of selected 16 MW DG was found to be $13,137,372 and the returned of investment cost for the selected DG integration is approximately in 8.545 year.

However, it is well known that the current existing electricity networks, particularly distribution systems, have been designed in radial topology with centralized generation as the main power source to supply the load. Nevertheless, with the presence of DG the power flow is no longer radial. This DG has definitely created both positive and negative impacts on distribution system. To deal with these impacts, various case study projects is conducted in this thesis and the overall research scenarios were investigated on the technical impact of DG on distribution system. The investigations involving a directly connected synchronous DG with proper capacity and place indicated that for a particular DG type the impact on total power loss, voltage profile and voltage stability were positive after integrating the DG as well as when penetration of DG increased with load and also the loading of the line segment is within a limit when it increases the peak demand. The results of the balanced and positive sequence load flow analysis at steady state condition after DG integration pointed out that they have good voltage stability, the total real and reactive power loss was reduced to 0.11 MW and 0.13 MVAR, respectively, and the line loading is reduced to acceptable range when the demand increases and all bus voltages were improved to within acceptable standard range with minimum voltage magnitude that was found at bus 57 and 58 with magnitude of 0.866 and it improves to the range of 0.974 - 1p.u at all bus from the existing distribution network.

Moreover, in order to reduce the impact of the DG on the protection device that comes due to capacity of DG increment in this thesis fast protection over current relay is implement and coordination’s. In this distribution network eleven relays are implemented and coordinated with different time/current setting based on fault tripping time and magnitude of the fault in the line. This implementing and coordination reduces the impact on the protection of overcurrent relay successfully. Also when the load increase with penetration of DG capacity above the current rating setting of the protection relay, the protection devices are upgraded by increasing the margin of the time interval of the each overcurrent relays coordination, then, the upgraded margin of the protection device of the distribution network is highly integrated with DG, when the load with penetration of DG increased.

5.2. Recommendations

Best on the findings of this thesis work, it is concluded that integration of DG with distribution network expansion planning enhances the grid capacity and results in reduction of power loss, improvement of voltage profile, reduction line loading and increases the voltage stability in the case study Adwa distribution substation. In addition, DG technology especially renewable energy based expects to have a key role in the future power distribution system for sustainable and emission free energy supply. Therefore, it is recommended that Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP) should make awareness and encouragements to promote the implementation of distributed generation in distribution networks.

5.3. Suggestions for Future Work

Wind and photovoltaic type of DG source have an impact on power output due to environmental variations and different nonlinear components. In this thesis DG technologies have been limited to Synchronous Generator which is standard models available in DigSILENT Power Factory 15.1.7 without considering their detail design. In addition to this, deep investigation on protection and interconnection of DG was done in radial distribution networks for the selected feeders having pronounced problems.

Therefore, it is suggested that researchers may focus on the following problems:

1. Detailed design of DGs using wind and photovoltaic energy sources.
2. Upgrading the radial distribution network to ring distribution network.
3. Implementation of automatic protection distribution network to isolate and reconnect the DG during disturbance and after disturbance has been cleared.

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Appendixes

Appendix A: Peak Load Demand Forecasting using Matlab

```
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');
```

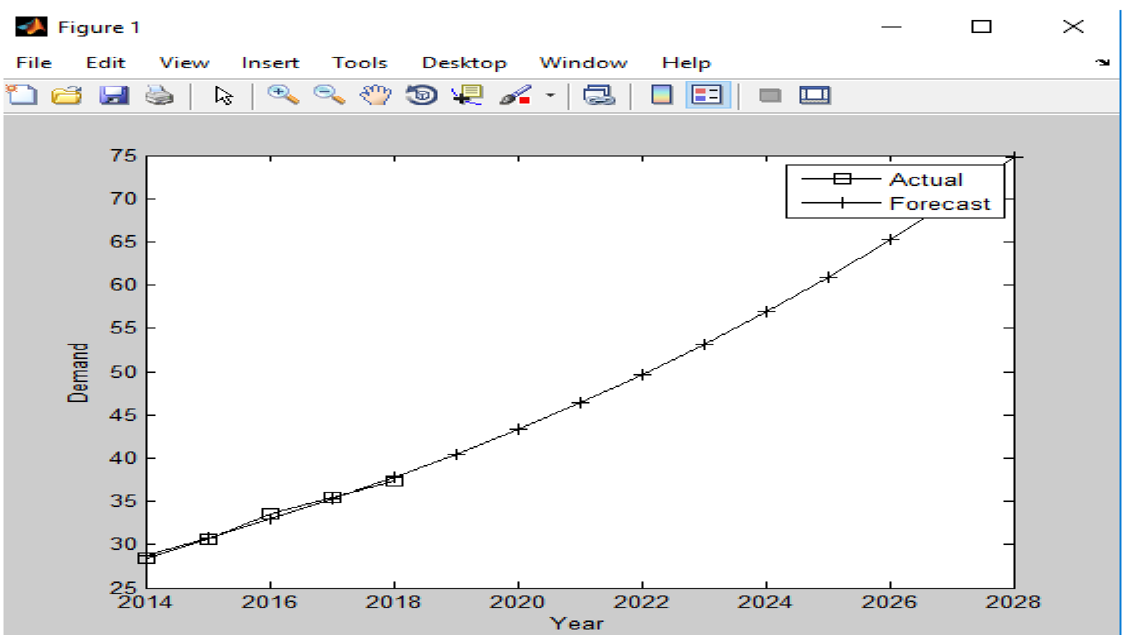
Enter an array of demand values in the form:

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

Enter year/demand values: [2014 28.5; 2015 30.7; 2016 33.5; 2017 35.5; 2018 37.3]

Enter the number of year to predict: 10

Rate of growth =7.07%



YEAR	ACTUAL	FORECAST
2014	28.50	28.74
2015	30.70	30.77
2016	33.50	32.95
2017	35.50	35.28
2018	-	37.77
2019	-	40.44
2020	-	43.30
2021	-	46.37
2022	-	49.65
2023	-	53.16
2024	-	56.92
2025	-	60.94
2026	-	65.25
2027	-	69.87
2028	-	74.81

Appendix B: Voltage Profiles of the Feeder

B1: Voltage Profiles before DG Integration

```
-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                        Complete System Report: Voltage Profiles |
-----------------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence         |    Automatic Model Adaptation for Convergence           No      |
|    Automatic Tap Adjust of Transformers          No  |    Max. Acceptable Load Flow Error for                          |
|    Consider Reactive Power Limits                No  |       Nodes                                             1.00 kVA |
|                                                      |       Model Equations                                   0.10 %   |
-----------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------
| Grid: Grid                System Stage: Grid         | Study Case: Study Case          | Annex:                 / 1 |
-----------------------------------------------------------------------------------------------------------------------
|                    rtd.V      Bus - voltage                          Voltage - Deviation [%]                          |
|                    [kV]  [p.u.]     [kV]   [deg]          -10       -5         0        +5        +10                  |
-----------------------------------------------------------------------------------------------------------------------
|BB21                                                                                                                   |
|                   15.00   0.937    14.05  -1.80                                                                       |
|BB24                                                                                                                   |
|                   15.00   0.937    14.05  -1.81                                                                       |
|BB23                                                                                                                   |
|                   15.00   0.937    14.05  -1.81                                                                       |
|BB22                                                                                                                   |
|                   15.00   0.937    14.05  -1.81                                                                       |
|BB10                                                                                                                   |
|                   15.00   0.894    13.41  -3.14                                                                       |
|BB11                                                                                                                   |
|                   15.00   0.886    13.28  -3.41                                                                       |
|BB12                                                                                                                   |
|                   15.00   0.877    13.16  -3.69                                                                       |
|BB25                                                                                                                   |
|                   15.00   0.876    13.14  -3.74                                                                       |
|BB16                                                                                                                   |
|                   15.00   0.988    14.81  -0.34                                                                       |
|BB15                                                                                                                   |
|                   15.00   0.988    14.81  -0.34                                                                       |
|BB14                                                                                                                   |
|                   15.00   0.988    14.82  -0.34                                                                       |
|BB13                                                                                                                   |
|                   15.00   0.988    14.82  -0.33                                                                       |
|BB9                                                                                                                    |
|                   15.00   0.902    13.53  -2.87                                                                       |
|BB89                                                                                                                   |
|                   15.00   0.911    13.66  -2.60                                                                       |
|BB8                                                                                                                    |
|                   15.00   0.919    13.79  -2.33                                                                       |
|BB7                                                                                                                    |
|                   15.00   0.928    13.92  -2.06                                                                       |
|BB6                                                                                                                    |
|                   15.00   0.937    14.06  -1.79                                                                       |
|BB5                                                                                                                    |
|                   15.00   0.947    14.20  -1.51                                                                       |
|BB4                                                                                                                    |
|                   15.00   0.956    14.34  -1.22                                                                       |
|BB3                                                                                                                    |
```

	15.00	0.967	14.50	-0.92
BB2	15.00	0.978	14.66	-0.62
BB20	15.00	0.954	14.31	-1.29
BB19	15.00	0.954	14.32	-1.28
BB18	15.00	0.955	14.33	-1.27
BB17	15.00	0.956	14.33	-1.24
BB27	15.00	0.876	13.14	-3.74
BB38	15.00	0.873	13.10	-3.82
BB35	15.00	0.874	13.11	-3.79
BB39	15.00	0.873	13.10	-3.82
BB36	15.00	0.874	13.11	-3.80
BB37	15.00	0.874	13.10	-3.81
BB41	15.00	0.872	13.08	-3.84
BB40	15.00	0.872	13.08	-3.84
BB65	15.00	0.872	13.08	-3.84
BB66	15.00	0.872	13.08	-3.84
BB67	15.00	0.872	13.07	-3.84
BB677	15.00	0.871	13.07	-3.84
BB52	15.00	0.867	13.01	-4.06
BB51	15.00	0.867	13.01	-4.05
BB49	15.00	0.868	13.01	-4.04
BB47	15.00	0.868	13.02	-4.04
BB48	15.00	0.868	13.01	-4.04
BB43	15.00	0.873	13.10	-3.83
BB45	15.00	0.873	13.10	-3.84
BB50	15.00	0.868	13.02	-4.03
BB46				

	15.00	0.872	13.08	-3.87
BB44	15.00	0.873	13.10	-3.84
BB53	15.00	0.867	13.00	-4.08
BB64	15.00	0.867	13.00	-4.08
BB54	15.00	0.866	13.00	-4.09
BB59	15.00	0.866	13.00	-4.09
BB60	15.00	0.866	12.99	-4.09
BB61	15.00	0.866	12.99	-4.09
BB63	15.00	0.867	13.00	-4.08
BB62	15.00	0.866	12.99	-4.09
BB28	15.00	0.876	13.14	-3.74
BB26	15.00	0.876	13.14	-3.74
B69	15.00	0.868	13.01	-4.04
BB70	15.00	0.867	13.01	-4.05
BB72	15.00	0.867	13.00	-4.07
BB73	15.00	0.867	13.00	-4.08
BB74	15.00	0.867	13.00	-4.08
BB75	15.00	0.866	13.00	-4.08
BB76	15.00	0.866	13.00	-4.09
BB77	15.00	0.866	12.99	-4.09
BB71	15.00	0.867	13.01	-4.06
BB1	15.00	0.988	14.83	-0.32
BB56	15.00	0.866	12.99	-4.09
BB57	15.00	0.866	12.99	-4.10
BB58	15.00	0.866	12.99	-4.10
BB55	15.00	0.866	12.99	-4.09

B2: Voltage Profile after DG Integration

```
----------------------------------------------------------------------------------------------------
|             |                                                 |  DIgSILENT  | Project:           |
|             |                                                 | PowerFactory |-------------------|
|             |                                                 |   15.1.7    | Date:  8/19/2019    |
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
| Load Flow Calculation                                      Complete System Report: Voltage Profiles |
----------------------------------------------------------------------------------------------------
|   AC Load Flow, balanced, positive sequence          |  Automatic Model Adaptation for Convergence    No      |
|   Automatic Tap Adjust of Transformers         No    |  Max. Acceptable Load Flow Error for                    |
|   Consider Reactive Power Limits               No    |     Nodes                                 1.00 kVA    |
|                                                      |     Model Equations                       0.10 %      |
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
| Grid: Grid            System Stage: Grid        | Study Case: Study Case          | Annex:           / 1 |
----------------------------------------------------------------------------------------------------
|                rtd.V     Bus - voltage                         Voltage - Deviation [%]             |
|                 [kV]  [p.u.]    [kV]  [deg]         -10        -5         0        +5        +10    |
----------------------------------------------------------------------------------------------------
|BB21                                                                                                |
|               15.00   0.983   14.75  -0.38                                                          |
|BB24                                                                                                |
|               15.00   0.983   14.75  -0.38                                                          |
|BB23                                                                                                |
|               15.00   0.983   14.75  -0.38                                                          |
|BB22                                                                                                |
|               15.00   0.983   14.75  -0.38                                                          |
|BB10                                                                                                |
|               15.00   0.978   14.67  -0.40                                                          |
|BB11                                                                                                |
|               15.00   0.977   14.66  -0.40                                                          |
|BB12                                                                                                |
|               15.00   0.977   14.65  -0.39                                                          |
|BB25                                                                                                |
|               15.00   0.976   14.65  -0.39                                                          |
|BB16                                                                                                |
|               15.00   0.995   14.93  -0.12                                                          |
|BB15                                                                                                |
|               15.00   0.995   14.93  -0.12                                                          |
|BB14                                                                                                |
|               15.00   0.996   14.93  -0.11                                                          |
|BB13                                                                                                |
|               15.00   0.996   14.94  -0.11                                                          |
|BB9                                                                                                 |
|               15.00   0.979   14.68  -0.40                                                          |
|BB89                                                                                                |
|               15.00   0.980   14.70  -0.40                                                          |
|BB8                                                                                                 |
|               15.00   0.981   14.71  -0.39                                                          |
|BB7                                                                                                 |
|               15.00   0.982   14.73  -0.38                                                          |
|BB6                                                                                                 |
|               15.00   0.984   14.75  -0.36                                                          |
|BB5                                                                                                 |
|               15.00   0.985   14.78  -0.33                                                          |
|BB4                                                                                                 |
|               15.00   0.987   14.81  -0.29                                                          |
|BB3                                                                                                 |
```

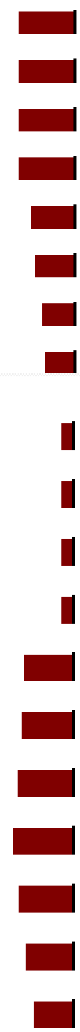
```
|                15.00   0.990   14.85  -0.23
|BB2
|                15.00   0.993   14.90  -0.16
|BB20
|                15.00   0.985   14.78  -0.36
|BB19
|                15.00   0.986   14.78  -0.35
|BB18
|                15.00   0.986   14.79  -0.34
|BB17
|                15.00   0.987   14.80  -0.31
|BB27
|                15.00   0.976   14.65  -0.39
|BB38
|                15.00   0.975   14.63  -0.40
|BB35
|                15.00   0.976   14.65  -0.38
|BB39
|                15.00   0.975   14.63  -0.41
|BB36
|                15.00   0.976   14.64  -0.39
|BB37
|                15.00   0.976   14.64  -0.40
|BB41
|                15.00   0.974   14.61  -0.42
|BB40
|                15.00   0.974   14.62  -0.42
|BB65
|                15.00   0.974   14.61  -0.42
|BB66
|                15.00   0.974   14.61  -0.42
|BB67
|                15.00   0.974   14.61  -0.42
|BB677
|                15.00   0.974   14.61  -0.42
|BB52
|                15.00   0.979   14.69  -0.28
|BB51
|                15.00   0.979   14.69  -0.27
|BB49
|                15.00   0.980   14.69  -0.26
|BB47
|                15.00   0.980   14.70  -0.26
|BB48
|                15.00   0.980   14.69  -0.26
|BB43
|                15.00   0.977   14.65  -0.37
|BB45
|                15.00   0.977   14.65  -0.37
|BB50
|                15.00   0.980   14.70  -0.25
|BB46
```

|	15.00	0.977	14.66	-0.35
|BB44				
|	15.00	0.977	14.65	-0.37
|BB53				
|	15.00	0.979	14.68	-0.29
|BB64				
|	15.00	0.979	14.68	-0.29
|BB54				
|	15.00	0.979	14.68	-0.29
|BB59				
|	15.00	0.978	14.68	-0.30
|BB60				
|	15.00	0.978	14.68	-0.30
|BB61				
|	15.00	0.978	14.68	-0.30
|BB63				
|	15.00	0.979	14.68	-0.29
|BB62				
|	15.00	0.978	14.68	-0.30
|BB28				
|	15.00	0.976	14.64	-0.39
|BB26				
|	15.00	0.976	14.65	-0.39
|B69				
|	15.00	0.980	14.69	-0.26
|BB70				
|	15.00	0.979	14.69	-0.27
|BB72				
|	15.00	0.979	14.68	-0.28
|BB73				
|	15.00	0.979	14.68	-0.29
|BB74				
|	15.00	0.979	14.68	-0.29
|BB75				
|	15.00	0.979	14.68	-0.29
|BB76				
|	15.00	0.978	14.68	-0.30
|BB77				
|	15.00	0.978	14.68	-0.30
|BB71				
|	15.00	0.979	14.69	-0.28
|BB1				
|	15.00	0.996	14.94	-0.09
|BB56				
|	15.00	0.978	14.68	-0.30
|BB57				
|	15.00	0.978	14.67	-0.30
|BB58				
|	15.00	0.978	14.67	-0.30
|BB55				
|	15.00	0.978	14.68	-0.30
|BUS 1				

B3: Voltage Profile after DG Integration when Increase the Load with Penetration of DG

```
---------------------------------------------------------------------------------------------------------
|                |                                            |  DIgSILENT  | Project:                  |
|                |                                            | PowerFactory |--------------------------
|                |                                            |    15.1.7   | Date:   8/29/2019         |
---------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                       Complete System Report: Voltage Profiles |
---------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence         |   Automatic Model Adaptation for Convergence      No      |
|    Automatic Tap Adjust of Transformers         No   |   Max. Acceptable Load Flow Error for                     |
|    Consider Reactive Power Limits               No   |      Nodes                                      1.00 kVA  |
|                                                      |      Model Equations                            0.10 %    |
---------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------
| Grid: Grid              System Stage: Grid          | Study Case: Study Case          | Annex:         / 1  |
---------------------------------------------------------------------------------------------------------
|                  rtd.V      Bus - voltage                          Voltage - Deviation [%]               |
|                  [kV]  [p.u.]    [kV]   [deg]          -10        -5          0          +5         +10   |
---------------------------------------------------------------------------------------------------------
|BB21                                                                                                      |
|                 15.00   0.976   14.63  -0.42                                                             |
|BB24                                                                                                      |
|                 15.00   0.975   14.63  -0.42                                                             |
|BB23                                                                                                      |
|                 15.00   0.975   14.63  -0.42                                                             |
|BB22                                                                                                      |
|                 15.00   0.975   14.63  -0.42                                                             |
|BB10                                                                                                      |
|                 15.00   0.981   14.71   0.08                                                             |
|BB11                                                                                                      |
|                 15.00   0.983   14.74   0.21                                                             |
|BB12                                                                                                      |
|                 15.00   0.986   14.79   0.38                                                             |
|BB25                                                                                                      |
|                 15.00   0.986   14.80   0.41                                                             |

|BB16                                                                                                      |
|                 15.00   0.994   14.91  -0.13                                                             |
|BB15                                                                                                      |
|                 15.00   0.994   14.91  -0.12                                                             |
|BB14                                                                                                      |
|                 15.00   0.994   14.92  -0.12                                                             |
|BB13                                                                                                      |
|                 15.00   0.995   14.92  -0.11                                                             |
|BB9                                                                                                       |
|                 15.00   0.979   14.68  -0.05                                                             |
|BB89                                                                                                      |
|                 15.00   0.977   14.65  -0.18                                                             |
|BB8                                                                                                       |
|                 15.00   0.975   14.63  -0.30                                                             |
|BB7                                                                                                       |
|                 15.00   0.973   14.60  -0.42                                                             |
|BB6                                                                                                       |
|                 15.00   0.976   14.64  -0.40                                                             |
|BB5                                                                                                       |
|                 15.00   0.979   14.69  -0.36                                                             |
|BB4                                                                                                       |
|                 15.00   0.982   14.74  -0.32                                                             |
|BB3                                                                                                       |
```



| 15.00 0.986 14.80 -0.25 |
|BB2 |
| 15.00 0.991 14.86 -0.18 |
|BB20 |
| 15.00 0.980 14.71 -0.38 |
|BB19 |
| 15.00 0.981 14.71 -0.38 |
|BB18 |
| 15.00 0.981 14.72 -0.36 |
|BB17 |
| 15.00 0.982 14.73 -0.34 |
|BB27 |
| 15.00 0.986 14.79 0.41 |
|BB38 |
| 15.00 0.986 14.79 0.43 |
|BB35 |
| 15.00 0.987 14.81 0.44 |
|BB39 |
| 15.00 0.986 14.79 0.43 |
|BB36 |
| 15.00 0.987 14.80 0.44 |
|BB37 |
| 15.00 0.986 14.80 0.43 |
|BB41 |
| 15.00 0.985 14.78 0.42 |
|BB40 |
| 15.00 0.985 14.78 0.42 |
|BB65 |
| 15.00 0.985 14.78 0.42 |
|BB66 |
| 15.00 0.985 14.77 0.42 |
|BB67 |
| 15.00 0.985 14.77 0.43 |
|BB677 |
| 15.00 0.985 14.77 0.43 |

|BB52 |
| 15.00 0.997 14.95 0.82 |
|BB51 |
| 15.00 0.998 14.96 0.84 |
|BB49 |
| 15.00 0.999 14.98 0.87 |
|BB47 |
| 15.00 0.999 14.98 0.88 |
|BB48 |
| 15.00 0.999 14.98 0.87 |
|BB43 |
| 15.00 0.988 14.82 0.48 |
|BB45 |
| 15.00 0.987 14.81 0.45 |
|BB50 |
| 15.00 0.999 14.98 0.88 |
|BB46 |

| 15.00 0.990 14.85 0.56 |
|BB44 |
| 15.00 0.987 14.81 0.46 |
|BB53 |
| 15.00 0.996 14.94 0.79 |
|BB64 |
| 15.00 0.996 14.94 0.79 |
|BB54 |
| 15.00 0.996 14.93 0.78 |
|BB59 |
| 15.00 0.995 14.93 0.77 |
|BB60 |
| 15.00 0.995 14.93 0.77 |
|BB61 |
| 15.00 0.995 14.93 0.77 |
|BB63 |
| 15.00 0.996 14.94 0.79 |
|BB62 |
| 15.00 0.995 14.93 0.77 |
|BB28 |
| 15.00 0.986 14.79 0.41 |
|BB26 |
| 15.00 0.986 14.80 0.41 |
|B69 |
| 15.00 0.998 14.97 0.86 |
|BB70 |
| 15.00 0.997 14.96 0.84 |
|BB72 |
| 15.00 0.996 14.95 0.80 |
|BB73 |
| 15.00 0.996 14.94 0.78 |
|BB74 |
| 15.00 0.995 14.93 0.77 |
|BB75 |
| 15.00 0.995 14.92 0.75 |
|BB76 |
| 15.00 0.994 14.92 0.74 |
|BB77 |
| 15.00 0.994 14.91 0.73 |
|BB71 |
| 15.00 0.997 14.95 0.82 |
|BB1 |
| 15.00 0.995 14.92 -0.10 |
|BB56 |
| 15.00 0.995 14.92 0.74 |
|BB57 |
| 15.00 0.994 14.91 0.73 |
|BB58 |
| 15.00 0.994 14.91 0.72 |
|BB55 |
| 15.00 0.995 14.93 0.76 |
|BUS 1 |

Appendix C: Percentage of Line loading after one year

C1: Percentage of Line Loading without DG Integration after one year

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| Load Flow Calculation                                                                                    Edge Elements |
---------------------------------------------------------------------------------------------------------------------------
|     AC Load Flow, balanced, positive sequence               |   Automatic Model Adaptation for Convergence          No       |
|     Automatic Tap Adjust of Transformers          No        |   Max. Acceptable Load Flow Error for                          |
|     Consider Reactive Power Limits                No        |      Nodes                                            1.00 kVA |
|                                                             |      Model Equations                                  0.10 %   |
---------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------------------
|               |                                                      |   DIgSILENT   | Project:                          |
|               |                                                      |  PowerFactory |-----------------------------------
|               |                                                      |     15.1.7    | Date:  8/19/2019                  |
---------------------------------------------------------------------------------------------------------------------------
| Grid: Grid              System Stage: Grid          | Study Case: Study Case              | Annex:                  / 1  |
---------------------------------------------------------------------------------------------------------------------------
|                                                                     Active     Reactive      Power.-                      |
|                                  Loading                            Power      Power         factor         Current       |
|Name                      Type      [%]            Busbar             [MW]      [Mvar]         [-]       [kA]      [p.u.]   |
---------------------------------------------------------------------------------------------------------------------------
```

Name	Type	Loading [%]	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power-factor [-]	Current [kA]	Current [p.u.]
External Grid	Xnet		BUS 1	32.187	19.397	0.86	1.446	0.021
L1	Lne	114.96	BB1	30.297	18.159	0.86	1.380	1.150
			BB2	-29.989	-17.712	-0.86	1.380	1.150
L10	Lne	90.41	BB9	21.669	11.886	0.88	1.085	0.904
			BB10	-21.478	-11.609	-0.88	1.085	0.904
L11	Lne	89.18	BB10	21.178	11.464	0.88	1.070	0.892
			BB11	-20.993	-11.195	-0.88	1.070	0.892
L12	Lne	88.35	BB11	20.793	11.098	0.88	1.060	0.883
			BB12	-20.610	-10.835	-0.89	1.060	0.883
L13	Lne	3.79	BB1	1.050	0.505	0.90	0.046	0.038
			BB13	-1.050	-0.505	-0.90	0.046	0.038
L14	Lne	1.99	BB13	0.550	0.263	0.90	0.024	0.020
			BB14	-0.550	-0.264	-0.90	0.024	0.020
L15	Lne	1.27	BB14	0.350	0.167	0.90	0.015	0.013
			BB15	-0.350	-0.168	-0.90	0.015	0.013
L16	Lne	0.18	BB15	0.050	0.023	0.91	0.002	0.002
			BB16	-0.050	-0.024	-0.90	0.002	0.002
L17	Lne	9.44	BB17	-2.501	-1.210	-0.90	0.113	0.094
			BB4	2.503	1.212	0.90	0.113	0.094
L18	Lne	5.67	BB17	1.501	0.725	0.90	0.068	0.057
			BB18	-1.501	-0.725	-0.90	0.068	0.057
L19	Lne	4.91	BB18	1.301	0.628	0.90	0.059	0.049
			BB19	-1.300	-0.629	-0.90	0.059	0.049
L2	Lne	113.14	BB2	29.489	17.470	0.86	1.358	1.131

			BB3	-29.190	-17.037	-0.86	1.358	1.131
L20	Lne	1.89	BB19	0.500	0.241	0.90	0.023	0.019
			BB20	-0.500	-0.242	-0.90	0.023	0.019
L21	Lne	4.06	BB6	1.050	0.508	0.90	0.049	0.041
			BB21	-1.050	-0.508	-0.90	0.049	0.041
L22	Lne	2.90	BB21	0.750	0.363	0.90	0.035	0.029
			BB22	-0.750	-0.363	-0.90	0.035	0.029
L23	Lne	0.97	BB22	0.250	0.121	0.90	0.012	0.010
			BB23	-0.250	-0.121	-0.90	0.012	0.010
L24	Lne	0.19	BB23	0.050	0.024	0.90	0.002	0.002
			BB24	-0.050	-0.024	-0.90	0.002	0.002
L25	Lne	87.93	BB12	20.510	10.786	0.89	1.055	0.879
			BB25	-20.474	-10.734	-0.89	1.055	0.879
L26	Lne	1.37	BB25	0.325	0.157	0.90	0.016	0.014
			BB26	-0.325	-0.157	-0.90	0.016	0.014
L27	Lne	1.27	BB26	0.300	0.145	0.90	0.015	0.013
			BB27	-0.300	-0.145	-0.90	0.015	0.013
L28	Lne	1.27	BB27	0.300	0.145	0.90	0.015	0.013
			BB28	-0.300	-0.145	-0.90	0.015	0.013
L3	Lne	111.29	BB3	28.690	16.795	0.86	1.335	1.113
			BB4	-28.401	-16.376	-0.87	1.335	1.113
L31	Lne	84.44	BB25	19.649	10.335	0.89	1.013	0.844
			BB35	-19.616	-10.287	-0.89	1.013	0.844
L38	Lne	10.99	BB37	2.278	1.763	0.79	0.132	0.110
			BB38	-2.278	-1.762	-0.79	0.132	0.110
L39	Lne	10.78	BB38	2.228	1.738	0.79	0.129	0.108
			BB39	-2.227	-1.737	-0.79	0.129	0.108
L4	Lne	99.99	BB4	25.398	14.922	0.86	1.200	1.000
			BB5	-25.164	-14.584	-0.87	1.200	1.000
L40	Lne	9.55	BB39	1.927	1.592	0.77	0.115	0.095
			BB40	-1.926	-1.590	-0.77	0.115	0.095
L41	Lne	5.51	BB40	0.926	1.106	0.64	0.066	0.055
			BB41	-0.925	-1.106	-0.64	0.066	0.055
L42	Lne	5.42	BB41	0.900	1.094	0.64	0.065	0.054
			BB65	-0.900	-1.094	-0.64	0.065	0.054
L43	Lne	5.42	BB65	0.900	1.094	0.64	0.065	0.054
			BB66	-0.900	-1.094	-0.64	0.065	0.054
L44	Lne	4.66	BB66	0.700	0.997	0.57	0.056	0.047
			BB67	-0.700	-0.997	-0.57	0.056	0.047
L45	Lne	3.94	BB67	0.500	0.900	0.49	0.047	0.039
			BB677	-0.500	-0.900	-0.49	0.047	0.039
L46	Lne	62.63	BB35	14.736	7.262	0.90	0.752	0.626
			BB42	-14.717	-7.236	-0.90	0.752	0.626
L47	Lne	3.61	BB42	0.850	0.411	0.90	0.043	0.036
			BB43	-0.850	-0.411	-0.90	0.043	0.036
L48	Lne	2.33	BB43	0.550	0.266	0.90	0.028	0.023
			BB44	-0.550	-0.266	-0.90	0.028	0.023
L49	Lne	2.12	BB44	0.500	0.242	0.90	0.025	0.021
			BB45	-0.500	-0.242	-0.90	0.025	0.021
L5	Lne	99.61	BB5	25.064	14.536	0.87	1.195	0.996
			BB6	-24.833	-14.200	-0.87	1.195	0.996
L50	Lne	59.02	BB42	13.867	6.825	0.90	0.708	0.590
			BB46	-13.851	-6.801	-0.90	0.708	0.590

L51	Lne	56.90	BB46	13.351	6.559	0.90	0.683	0.569
			BB50	-13.275	-6.450	-0.90	0.683	0.569
L52	Lne	4.71	BB50	1.100	0.532	0.90	0.057	0.047
			BB47	-1.100	-0.533	-0.90	0.057	0.047
L53	Lne	3.43	BB47	0.800	0.387	0.90	0.041	0.034
			BB48	-0.800	-0.387	-0.90	0.041	0.034
L54	Lne	2.14	BB48	0.500	0.242	0.90	0.026	0.021
			BB49	-0.500	-0.242	-0.90	0.026	0.021
L55	Lne	35.89	BB50	8.371	4.072	0.90	0.431	0.359
			BB51	-8.365	-4.063	-0.90	0.431	0.359
L56	Lne	30.74	BB51	7.165	3.482	0.90	0.369	0.307
			BB52	-7.160	-3.476	-0.90	0.369	0.307
L57	Lne	30.53	BB52	7.110	3.452	0.90	0.366	0.305
			BB53	-7.106	-3.445	-0.90	0.366	0.305
L58	Lne	5.58	BB53	1.300	0.629	0.90	0.067	0.056
			BB63	-1.300	-0.629	-0.90	0.067	0.056
L59	Lne	0.43	BB63	0.100	0.048	0.90	0.005	0.004
			BB64	-0.100	-0.048	-0.90	0.005	0.004
L6	Lne	94.79	BB6	23.582	13.596	0.87	1.137	0.948
			BB7	-23.372	-13.292	-0.87	1.138	0.948
L60	Lne	24.51	BB53	5.706	2.768	0.90	0.294	0.245
			BB54	-5.703	-2.764	-0.90	0.294	0.245
L61	Lne	10.32	BB54	2.401	1.164	0.90	0.124	0.103
			BB59	-2.401	-1.163	-0.90	0.124	0.103
L62	Lne	9.03	BB59	2.101	1.018	0.90	0.108	0.090
			BB60	-2.100	-1.017	-0.90	0.108	0.090
L63	Lne	8.60	BB60	2.000	0.969	0.90	0.103	0.086
			BB61	-2.000	-0.969	-0.90	0.103	0.086
L64	Lne	4.30	BB61	1.000	0.484	0.90	0.052	0.043
			BB62	-1.000	-0.484	-0.90	0.052	0.043
L65	Lne	13.76	BB54	3.202	1.552	0.90	0.165	0.138
			BB55	-3.201	-1.551	-0.90	0.165	0.138
L66	Lne	9.46	BB55	2.201	1.066	0.90	0.114	0.095
			BB56	-2.200	-1.066	-0.90	0.114	0.095
L67	Lne	8.60	BB56	2.000	0.969	0.90	0.103	0.086
			BB57	-2.000	-0.969	-0.90	0.103	0.086
L68	Lne	4.30	BB57	1.000	0.484	0.90	0.052	0.043
			BB58	-1.000	-0.484	-0.90	0.052	0.043
L69	Lne	15.45	BB50	3.605	1.749	0.90	0.185	0.154
			B69	-3.604	-1.747	-0.90	0.185	0.154
L7	Lne	94.01	BB7	23.172	13.195	0.87	1.128	0.940
			BB8	-22.966	-12.897	-0.87	1.128	0.940
L70	Lne	15.02	B69	3.504	1.699	0.90	0.180	0.150
			BB70	-3.502	-1.698	-0.90	0.180	0.150
L71	Lne	12.87	BB70	3.002	1.455	0.90	0.154	0.129
			BB71	-3.002	-1.454	-0.90	0.154	0.129
L72	Lne	11.59	BB71	2.702	1.309	0.90	0.139	0.116
			BB72	-2.701	-1.308	-0.90	0.139	0.116
L73	Lne	9.44	BB72	2.201	1.066	0.90	0.113	0.094
			BB73	-2.201	-1.066	-0.90	0.113	0.094
L74	Lne	8.16	BB73	1.901	0.921	0.90	0.098	0.082
			BB74	-1.900	-0.920	-0.90	0.098	0.082
L75	Lne	6.01	BB74	1.400	0.678	0.90	0.072	0.060

C2: Percentage of line loading with DG Integration after one year

Load Flow Calculation		Edge Elements
AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergence: No
Automatic Tap Adjust of Transformers	No	Max. Acceptable Load Flow Error for
Consider Reactive Power Limits	No	Nodes: 1.00 kVA
		Model Equations: 0.10 %

	DIgSILENT PowerFactory 15.1.7	Project:
		Date: 8/19/2019

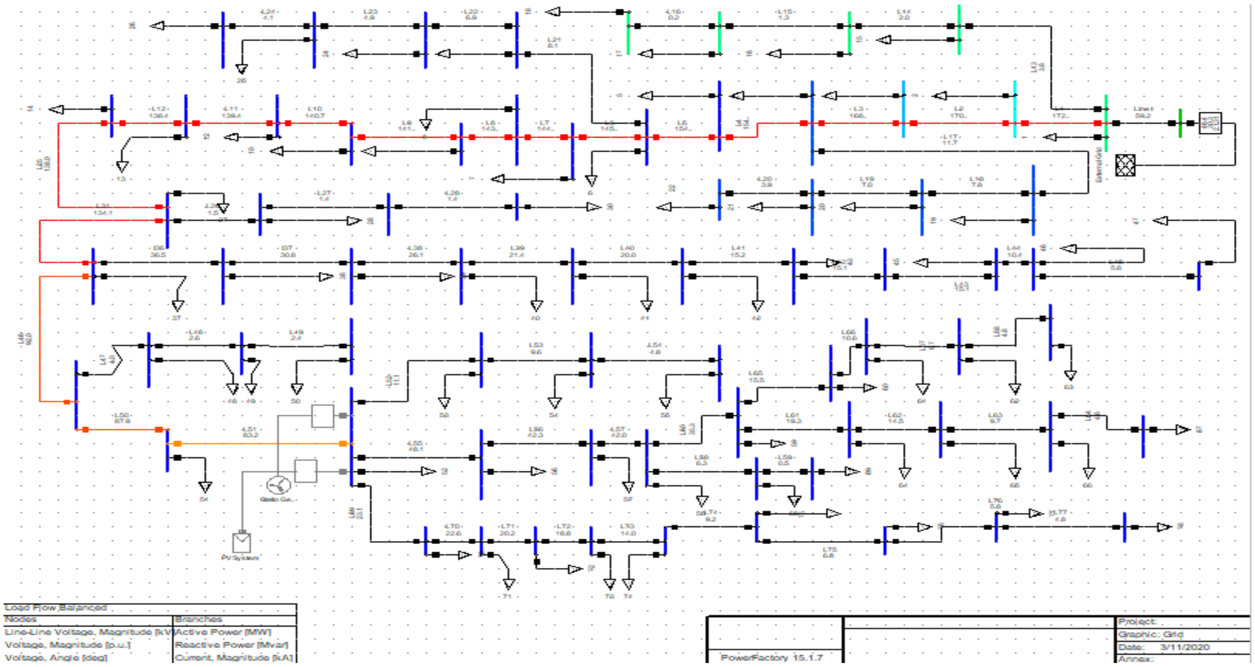
Grid: Grid	System Stage: Grid	Study Case: Study Case	Annex: / 1

Name	Type	Loading [%]	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power.-factor [-]	Current [kA]	Current [p.u.]
External Grid	Xnet		BUS 1	11.114	6.727	0.86	0.500	0.007
L1	Lne	36.15	BB1	9.523	5.922	0.85	0.434	0.362
			BB2	-9.493	-5.879	-0.85	0.434	0.362
L10	Lne	13.05	BB9	2.942	2.625	0.75	0.157	0.130
			BB10	-2.938	-2.620	-0.75	0.157	0.131
L11	Lne	12.00	BB10	2.638	2.475	0.73	0.144	0.120
			BB11	-2.635	-2.471	-0.73	0.144	0.120
L12	Lne	11.30	BB11	2.435	2.375	0.72	0.136	0.113
			BB12	-2.432	-2.371	-0.72	0.136	0.113
L13	Lne	3.76	BB1	1.050	0.504	0.90	0.045	0.038
			BB13	-1.050	-0.505	-0.90	0.045	0.038
L14	Lne	1.97	BB13	0.550	0.263	0.90	0.024	0.020
			BB14	-0.550	-0.264	-0.90	0.024	0.020
L15	Lne	1.25	BB14	0.350	0.167	0.90	0.015	0.013
			BB15	-0.350	-0.168	-0.90	0.015	0.013
L16	Lne	0.18	BB15	0.050	0.023	0.91	0.002	0.002
			BB16	-0.050	-0.024	-0.90	0.002	0.002
L17	Lne	9.08	BB17	-2.501	-1.209	-0.90	0.109	0.091
			BB4	2.503	1.211	0.90	0.109	0.091
L18	Lne	5.45	BB17	1.501	0.725	0.90	0.065	0.054
			BB18	-1.501	-0.725	-0.90	0.065	0.054
L19	Lne	4.72	BB18	1.301	0.628	0.90	0.057	0.047

			BB19	-1.300	-0.629	-0.90	0.057	0.047
L2	Lne	34.37	BB2	8.993	5.637	0.85	0.412	0.344
			BB3	-8.965	-5.598	-0.85	0.412	0.344
L20	Lne	1.82	BB19	0.500	0.241	0.90	0.022	0.018
			BB20	-0.500	-0.242	-0.90	0.022	0.018
L21	Lne	3.83	BB6	1.050	0.507	0.90	0.046	0.038
			BB21	-1.050	-0.508	-0.90	0.046	0.038
L22	Lne	2.74	BB21	0.750	0.363	0.90	0.033	0.027
			BB22	-0.750	-0.363	-0.90	0.033	0.027
L23	Lne	0.91	BB22	0.250	0.121	0.90	0.011	0.009
			BB23	-0.250	-0.121	-0.90	0.011	0.009
L24	Lne	0.18	BB23	0.050	0.024	0.90	0.002	0.002
			BB24	-0.050	-0.024	-0.90	0.002	0.002
L25	Lne	10.95	BB12	2.332	2.323	0.71	0.131	0.109
			BB25	-2.332	-2.322	-0.71	0.131	0.109
L26	Lne	1.20	BB25	0.325	0.157	0.90	0.014	0.012
			BB26	-0.325	-0.157	-0.90	0.014	0.012
L27	Lne	1.11	BB26	0.300	0.145	0.90	0.013	0.011
			BB27	-0.300	-0.145	-0.90	0.013	0.011
L28	Lne	1.11	BB27	0.300	0.145	0.90	0.013	0.011
			BB28	-0.300	-0.145	-0.90	0.013	0.011
L3	Lne	32.57	BB3	8.465	5.356	0.85	0.391	0.326
			BB4	-8.441	-5.321	-0.85	0.391	0.326
L31	Lne	8.13	BB25	1.507	1.923	0.62	0.098	0.081
			BB35	-1.506	-1.923	-0.62	0.098	0.081
L38	Lne	9.58	BB37	2.277	1.761	0.79	0.115	0.096
			BB38	-2.277	-1.760	-0.79	0.115	0.096
L39	Lne	9.40	BB38	2.227	1.736	0.79	0.113	0.094
			BB39	-2.227	-1.736	-0.79	0.113	0.094
L4	Lne	21.79	BB4	5.437	3.868	0.81	0.261	0.218
			BB5	-5.426	-3.853	-0.82	0.261	0.218
L40	Lne	8.32	BB39	1.927	1.591	0.77	0.100	0.083
			BB40	-1.925	-1.590	-0.77	0.100	0.083
L41	Lne	4.81	BB40	0.925	1.105	0.64	0.058	0.048
			BB41	-0.925	-1.105	-0.64	0.058	0.048
L42	Lne	4.72	BB41	0.900	1.093	0.64	0.057	0.047
			BB65	-0.900	-1.093	-0.64	0.057	0.047
L43	Lne	4.72	BB65	0.900	1.093	0.64	0.057	0.047
			BB66	-0.900	-1.093	-0.64	0.057	0.047
L44	Lne	4.06	BB66	0.700	0.997	0.57	0.049	0.041
			BB67	-0.700	-0.997	-0.57	0.049	0.041
L45	Lne	3.43	BB67	0.500	0.900	0.49	0.041	0.034
			BB677	-0.500	-0.900	-0.49	0.041	0.034
L46	Lne	11.80	BB35	-3.373	-1.098	-0.95	0.142	0.118
			BB42	3.373	1.099	0.95	0.142	0.118
L47	Lne	3.14	BB42	0.850	0.411	0.90	0.038	0.031
			BB43	-0.850	-0.411	-0.90	0.038	0.031
L48	Lne	2.03	BB43	0.550	0.266	0.90	0.024	0.020
			BB44	-0.550	-0.266	-0.90	0.024	0.020
L49	Lne	1.85	BB44	0.500	0.242	0.90	0.022	0.018
			BB45	-0.500	-0.242	-0.90	0.022	0.018
L5	Lne	21.43	BB5	5.326	3.805	0.81	0.257	0.214
			BB6	-5.316	-3.791	-0.81	0.257	0.214

L50	Lne	14.92	BB42	-4.223	-1.510	-0.94	0.179	0.149
			BB46	4.224	1.511	0.94	0.179	0.149
L51	Lne	16.76	BB46	-4.724	-1.754	-0.94	0.201	0.168
			BB50	4.731	1.762	0.94	0.201	0.168
L52	Lne	4.06	BB50	1.100	0.532	0.90	0.049	0.041
			BB47	-1.100	-0.532	-0.90	0.049	0.041
L53	Lne	2.95	BB47	0.800	0.387	0.90	0.035	0.029
			BB48	-0.800	-0.387	-0.90	0.035	0.030
L54	Lne	1.84	BB48	0.500	0.242	0.90	0.022	0.018
			BB49	-0.500	-0.242	-0.90	0.022	0.018
L55	Lne	30.86	BB50	8.365	4.063	0.90	0.370	0.309
			BB51	-8.360	-4.057	-0.90	0.370	0.309
L56	Lne	26.44	BB51	7.161	3.475	0.90	0.317	0.264
			BB52	-7.157	-3.471	-0.90	0.317	0.264
L57	Lne	26.25	BB52	7.107	3.447	0.90	0.315	0.263
			BB53	-7.104	-3.442	-0.90	0.315	0.263
L58	Lne	4.80	BB53	1.300	0.629	0.90	0.058	0.048
			BB63	-1.300	-0.629	-0.90	0.058	0.048
L59	Lne	0.37	BB63	0.100	0.048	0.90	0.004	0.004
			BB64	-0.100	-0.048	-0.90	0.004	0.004
L6	Lne	16.96	BB6	4.065	3.187	0.79	0.203	0.170
			BB7	-4.059	-3.178	-0.79	0.203	0.170
L60	Lne	21.08	BB53	5.704	2.765	0.90	0.253	0.211
			BB54	-5.702	-2.762	-0.90	0.253	0.211
L61	Lne	8.88	BB54	2.401	1.163	0.90	0.107	0.089
			BB59	-2.400	-1.162	-0.90	0.107	0.089
L62	Lne	7.77	BB59	2.100	1.017	0.90	0.093	0.078
			BB60	-2.100	-1.017	-0.90	0.093	0.078
L63	Lne	7.40	BB60	2.000	0.969	0.90	0.089	0.074
			BB61	-2.000	-0.968	-0.90	0.089	0.074
L64	Lne	3.70	BB61	1.000	0.484	0.90	0.044	0.037
			BB62	-1.000	-0.484	-0.90	0.044	0.037
L65	Lne	11.84	BB54	3.201	1.551	0.90	0.142	0.118
			BB55	-3.200	-1.550	-0.90	0.142	0.118
L66	Lne	8.14	BB55	2.201	1.066	0.90	0.098	0.081
			BB56	-2.200	-1.065	-0.90	0.098	0.081
L67	Lne	7.40	BB56	2.000	0.969	0.90	0.089	0.074
			BB57	-2.000	-0.968	-0.90	0.089	0.074
L68	Lne	3.70	BB57	1.000	0.484	0.90	0.044	0.037
			BB58	-1.000	-0.484	-0.90	0.044	0.037
L69	Lne	13.29	BB50	3.603	1.746	0.90	0.159	0.133
			B69	-3.602	-1.745	-0.90	0.159	0.133
L7	Lne	16.25	BB7	3.859	3.081	0.78	0.195	0.162
			BB8	-3.852	-3.073	-0.78	0.195	0.162
L70	Lne	12.92	B69	3.502	1.697	0.90	0.155	0.129
			BB70	-3.502	-1.696	-0.90	0.155	0.129
L71	Lne	11.08	BB70	3.002	1.454	0.90	0.133	0.111
			BB71	-3.001	-1.453	-0.90	0.133	0.111
L72	Lne	9.97	BB71	2.701	1.308	0.90	0.120	0.100
			BB72	-2.701	-1.308	-0.90	0.120	0.100
L73	Lne	8.12	BB72	2.201	1.065	0.90	0.097	0.081
			BB73	-2.200	-1.065	-0.90	0.097	0.081
L74	Lne	7.02	BB73	1.900	0.920	0.90	0.084	0.070
			BB74	-1.900	-0.920	-0.90	0.084	0.070
L75	Lne	5.17	BB74	1.400	0.678	0.90	0.062	0.052
			BB75	-1.400	-0.678	-0.90	0.062	0.052
L76	Lne	4.43	BB75	1.200	0.581	0.90	0.053	0.044
			BB76	-1.200	-0.581	-0.90	0.053	0.044
L77	Lne	3.69	BB76	1.000	0.484	0.90	0.044	0.037
			BB77	-1.000	-0.484	-0.90	0.044	0.037
L8	Lne	15.54	BB8	3.652	2.976	0.78	0.186	0.155
			BB89	-3.647	-2.969	-0.78	0.186	0.155
L9	Lne	13.76	BB89	3.147	2.727	0.76	0.165	0.138
			BB9	-3.142	-2.722	-0.76	0.165	0.138

C3: Percentage of Line Loading without DG Integration after four year



Load Flow Calculation	Edge Elements

AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergence	No
Automatic Tap Adjust of Transformers	No	Max. Acceptable Load Flow Error for	
Consider Reactive Power Limits	No	Nodes	1.00 kVA
		Model Equations	0.10 %

DIgSILENT PowerFactory 15.1.7	Project:
	Date: 8/19/2019

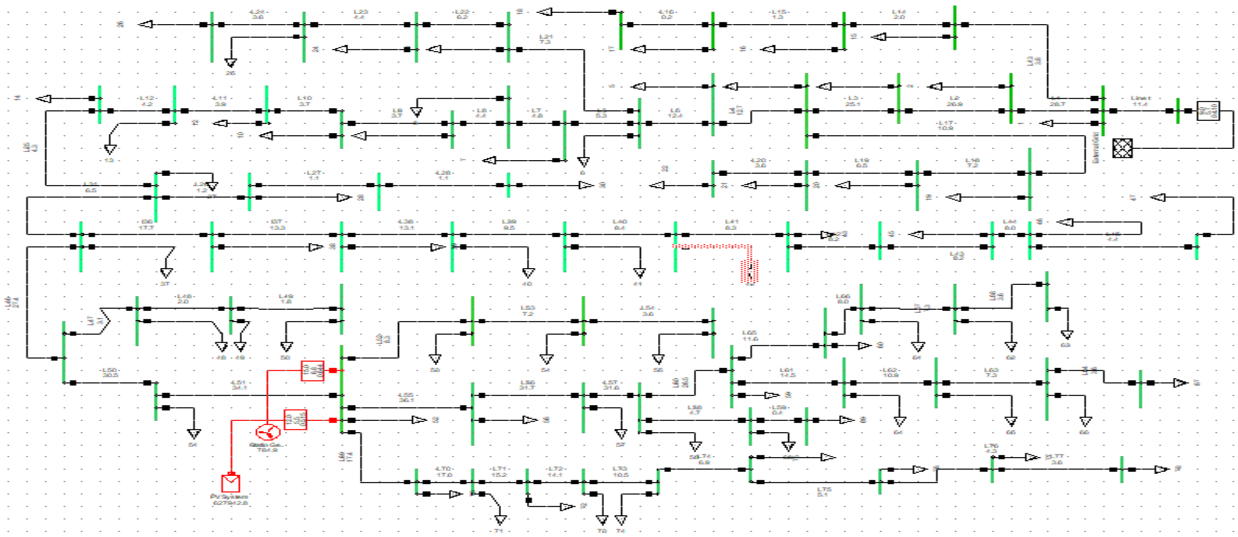
Grid: Grid	System Stage: Grid	Study Case: Study Case	Annex:	/ 1

Name	Type	Loading [%]	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power.-factor [-]	Current [kA]	Current [p.u.]
L1	Lne	171.97	BB1	44.073	28.442	0.84	2.064	1.720
			BB2	-43.382	-27.440	-0.85	2.064	1.720
L10	Lne	140.70	BB9	31.093	17.250	0.87	1.688	1.407
			BB10	-30.631	-16.580	-0.88	1.688	1.407
L11	Lne	139.35	BB10	30.331	16.435	0.88	1.672	1.394
			BB11	-29.878	-15.777	-0.88	1.672	1.394
L12	Lne	138.44	BB11	29.678	15.680	0.88	1.661	1.384
			BB12	-29.231	-15.031	-0.89	1.661	1.384
L13	Lne	3.82	BB1	1.050	0.505	0.90	0.046	0.038
			BB13	-1.050	-0.505	-0.90	0.046	0.038
L14	Lne	2.00	BB13	0.550	0.263	0.90	0.024	0.020
			BB14	-0.550	-0.264	-0.90	0.024	0.020
L15	Lne	1.27	BB14	0.350	0.167	0.90	0.015	0.013
			BB15	-0.350	-0.168	-0.90	0.015	0.013
L16	Lne	0.18	BB15	0.050	0.023	0.91	0.002	0.002
			BB16	-0.050	-0.024	-0.90	0.002	0.002
L17	Lne	11.69	BB17	-3.003	-1.454	-0.90	0.140	0.117
			BB4	3.006	1.458	0.90	0.140	0.117
L18	Lne	7.80	BB17	2.003	0.970	0.90	0.094	0.078
			BB18	-2.001	-0.969	-0.90	0.094	0.078
L19	Lne	7.02	BB18	1.801	0.872	0.90	0.084	0.070
			BB19	-1.800	-0.871	-0.90	0.084	0.070
L2	Lne	170.12	BB2	42.882	27.198	0.84	2.041	1.701

			BB3	-42.207	-26.217	-0.85	2.041	1.701
L20	Lne	3.90	BB19	1.000	0.484	0.90	0.047	0.039
			BB20	-1.000	-0.484	-0.90	0.047	0.039
L21	Lne	8.12	BB6	2.002	0.970	0.90	0.097	0.081
			BB21	-2.000	-0.969	-0.90	0.097	0.081
L22	Lne	6.90	BB21	1.700	0.823	0.90	0.083	0.069
			BB22	-1.700	-0.823	-0.90	0.083	0.069
L23	Lne	4.87	BB22	1.200	0.581	0.90	0.058	0.049
			BB23	-1.200	-0.581	-0.90	0.058	0.049
L24	Lne	4.06	BB23	1.000	0.484	0.90	0.049	0.041
			BB24	-1.000	-0.484	-0.90	0.049	0.041
L25	Lne	137.97	BB12	29.131	14.982	0.89	1.656	1.380
			BB25	-29.042	-14.853	-0.89	1.656	1.380
L26	Lne	1.53	BB25	0.325	0.157	0.90	0.018	0.015
			BB26	-0.325	-0.157	-0.90	0.018	0.015
L27	Lne	1.41	BB26	0.300	0.145	0.90	0.017	0.014
			BB27	-0.300	-0.145	-0.90	0.017	0.014
L28	Lne	1.41	BB27	0.300	0.145	0.90	0.017	0.014
			BB28	-0.300	-0.145	-0.90	0.017	0.014
L3	Lne	168.23	BB3	41.707	25.975	0.85	2.019	1.682
			BB4	-41.046	-25.017	-0.85	2.019	1.682
L31	Lne	134.10	BB25	28.217	14.454	0.89	1.609	1.341
			BB35	-28.133	-14.333	-0.89	1.609	1.341
L38	Lne	26.10	BB37	5.340	3.016	0.87	0.313	0.261
			BB38	-5.337	-3.011	-0.87	0.313	0.261
L39	Lne	21.38	BB38	4.338	2.527	0.86	0.257	0.214
			BB39	-4.335	-2.524	-0.86	0.257	0.214
L4	Lne	154.66	BB4	37.540	23.317	0.85	1.856	1.547
			BB5	-36.982	-22.506	-0.85	1.856	1.547
L40	Lne	19.97	BB39	4.035	2.379	0.86	0.240	0.200
			BB40	-4.028	-2.369	-0.86	0.240	0.200
L41	Lne	15.24	BB40	3.028	1.885	0.85	0.183	0.152
			BB41	-3.027	-1.883	-0.85	0.183	0.152
L42	Lne	15.12	BB41	3.002	1.871	0.85	0.181	0.151
			BB65	-3.001	-1.870	-0.85	0.181	0.151
L43	Lne	15.12	BB65	3.001	1.870	0.85	0.181	0.151
			BB66	-3.000	-1.868	-0.85	0.181	0.151
L44	Lne	10.41	BB66	2.000	1.384	0.82	0.125	0.104
			BB67	-2.000	-1.384	-0.82	0.125	0.104
L45	Lne	5.76	BB67	1.000	0.900	0.74	0.069	0.058
			BB677	-1.000	-0.900	-0.74	0.069	0.058
L46	Lne	91.97	BB35	19.383	9.656	0.90	1.104	0.920
			BB42	-19.343	-9.599	-0.90	1.104	0.920
L47	Lne	4.02	BB42	0.850	0.411	0.90	0.048	0.040
			BB43	-0.850	-0.411	-0.90	0.048	0.040
L48	Lne	2.60	BB43	0.550	0.266	0.90	0.031	0.026
			BB44	-0.550	-0.266	-0.90	0.031	0.026
L49	Lne	2.37	BB44	0.500	0.242	0.90	0.028	0.024
			BB45	-0.500	-0.242	-0.90	0.028	0.024
L5	Lne	154.27	BB5	36.882	22.458	0.85	1.851	1.543
			BB6	-36.326	-21.652	-0.86	1.851	1.543
L50	Lne	87.95	BB42	18.493	9.188	0.90	1.055	0.879
			BB46	-18.457	-9.135	-0.90	1.055	0.879

L51	Lne	83.21	BB46	17.457	8.651	0.90	0.998	0.832
			BB50	-17.296	-8.417	-0.90	0.998	0.832
L52	Lne	11.06	BB50	2.301	1.114	0.90	0.133	0.111
			BB47	-2.300	-1.114	-0.90	0.133	0.111
L53	Lne	9.62	BB47	2.000	0.968	0.90	0.115	0.096
			BB48	-2.000	-0.968	-0.90	0.115	0.096
L54	Lne	4.81	BB48	1.000	0.484	0.90	0.058	0.048
			BB49	-1.000	-0.484	-0.90	0.058	0.048
L55	Lne	48.06	BB50	9.986	4.870	0.90	0.577	0.481
			BB51	-9.975	-4.854	-0.90	0.577	0.481
L56	Lne	42.29	BB51	8.776	4.273	0.90	0.507	0.423
			BB52	-8.767	-4.261	-0.90	0.507	0.423
L57	Lne	42.05	BB52	8.717	4.237	0.90	0.505	0.420
			BB53	-8.709	-4.225	-0.90	0.505	0.420
L58	Lne	6.27	BB53	1.300	0.629	0.90	0.075	0.063
			BB63	-1.300	-0.629	-0.90	0.075	0.063
L59	Lne	0.48	BB63	0.100	0.048	0.90	0.006	0.005
			BB64	-0.100	-0.048	-0.90	0.006	0.005
L6	Lne	145.38	BB6	34.124	20.585	0.86	1.745	1.454
			BB7	-33.631	-19.869	-0.86	1.745	1.454
L60	Lne	35.29	BB53	7.309	3.548	0.90	0.423	0.353
			BB54	-7.303	-3.540	-0.90	0.423	0.353
L61	Lne	19.34	BB54	4.002	1.940	0.90	0.232	0.193
			BB59	-4.000	-1.938	-0.90	0.232	0.193
L62	Lne	14.51	BB59	3.001	1.454	0.90	0.174	0.145
			BB60	-3.000	-1.452	-0.90	0.174	0.145
L63	Lne	9.67	BB60	2.000	0.968	0.90	0.116	0.097
			BB61	-2.000	-0.968	-0.90	0.116	0.097
L64	Lne	4.84	BB61	1.000	0.484	0.90	0.058	0.048
			BB62	-1.000	-0.484	-0.90	0.058	0.048
L65	Lne	15.47	BB54	3.201	1.551	0.90	0.186	0.155
			BB55	-3.200	-1.550	-0.90	0.186	0.155
L66	Lne	10.64	BB55	2.200	1.066	0.90	0.128	0.106
			BB56	-2.200	-1.065	-0.90	0.128	0.106
L67	Lne	9.67	BB56	2.000	0.968	0.90	0.116	0.097
			BB57	-2.000	-0.968	-0.90	0.116	0.097
L68	Lne	4.84	BB57	1.000	0.484	0.90	0.058	0.048
			BB58	-1.000	-0.484	-0.90	0.058	0.048
L69	Lne	23.13	BB50	4.809	2.337	0.90	0.278	0.231
			B69	-4.806	-2.333	-0.90	0.278	0.231
			B69	-4.806	-2.333	-0.90	0.278	0.231
L7	Lne	144.56	BB7	33.431	19.772	0.86	1.735	1.446
			BB8	-32.943	-19.065	-0.87	1.735	1.446
L70	Lne	22.65	B69	4.707	2.285	0.90	0.272	0.226
			BB70	-4.704	-2.281	-0.90	0.272	0.226
L71	Lne	20.24	BB70	4.204	2.039	0.90	0.243	0.202
			BB71	-4.202	-2.037	-0.90	0.243	0.202
L72	Lne	18.80	BB71	3.902	1.892	0.90	0.226	0.188
			BB72	-3.901	-1.889	-0.90	0.226	0.188
L73	Lne	13.98	BB72	2.901	1.405	0.90	0.168	0.140
			BB73	-2.900	-1.404	-0.90	0.168	0.140
L74	Lne	9.16	BB73	1.900	0.920	0.90	0.110	0.092
			BB74	-1.900	-0.920	-0.90	0.110	0.092
L75	Lne	6.75	BB74	1.400	0.678	0.90	0.081	0.068
			BB75	-1.400	-0.678	-0.90	0.081	0.068
L76	Lne	5.79	BB75	1.200	0.581	0.90	0.069	0.058
			BB76	-1.200	-0.581	-0.90	0.069	0.058
L77	Lne	4.82	BB76	1.000	0.484	0.90	0.058	0.048
			BB77	-1.000	-0.484	-0.90	0.058	0.048
L8	Lne	143.72	BB8	32.743	18.968	0.87	1.725	1.437

C4: Percentage of Line Loading with DG Integration after four year



Load Flow Calculation	Edge Elements
AC Load Flow, balanced, positive sequence	Automatic Model Adaptation for Convergence: No
Automatic Tap Adjust of Transformers: No	Max. Acceptable Load Flow Error for
Consider Reactive Power Limits: No	Nodes: 1.00 kVA
	Model Equations: 0.10 %

	DIgSILENT PowerFactory 15.1.7	Project: / Date: 8/19/2019
Grid: Grid — System Stage: Grid	Study Case: Study Case	Annex: / 1

Name	Type	Loading [%]	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power.-factor [-]	Current [kA]	Current [p.u.]
L1	Lne	28.68	BB1	7.438	4.893	0.84	0.344	0.287
			BB2	-7.419	-4.867	-0.84	0.344	0.287
L10	Lne	3.67	BB9	-0.529	0.987	-0.47	0.044	0.037
			BB10	0.529	-0.988	0.47	0.044	0.037
L11	Lne	3.87	BB10	-0.829	0.842	-0.70	0.046	0.039
			BB11	0.830	-0.843	0.70	0.046	0.039
L12	Lne	4.16	BB11	-1.030	0.746	-0.81	0.050	0.042
			BB12	1.030	-0.747	0.81	0.050	0.042
L13	Lne	3.75	BB1	1.050	0.504	0.90	0.045	0.038
			BB13	-1.050	-0.505	-0.90	0.045	0.038
L14	Lne	1.97	BB13	0.550	0.263	0.90	0.024	0.020
			BB14	-0.550	-0.264	-0.90	0.024	0.020
L15	Lne	1.25	BB14	0.350	0.167	0.90	0.015	0.013
			BB15	-0.350	-0.168	-0.90	0.015	0.013
L16	Lne	0.18	BB15	0.050	0.023	0.91	0.002	0.002
			BB16	-0.050	-0.024	-0.90	0.002	0.002
L17	Lne	10.87	BB17	-3.003	-1.453	-0.90	0.130	0.109
			BB4	3.005	1.456	0.90	0.130	0.109
L18	Lne	7.25	BB17	2.003	0.969	0.90	0.087	0.072
			BB18	-2.001	-0.968	-0.90	0.087	0.072
L19	Lne	6.52	BB18	1.801	0.871	0.90	0.078	0.065

			BB19	-1.800	-0.871	-0.90	0.078	0.065
L2	Lne	26.90	BB2	6.919	4.624	0.83	0.323	0.269
			BB3	-6.902	-4.601	-0.83	0.323	0.269
L20	Lne	3.63	BB19	1.000	0.484	0.90	0.043	0.036
			BB20	-1.000	-0.484	-0.90	0.044	0.036
L21	Lne	7.26	BB6	2.002	0.969	0.90	0.087	0.073
			BB21	-2.000	-0.968	-0.90	0.087	0.073
L22	Lne	6.17	BB21	1.700	0.823	0.90	0.074	0.062
			BB22	-1.700	-0.823	-0.90	0.074	0.062
L23	Lne	4.36	BB22	1.200	0.581	0.90	0.052	0.044
			BB23	-1.200	-0.581	-0.90	0.052	0.044
L24	Lne	3.63	BB23	1.000	0.484	0.90	0.044	0.036
			BB24	-1.000	-0.484	-0.90	0.044	0.036
L25	Lne	4.35	BB12	-1.130	0.698	-0.85	0.052	0.043
			BB25	1.130	-0.698	0.85	0.052	0.043
L26	Lne	1.18	BB25	0.325	0.157	0.90	0.014	0.012
			BB26	-0.325	-0.157	-0.90	0.014	0.012
L27	Lne	1.09	BB26	0.300	0.145	0.90	0.013	0.011
			BB27	-0.300	-0.145	-0.90	0.013	0.011
L28	Lne	1.09	BB27	0.300	0.145	0.90	0.013	0.011
			BB28	-0.300	-0.145	-0.90	0.013	0.011
L3	Lne	25.12	BB3	6.402	4.359	0.83	0.301	0.251
			BB4	-6.387	-4.339	-0.83	0.301	0.251
L31	Lne	6.47	BB25	-1.955	0.300	-0.99	0.078	0.065
			BB35	1.955	-0.300	0.99	0.078	0.065
L38	Lne	13.13	BB37	3.429	2.078	0.86	0.158	0.131
			BB38	-3.428	-2.077	-0.86	0.158	0.131
L39	Lne	9.51	BB38	2.428	1.592	0.84	0.114	0.095
			BB39	-2.428	-1.592	-0.84	0.114	0.095
L4	Lne	12.72	BB4	2.882	2.641	0.74	0.153	0.127
			BB5	-2.878	-2.636	-0.74	0.153	0.127
L40	Lne	8.43	BB39	2.128	1.447	0.83	0.101	0.084
			BB40	-2.126	-1.446	-0.83	0.101	0.084
L41	Lne	8.25	BB40	2.076	1.421	0.83	0.099	0.083
			BB41	-2.076	-1.421	-0.83	0.099	0.083
L42	Lne	8.16	BB41	2.051	1.409	0.82	0.098	0.082
			BB65	-2.051	-1.409	-0.82	0.098	0.082
L43	Lne	8.16	BB65	2.051	1.409	0.82	0.098	0.082
			BB66	-2.050	-1.409	-0.82	0.098	0.082
L44	Lne	7.98	BB66	2.000	1.384	0.82	0.096	0.080
			BB67	-2.000	-1.384	-0.82	0.096	0.080
L45	Lne	4.42	BB67	1.000	0.900	0.74	0.053	0.044
			BB677	-1.000	-0.900	-0.74	0.053	0.044
L46	Lne	27.42	BB35	-7.837	-2.967	-0.94	0.329	0.274
			BB42	7.840	2.972	0.94	0.329	0.274
L47	Lne	3.09	BB42	0.850	0.411	0.90	0.037	0.031
			BB43	-0.850	-0.411	-0.90	0.037	0.031
L48	Lne	2.00	BB43	0.550	0.266	0.90	0.024	0.020
			BB44	-0.550	-0.266	-0.90	0.024	0.020
L49	Lne	1.82	BB44	0.500	0.242	0.90	0.022	0.018
			BB45	-0.500	-0.242	-0.90	0.022	0.018
L5	Lne	12.37	BB5	2.778	2.588	0.73	0.148	0.124
			BB6	-2.774	-2.584	-0.73	0.148	0.124

L50	Lne	30.49	BB42	-8.690	-3.383	-0.93	0.366	0.305
			BB46	8.694	3.389	0.93	0.366	0.305
L51	Lne	34.11	BB46	-9.694	-3.874	-0.93	0.409	0.341
			BB50	9.722	3.912	0.93	0.409	0.341
L52	Lne	8.32	BB50	2.301	1.114	0.90	0.100	0.083
			BB47	-2.300	-1.114	-0.90	0.100	0.083
L53	Lne	7.24	BB47	2.000	0.969	0.90	0.087	0.072
			BB48	-2.000	-0.968	-0.90	0.087	0.072
L54	Lne	3.62	BB48	1.000	0.484	0.90	0.043	0.036
			BB49	-1.000	-0.484	-0.90	0.043	0.036
L55	Lne	36.09	BB50	9.972	4.847	0.90	0.433	0.361
			BB51	-9.966	-4.839	-0.90	0.433	0.361
L56	Lne	31.75	BB51	8.766	4.258	0.90	0.381	0.317
			BB52	-8.761	-4.251	-0.90	0.381	0.317
L57	Lne	31.57	BB52	8.711	4.227	0.90	0.379	0.316
			BB53	-8.706	-4.220	-0.90	0.379	0.316
L58	Lne	4.71	BB53	1.300	0.629	0.90	0.057	0.047
			BB63	-1.300	-0.629	-0.90	0.057	0.047
L59	Lne	0.36	BB63	0.100	0.048	0.90	0.004	0.004
			BB64	-0.100	-0.048	-0.90	0.004	0.004
L6	Lne	5.30	BB6	0.573	1.518	0.35	0.064	0.053
			BB7	-0.572	-1.518	-0.35	0.064	0.053
L60	Lne	26.49	BB53	7.306	3.543	0.90	0.318	0.265
			BB54	-7.303	-3.538	-0.90	0.318	0.265
L61	Lne	14.52	BB54	4.002	1.939	0.90	0.174	0.145
			BB59	-4.001	-1.938	-0.90	0.174	0.145
L62	Lne	10.89	BB59	3.001	1.453	0.90	0.131	0.109
			BB60	-3.000	-1.453	-0.90	0.131	0.109
L63	Lne	7.26	BB60	2.000	0.969	0.90	0.087	0.073
			BB61	-2.000	-0.968	-0.90	0.087	0.073
L64	Lne	3.63	BB61	1.000	0.484	0.90	0.044	0.036
			BB62	-1.000	-0.484	-0.90	0.044	0.036
L65	Lne	11.61	BB54	3.201	1.551	0.90	0.139	0.116
			BB55	-3.201	-1.550	-0.90	0.139	0.116
L66	Lne	7.98	BB55	2.201	1.066	0.90	0.096	0.080
			BB56	-2.200	-1.065	-0.90	0.096	0.080
L67	Lne	7.26	BB56	2.000	0.969	0.90	0.087	0.073
			BB57	-2.000	-0.968	-0.90	0.087	0.073
L68	Lne	3.63	BB57	1.000	0.484	0.90	0.044	0.036
			BB58	-1.000	-0.484	-0.90	0.044	0.036
			BB58	-1.000	-0.484	-0.90	0.044	0.036
L69	Lne	17.39	BB50	4.806	2.331	0.90	0.209	0.174
			B69	-4.804	-2.329	-0.90	0.209	0.174
L7	Lne	4.80	BB7	0.372	1.421	0.25	0.058	0.048
			BB8	-0.372	-1.422	-0.25	0.058	0.048
L70	Lne	17.02	B69	4.704	2.281	0.90	0.204	0.170
			BB70	-4.703	-2.279	-0.90	0.204	0.170
L71	Lne	15.22	BB70	4.203	2.037	0.90	0.183	0.152
			BB71	-4.202	-2.036	-0.90	0.183	0.152
L72	Lne	14.13	BB71	3.902	1.890	0.90	0.170	0.141
			BB72	-3.901	-1.889	-0.90	0.170	0.141
L73	Lne	10.51	BB72	2.901	1.405	0.90	0.126	0.105
			BB73	-2.900	-1.404	-0.90	0.126	0.105
L74	Lne	6.89	BB73	1.900	0.920	0.90	0.083	0.069
			BB74	-1.900	-0.920	-0.90	0.083	0.069
L75	Lne	5.07	BB74	1.400	0.678	0.90	0.061	0.051
			BB75	-1.400	-0.678	-0.90	0.061	0.051
L76	Lne	4.35	BB75	1.200	0.581	0.90	0.052	0.043
			BB76	-1.200	-0.581	-0.90	0.052	0.043
L77	Lne	3.62	BB76	1.000	0.484	0.90	0.043	0.036
			BB77	-1.000	-0.484	-0.90	0.043	0.036
L8	Lne	4.37	BB8	0.172	1.325	0.13	0.052	0.044
			BB89	-0.171	-1.325	-0.13	0.052	0.044
L9	Lne	3.71	BB89	-0.329	1.083	-0.29	0.044	0.037
			BB9	0.329	-1.084	0.29	0.044	0.037

C5: Percentage of Line Loading with DG Integration after six year

After six year without DG integration the distribution network is automatically fail due to highly overloaded. Therefore, it is mandatory to integrate the DG to the distribution network to reduce the line loading.

After the integration of DG the result of line loading in percentage is as follow.

```
| Load Flow Calculation                                                              Edge Elements |
|    AC Load Flow, balanced, positive sequence            |  Automatic Model Adaptation for Convergence      No      |
|    Automatic Tap Adjust of Transformers       No        |  Max. Acceptable Load Flow Error for                     |
|    Consider Reactive Power Limits             No        |     Nodes                                   1.00 kVA     |
|                                                         |     Model Equations                         0.10 %       |

|          |                                    |   DIgSILENT   | Project:                 |
|          |                                    | PowerFactory  |--------------------------
|          |                                    |    15.1.7     | Date:  8/19/2019         |

| Grid: Grid           System Stage: Grid       | Study Case: Study Case        | Annex:           / 1  |
```

Name	Type	Loading [%]	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power.-factor [-]	Current [kA]	Current [p.u.]
L1	Lne	43.48	BB1	11.386	7.209	0.84	0.522	0.435
			BB2	-11.342	-7.146	-0.85	0.522	0.435
L10	Lne	6.72	BB9	0.716	1.893	0.35	0.081	0.067
			BB10	-0.715	-1.892	-0.35	0.081	0.067
L11	Lne	4.77	BB10	-0.285	1.408	-0.20	0.057	0.048
			BB11	0.286	-1.408	0.20	0.057	0.048
L12	Lne	6.35	BB11	-1.786	0.682	-0.93	0.076	0.063
			BB12	1.786	-0.682	0.93	0.076	0.064
L13	Lne	3.76	BB1	1.050	0.504	0.90	0.045	0.038
			BB13	-1.050	-0.505	-0.90	0.045	0.038
L14	Lne	1.97	BB13	0.550	0.263	0.90	0.024	0.020
			BB14	-0.550	-0.264	-0.90	0.024	0.020
L15	Lne	1.25	BB14	0.350	0.167	0.90	0.015	0.013
			BB15	-0.350	-0.168	-0.90	0.015	0.013
L16	Lne	0.18	BB15	0.050	0.023	0.91	0.002	0.002
			BB16	-0.050	-0.024	-0.90	0.002	0.002
L17	Lne	10.94	BB17	-3.003	-1.453	-0.90	0.131	0.109
			BB4	3.005	1.456	0.90	0.131	0.109
L18	Lne	7.30	BB17	2.003	0.969	0.90	0.088	0.073
			BB18	-2.001	-0.968	-0.90	0.088	0.073
L19	Lne	6.57	BB18	1.801	0.871	0.90	0.079	0.066

			BB19	-1.800	-0.871	-0.90	0.079	0.066
L2	Lne	41.70	BB2	10.842	6.903	0.84	0.500	0.417
			BB3	-10.802	-6.846	-0.84	0.500	0.417
L20	Lne	3.65	BB19	1.000	0.484	0.90	0.044	0.037
			BB20	-1.000	-0.484	-0.90	0.044	0.037
L21	Lne	7.34	BB6	2.002	0.969	0.90	0.088	0.073
			BB21	-2.000	-0.968	-0.90	0.088	0.073
L22	Lne	6.24	BB21	1.700	0.823	0.90	0.075	0.062
			BB22	-1.700	-0.823	-0.90	0.075	0.062
L23	Lne	4.40	BB22	1.200	0.581	0.90	0.053	0.044
			BB23	-1.200	-0.581	-0.90	0.053	0.044
L24	Lne	3.67	BB23	1.000	0.484	0.90	0.044	0.037
			BB24	-1.000	-0.484	-0.90	0.044	0.037
L25	Lne	6.61	BB12	-1.886	0.633	-0.95	0.079	0.066
			BB25	1.887	-0.633	0.95	0.079	0.066
L26	Lne	1.20	BB25	0.325	0.157	0.90	0.014	0.012
			BB26	-0.325	-0.157	-0.90	0.014	0.012
L27	Lne	1.11	BB26	0.300	0.145	0.90	0.013	0.011
			BB27	-0.300	-0.145	-0.90	0.013	0.011
L28	Lne	1.11	BB27	0.300	0.145	0.90	0.013	0.011
			BB28	-0.300	-0.145	-0.90	0.013	0.011
L3	Lne	39.90	BB3	10.302	6.604	0.84	0.479	0.399
			BB4	-10.264	-6.551	-0.84	0.479	0.399
L31	Lne	9.04	BB25	-2.712	0.234	-1.00	0.108	0.090
			BB35	2.712	-0.234	1.00	0.108	0.090
L38	Lne	13.32	BB37	3.429	2.078	0.86	0.160	0.133
			BB38	-3.428	-2.077	-0.86	0.160	0.133
L39	Lne	9.65	BB38	2.428	1.593	0.84	0.116	0.097
			BB39	-2.428	-1.592	-0.84	0.116	0.097
L4	Lne	25.47	BB4	6.259	4.610	0.81	0.306	0.255
			BB5	-6.244	-4.589	-0.81	0.306	0.255
L40	Lne	8.56	BB39	2.128	1.447	0.83	0.103	0.086
			BB40	-2.126	-1.446	-0.83	0.103	0.086
L41	Lne	8.37	BB40	2.076	1.422	0.83	0.100	0.084
			BB41	-2.076	-1.421	-0.83	0.100	0.084
L42	Lne	8.28	BB41	2.051	1.409	0.82	0.099	0.083
			BB65	-2.051	-1.409	-0.82	0.099	0.083
L43	Lne	8.28	BB65	2.051	1.409	0.82	0.099	0.083
			BB66	-2.050	-1.409	-0.82	0.099	0.083
L44	Lne	8.10	BB66	2.000	1.384	0.82	0.097	0.081
			BB67	-2.000	-1.384	-0.82	0.097	0.081
L45	Lne	4.48	BB67	1.000	0.900	0.74	0.054	0.045
			BB677	-1.000	-0.900	-0.74	0.054	0.045
L46	Lne	33.19	BB35	-9.393	-3.421	-0.94	0.398	0.332
			BB42	9.399	3.428	0.94	0.398	0.332
L47	Lne	9.22	BB42	2.501	1.211	0.90	0.111	0.092
			BB43	-2.500	-1.211	-0.90	0.111	0.092
L48	Lne	5.53	BB43	1.500	0.726	0.90	0.066	0.055
			BB44	-1.500	-0.726	-0.90	0.066	0.055
L49	Lne	1.84	BB44	0.500	0.242	0.90	0.022	0.018
			BB45	-0.500	-0.242	-0.90	0.022	0.018
L5	Lne	25.12	BB5	6.144	4.541	0.80	0.301	0.251
			BB6	-6.129	-4.521	-0.80	0.301	0.251

L50	Lne	42.38	BB42	-11.899	-4.639	-0.93	0.509	0.424	
			BB46	11.907	4.651	0.93	0.508	0.424	
L51	Lne	46.05	BB46	-12.907	-5.135	-0.93	0.553	0.460	
			BB50	12.957	5.206	0.93	0.553	0.460	
L52	Lne	9.16	BB50	2.501	1.211	0.90	0.110	0.092	
			BB47	-2.500	-1.211	-0.90	0.110	0.092	
L53	Lne	8.06	BB47	2.200	1.066	0.90	0.097	0.081	
			BB48	-2.200	-1.065	-0.90	0.097	0.081	
L54	Lne	4.40	BB48	1.200	0.581	0.90	0.053	0.044	
			BB49	-1.200	-0.581	-0.90	0.053	0.044	
L55	Lne	47.80	BB50	13.034	6.342	0.90	0.574	0.478	
			BB51	-13.023	-6.326	-0.90	0.574	0.478	
L56	Lne	42.29	BB51	11.523	5.600	0.90	0.508	0.423	
			BB52	-11.514	-5.588	-0.90	0.508	0.423	
L57	Lne	38.62	BB52	10.514	5.104	0.90	0.463	0.386	
			BB53	-10.508	-5.094	-0.90	0.463	0.386	
L58	Lne	4.78	BB53	1.300	0.629	0.90	0.057	0.048	
			BB63	-1.300	-0.629	-0.90	0.057	0.048	
L59	Lne	0.37	BB63	0.100	0.048	0.90	0.004	0.004	
			BB64	-0.100	-0.048	-0.90	0.004	0.004	
L6	Lne	14.45	BB6	3.128	3.067	0.71	0.173	0.144	
			BB7	-3.123	-3.061	-0.71	0.173	0.144	
L60	Lne	30.17	BB53	8.207	3.980	0.90	0.362	0.302	
			BB54	-8.203	-3.974	-0.90	0.362	0.302	
L61	Lne	14.72	BB54	4.002	1.939	0.90	0.177	0.147	
			BB59	-4.001	-1.938	-0.90	0.177	0.147	
L62	Lne	11.04	BB59	3.001	1.454	0.90	0.132	0.110	
			BB60	-3.000	-1.453	-0.90	0.132	0.110	
L63	Lne	7.36	BB60	2.000	0.969	0.90	0.088	0.074	
			BB61	-2.000	-0.968	-0.90	0.088	0.074	
L64	Lne	3.68	BB61	1.000	0.484	0.90	0.044	0.037	
			BB62	-1.000	-0.484	-0.90	0.044	0.037	
L65	Lne	11.77	BB54	3.201	1.551	0.90	0.141	0.118	
			BB55	-3.201	-1.550	-0.90	0.141	0.118	
L66	Lne	8.10	BB55	2.201	1.066	0.90	0.097	0.081	
			BB56	-2.200	-1.066	-0.90	0.097	0.081	
L67	Lne	7.36	BB56	2.000	0.969	0.90	0.088	0.074	
			BB57	-2.000	-0.969	-0.90	0.088	0.074	
L68	Lne	3.68	BB57	1.000	0.484	0.90	0.044	0.037	
			BB58	-1.000	-0.484	-0.90	0.044	0.037	
L69	Lne	23.86	BB50	6.509	3.159	0.90	0.286	0.239	
			B69	-6.506	-3.155	-0.90	0.286	0.239	
L7	Lne	11.03	BB7	2.123	2.577	0.64	0.132	0.110	
			BB8	-2.120	-2.574	-0.64	0.132	0.110	
L70	Lne	23.49	B69	6.406	3.107	0.90	0.282	0.235	
			BB70	-6.404	-3.103	-0.90	0.282	0.235	
L71	Lne	17.99	BB70	4.904	2.377	0.90	0.216	0.180	
			BB71	-4.902	-2.375	-0.90	0.216	0.180	
L72	Lne	14.32	BB71	3.902	1.890	0.90	0.172	0.143	
			BB72	-3.901	-1.889	-0.90	0.172	0.143	
L73	Lne	10.65	BB72	2.901	1.405	0.90	0.128	0.106	
			BB73	-2.901	-1.404	-0.90	0.128	0.106	
L74	Lne	6.98	BB73	1.901	0.920	0.90	0.084	0.070	
			BB74	-1.900	-0.920	-0.90	0.084	0.070	
L75	Lne	5.14	BB74	1.400	0.678	0.90	0.062	0.051	
			BB75	-1.400	-0.678	-0.90	0.062	0.051	
L76	Lne	4.41	BB75	1.200	0.581	0.90	0.053	0.044	
			BB76	-1.200	-0.581	-0.90	0.053	0.044	
L77	Lne	3.67	BB76	1.000	0.484	0.90	0.044	0.037	
			BB77	-1.000	-0.484	-0.90	0.044	0.037	
L8	Lne	10.37	BB8	1.920	2.477	0.61	0.124	0.104	
			BB89	-1.917	-2.475	-0.61	0.124	0.104	
L9	Lne	7.27	BB89	0.917	1.990	0.42	0.087	0.073	
			BB9	-0.916	-1.990	-0.42	0.087	0.073	

Percentage of Line Loading with DG Integration after ten year

The same is true after ten year without DG the distribution network is automatically fail. Therefore, it is mandatory to integrate the DG to the distribution network, after that the distribution network comes to work. The result of line loading in percentage after integration the DG is as follow.

Load Flow Calculation — Edge Elements

AC Load Flow, balanced, positive sequence | Automatic Model Adaptation for Convergence: No
Automatic Tap Adjust of Transformers: No | Max. Acceptable Load Flow Error for
Consider Reactive Power Limits: No | Nodes: 1.00 kVA
Model Equations: 0.10 %

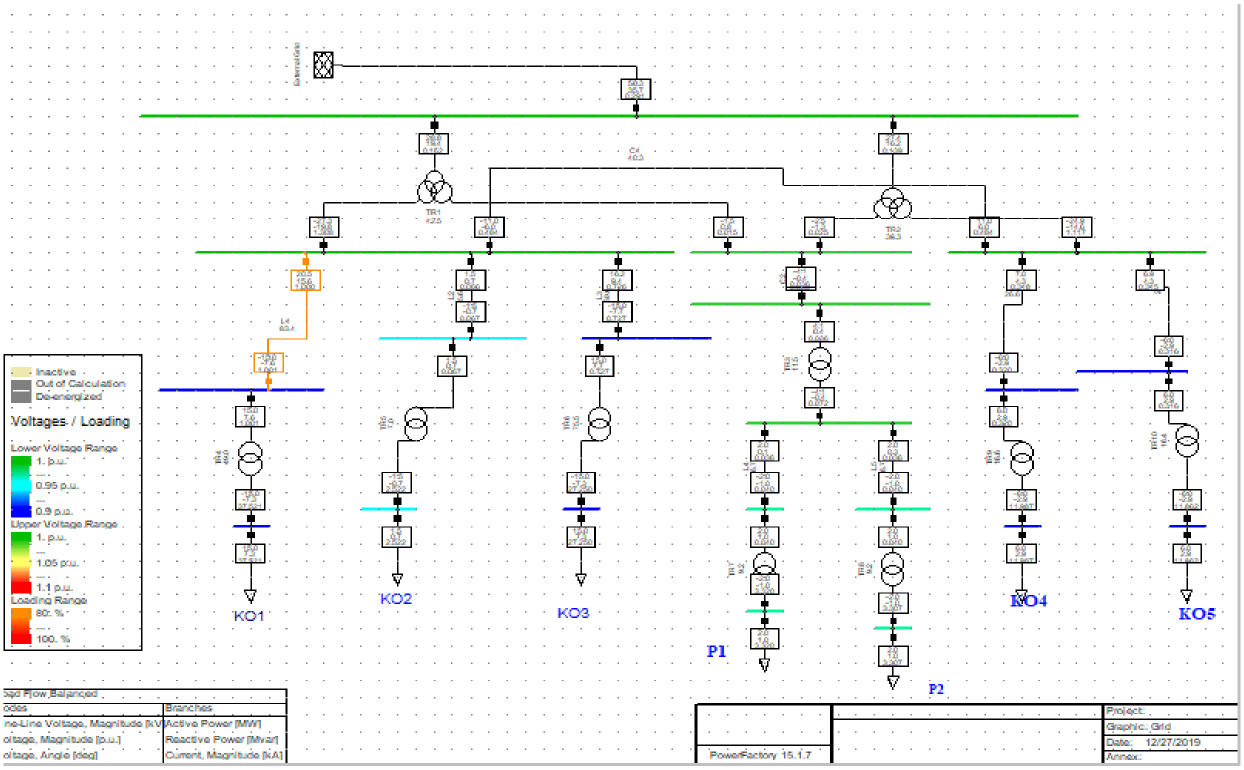
DIgSILENT PowerFactory 15.1.7 | Project: | Date: 8/19/2019

Grid: Grid | System Stage: Grid | Study Case: Study Case | Annex: / 1

Name	Type	Loading [%]	Busbar	Active Power [MW]	Reactive Power [Mvar]	Power-factor [-]	Current [kA]	Current [p.u.]
L1	Lne	34.63	BB1	8.428	6.660	0.78	0.416	0.346
			BB2	-8.400	-6.620	-0.79	0.416	0.346
L10	Lne	22.78	BB9	-6.895	-0.888	-0.99	0.273	0.228
			BB10	6.907	0.904	0.99	0.273	0.228
L11	Lne	23.82	BB10	-7.207	-1.050	-0.99	0.286	0.238
			BB11	7.220	1.068	0.99	0.286	0.238
L12	Lne	30.82	BB11	-9.220	-2.036	-0.98	0.370	0.308
			BB12	9.242	2.067	0.98	0.370	0.308
L13	Lne	3.76	BB1	1.050	0.504	0.90	0.045	0.038
			BB13	-1.050	-0.505	-0.90	0.045	0.038
L14	Lne	1.97	BB13	0.550	0.263	0.90	0.024	0.020
			BB14	-0.550	-0.264	-0.90	0.024	0.020
L15	Lne	1.25	BB14	0.350	0.167	0.90	0.015	0.013
			BB15	-0.350	-0.168	-0.90	0.015	0.013
L16	Lne	0.18	BB15	0.050	0.023	0.91	0.002	0.002
			BB16	-0.050	-0.024	-0.90	0.002	0.002
L17	Lne	5.54	BB17	-1.526	-0.737	-0.90	0.066	0.055
			BB4	1.527	0.737	0.90	0.066	0.055
L18	Lne	5.45	BB17	1.501	0.725	0.90	0.065	0.054
			BB18	-1.501	-0.725	-0.90	0.065	0.054
L19	Lne	4.72	BB18	1.301	0.628	0.90	0.057	0.047
			BB19	-1.300	-0.629	-0.90	0.057	0.047
L2	Lne	32.88	BB2	7.900	6.378	0.78	0.395	0.329
			BB3	-7.875	-6.343	-0.78	0.395	0.329
L20	Lne	1.82	BB19	0.500	0.241	0.90	0.022	0.018
			BB20	-0.500	-0.242	-0.90	0.022	0.018
L21	Lne	3.84	BB6	1.050	0.507	0.90	0.046	0.038
			BB21	-1.050	-0.508	-0.90	0.046	0.038
L22	Lne	2.74	BB21	0.750	0.363	0.90	0.033	0.027
			BB22	-0.750	-0.363	-0.90	0.033	0.027
L23	Lne	0.91	BB22	0.250	0.121	0.90	0.011	0.009
			BB23	-0.250	-0.121	-0.90	0.011	0.009
L24	Lne	0.18	BB23	0.050	0.024	0.90	0.002	0.002
			BB24	-0.050	-0.024	-0.90	0.002	0.002
L25	Lne	31.17	BB12	-9.342	-2.116	-0.98	0.374	0.312
			BB25	9.347	2.122	0.98	0.374	0.312
L26	Lne	1.17	BB25	0.325	0.157	0.90	0.014	0.012
			BB26	-0.325	-0.157	-0.90	0.014	0.012
L27	Lne	1.08	BB26	0.300	0.145	0.90	0.013	0.011
			BB27	-0.300	-0.145	-0.90	0.013	0.011
L28	Lne	1.08	BB27	0.300	0.145	0.90	0.013	0.011
			BB28	-0.300	-0.145	-0.90	0.013	0.011
L3	Lne	32.18	BB3	7.675	6.246	0.78	0.386	0.322
			BB4	-7.651	-6.212	-0.78	0.386	0.322
L31	Lne	34.08	BB25	-10.172	-2.521	-0.97	0.409	0.341
			BB35	10.177	2.529	0.97	0.409	0.341
L38	Lne	8.37	BB37	1.877	1.760	0.73	0.100	0.084
			BB38	-1.877	-1.760	-0.73	0.100	0.084
L39	Lne	8.19	BB38	1.827	1.735	0.72	0.098	0.082
			BB39	-1.826	-1.735	-0.72	0.098	0.082
L4	Lne	25.78	BB4	5.824	5.330	0.74	0.309	0.258
			BB5	-5.808	-5.308	-0.74	0.309	0.258
L40	Lne	7.17	BB39	1.526	1.590	0.69	0.086	0.072
			BB40	-1.525	-1.589	-0.69	0.086	0.072
L41	Lne	3.98	BB40	0.525	1.105	0.43	0.048	0.040
			BB41	-0.525	-1.105	-0.43	0.048	0.040

L42	Lne	3.91	BB41	0.500	1.093	0.42	0.047	0.039
			BB65	-0.500	-1.093	-0.42	0.047	0.039
L43	Lne	3.92	BB65	0.500	1.093	0.42	0.047	0.039
			BB66	-0.500	-1.093	-0.42	0.047	0.039
L44	Lne	3.39	BB66	0.300	0.997	0.29	0.041	0.034
			BB67	-0.300	-0.997	-0.29	0.041	0.034
L45	Lne	2.95	BB67	0.100	0.900	0.11	0.035	0.029
			BB677	-0.100	-0.900	-0.11	0.035	0.029
L46	Lne	57.40	BB35	-16.455	-6.421	-0.93	0.689	0.574
			BB42	16.471	6.443	0.93	0.689	0.574
L47	Lne	19.32	BB42	5.355	2.597	0.90	0.232	0.193
			BB43	-5.353	-2.595	-0.90	0.232	0.193
L48	Lne	18.23	BB43	5.053	2.450	0.90	0.219	0.182
			BB44	-5.052	-2.448	-0.90	0.219	0.182
L49	Lne	18.05	BB44	5.002	2.424	0.90	0.217	0.181
			BB45	-5.000	-2.422	-0.90	0.217	0.181
L5	Lne	24.04	BB5	5.308	5.066	0.72	0.288	0.240
			BB6	-5.295	-5.048	-0.72	0.289	0.240
L50	Lne	76.67	BB42	-21.826	-9.040	-0.92	0.920	0.767
			BB46	21.853	9.080	0.92	0.920	0.767
L51	Lne	78.47	BB46	-22.353	-9.322	-0.92	0.942	0.785
			BB50	22.497	9.530	0.92	0.942	0.785
L52	Lne	3.93	BB50	1.100	0.532	0.90	0.047	0.039
			BB47	-1.100	-0.532	-0.90	0.047	0.039
L53	Lne	2.85	BB47	0.800	0.387	0.90	0.034	0.029
			BB48	-0.800	-0.387	-0.90	0.034	0.029
L54	Lne	1.78	BB48	0.500	0.242	0.90	0.021	0.018
			BB49	-0.500	-0.242	-0.90	0.021	0.018
L55	Lne	49.22	BB50	13.781	6.702	0.90	0.591	0.492
			BB51	-13.770	-6.685	-0.90	0.591	0.492
L56	Lne	31.35	BB51	8.770	4.264	0.90	0.376	0.314
			BB52	-8.765	-4.257	-0.90	0.376	0.314
L57	Lne	31.18	BB52	8.715	4.233	0.90	0.374	0.312
			BB53	-8.711	-4.227	-0.90	0.374	0.312
L58	Lne	4.65	BB53	1.300	0.629	0.90	0.056	0.047
			BB63	-1.300	-0.629	-0.90	0.056	0.047
L59	Lne	0.36	BB63	0.100	0.048	0.90	0.004	0.004
			BB64	-0.100	-0.048	-0.90	0.004	0.004
L6	Lne	19.75	BB6	4.044	4.444	0.67	0.237	0.197
			BB7	-4.035	-4.431	-0.67	0.237	0.197
L60	Lne	26.17	BB53	7.311	3.549	0.90	0.314	0.262
			BB54	-7.308	-3.545	-0.90	0.314	0.262
L61	Lne	2.51	BB54	0.700	0.338	0.90	0.030	0.025
			BB59	-0.700	-0.338	-0.90	0.030	0.025
L62	Lne	1.43	BB59	0.400	0.193	0.90	0.017	0.014
			BB60	-0.400	-0.193	-0.90	0.017	0.014
L63	Lne	1.07	BB60	0.300	0.145	0.90	0.013	0.011
			BB61	-0.300	-0.145	-0.90	0.013	0.011
L64	Lne	0.72	BB61	0.200	0.097	0.90	0.009	0.007
			BB62	-0.200	-0.097	-0.90	0.009	0.007
L65	Lne	23.31	BB54	6.508	3.158	0.90	0.280	0.233
			BB55	-6.505	-3.155	-0.90	0.280	0.233
L66	Lne	19.72	BB55	5.505	2.670	0.90	0.237	0.197
			BB56	-5.503	-2.668	-0.90	0.237	0.197
L67	Lne	19.01	BB56	5.303	2.571	0.90	0.228	0.190
			BB57	-5.302	-2.569	-0.90	0.228	0.190
L68	Lne	17.93	BB57	5.002	2.424	0.90	0.215	0.179
			BB58	-5.000	-2.422	-0.90	0.215	0.179
L69	Lne	27.22	BB50	7.622	3.710	0.90	0.327	0.272
			B69	-7.618	-3.705	-0.90	0.327	0.272
L7	Lne	19.70	BB7	-5.965	-0.412	-1.00	0.236	0.197
			BB8	5.974	0.424	1.00	0.236	0.197
L70	Lne	26.87	B69	7.518	3.657	0.90	0.322	0.269
			BB70	-7.515	-3.652	-0.90	0.322	0.269
L71	Lne	25.08	BB70	7.015	3.410	0.90	0.301	0.251
			BB71	-7.012	-3.406	-0.90	0.301	0.251
L72	Lne	24.01	BB71	6.712	3.261	0.90	0.288	0.240
			BB72	-6.709	-3.257	-0.90	0.288	0.240
L73	Lne	22.22	BB72	6.209	3.015	0.90	0.267	0.222
			BB73	-6.207	-3.012	-0.90	0.267	0.222
L74	Lne	21.15	BB73	5.907	2.867	0.90	0.254	0.211
			BB74	-5.905	-2.864	-0.90	0.254	0.211
L75	Lne	19.36	BB74	5.405	2.622	0.90	0.232	0.194
			BB75	-5.403	-2.619	-0.90	0.232	0.194
L76	Lne	18.64	BB75	5.203	2.523	0.90	0.224	0.186
			BB76	-5.202	-2.520	-0.90	0.224	0.186
L77	Lne	17.93	BB76	5.002	2.424	0.90	0.215	0.179
			BB77	-5.000	-2.422	-0.90	0.215	0.179
L8	Lne	20.38	BB8	-6.174	-0.521	-1.00	0.245	0.204
			BB89	6.183	0.534	1.00	0.245	0.204
L9	Lne	22.10	BB89	-6.683	-0.776	-0.99	0.265	0.221
			BB9	6.695	0.791	0.99	0.265	0.221

Appendix D: Comparisons of Outgoing Feeders Loading



Appendix E: Bus Voltage when the DG Installed at Different Location at Appropriate Capacity

Bus No	When DG install at BB1	When DG install at BB16	When DG install at BB19	When DG install at BB25	When DG install at BB34	When DG install at BB43	When DG install at BB50	When DG install at BB55	When DG install at BB70
	Bus voltage	Bus voltage	Bus voltage	Bus voltage	Bus voltage	Bus voltage	Bus voltage	Bus voltage	Bus voltage
BB1	1	0.992	0.993	0.993	0.993	0.993	0.996	0.993	0.993
BB2	0.982	0.981	0.986	0.987	0.987	0.987	0.993	0.988	0.987
BB3	0.971	0.971	0.9879	0.982	0.982	0.982	0.990	0.982	0.982
BB4	0.960	0.960	0.973	0.976	0.976	0.976	0.987	0.976	0.976
BB5	0.951	0.951	0.963	0.971	0.971	0.976	0.985	0.971	0.971
BB6	0.941	0.941	0.954	0.967	0.967	0.967	0.984	0.967	0.966
BB7	0.932	0.932	0.945	0.962	0.962	0.962	0.982	0.962	0.962
BB8	0.924	0.923	0.936	0.958	0.954	0.954	0.981	0.958	0.958
BB9	0.906	0.915	0.920	0.951	0.951	0.951	0.979	0.951	0.954
BB10	0.898	0.898	0.911	0.946	0.947	0.947	0.978	0.947	0.951
BB11	0.890	0.890	0.903	0.966	0.944	0.943	0.977	0.944	0.947
BB12	0.882	0.882	0.895	0.940	0.940	0.940	0.977	0.940	0.943
BB13	0.992	0.995	0.992	0.993	0.993	0.993	0.996	0.993	0.940
BB14	0.992	0.999	0.992	0.993	0.993	0.993	0.996	0.993	0.993
BB15	0.992	1.003	0.992	0.993	0.993	0.993	0.996	0.993	0.993
BB16	0.992	1.006	0.992	0.993	0.993	0.993	0.996	0.993	0.993
BB17	0.960	0.960	0.978	0.975	0.975	0.975	0.987	0.976	0.975
BB18	0.959	0.959	0.979	0.975	0.975	0.975	0.986	0.975	0.975
BB19	0.959	0.958	0.983	0.974	0.974	0.975	0.986	0.975	0.975
BB20	0.958	0.958	0.982	0.974	0.974	0.975	0.985	0.975	0.975
BB21	0.941	0.941	0.953	0.966	0.966	0.966	0.983	0.966	0.966

BB22	0.941	0.941	0.953	0.966	0.966	0.966	0.983	0.966	0.996
BB23	0.941	0.941	0.953	0.966	0.966	0.966	0.983	0.966	0.996
BB24	0.941	0.941	0.953	0.966	0.966	0.966	0.983	0.966	0.966
BB25	0.880	0.880	0.895	0.939	0.939	0.939	0.976	0.939	0.939
BB26	0.880	0.878	0.894	0.939	0.939	0.939	0.976	0.939	0.939
BB27	0.880	0.878	0.894	0.939	0.939	0.939	0.976	0.939	0.939
BB28	0.880	0.878	0.885	0.939	0.939	0.939	0.976	0.939	0.939
BB29	0.890	0.877	0.884	0.939	0.939	0.939	0.976	0.939	0.938
BB30	0.872	0.877	0.884	0.939	0.939	0.939	0.976	0.939	0.938
BB31	0.874	0.874	0.884	0.939	0.939	0.939	0.976	0.939	0.938
BB32	0.874	0.874	0.885	0.939	0.939	0.939	0.976	0.939	0.938
BB33	0.873	0.872	0.885	0.939	0.939	0.939	0.976	0.939	0.938
BB34	0.872	0.872	0.884	0.937	0.939	0.939	0.976	0.939	0.939
BB35	0.882	0.872	0.892	0.939	0.939	0.939	0.976	0.939	0.939
BB36	0.880	0.872	0.892	0.939	0.938	0.938	0.976	0.938	0.939
BB37	0.880	0.872	0.892	0.939	0.938	0.938	0.976	0.938	0.939
BB38	0.880	0.872	0.892	0.939	0.938	0.938	0.976	0.938	0.937
BB39	0.879	0.872	0.891	0.939	0.938	0.938	0.975	0.938	0.937
BB40	0.878	0.871	0.890	0.936	0.937	0.937	0.974	0.937	0.937
BB41	0.906	0.871	0.891	0.936	0.937	0.937	0.974	0.937	0.936
BB42	0.902	0.871	0.891	0.936	0.937	0.937	0.974	0.937	0.938
BB43	0.878	0.872	0.891	0.936	0.937	0.939	0.974	0.937	0.938
BB44	0.878	0.872	0.891	0.936	0.938	0.939	0.977	0.937	0.938
BB45	0.880	0.877	0.891	0.937	0.938	0.939	0.977	0.939	0.938
BB46	0.877	0.872	0.886	0.936	0.938	0.936	0.977	0.939	0.938
BB47	0.878	0.872	0.886	0.932	0.933	0.933	0.980	0.939	0.938
BB48	0.877	0.842	0.886	0.932	0.933	0.933	0.980	0.939	0.938
BB49	0.877	0.872	0.886	0.932	0.933	0.933	0.980	0.938	0.938
BB50	0.872	0.872	0.886	0.932	0.933	0.934	0.980	0.938	0.939
BB51	0.872	0.872	0.886	0.932	0.932	0.933	0.979	0.938	0.939

BB52	0.872	0.872	0.885	0.932	0.932	0.933	0.979	0.937	0.939
BB53	0.871	0.872	0.884	0.932	0.932	0.932	0.979	0.937	0.939
BB54	0.871	0.872	0.884	0.932	0.932	0.932	0.978	0.937	0.939
BB55	0.871	0.872	0.884	0.930	0.932	0.932	0.978	0.939	0.941
BB56	0.871	0.872	0.884	0.932	0.931	0.932	0.978	0.939	0.941
BB57	0.871	0.872	0.885	0.930	0.931	0.932	0.978	0.937	0.941
BB58	0.871	0.871	0.885	0.930	0.931	0.932	0.979	0.937	0.941
BB59	0.871	0.871	0.885	0.930	0.931	0.932	0.979	0.937	0.941
BB60	0.871	0.872	0.885	0.931	0.931	0.932	0.979	0.937	0.940
BB61	0.871	0.871	0.885	0.931	0.931	0.932	0.978	0.937	0.940
BB62	0.871	0871	0.885	0.931	0.931	0.932	0.978	0.937	0.941
BB63	0.871	0.871	0.885	0.931	0.931	0.932	0.971	0.939	0.940
BB64	0.871	0.871	0.885	0.930	0.931	0.937	0.971	0.939	0.940
BB65	0.871	0.871	0.885	0.935	0.936	0.936	0.979	0.939	0.940
BB66	0.871	0.871	0.890	0.935	0.936	0.936	0.979	0.939	0.940
BB67	0.871	0.871	0.890	0.935	0.936	0.936	0.979	0.936	0.940
BB68	0.871	0.871	0.885	0.935	0.936	0.936	0.979	0.936	0.936
BB69	0.872	0.871	0.885	0.930	0.936	0.933	0.980	0.936	0.936
BB70	0.872	0.871	0.885	0.931	0.936	0.933	0.979	0.936	0.936
BB71	0.871	0.871	0.885	0.931	0.931	0.933	0.979	0.940	0.938
BB72	0.871	0.871	0.885	0.931	0.932	0.933	0.979	0.939	0.938
BB73	0.871	0.871	0.885	0.931	0.932	0.932	0.979	0.939	0.938
BB74	0.871	0.871	0.885	0.931	0.932	0.932	0.979	0.939	0.938
BB75	0.871	0.871	0.885	0.931	0.931	0.932	0.979	0.937	0.937
BB76	0.871	0.871	0.885	0.931	0.931	0.932	0.978	0.939	0.937
BB77	0.871	0.871	0.885	0.930	0.931	0.932	0.978	0.939	0.937