ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

STUDY ON PLANNING OF DISTRIBUTION SYSTEM EXPANSION WITH DISTRIBUTED GENERATION

(A CASE STUDY AT COTOBIE 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:

ARAYA HAILEMARIAM

ADVISOR: Dr. GETACHEW BEKELE

DATE: March 2018

ADDIS ABABA, ETHIOPIA

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

STUDY ON PLANNING OF DISTRIBUTION SYSTEM EXPANSION WITH DISTRIBUTED GENERATION

(A CASE STUDY AT COTOBIE SUBSTATION)

BY:
ARAYA HAILEMARIAM
ADVISOR: Dr. GETACHEW BEKELE

APPROVAL BY BOARD OF EXAMINERS

Chairman Department of Graduate Committee	Signature
Advisor	Signature
Internal Examiner	Signature
External Examiner	Signature

Declaration

I, the undersigned, 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.

Araya Hailemariam ______________

Name Signature

Place: Addis Ababa

Date of Submission: March, 2018

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

Dr. Getachew Bekele ________________

Advisor's Name Signature

Acknowledgments

First of all, I would like to thank the Almighty God for his provision of grace to overcome trials and temptation to complete the entire work.

Secondly, I would like to express my utmost gratitude to my advisor Dr. Getachew Bekele for his expert guidance, constructive comments, suggestions and encouragement without which this work could have not been completed. I am grateful to his motivation for the timely completion of the research and his dynamic suggestions for solutions to any challenges during the total work of this thesis.

I take this opportunity to extend my thanks to the staff of EEP and the respective managers and especially to Mr. Weldemarkos Damte, A.A region transmission system regional substation and transmission lines, who provided me with numerous valuable data and for his hospitable service. I had a wonderful time and received a very keen support from the Electrical Engineering office during my data collection for the successful completion of this thesis. Finally, I also highly appreciate and acknowledge the assistances kindly provided by School of Electrical & computer Engineering and also I would like to thank my family and friends for their useful idea and constructive suggestions on this thesis work.

Abstract

Distribution System Expansion Planning answers the services to be mounted, so that the distribution network fulfills the predicted load requirement to satisfy all operational and technical constraints. It is used to particular planning horizon, ensuring the consumer reliability and power quality standards. The operating characteristics of modern power system are modified due to the integration of Distributed Generations which have noteworthy economic and technical benefits such as, reduction of complications in expansion planning of distribution network, reduction in losses, improving voltage profile, flatter of peak load and increase reliability. This thesis work mainly provides planning of Cotobie distribution substation with voltage sensitivity analysis methods to facilitate the integration of Distributed Generation into the grid distribution network. The results of Distributed Generation are presented to determine the appropriate places and the capacity to make the distribution network highly reliable. It is shown that outgoing feeder no-4 and feeder no-1 have the least tail end voltage sensitivity index of 0.00132 and 0.00221 respectively. Appropriate places are selected for the DGs and their ratings are determined on the principle of minimum system power loss. The power capacity of DG for feeder no-1 is found to be 2.7MW and for feeder no-4 is found to be 4.5MW in MV feeders. Finally for Cotobie distribution system reliability, voltage profile and power loss before and after DG integration were compared. The results showed a reliability improvement of 37.08%, voltage profile within limit of 0.95 - 1.05 p.u and active power loss reduction of 71.68% as well as reactive power loss reduction of 61.61%. In addition installing as backup a 6MW DG source in LV feeders results the reliability improvement of 82.428%. So this result shown that even if load demand increases 8.8% each year then DG units are able to meet the demand requirements until year-5.

Key words: DG location, DG size, Distribution network expansion, DG, Distribution network reliability, technical constraints, loss reduction, Cotobie.

Table of Contents

List of figures

List of Tables

List of Abbreviations

ASAI: Average Service Availability Index

CAIDI: Customer Average Interruption Duration Index

CAIFI: Customer Average Interruption Frequency Index

CC: Current Capacity

CHP: Combined Heat Power

DER: Distributed energy resources

DG: Distributed Generation

DNO: Distribution Network Operator

DSEP: Distribution System Expansion Planning

EEP: Ethiopian Electric Power

EEU: Ethiopian Electric Utility

EIC: Expected Interruption Cost

ENS: Energy Not Supplied

FC: Fuel Cell

HV: High Voltage

IPP: Independent Power Producers

LV: Low Voltage

MV: Medium Voltage

MT: Micro Turbines

NR: Newton Raphson

PL: Power Losses

PV: Photovoltaic

SAIDI: System Average Interruption Duration Index

SAIFI: System Average Interruption Frequency Index

TEN: Tail End Node

TENVDE: Tail End Node Voltage Deviation Index

T&D: Transmission and Distribution

VR: Voltage Regulators

CHAPTER ONE

INTRODUCTION

1.1 Background

Distributed generation is generally regarded as small generators, both in terms of power output and physical size, connected to the existing power distribution grid. The technology and concept are also being revisited because of the benefits it can provide. The use of DG can improve power quality for utilities in different ways, although each depends on the location and type of DG used. The use of DG can improve the system voltage profile and can reduce power system losses when located near loads. The units that can operate in standalone mode can provide power quality benefits to customers by supplying sections of the power system grid when there are outages on other sections of the distribution system [1].

Distribution systems are generally the main source that causes power system outages [2]. These effects will cause enormous amounts of money losses to both the Ethiopian electric utility and the customers, and reliable operations of distribution systems are always desired. With more and more small generation units being connected online at the customer sides in these days, the traditional scheme of supplying power from the substation downstream to all the load buses located in the radial-type feeders no longer holds. Proper guidance for determining the adequate locations of those distributed generators and the associated operational impacts to the distribution system is certainly expected. Based on the operational experiences and the load forecasting results, utility companies can periodically predict the required substation installation capacities [3].

With certain specified operational margins, the related facilities must be able to meet the peak load demands. To avoid the possible congestions, either expanding the transformer capacities or constructing new substations must be conducted. However, these substation facility expansion options have been restricted by many surrounding communities with high population densities. Consequently, the schedules for installing new facilities to meet load demands at certain safety constraints have become even harder to satisfy, and lower power service.

With the growing awareness of environmental protection and energy conservation, installations of DGs that can harness those renewable energies have increased dramatically [4]. No matter the power generations are as part of their production lines or as supplemental energy supports, one of the objectives of these independent power producers is to sell their remaining electrical power generations to the utilities. On the other hand, in addition to the power generation and load requirement issues, operational impacts with these DGs that being connected to the existing distribution systems will greatly affect the determinations of pricing policies for the utility companies [5], [6].

In this research, a systematic scheme that can identify the appropriate locations for installing DGs in a distribution system will be reported. With a specified number of DGs in a distribution system, the analyzed results will provide a reference for utility companies to set up the corresponding installation incentives. Besides alleviating the substation congestion problems, along with some forecasted load incremental rates, the DG combinations for switching on-line to the distribution systems have been investigated based on proper system reliability indices. Results have shown that not only some part of the system load requirements can be taken care of by the DGs, but the entire system operational reliability can also be enhanced.

1.2 Statement of the Problem

A number of factors are motivating distribution system planning to determine expansion strategies to serve the load growth and provide their customers with reliable. Furthermore, advancements in DG technologies have made them feasible and an attractive option for the planning of the system. Among the various possible benefits of DG, some of the significant ones are environmental sustainability, reduced need of constructing new transmission lines and large power plants, improvement in voltage profile and reliability, reduced line losses and network congestion.

1.3 Objectives of the study

General objective

This thesis aims to study on distribution system expansion planning with distributed generation system fulfills the predicted load requirement to satisfy all operational and technical constraints in the particular planning horizon while ensuring the consumer reliability and power quality standards.

The Specific objectives of thesis are:

1. Study distribution reliability improvement by using Distributed Generation.
2. Forecast future loads of the Cotobie substation for the coming ten years (2017-2027).
3. Determine appropriate placement and sizing of DGs considering uncertainty using the sensitivities index analytical method.

4. Examine the impacts of integrating of different DG technologies on distribution network performance, especially in terms of system voltage profiles and energy losses.

1.4. Significance and scope of the Study

As the demand of electricity consumption increases, conventional power system leads to several disadvantages like the considerable amount of transmission loss, transmission line congestion, increasing environmental impact, increasing fuel crises etc. Recent researches show that these problems can be solved by the introduction of Distributed Generation. DG possesses several following mentioned advantages, such as:

*Economical***:** The economic advantages are due to the reduction of transmission and distribution cost, electricity price and saving of fuel.

Environmental: Environmental advantages are due to the reductions of sound pollution and emission of greenhouse gases.

Technical: Technical advantages are due to line loss reduction, peak shaving, improved system voltage profile and hence improve power quality and relieved transmission and distribution congestion as well as grid reinforcement.

The scope of the study is starting from studying and analyzing of Distribution System expansion planning with Distributed Generation in Case of Cotobie substation. In this Thesis, DG resources are used to increase power capacity, improved system reliability and also its impacts on the system. The results are explained using simulation on Power factory digsilent software.

1.5 Methodology

The methodology of this thesis goes starting from the problem identification and reading helpful literatures. The problem identification is the first step towards solving the public problem. For this particular problem in power distribution reliability, the study goes through literature survey on Distribution System expansion planning with Distributed Generation and come up with ideas for mitigating the problems.

Site Selection

Cotobie substation is selected as case study area where interruption problems are highly pronounced due to load growth from time to time. It has more DG resources in medium voltage distribution like wind energy and for low voltage distribution has more availability of solar energy to consider in distribution system expansion planning.

Data Collection

Data of this research 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 EEU and checked the data collected
- Data has been collected from the following offices in order to analysis existing structure Cotobie substation.
  - ✓ Data’s on EEU
  - ✓ Data’s on planning and design of EEU

Data Analysis and Modelling

- Cotobie distribution system expansion integrating with DG is analyzed and discussed.
- To see the effect of DG, Power factory digsilent software is used.

1.6 Organization of the thesis

This thesis is organized into 5 chapters. Chapter 1 presents the problem background, thesis objectives and have a literature review on distribution system planning expansion with Distributed Generation energies. Chapter 2 introduces different types of load forecasting techniques, this chapter also describes possible appropriate place and size of DG installation based on the minimization of power losses. Chapter 3 presents data collection and analysis of Cotobie distribution system and analyses reliability of the system. Chapter 4 result and discussion to illustrate the integration of DG into the system such that voltage profile improvement, energy losses minimization and improve reliability can be alleviated. Finally, conclusions and recommendation are drawn in Chapter 5.

CHAPTER TWO

Theoretical Background and Literature Review

2.1 The Need for Power Systems Planning

Power System Planning is part of a more general problem, that of energy and economic development planning. Its objective is therefore 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 [7].

The objective of power system planning is the 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 [8]:

- 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 reliable 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, by classification by land development plans, by fiscal incentives and taxes measures. 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.

2.2 Modern Distribution System Planning with DG

The current existing distribution systems are seen to be passive networks units due to the unidirectional power flow from distribution substation to end users. Usually, distribution system 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 units has been as one of the attractive options for distribution system due to the incentives and environmental considerations. Distribution system with DG unit's demands for dedicated operational strategies since the DG units located near the load centers can possibly change the direction of power flows and consequently modify system operations. It is very important to allocate DG units in distribution networks with comprehensive technical and economic considerations to avoid the overall degradation of system performance.

The method for radial distribution network reliability assessment planning based on a combination of the analytical and Monte Carlo simulation approaches. The analyzing procedure starts by applying the analytical method continued by applying the method of Monte Carlo simulation. The method takes into account the reliability indices, energy loss, and interruption energy costs [9].

S. Wong, et al., in [10], a long-term assessment approach to distribution systems planning for existing system configurations is presented. It allows substation, feeder, and DG upgrades while accounting for line limits, technology limitations, varying energy prices, environmental (emissions) limits, and zoning restrictions.

A probabilistic reliability assessment model is used to determine the proper DG locations and sizes. I 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 [11]. 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 [12].

2.3 Planning of Distribution Networks under Load Growth

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 [13]. 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 and can improve the reliability by supplying isolated loads after an outage.

A DG-based planning method is presented in to minimize the line loss in a planning area. In this paper, two scenarios are discussed to evaluate the feasibility of implementing DG investment versus other traditional planning choices. Dynamic ant colony search algorithm is employed in [14] to minimize the line loss for a planning period. Similarly, the DG installation is studied in this paper instead of traditional options to meet the load growth. In [15, 16], an optimization software, based on the branch and bound method, is used to solve the planning problem. In these two papers, a multistage model is proposed to consider the traditional planning options as well as the use of DGs.

In addition to DGs, capacitors can postpone the need to upgrade the HV/MV transformer required due to the load growth [17]. The capacitors are used commonly for minimizing the line loss and improving the voltage profile by reducing the reactive component of the feeder current [18]. In [19], a dynamic programming method is used for solving the reactive power and voltage control. The capacitors and the main transformer tap changer are dispatched in this paper to minimize the line loss and to improve the voltage profile. A similar procedure is implemented in [20, 21] using the GA. A mechanism for optimal voltage support is proposed in [22], which introduces a procedure to optimize 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, papers [23-24] 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, 26]. Such reductions of the line loss at peak load level can reduce the need for investment in equipment of a greater power rating.

In addition to reducing the line loss and improving the voltage profile, increasing reliability is another benefit that DGs can provide for electric utilities. An economical DG planning method is implemented in [26] to improve reliability as well as the line loss. In [27], the impact of DG location on reliability is studied, and the placement of DGs for maximizing the reliability improvement and minimizing the line loss is obtained. Ant colony algorithm is employed in [28] to optimize the location of DG and reclosers to enhance the system reliability.

Improving the voltage profile, minimizing the line loss and reliability costs, and supporting the load growth are the main objective in the planning of a distribution network.

Since capacitors improve the voltage profile and line loss and DGs increase system reliability and that both these elements can help the HV/MV transformers for supporting the load growth, capacitors and 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 research.

2.4 Distributed Generation Technology

Various DG technologies are involved in power systems. Some of these technologies have been in use for a long time while others are newly emerging. In spite of that, the features that all DG technologies have in common are to increase efficiency and decrease costs related to installation, running and maintenance. DG technologies are packaged together categorized into two types: renewable technologies (e.g., photovoltaic and wind turbine) and non-renewable technologies (e.g., mini and micro-turbines, combustion turbines and fuel cells). DG technologies have a significant impact on the selection of the appropriate capacity and place of a DG unit to be connected to a grid or customer loads and figure shown below detail over all summary of DG applications.

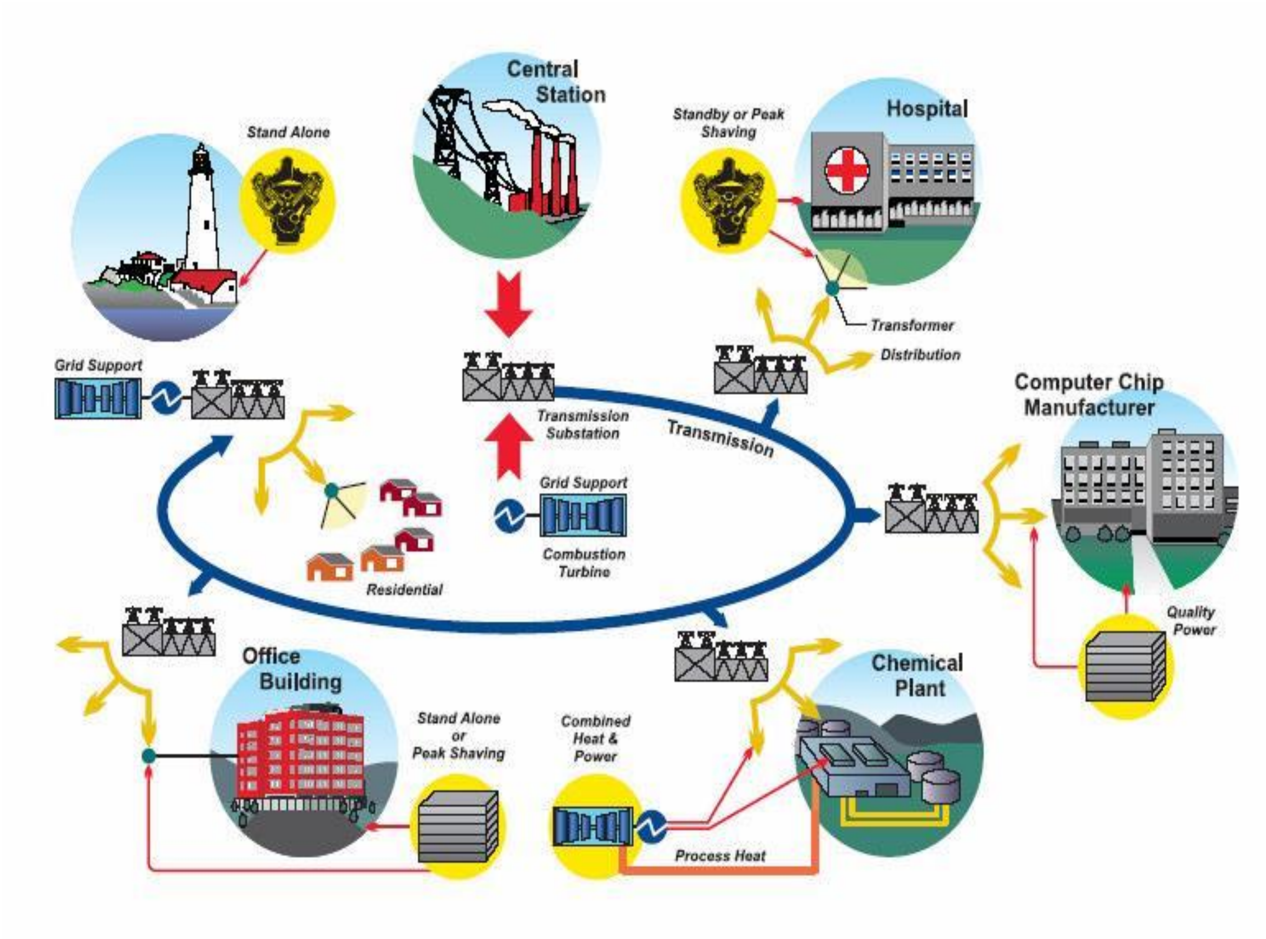


Figure2.1-Summary of DG applications [29]

The following sections provide details on the most popular DG technologies currently in the market:

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 [29]. 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.

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 [30]. 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.

Photovoltaic

Photovoltaic **(PV)** generation, directly converting sunlight into electricity, is a well-established technology for supplying power to sites in a way the distribution substation. It is currently being considered for integration into the distribution system for large-scale, medium-scale and small-scale DG. The power generated by PV based DG units are inherently intermittent; it is less variable and is much easier to predict. The modular design of PV based DG systems allows them to be easily incorporated into various places such as buildings and rooftops. However, the power quality problems arising from the integration of a large amount of PV based DG units and high cost associated with PV cells and ancillary equipment are the two main factors limiting the widespread implementation of this technology [31].

The PV energy is produced when the solar cells are exposed to direct sunlight, each cell generates less than one watt of DC power, with the lowest voltage around 0.5 V. A solar cell is basically a semiconductor diode in which the photons of sunlight fall on the cell and generate electron-hole pairs separated on the diode junction, thus forming the junction potential or voltage. The generated voltage potential is limited by the forward potential drop across the semiconductor p-n junction. The current produced is proportional to the surface area and to the density of the solar power radiation [32].

Wind Turbines

Wind turbines are among the most popular renewable electrical sources in the world. A large number of wind turbine systems have already been installed and connected to the grid, generating globally around 238,000 megawatts of electricity in 2011, and many new systems are being planned. Manufacturers offer wind turbines in a capacity range from less than 5 to over 1,000 kW. Wind turbines are usually integrated to the transmission voltage level and combined to make a wind farm. However, wind turbines are sometimes considered distributed generation, because the size and location of some small wind farms make them suitable for connection at the distribution voltage level.

Wind turbines consist of a rotor, turbine blades, generator, drive or coupling device, shaft, and nacelle. The energy of the raw wind turns the blades and the common shaft, producing electrical power. Like PV systems, wind turbines require no fuel, no emissions, and produce DC power that needs AC/DC inverters to be connected to the grid. Moreover, small wind turbines can be combined with PV and battery systems to cover loads of 25 to 100 kW. The main drawbacks of wind turbines are their high initial costs and unpredictability of energy production. As well, they are not suited to CHP applications [32].

CHAPTER THREE

Integration Issues of DG in Distribution Networks

3.1 Planning of Distribution Networks with DG

In the study, Distribution Generation are included in the system for minimizing the distribution line loss and for improving the voltage profile and significantly, they influence system reliability which is the dominant factor in the system. To increase system reliability, DGs are allocated and sized in this chapter as part of the integrated planning. Since these elements are quite expensive, the peak loads are also simultaneously planned. In this chapter, a comprehensive planning methodology is proposed that can minimize the line loss, maximize the reliability and improve the voltage profile in a distribution network.

When viewed from a total system point of view, a power system typically exhibits a smooth, continuous growth trend in annual peak load. Local area load growth usually occurs only over a few years, from a near zero to a value close to the final ‘saturated’ peak load. The analyses are carried out considering various load growth and associated supply conditions. The operation and planning of distribution systems under such conditions is explored.

Long-term planning involves principle to grow a strategy to meet the utility’s long-term power delivery needs, usually minimizing cost by bring about an optimal balance between capital additions and operational cost. It particularly requires that the distribution planner review every alternative, including load forecasts, revenue constraints, reliability and a lot of other factors. However, the long-term planning has to meet the basic constraints or requirements for the distribution network. In this thesis, the proposed method addresses a solution for long-term planning while meeting the proposed constraints of the network.

DG Operation

There are many factors affecting DG operation such as DG technologies, types, operational modes, and others. DGs installed in the distribution network can be owned, operated and controlled 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:

a) Limited operating time units for peak load shaving (Internal combustion engines, small fuel cell units).

b) Limited operating time units to share the load with different operating cycles (Micro-turbines and fuel cells).

c) Base load power supply (Micro-turbines and large fuel cells).

d) Renewable energy units affected by environmental conditions such as wind speed and sunlight respectively (Wind generators and solar cells)

On the other hand, customer-owned DG operating cycles are not known to the operators unless there is a unit commitment agreement between the electric utility and the customer, which is not very likely. Thus, small customer-owned DG operating cycles are considered to be unpredictable processes from the point of view of the electric utility. The utility has no control over their operation. This randomness changes the planning and operation problem from a deterministic problem to a non-deterministic one.

DG Siting

There are no clear restrictions on the location of DG units in the distribution network, as there are no geographical limitations as in the case of substations. Hence, the only limitations arise from electrical requirements. 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:

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

DG Sizing

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:

a) 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.

b) 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.

3.2 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.

Intuitive

The term intuitive forecasting can be used to describe methods which rely largely on experience and quick calculations using simple assumptions (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 discounted, as it is after all in the background of reviewers' minds when they appraise other peoples' demand forecasts. In some instances, the lack of available data may make intuitive forecasting the only possible option. The forecast may be appropriate for minor developments, isolated systems and small island utilities.

An alternative approach, but still within the intuitive forecasting framework, would be to apply a growth factor that is obtained for a country with similar economic characteristics. Indeed, it may be beneficial to compare load forecasts with the performance of a similar system in another part of the world at a comparable stage of development. This will particularly be the case where (i) there is little statistical information available on past loads, such as in new areas of supply, (ii) data errors that cannot be easily corrected, or, (iii) it becomes necessary to forecast on the results of direct enquiry and demographic and economic statistics. Such forecasting is no more than guesswork, but the results can be used to cross-check on forecasts prepared by more scientific methods. Where a new system of forecasting is to be prepared, it is often helpful to make a comparison of the intuitive forecasts prepared in the past and subsequent performance.

Extrapolation

Extrapolation techniques look at past trends in energy and power demand over time and, extend them into the future. Any time series may be decomposed into three elements:

- Trend;
- Seasonal variation;
- Serial dependency (auto-regression).

The Trend is defined as “the long-term average growth and may be regarded in some way as an average increase in a time series”. Superimposed on this may be a seasonal variation. Seasonal in this sense is defined as “a cyclic variable that has roughly the same beginning and end values for a given period of time (similar to the properties of a sine wave)”. Such variations may be seen over a 24 hour period, a weekly period, an annual period, or even a longer period. Finally, there may be a dependency between successive values. For example, if the value in the previous period was high, the value in the current period may be high. Such behavior could relate to the random use of batch processing equipment. This interdependency is known as auto-regression.

There are a wide range of techniques for analyzing data on a time series basis including:

- Moving average;
- Exponential smoothing;
- Autoregressive techniques;
- Simple regression;
- ARIMA (autoregressive integrated moving average).

End-user

End-user demand forecast modeling draws on many utility forecasting methods. The distinguishing characteristic of end-user modeling is the detailed description of how energy is used. Such models usually begin by specifying uses for which energy is ultimately required, such as heating water, cooling buildings and cooking food. The model then describes, via mathematical equations and accounting identities, the types of energy-using equipment that businesses and households have, and how much energy is used by each type of equipment to satisfy the predetermined levels of end-use energy demanded. A large amount of survey data and statistics are needed by such a model. By summing up the units of equipment times the average energy used by each class of equipment, total energy demand by fuel type is revealed. Multiplying types of equipment by average use values is just an accounting framework, but even so, it can generate insights into the way energy is used now and in the future. Optimization end-user models are a step beyond accounting end-user models. By specifying an objective function (such as minimizing cost) and identifying both the unit costs of using energy in the given processes and the constraints to the system, the accounting 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 assumptions about costs and constraints. End-user models are often linked to econometric models. End-user models are often weakest in predicting consumers' fuel-use decisions. With the available data, they can easily describe where the energy is being used and for what purposes but, without a theory to explain choices, they are limited in their ability to predict the future. The ideal end-user model (which is rarely achieved) would, for example, not only tell us the average watts of lighting energy in households, 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 highly accurate, particularly for green-field developments, and for forecasts of residential demand. An extension of end-user demand forecasting is load density-based forecasting, in which the maximum load in any area is based upon the surface area occupied by each consumer type and a power density (i.e. watts per square meter) associated with that consumer type. This can be especially useful for distribution planning. End-user forecasts also encompass developments in sectors such as industry and agriculture where consumption patterns can be established for, say, cement production or water pumping.

Econometric analysis

This class of model, like the time series model (extrapolation), uses historical data to predict the future. Econometric analysis however, attempts to go beyond time series models by explaining the causes of the identified trends. Econometric models postulate explicit causal relationships between the dependent variable (either energy or power) and independent variables (either economic e.g. GDP), technological (e.g. number and type of appliances; industrial processes), demographic (e.g. population) or other variables (e.g. weather).

Assuming these relationships are true it should then be possible to determine the historical relationships between electrical demand and such parameters as GDP by sector, personal income, the price of electricity etc. Future levels of these economic variables are then forecast and used as inputs to determine future levels of consumption. One advantage of econometric forecasting is the ease with which high and low scenario load forecasts can be derived and the logical basis on which they can be formed. This merely requires changes in the forecast rate of the input variables, e.g. economic growth and electricity price. A faster economic growth will produce a higher load forecast whilst the imposition of price increases will reduce forecast levels of energy demand. Econometric modeling would be preferred to time series analysis. Even if both techniques could predict changes in demand with equal accuracy, the econometric model would be more valuable since it might help in understanding why changes in demand were occurring.

Distribution System Peak Demand Forecasting

Historical peak load demand of Cotobie distribution network is shown in table 3.1 below. These values are then used as input to forecast for the coming 10 years using extrapolation list-square method of forecasting.

Table 3.1: Historical peak load data from 2012-2016 G.C

Year	2012	2013	2014	2015	2016
Peak load (MW)	20.21	21.31	22.66	25.30	28.28
Peak load (MVA)	22.21	23.42	24.90	27.80	31.08

Thus, the principle of regression theory is used to forecast the load for the coming ten years by using the results in table 3.1 as a previous data. Its principle is that any function y=f(x) can be fitted to a set of points (X_1, Y_1), (X_2, Y_2) so as to minimize the sum of errors squared at each point, i.e.

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

Among the different typical regression curves used in power system forecasting the simple least square line is used for forecasting the load in this thesis. The line $y=a_0+a_1x$ is fitted to the sets of points (X_1, Y_1), (X_2, Y_2) … (Xn, Yn)

$$\varepsilon^2=\sum_{i=1}^{n}[\mathrm{Y_i}-(\mathrm{a_0}+\mathrm{a_1X_i})]^2 \text{ =minimum} \tag{3.2}$$

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:

$$Na_0+a_1\sum X_{\mathrm{i}}=\sum Y_i \tag{3.3}$$

$$a_0\sum \mathrm{X_i}+a_1\sum \mathrm{X_i}^2=\sum \mathrm{X}_i Y_I \tag{3.4}$$

Table 3.2: all input historical data of the analysis

Year	Peak demand	X_i	$P_{Di}=\frac{\text{peak Demand}}{10}$	Y_i=lnP_{Di}	X_iY_i	x_i^2
2012	20.21	-2	2.021	0.70359	-1.40718	4
2013	21.31	-1	2.131	0.75659	-0.75059	1
2014	22.66	0	2.266	0.818016	0	0
2015	25.30	1	2.530	0.92801	0.92801	1
2016	28.28	2	2.828	1.0395	2.0701	4
		$\sum X_i$=0		$\sum Y_i$=4.2457	$\sum X_iY_i$=0.84034	$\sum X_i^2$=10

a_0	a1
0.84914	0.08403

Finally, the values in Table 3-2 are used to determine the load of the selected area up to 2027 G.C. The forecasting is then done using equation 3-5 (a) and (b) shown below by considering 2014 as a reference year and all the above equations are formulated using Mat lab M. file in **appendix C** in detail.

$$Y=a_0+a_1.x_i \qquad 3.5\ (a)$$

$$P_n=10e^{Y} \qquad 3.5\ (b)$$

Table 3.3: Power demand forecast for of Cotobie sub city from 2016-2027

Year	Forecasted Demand in (MW)	Forecasted Demand in (MVA)
2017	30.10	33.07
2018	32.72	35.95
2019	35.58	39.09
2020	38.70	42.52
2021	42.09	46.25
2022	45.79	50.32
2023	49.80	54.72
2024	54.17	59.52
2025	58.92	64.75
2026	64.08	70.42
2027	69.69	76.58

From Table 3.3 the power demand at Cotobie substation after 10 years will be approximately 69.69MW of active power and 76.58MVA by considering a power factor of 0.91 and the overall demand after Y-1 years will be approximate as shown in the Table. Therefore Planning and operation of Cotobie substation will be integrated with different DG by consideration of the maximum load of the substation.

3.3 Rapid Load Growth

The study presents an approach to obtain the appropriate DG sizing that meets a rapid growth of system load. A preliminary set of candidate DGs are selected. DG capacity requirement varies across buses because of the load distribution pattern, differences in total primary distribution feeder parameters and hence losses in each feeder being different. The scenario is to obtain the DG power requirement at these selected buses, and also the power requirement from the station source while and load demand increases. Therefore, in the Cotobie distribution network, it is assumed that

- DG is connected to the buses of the proposed network,
- Peak load demand increases by 8.8% every year over a period of 10 years

The required power from DG units increases at each bus in a linear manner. In table 3.3, it is shown that although the load demand increases rapidly each year, the DG units are able to meet the demand requirements until year-5, when the demand is 50% higher than the base year demand, and the distribution system needs to upgrade in order to draw power from the substation at year-6. Thereafter, the power drawn from the substation increases significantly.

3.4. Methodology for appropriate Location and size of DG

The allocation of DG problem consists of three important steps. Via Selection of Load flow analysis technique, finding appropriate location and selection of the appropriate size of DG.

Voltage Drop Constraints: The voltage drop constraints depend on the voltage regulation limits provided by the DISCO on each year.

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

Distribution Substation Capacity Constraint: Every plan year, the total power delivered by the substation over the outgoing distribution feeders from that bus must be within the substation capacity limit. The rated current of the lines and the transformer rating must not be exceeded. The extent of generation connected minus the lowest load must not exceed the transformer rating at the higher voltage. If there is some existing generation then this must be subtracted from the total. The result is the remaining capacity available below that station. In the case of two parallel transformers, the capacity is taken as the rating of the smaller transformer plus the lowest load. The constraint is expressed formally as in Equation (3.6)

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

Where P_{Tx} refers to power flow through the transmission substation transformer and $P_{TrafoCap}$ refers to the rating of that transformer. And also simply the rated current of the lines could not be exceeded. It is given by Equation (3.7).

$$I_i<I_i^{rated} \quad (3.7)$$

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 between each generator and its corresponding bus. Under standard voltage and power factor conditions, the rated current of the line can be translated directly into a rated active power for that line. If DG is connected to a network unit, it will change the active and reactive power flows and therefore change the voltage dropped across the lines. It has been shown that DG leads to a significant 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 large amount of power flow along lightly loaded lines with high impedance from the circuit shown below the voltage at the generator is given by Equation (3.8).

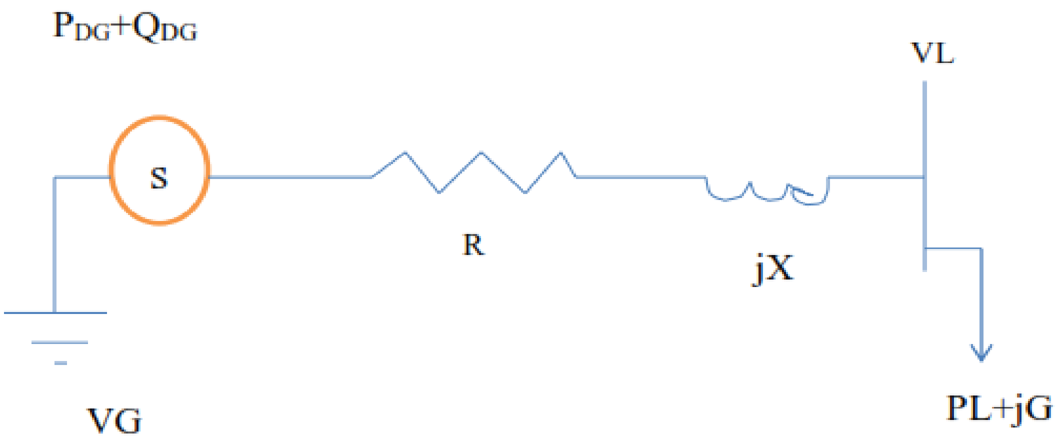


Figure3.1 Voltage rise effect

$$V_G=V_L+\frac{R+X}{V_L}+j\frac{X-R}{V_L} \tag{3.8}$$

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 respectively. Thus it can be seen that the generator voltage will be the load/bus voltage plus some value related to the impedance of the line and the power flows along that line. It is evident that the larger the impedance and power flow the larger the voltage rise. The increased active power flows on the distribution network have a large impact on the voltage level because the resistive elements of the lines on distribution networks are higher than other lines. The voltage must be kept within standard limits at each bus as given by Equation (3.9).

$$V_{mini}< V_i <V_{maxi} \tag{3.9}$$

Losses are a significant consideration when designing and planning the distribution system. Losses are unavoidable on any network; however, the amount can differ greatly depending on the design of the network. With the introduction of distributed generation, the network is being used in a different way with more variable and bidirectional power flows. The level of losses is closely linked to the power flows. Losses are a function of the square of the current, i.e. a doubling in current results in losses being quadrupled. Therefore the allocation of DG and the altered power flows that result may have a significant impact on losses and may provide an opportunity to improve them.

Load Flow Analysis

Conventional NR and Gauss-Seidel (GS) methods may become inefficient in the analysis of distribution systems, due to the special features of distribution networks, i.e. radial structure, high R/X ratio and unbalanced loads, etc. These features make the distribution systems power flow computation different and somewhat difficult to analyze as compared to the transmission systems. Various methods are available to carry out the analysis of balanced and unbalanced radial distribution systems and can be divided into two categories. The type of methods is utilized by proper modification of existing methods such as NR and GS methods. On the other hand, based on backward and forward sweep processes using Kirchhoff's laws.

Appropriate Placement of DG using TENVDI

In order to restrict solution space to few buses, tail end nodes are first identified by viewing the distribution network topology. By penetrating DG with 50% of the total feeder loading capacity at each node at a time, the *Tail End Nodes Voltage Deviation Index (TENVDI)* is calculated using equation (3.10). When DG is connected at bus *i*, TENVDI for bus *i* is defined as:

$$\text{TENVDIi} = \sum_{m=1}^{NTE} \frac{(Vnominal - vm)^2}{NTE} \tag{3.10}$$

Where, 'm' corresponds to each tail end node element of Tail End Nodes (TEN); Vnominal is taken as 1.0 Pu;

Appropriate Sizing of DG at appropriate Location

For deciding the best size of DG to be placed at the best location obtained from TENVDI, the DG is inserted at the optimal bus, size is varied from a minimum value (SDG_{min}) to the maximum value (SDG_{max}) with a step size of (ΔS). The size which gives the minimum complex power loss is the best size of DG to be placed at the best location.

For radial distribution system, 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 PLR as loss saving based on total real power loss in radial distribution system as;

$$P_{losses} = \sum_{i=1}^{n} (I_i^2) R_i \tag{3.11}$$

Where Ii is the current magnitude of each branch and R is the resistance of the i_{th} branch. The current Ii is determined by load flow using the Newton-Raphson method. This loss in equation (3.11) 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 ith branch is given by:

$$I_i^{new} = I_i + I_{DG} D_i \tag{3.12}$$

Where D is 1 if branch i has DG connected 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:

$$P_{Losses-new=} \sum_{i=1}^{n} (I_i^{new})^2 R_i \tag{3.13}$$

$$P_{Losses-new=} \sum_{i=1}^{n} I_i^2 R_i + 2 I_i D_i \, I_{DG} R_i + D_i \, I_{DG}^2 R_i \tag{3.14}$$

The power losses reduction (PLR) which is the objective for placement is determined by subtracting equation (3.11) from equation (3.14) which is the difference between power losses with DG and without DG connection as expressed below:

$$PLR_i = P_{Losses-new} - P_{Losses} \tag{3.15}$$

$$PLR_i = \sum_{i=1}^{n}(2I_i D_i I_{DG} + D_i I_{DG}^2) R_i \tag{3.16}$$

The DG current that gives maximum PLR value can be determined by differentiating equation

(3.16) With respect to I_{DG} and equate to zero as:

$$\frac{dPLR_i}{dI_{DG}} = 2 \sum_{i=1}^{n}(I_i D_i + I_{DG} D_i) R_i = 0 \tag{3.17}$$

Hence, the current for maximum power loss reduction value is

$$I_{DGi} = \frac{\sum_{i=1}^{n} D_i I_i R_i}{\sum_{i=1}^{n} R_i} \tag{3.18}$$

The emphasis is to place the DG at a location that will give maximum loss reduction. This procedure is repeated for all the buses in order to obtain the highest power loss reduction value as the DG units are singly located. Assuming no significant change in voltage as DG units are connected, the corresponding DG size is;

$$P_{DGi} = I_{DG} V_i Pf \tag{3.19}$$

The DG size from equation (3.19) must be located at bus i for maximum power loss reduction.

To determine the best size of DG, the following steps are taken:
Step 1: Run load flow for the base case.
Step 2: Find the Bus voltage sensitivity indices at each node using TENVDI equation by penetrating the 50 % of feeder load DG value at the respective node and rank the sensitivities of all nodes in ascending order to form priority list.

Step 3: Select the bus with the lowest priority and place DG at that bus.

Step 4: Keeping the power factor of DG constant, its size is varied from a minimum value to a value equal to feeder loading capacity in constant steps until the minimum system losses are found.

Step 5: The DG size which results in minimum losses is taken as optimal.

Step 6: Repeat Step 3 to Step 5 for all buses in the priority list.

Step 7: End

3.5 Reliability

The main purpose of this section is to study the reliability improvement due to the employment of distributed generations (DG) to the distribution system. The system under this study is under Cotobie distribution system. Data of the distance of distribution line and location of load that are a parameter of the substation is simulated using digital simulation and electrical network calculation program (Digsilent) to analyze the impact of installing DG on the reliability of distribution system. The system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI), customer average interruption frequency index (CAIFI), customer average interruption duration index (CAIDI), energy not supplied (ENS), average service availability index (ASAI) and average service unavailability index (ASUI) are assessed an index of reliability by comparing the SAIFI, SAIDI, CAIFI, ENS, ASAI, and ASUI between the base case (no DG) and the case when DG is connected to the distribution system. The results can be summarized by focusing on the location of DG, the capacity of DG, the size of the load, and the distance load which is factors able to affect the above indexes.

Sustained Interruption Indices

System average interruption frequency index (SAIFI)

SAIFI (sustained interruptions). This index is designed to give information about the average frequency of sustained interruptions per customer over a predefined area. Therefore,

$$\text{SAIFI}=\frac{\textit{total number of customers interruption}}{\textit{total number of customers served}} \quad \textbf{or } \text{SAIFI}=\frac{\sum Ni}{Nt} \tag{3.20}$$

Where

Ni is the number of interrupted customers for each interruption event during reporting period

NT is the total number of customers served for the area being indexed

Customer average interruption frequency index (CAIFI).

CAIFI This index gives the average frequency of sustained interruptions for those customers experiencing sustained interruptions. The customer is counted only once regardless of the number of times interrupted. Thus,

$$\text{CAI FI}=\frac{\boldsymbol{total\ number\ of\ customers\ interruption}}{\boldsymbol{total\ number\ of\ customers\ interrupted}} \tag{3.21}$$

System average interruption duration index (SAIDI).

SAIDI This index is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information about the average time the customers are interrupted. Thus,

$$\text{SAIDI}=\frac{\sum\text{customer interruption durations}}{\boldsymbol{total\ number\ of\ custemers\ served}}\ \textbf{ or }\ \text{SAIDI}=\frac{\sum\boldsymbol{riNi}}{\boldsymbol{Cn}} \tag{3.22}$$

Where r_i is the restoration time for each interruption event.

Customer average interruption duration index (CAIDI)

CAIDI It represents the average time required to restore service to the average customer per sustained interruption. Hence,

$$\text{CAIDI}=\frac{\sum\text{customer interruption durations}}{\boldsymbol{total\ number\ of\ customers\ i}\text{nterruptions}}\ \textbf{ or }\ \text{CAIDI}=\frac{\sum\boldsymbol{riNi}}{\boldsymbol{Ni}}=\frac{\boldsymbol{SAIDI}}{\boldsymbol{SAIFI}} \tag{3.23}$$

Average service availability index (ASAI).

ASAI This index represents the fraction of time (often in percentage) that a customer has power provided during 1 year or the defined reporting period. Hence,

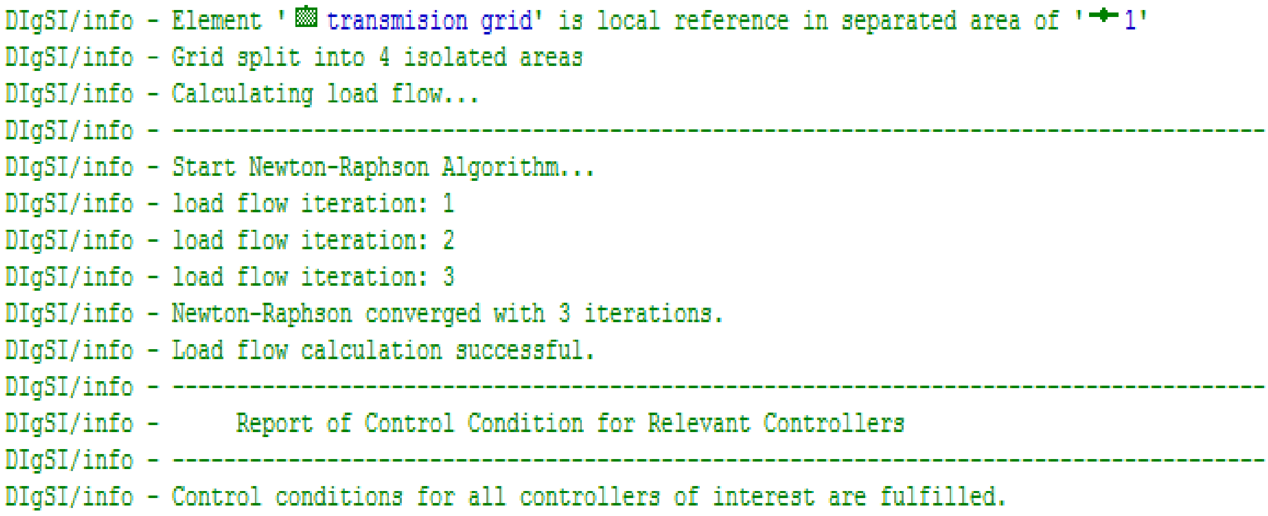
$$\text{ASAI}=\frac{\text{customer hours service availability}}{\text{customer hours service demand}}\ \textbf{ or }\ \text{ASAI}=\frac{\boldsymbol{NtX}\left(\boldsymbol{number\ of}\frac{\boldsymbol{hours}}{\boldsymbol{year}}\right)-\sum\boldsymbol{riNi}}{\boldsymbol{NtX}\left(\boldsymbol{number\ of}\frac{\boldsymbol{hours}}{\boldsymbol{year}}\right)} \tag{3.24}$$

CHAPTER FOUR

Distribution System Modelling and Simulation Studies

4.1 Distribution System Modelling

The Digsilent model of the distribution substation network is shown in Fig.4.1. The network is formed by five radial feeders, namely Feeder no-1, Feeder no-2, Feeder no- 3, Feeder no-4 and Feeder no-5 of 15 kV Cotobie distribution system in Addis Ababa, owned by Ethiopian Electric Utility (EEU).



```
DIgSI/info - Element '▦ transmision grid' is local reference in separated area of '╋1'
DIgSI/info - Grid split into 4 isolated areas
DIgSI/info - Calculating load flow...
DIgSI/info - -------------------------------------------------------------------------------------
DIgSI/info - Start Newton-Raphson Algorithm...
DIgSI/info - load flow iteration: 1
DIgSI/info - load flow iteration: 2
DIgSI/info - load flow iteration: 3
DIgSI/info - Newton-Raphson converged with 3 iterations.
DIgSI/info - Load flow calculation successful.
DIgSI/info - -------------------------------------------------------------------------------------
DIgSI/info -      Report of Control Condition for Relevant Controllers
DIgSI/info - -------------------------------------------------------------------------------------
DIgSI/info - Control conditions for all controllers of interest are fulfilled.
```

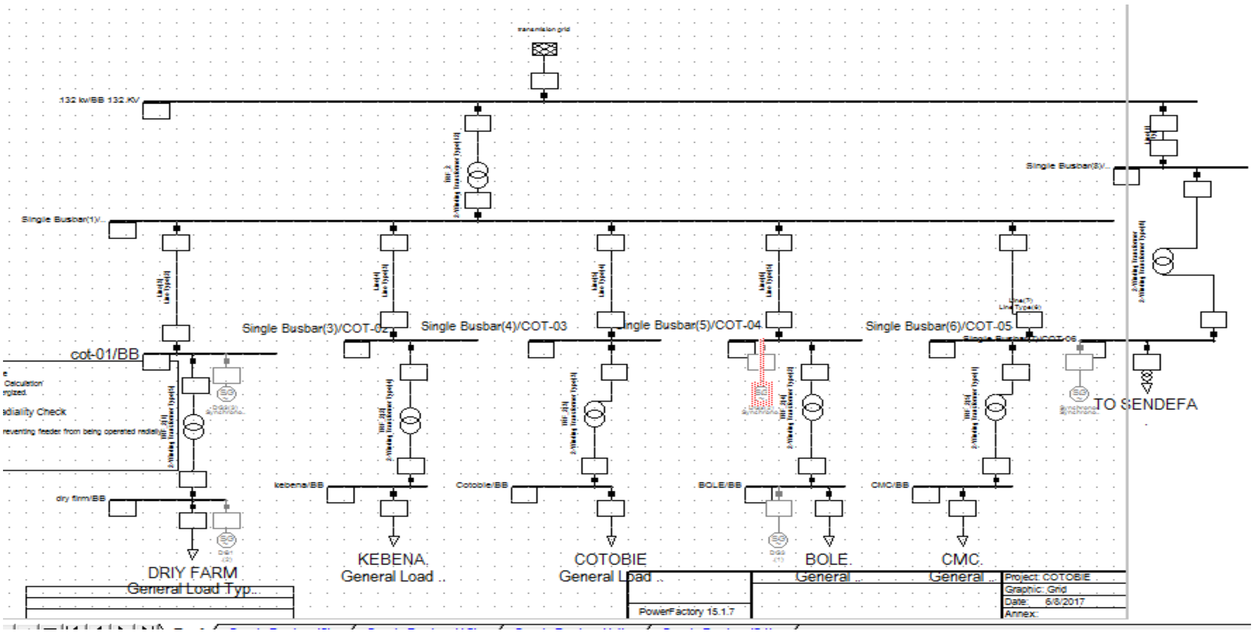


Figure4.1: Digsilent model of Cotobie distribution substation

This research considers only the 132/15 kV and 132/33 kV transformer through five 15kV outgoing feeders and it also 359 low voltage distribution transformers with the total capacity of 88.048MVA. The system serves mostly residential and a few industrial units (i.e. most of the loads in the Cotobie distribution system are residential and only a few are industrial). The customers can either be on the main distribution line or the 1-phase lateral. The circuit is fed by 15kV substation termed as. Each distributor lateral is considered as one load point. Each load connected to the main distribution line is also considered as one load point.

In the operation of a real distribution system with a high penetration of distributed generation, a case study based on the distribution system around COTEBE in Eastern Addis Ababa has been performed. The study has a power flow analysis of the 33Kv, 15 kV and 0.4 kV network which has been created and is maintained by the distribution network.

The substation supplies 68140 customers. The utility owns the distribution lines at 33, 15 and 0.4 kV levels. There are one 132/33 kV transformer stations and another 132/15 kV transformer stations. The 33, 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. A general one-line diagram of the 33, 15 kV and 0.4 grid is shown in Figure 4-2. The 15 kV network is operated as radials and the total capacity of 132/15 kV transformer is 31.5 MVA supply to five 15 kV outgoing feeders. The total load connected to the 15 kV feeders is 31.8 MW

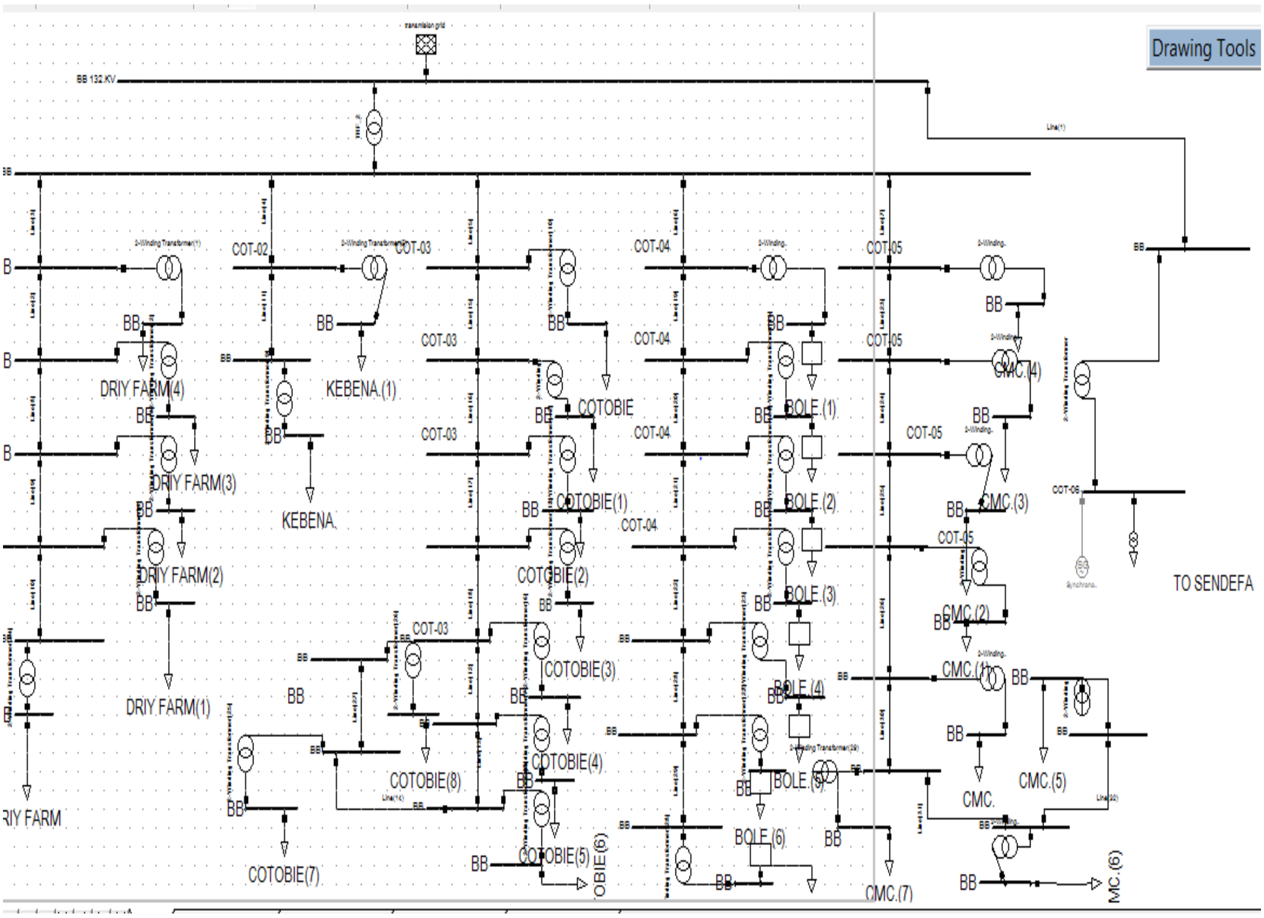


Figure4.2: Representation of overall Cotobie distribution system

TENVDI gives the total deviation of voltages of all tail end nodes of the network with respect to the nominal voltage. The bus corresponding to the minimum TENVDI value when DG is inserted at the same bus is the appropriate location of DG in the distribution system.

Table4.1: Base case Bus Voltages for 15KV feeders test system

Bus no	1	2	3	4	5
Bus voltage (p.u)	0.93	0.98	0.96	0.88	0.95

Table4.2: Variation of TENVDI with DG Placement

Bus no	1	2	3	4	5
TENVDI	**0.00221**	0.0027	0.00252	**0.00132**	0.00228

In the MV bus feeders DG to be placed on bus 4 and bus 1 due to lest of TENVDI from table 4.2 calculated with formula equation 3.10 in the section 3.4.2.

After getting the appropriate DG location and size analytically, these sizes obtained are then optimized. From equation (3.18) and (3.19) we get I_{DG1} and I_{DG4} is 0.182 and 0.304 kA respectively and their size is 2.7 MW and 4.5MW by considering 0.91 power factor of the distributed generation.

4.2 Distribution System Data

The existing loadings of all LV transformers and number of customers connected to the base system are tabulated in table 4.3 some new customers are also added to Cotobie substation.

Table4.3: Existing all transformers and number of customers connected

Substation Feeder Name	Transformer Rating MVA	No of Transformer	NO of customers	Location
COT-01	0.1	6	319	DIARY FARM
	0.2	5	1100	
	0.3	2	628	
	0.315	5	1665	
	0.8	1	882	
Sum	**4.575**		**4,594**	
COT-02	0.63	1	288	KEBENA
	0.8	2	1754	
Sum	**2.23**		**2,042**	
COT-03	0.025	1	30	COTOBIE
	0.05	22	1083	
	0.1	46	4415	
	0.2	38	9437	
	0.315	30	9275	
	0.63	8	2229	
	0.8	1	877	
	1.25	1	1230	

	3.15	1	1395	
Sum	**33.015**		**29,971**	
COT-04	0.025	1	61	BOLE
	0.05	5	313	
	0.1	10	95	
	0.2	28	4055	
	0.315	19	3995	
	0.63	7	2945	
	1.250	1	839	
Sum	**18.52**		**12,303**	
COT-05	0.05	4	413	CMC
	0.063	1	33	
	0.1	8	1621	
	0.2	23	3329	
	0.3	1	3014	
	0.315	21	5165	
	0.5	1	520	
	0.63	1	623	
Sum	**13.708**		**14,718**	
COT-S1	16	56	4512	Sendafa
Total	**88.048**		**68,140**	

From the above substation transformers data, the one calendar year and 16 hours per day of the medium voltage of five outgoing feeders load obtained. According to this data average and peak load of each feeder is shown in **figure 4.3.**

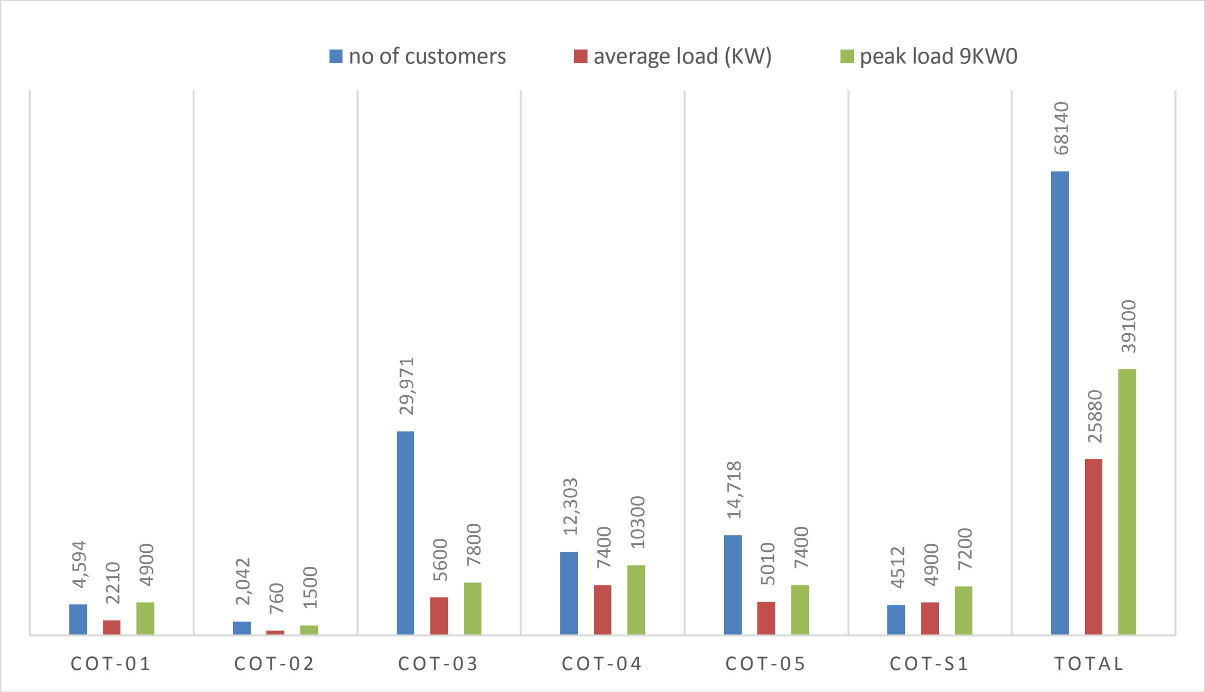


Figure4.3: Average, Peak load and no of customer's data of each feeder

Base case studies provide appropriate information of reliability to obtain the system reliability index. The calculated value of substation reliability indices of each feeder are shown in Table 4.4, as a radial system with no meshed connections the failure rate (λ/yr), the outage durations (hr) and average outage durations (hr/yr), all data are recorded from the **Appendix D** detailed interruption data of 2016 G.C.

Table4.4: Radial system reliability indices for main existing feeders

Feeder name	Total outage duration (hrs)	Total (Int/yr.)	Failure rate λ (Failures/year)	Average outage U (hrs/yr)
COT-01	111.05	143	0.0163	1.810115
COT-02	35.034	38	0.00434	0.152
COT-03	134.23	176	0.02	2.6846
COT-04	233.98	339	0.0387	9.055
COT-05	117.167	128	0.0146	1.711
COT-S1	206.99	316	0.03607	7.466

Average	**139.736**	**190.4**	**0.022006**	**3.813**

In the distribution system, there are no disconnects on the outgoing feeders. The only protections are the fuses that connect the main feeders and the lateral distributors. Hence, any fault on the main line will require the system to be isolated from the main breaker. The reliability assessment of each feeder can be calculated by considering the impact of each section and load point on the corresponding load point. Let us examine the reliability assessment of the system.

First, the impact of each section failure on the load point's reliability is considered. Any section failure will result in a power outage for load point since there are no disconnects on the impact of each section and lateral distributor, the average failure rate, outage duration, and annual outage duration for the main feeders can be calculated as by using equation (4.1), (4.2) and (4.3).

$$\boldsymbol{\lambda}_s = \sum_i^n \lambda_i \tag{4.1}$$

$$U_s = \sum_i^n \lambda_i r_i \tag{4.2}$$

$$r_i = \frac{U_S}{\lambda_S} \tag{4.3}$$

Table4.5 Elements typical failure data

Element	Failure rate		Duration		
	Permanent	Active	Permanent	Maintenance	Switching
Bus bar	0.001	0.001	2.0	1.0	0.0
Cir. Breaker	0.02	0.02	24	1.0	0.0
Transformer	0.015	0.015	15	1.0	0.0
Disc. Switch	0.002	0.002	4.0	1.0	0.0
DG	0.02	0.0	0.5	1.0	0.0

For parallel components or second order failure combination

$$\boldsymbol{\lambda}_{12} = \frac{\lambda 1.\lambda 2.(r_{1+} r_2)}{1+ \lambda 1.r_1 + \lambda 2.r_2} \tag{4.4}$$

From the above equations, the other parameters of each feeder were calculated as shown in Table 4.6.

Table4.6: The main feeder availability and unavailability indices of existing distribution system

Feeder name	(Ni)	λ_i	r_i	λ_{i*Ni}	ASAI (%)	ASUI (%)
COT-01	4,594	0.0163	111.05	74.8822	98.73	1.27
COT-02	2,042	0.00434	35.034	8.86228	99.6	0.399
COT-03	29,971	0.02	134.23	599.42	98.467	1.53
COT-04	12,303	0.0387	233.98	476.1261	97.32	2.67
COT-05	14,718	0.0146	117.167	214.8828	98.66	1.34
COT-S1	4512	0.01609	206.99	72.598	97.63	2.36
Average					98.4	1.5988

The load and energy based indices are calculated, using outage duration and an average load of each feeder. Those are the expected Energy Not Supplied, the Expected interruption Cost (EIC) and the Average Energy Not Supplied values are shown in Table 4.7. The priority order based on the EIC was used for load curtailment level; the EIC is the average monetary impact on the customers at a load point. This higher the EIC the higher priority this load may have a load curtailment at that load point will contribute to the higher economic cost.

Table4.7: Expected Energy not supplied and Interruption Costs indices for each feeder.

Feeder name	Expected Energy not Supplied (MW hr/yr)	Expected Interruption Cost EIC ($/yr) 0.046$/Kwh	Average Energy Not Supplied (MW hr/yr. ca.)
COT-01	245.4205	11289.343	0.0534
COT-02	26.62584	1224.78864	0.0131
COT-03	751.688	34577.648	0.0251
COT-04	1731.452	79646.792	0.1407
COT-05	587.00667	27002.30682	0.0398

COT-S1	1014.251	46655.546	0.2247
Total	4356.444	0.200396 million$/yr	0.0828

From the table 4.4, the reliability index of the main feeder provides different information and some indices are more important than others. The main feeder indices are useful in assessing the load point impact of system modifications and provide input to reliability evaluation at the actual customer level. Furthermore, there are the system reliability indices which provide valuable information on the overall ability of the system to supply the customer load. The probability of a customer receiving interrupted power supply is obtained in Table 4.6 and Table 4.7. The higher the value of the reliability indices the higher is the unreliability of the system.

Using the data from the above table, the overall base case reliability indices can be determined is shown in Table 4.8:

Table4.8: One year Reliability indices

Indices	Value
SAIFI	190.4
SAIDI	139.736
CAIDI	0.7321 Hrs / customer interruption
ASAI	98.4%
ASUI	1.5988%
EENS	4356.444 MWh/yr
EIC	0.200396 m$ /yr
AENS	0.0828 MWh/ ca. yr

From Table 4.8, can be concluded that the base case system indices (no DG); SAIDI is 139.736hr/customer yr, SAIFI is 190.4 inter./customer yr system's average interruption frequency for each customer during a year, CAIDI is 0.7321 hrs/ customer interruption during a year and system availability and unavailability are 98.4% and 1.5988% are respectively. Also, the expected energy not supplied (EENS) of the system due to the failures is 4356.444MWh/yr and the energy not supplied per customer is 0.064MWh/yr. And finally, expected interruption cost of the system is 0.200396 million$/yr during a year in the next sections; it is observed that how these indices are improved by the installation of DG.

4.3 Distribution system Simulation using DIgSILENT

In this section simulation studies are carried out under three different conditions. Case I considers the load flow analysis without integration of DG while in Case II load flow analysis with integration of DG is carried out and in case III considers the integrating DG in MV and LV feeders to improve reliability.

Case I: load flow before the integration of DG

Under this case, the Cotobie distribution system is used without any change to the existing system and by using data obtained from Cotobie distribution system for reliability and load flow analysis.

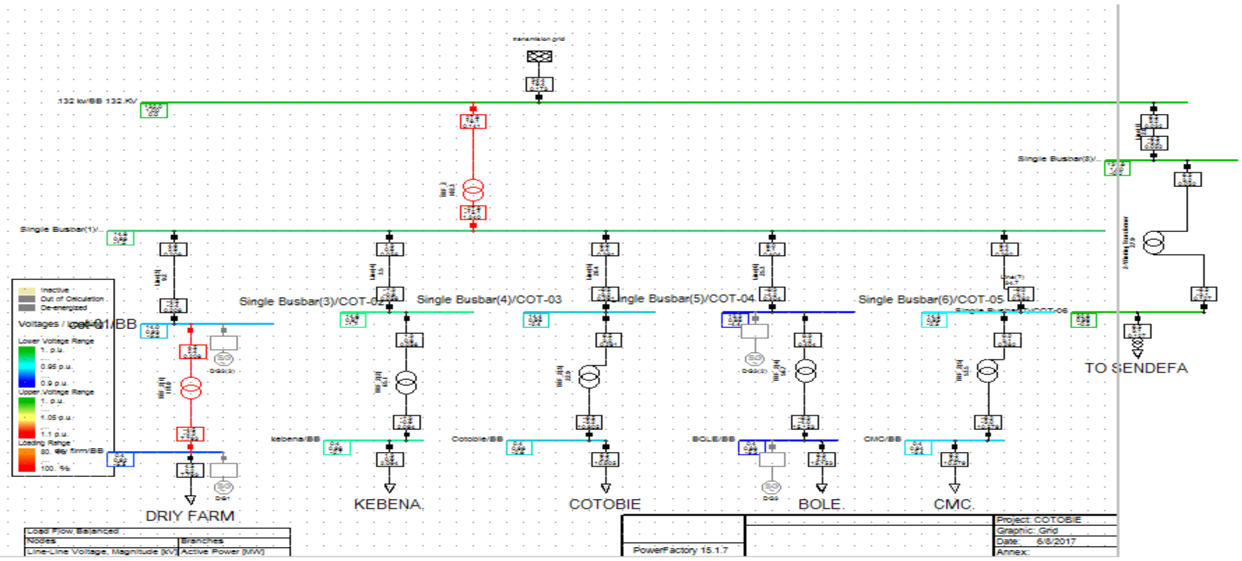
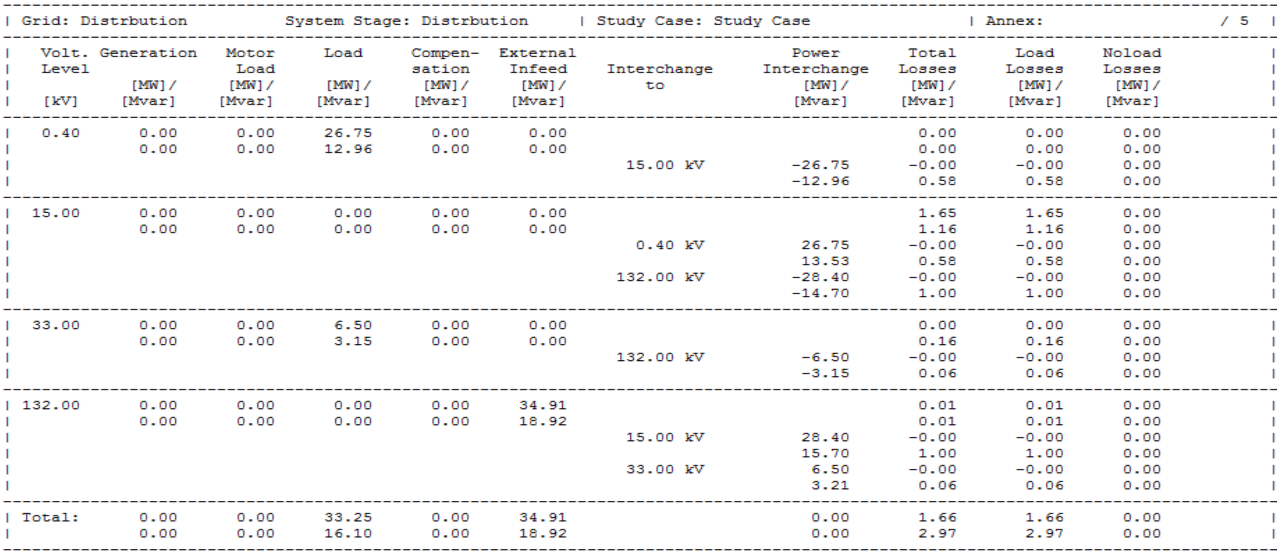
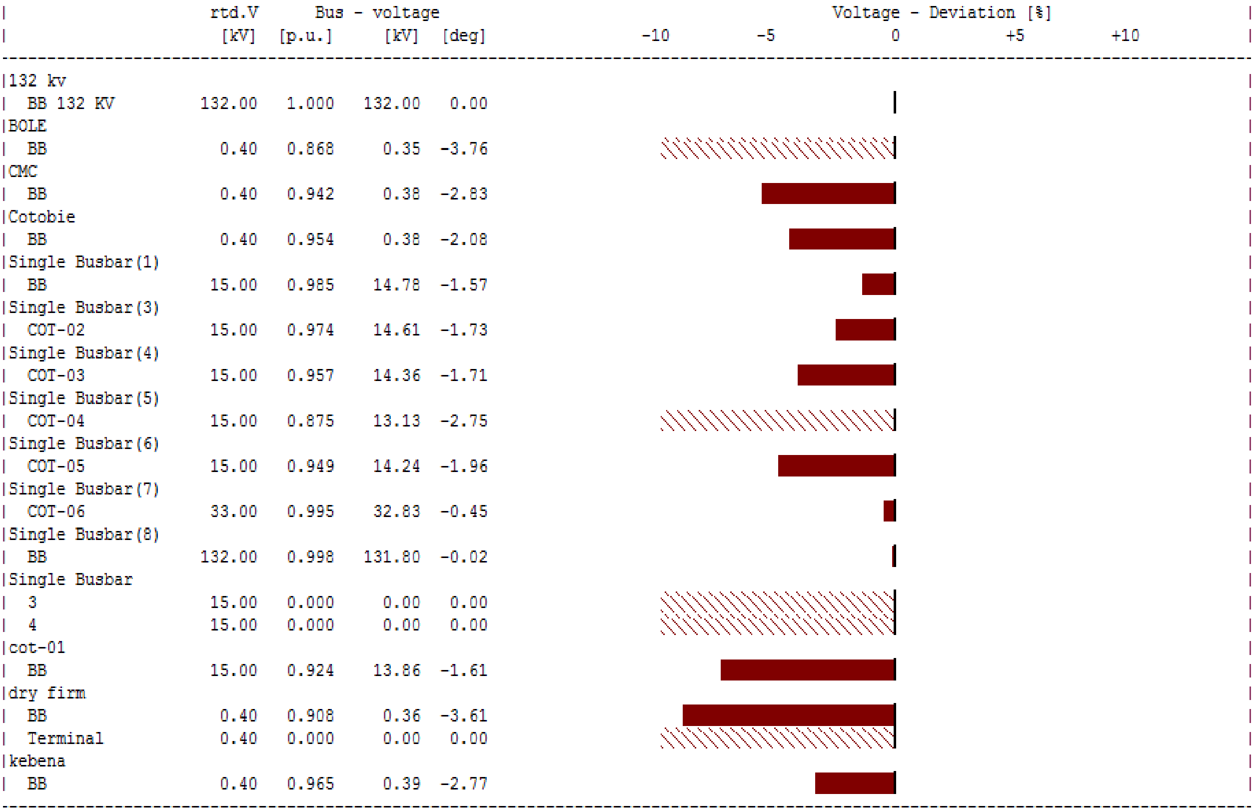


Figure4.4: A radial system without integrating DG



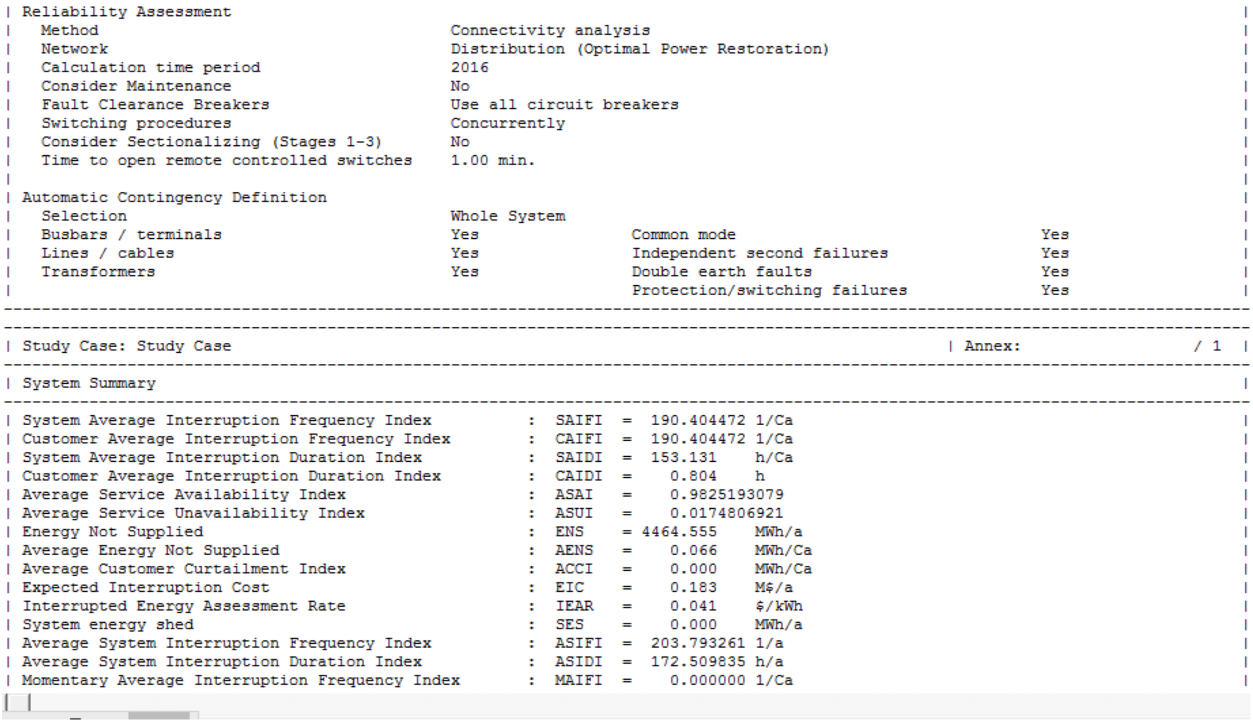
```
----------------------------------------------------------------------------------------------------------------------------
| Grid: Distrbution            System Stage: Distrbution     | Study Case: Study Case                | Annex:            / 5  |
----------------------------------------------------------------------------------------------------------------------------
|   Volt. Generation   Motor     Load     Compen-  External                   Power     Total     Load     Noload          |
|   Level               Load              sation    Infeed   Interchange  Interchange   Losses    Losses    Losses          |
|             [MW]/    [MW]/     [MW]/    [MW]/     [MW]/        to           [MW]/     [MW]/     [MW]/     [MW]/         |
|   [kV]     [Mvar]   [Mvar]    [Mvar]   [Mvar]    [Mvar]                     [Mvar]    [Mvar]    [Mvar]    [Mvar]         |
----------------------------------------------------------------------------------------------------------------------------
|   0.40       0.00     0.00     26.75     0.00      0.00                                 0.00      0.00      0.00         |
|              0.00     0.00     12.96     0.00      0.00                                 0.00      0.00      0.00         |
|                                                           15.00 kV      -26.75        -0.00     -0.00      0.00         |
|                                                                         -12.96         0.58      0.58      0.00         |
----------------------------------------------------------------------------------------------------------------------------
|  15.00       0.00     0.00      0.00     0.00      0.00                                 1.65      1.65      0.00         |
|              0.00     0.00      0.00     0.00      0.00                                 1.16      1.16      0.00         |
|                                                            0.40 kV       26.75        -0.00     -0.00      0.00         |
|                                                                          13.53         0.58      0.58      0.00         |
|                                                          132.00 kV      -28.40        -0.00     -0.00      0.00         |
|                                                                         -14.70         1.00      1.00      0.00         |
----------------------------------------------------------------------------------------------------------------------------
|  33.00       0.00     0.00      6.50     0.00      0.00                                 0.00      0.00      0.00         |
|              0.00     0.00      3.15     0.00      0.00                                 0.16      0.16      0.00         |
|                                                          132.00 kV       -6.50        -0.00     -0.00      0.00         |
|                                                                          -3.15         0.06      0.06      0.00         |
----------------------------------------------------------------------------------------------------------------------------
| 132.00       0.00     0.00      0.00     0.00     34.91                                 0.01      0.01      0.00         |
|              0.00     0.00      0.00     0.00     18.92                                 0.01      0.01      0.00         |
|                                                           15.00 kV       28.40        -0.00     -0.00      0.00         |
|                                                                          15.70         1.00      1.00      0.00         |
|                                                           33.00 kV        6.50        -0.00     -0.00      0.00         |
|                                                                           3.21         0.06      0.06      0.00         |
----------------------------------------------------------------------------------------------------------------------------
| Total:       0.00     0.00     33.25     0.00     34.91                   0.00          1.66      1.66      0.00         |
|              0.00     0.00     16.10     0.00     18.92                   0.00          2.97      2.97      0.00         |
----------------------------------------------------------------------------------------------------------------------------
```

Figure4.5: Power loss Simulation result without DG



```
|                   rtd.V      Bus - voltage                             Voltage - Deviation [%]                   |
|                   [kV]   [p.u.]     [kV]   [deg]        -10        -5         0          +5         +10           |
---------------------------------------------------------------------------------------------------------------------
|132 kv                                                                                                              |
|  BB 132 KV       132.00   1.000   132.00   0.00                                                                    |
|BOLE                                                                                                                |
|  BB                0.40   0.868     0.35  -3.76                                                                    |
|CMC                                                                                                                 |
|  BB                0.40   0.942     0.38  -2.83                                                                    |
|Cotobie                                                                                                             |
|  BB                0.40   0.954     0.38  -2.08                                                                    |
|Single Busbar(1)                                                                                                    |
|  BB               15.00   0.985    14.78  -1.57                                                                    |
|Single Busbar(3)                                                                                                    |
|  COT-02           15.00   0.974    14.61  -1.73                                                                    |
|Single Busbar(4)                                                                                                    |
|  COT-03           15.00   0.957    14.36  -1.71                                                                    |
|Single Busbar(5)                                                                                                    |
|  COT-04           15.00   0.875    13.13  -2.75                                                                    |
|Single Busbar(6)                                                                                                    |
|  COT-05           15.00   0.949    14.24  -1.96                                                                    |
|Single Busbar(7)                                                                                                    |
|  COT-06           33.00   0.995    32.83  -0.45                                                                    |
|Single Busbar(8)                                                                                                    |
|  BB              132.00   0.998   131.80  -0.02                                                                    |
|Single Busbar                                                                                                       |
|  3                15.00   0.000     0.00   0.00                                                                    |
|  4                15.00   0.000     0.00   0.00                                                                    |
|cot-01                                                                                                              |
|  BB               15.00   0.924    13.86  -1.61                                                                    |
|dry firm                                                                                                            |
|  BB                0.40   0.908     0.36  -3.61                                                                    |
|  Terminal          0.40   0.000     0.00   0.00                                                                    |
|kebena                                                                                                              |
|  BB                0.40   0.965     0.39  -2.77                                                                    |
---------------------------------------------------------------------------------------------------------------------
```

Figure4.6: Voltage profile Simulation result without DG



```
| Reliability Assessment                                                                                                           |
|   Method                                      Connectivity analysis                                                              |
|   Network                                     Distribution (Optimal Power Restoration)                                           |
|   Calculation time period                     2016                                                                               |
|   Consider Maintenance                        No                                                                                 |
|   Fault Clearance Breakers                    Use all circuit breakers                                                           |
|   Switching procedures                        Concurrently                                                                       |
|   Consider Sectionalizing (Stages 1-3)        No                                                                                 |
|   Time to open remote controlled switches     1.00 min.                                                                          |
|                                                                                                                                  |
| Automatic Contingency Definition                                                                                                 |
|   Selection                                   Whole System                                                                       |
|   Busbars / terminals                         Yes                Common mode                               Yes                  |
|   Lines / cables                              Yes                Independent second failures               Yes                  |
|   Transformers                                Yes                Double earth faults                       Yes                  |
|                                                                  Protection/switching failures             Yes                  |
-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                                           | Annex:                  / 1  |
-----------------------------------------------------------------------------------------------------------------------------------
| System Summary                                                                                                                   |
-----------------------------------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index          :  SAIFI  =  190.404472 1/Ca                                               |
| Customer Average Interruption Frequency Index        :  CAIFI  =  190.404472 1/Ca                                               |
| System Average Interruption Duration Index           :  SAIDI  =  153.131    h/Ca                                               |
| Customer Average Interruption Duration Index         :  CAIDI  =    0.804    h                                                  |
| Average Service Availability Index                   :  ASAI   =    0.9825193079                                                 |
| Average Service Unavailability Index                 :  ASUI   =    0.0174806921                                                 |
| Energy Not Supplied                                  :  ENS    = 4464.555    MWh/a                                              |
| Average Energy Not Supplied                          :  AENS   =    0.066    MWh/Ca                                             |
| Average Customer Curtailment Index                   :  ACCI   =    0.000    MWh/Ca                                             |
| Expected Interruption Cost                           :  EIC    =    0.183    M$/a                                               |
| Interrupted Energy Assessment Rate                   :  IEAR   =    0.041    $/kWh                                              |
| System energy shed                                   :  SES    =    0.000    MWh/a                                              |
| Average System Interruption Frequency Index          :  ASIFI  =  203.793261 1/a                                                |
| Average System Interruption Duration Index           :  ASIDI  =  172.509835 h/a                                                |
| Momentary Average Interruption Frequency Index       :  MAIFI  =    0.000000 1/Ca                                               |
```

Figure4.7: Reliability assessment Simulation result for the Base case (without DG)

Table4.9: The reliability indices for the base case (without DG) integration into the distribution system.

Case I	NO Generation at buses(Mw)	One year Reliability indices
Base case (without DG)	$P_{DGfeeder\ noi}=0$	SAIFI=190.4044 CAIFI=190.4044 SAIDI=153.131 CAIDI=0.801 ASAI=0.982 ASUI=0.0174 ENS=4464.555 AENS=0.066

Case II: load flow after integration of DG

The proposed method was applied to a 15 kV bus radial distribution system by installing DG at least voltage sensitivity index of outgoing feeders. All 15 kV bus feeders are considered as candidate buses in this test and in all subsequent tests. Installing the DG at 15 kV buses with a size of 7.2 MW in order to improve voltage deviation level and power loss minimization. Figure 4.9 shows the power loss minimization and Figure 4.10 shows improvement in the voltage profile after installing the DG unit.

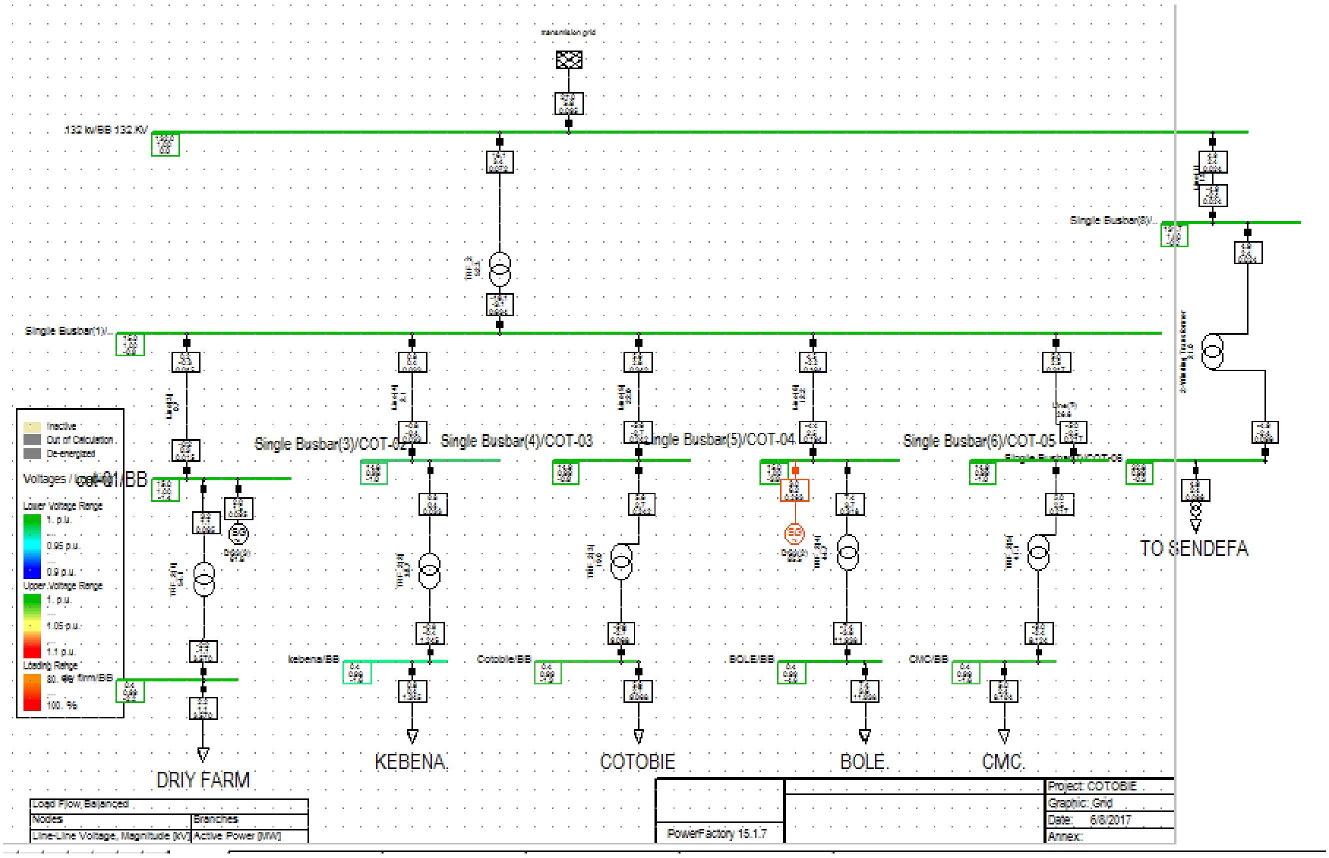
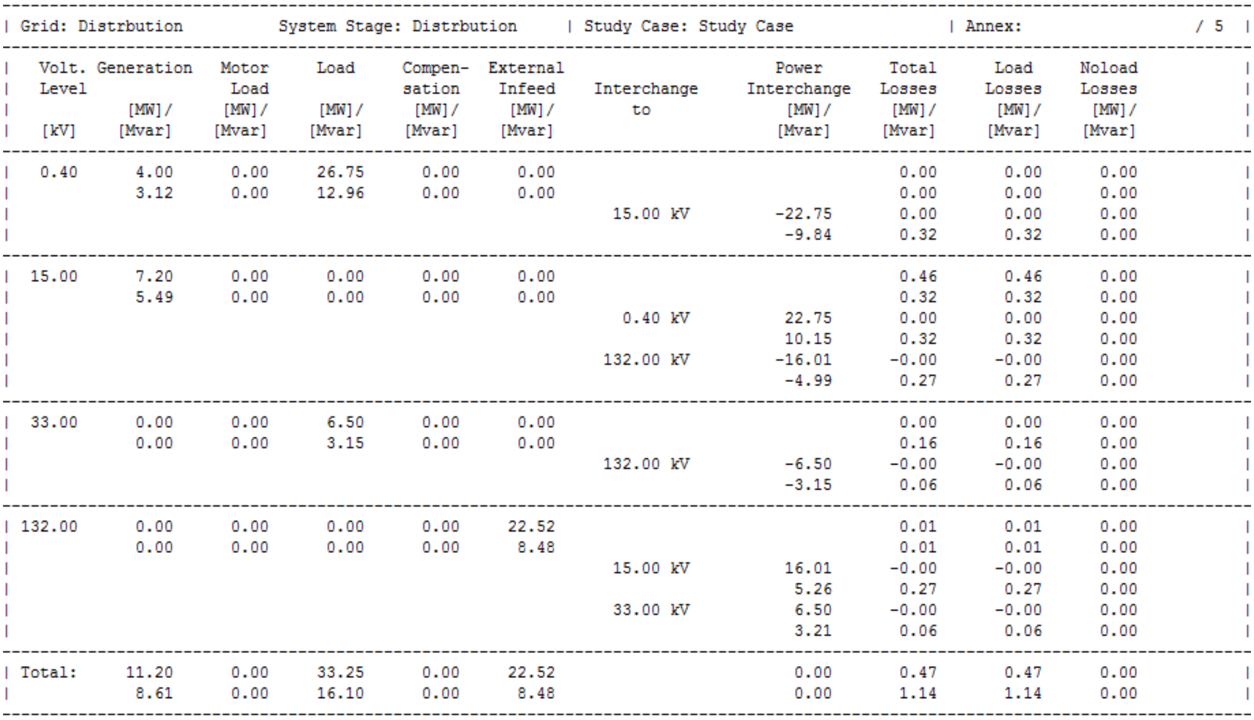
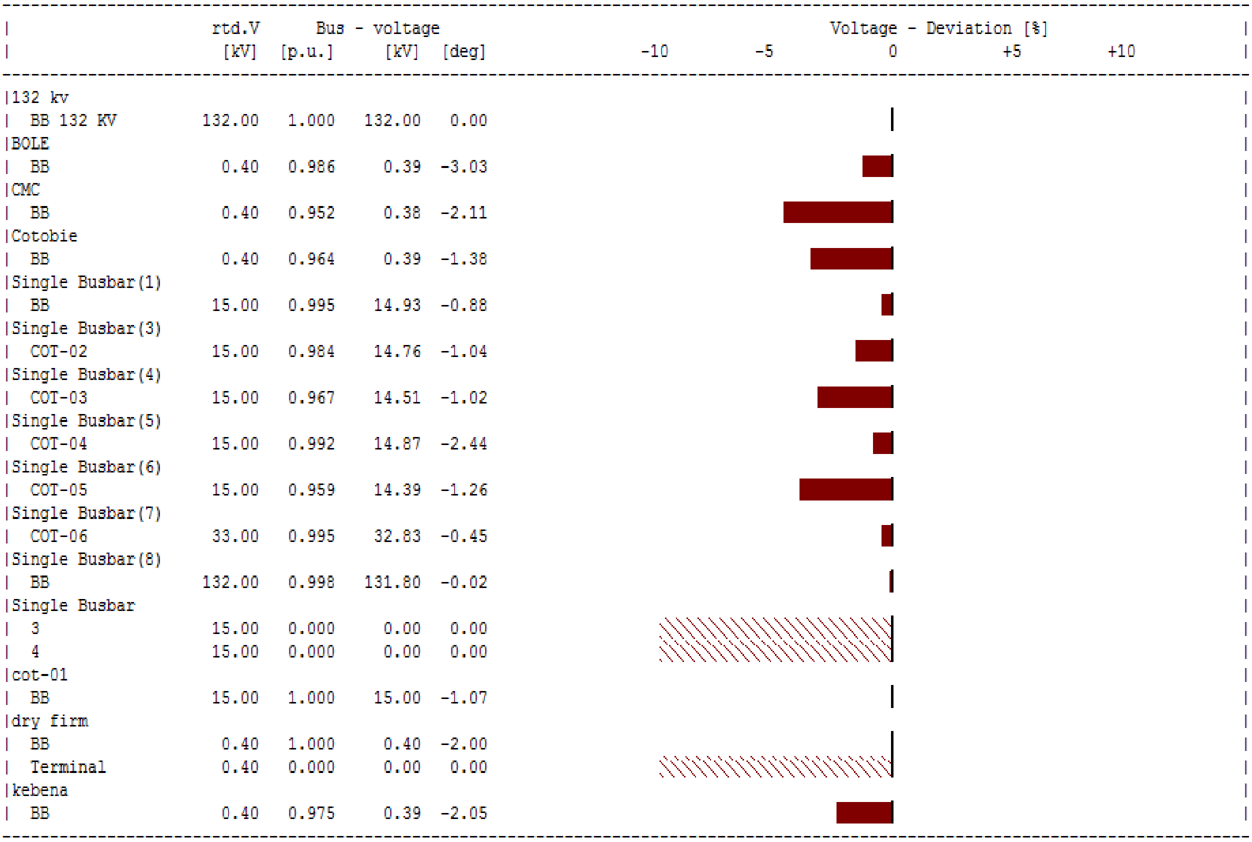


Figure4.8: A radial system after integrating of DG



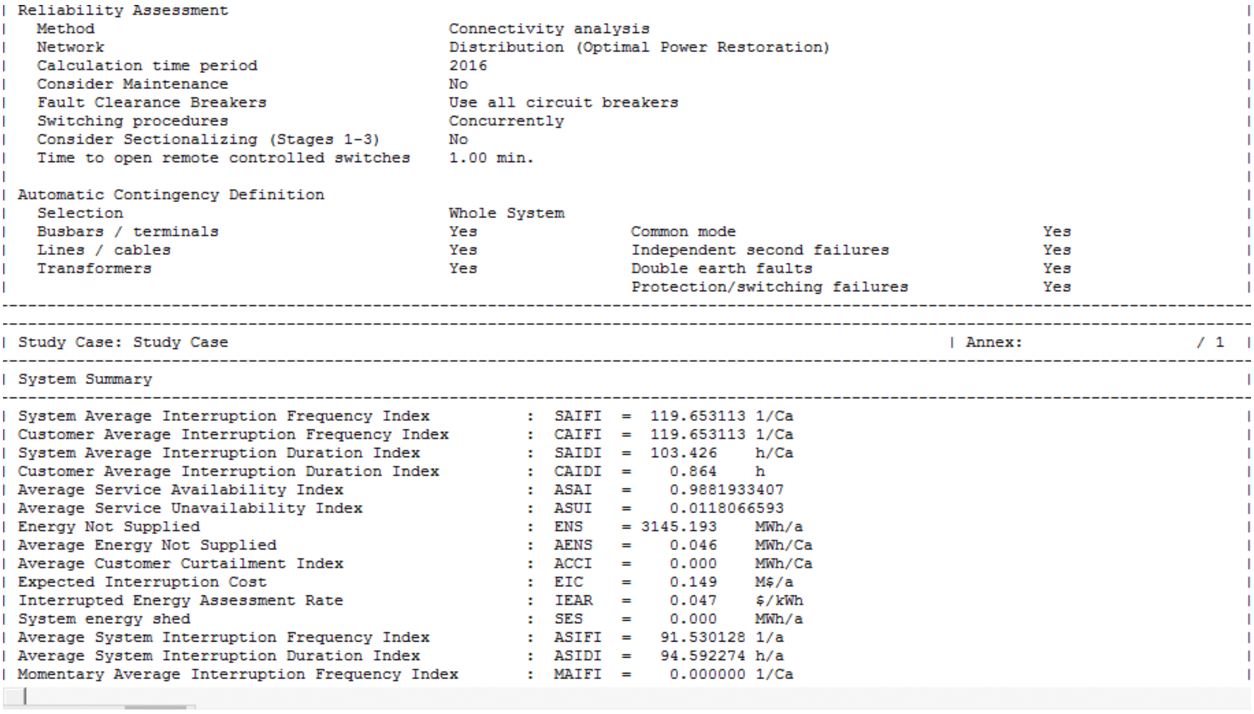
```
-------------------------------------------------------------------------------------------------------------------------------
| Grid: Distrbution           System Stage: Distrbution      | Study Case: Study Case                | Annex:              / 5   |
-------------------------------------------------------------------------------------------------------------------------------
|   Volt. Generation   Motor      Load     Compen-   External                      Power      Total      Load      Noload     |
|   Level               Load               sation    Infeed     Interchange    Interchange    Losses     Losses     Losses     |
|            [MW]/     [MW]/     [MW]/     [MW]/     [MW]/          to            [MW]/      [MW]/      [MW]/      [MW]/      |
|    [kV]    [Mvar]    [Mvar]    [Mvar]    [Mvar]    [Mvar]                      [Mvar]     [Mvar]     [Mvar]     [Mvar]     |
-------------------------------------------------------------------------------------------------------------------------------
|   0.40       4.00      0.00     26.75      0.00      0.00                                  0.00       0.00       0.00      |
|              3.12      0.00     12.96      0.00      0.00                                  0.00       0.00       0.00      |
|                                                                15.00 kV      -22.75       0.00       0.00       0.00      |
|                                                                               -9.84       0.32       0.32       0.00      |
-------------------------------------------------------------------------------------------------------------------------------
|  15.00       7.20      0.00      0.00      0.00      0.00                                  0.46       0.46       0.00      |
|              5.49      0.00      0.00      0.00      0.00                                  0.32       0.32       0.00      |
|                                                                 0.40 kV       22.75       0.00       0.00       0.00      |
|                                                                               10.15       0.32       0.32       0.00      |
|                                                               132.00 kV      -16.01      -0.00      -0.00       0.00      |
|                                                                               -4.99       0.27       0.27       0.00      |
-------------------------------------------------------------------------------------------------------------------------------
|  33.00       0.00      0.00      6.50      0.00      0.00                                  0.00       0.00       0.00      |
|              0.00      0.00      3.15      0.00      0.00                                  0.16       0.16       0.00      |
|                                                               132.00 kV       -6.50      -0.00      -0.00       0.00      |
|                                                                               -3.15       0.06       0.06       0.00      |
-------------------------------------------------------------------------------------------------------------------------------
| 132.00       0.00      0.00      0.00      0.00     22.52                                  0.01       0.01       0.00      |
|              0.00      0.00      0.00      0.00      8.48                                  0.01       0.01       0.00      |
|                                                                15.00 kV       16.01      -0.00      -0.00       0.00      |
|                                                                                5.26       0.27       0.27       0.00      |
|                                                                33.00 kV        6.50      -0.00      -0.00       0.00      |
|                                                                                3.21       0.06       0.06       0.00      |
-------------------------------------------------------------------------------------------------------------------------------
| Total:      11.20      0.00     33.25      0.00     22.52                       0.00       0.47       0.47       0.00      |
|              8.61      0.00     16.10      0.00      8.48                       0.00       1.14       1.14       0.00      |
-------------------------------------------------------------------------------------------------------------------------------
```

Figure4.9: Power loss Simulation result with DG



```
-------------------------------------------------------------------------------------------------------------------------------
|                    rtd.V      Bus - voltage                                     Voltage - Deviation [%]                      |
|                     [kV]  [p.u.]     [kV]  [deg]           -10          -5            0           +5           +10          |
-------------------------------------------------------------------------------------------------------------------------------
|132 kv                                                                                                                       |
|  BB 132 KV        132.00   1.000   132.00   0.00                                                                            |
|BOLE                                                                                                                         |
|  BB                 0.40   0.986     0.39  -3.03                                                                            |
|CMC                                                                                                                          |
|  BB                 0.40   0.952     0.38  -2.11                                                                            |
|Cotobie                                                                                                                      |
|  BB                 0.40   0.964     0.39  -1.38                                                                            |
|Single Busbar(1)                                                                                                             |
|  BB                15.00   0.995    14.93  -0.88                                                                            |
|Single Busbar(3)                                                                                                             |
|  COT-02            15.00   0.984    14.76  -1.04                                                                            |
|Single Busbar(4)                                                                                                             |
|  COT-03            15.00   0.967    14.51  -1.02                                                                            |
|Single Busbar(5)                                                                                                             |
|  COT-04            15.00   0.992    14.87  -2.44                                                                            |
|Single Busbar(6)                                                                                                             |
|  COT-05            15.00   0.959    14.39  -1.26                                                                            |
|Single Busbar(7)                                                                                                             |
|  COT-06            33.00   0.995    32.83  -0.45                                                                            |
|Single Busbar(8)                                                                                                             |
|  BB               132.00   0.998   131.80  -0.02                                                                            |
|Single Busbar                                                                                                                |
|  3                 15.00   0.000     0.00   0.00                                                                            |
|  4                 15.00   0.000     0.00   0.00                                                                            |
|cot-01                                                                                                                       |
|  BB                15.00   1.000    15.00  -1.07                                                                            |
|dry firm                                                                                                                     |
|  BB                 0.40   1.000     0.40  -2.00                                                                            |
|  Terminal           0.40   0.000     0.00   0.00                                                                            |
|kebena                                                                                                                       |
|  BB                 0.40   0.975     0.39  -2.05                                                                            |
-------------------------------------------------------------------------------------------------------------------------------
```

Figure4.10: Voltage profile Simulation result with DG



```
| Reliability Assessment                                                                                               |
|   Method                                    Connectivity analysis                                                    |
|   Network                                   Distribution (Optimal Power Restoration)                                 |
|   Calculation time period                   2016                                                                     |
|   Consider Maintenance                      No                                                                       |
|   Fault Clearance Breakers                  Use all circuit breakers                                                 |
|   Switching procedures                      Concurrently                                                             |
|   Consider Sectionalizing (Stages 1-3)      No                                                                       |
|   Time to open remote controlled switches   1.00 min.                                                                |
|                                                                                                                      |
| Automatic Contingency Definition                                                                                     |
|   Selection                                 Whole System                                                             |
|   Busbars / terminals                       Yes                Common mode                           Yes             |
|   Lines / cables                            Yes                Independent second failures           Yes             |
|   Transformers                              Yes                Double earth faults                   Yes             |
|                                                                Protection/switching failures         Yes             |
------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                                 | Annex:                / 1   |
------------------------------------------------------------------------------------------------------------------------
| System Summary                                                                                                       |
------------------------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index        :  SAIFI  =  119.653113 1/Ca                                     |
| Customer Average Interruption Frequency Index      :  CAIFI  =  119.653113 1/Ca                                     |
| System Average Interruption Duration Index         :  SAIDI  =  103.426    h/Ca                                     |
| Customer Average Interruption Duration Index       :  CAIDI  =    0.864    h                                        |
| Average Service Availability Index                 :  ASAI   =    0.9881933407                                     |
| Average Service Unavailability Index               :  ASUI   =    0.0118066593                                     |
| Energy Not Supplied                                :  ENS    = 3145.193    MWh/a                                    |
| Average Energy Not Supplied                        :  AENS   =    0.046    MWh/Ca                                   |
| Average Customer Curtailment Index                 :  ACCI   =    0.000    MWh/Ca                                   |
| Expected Interruption Cost                         :  EIC    =    0.149    M$/a                                     |
| Interrupted Energy Assessment Rate                 :  IEAR   =    0.047    $/kWh                                    |
| System energy shed                                 :  SES    =    0.000    MWh/a                                    |
| Average System Interruption Frequency Index        :  ASIFI  =   91.530128 1/a                                      |
| Average System Interruption Duration Index         :  ASIDI  =   94.592274 h/a                                      |
| Momentary Average Interruption Frequency Index     :  MAIFI  =    0.000000 1/Ca                                     |
```

Figure4.11: Reliability assessment Simulation result with DG

Here the reliability of Cotobie distribution system is analyzed by installing **7.2** MW DG and keeping the same data used for reliability analysis as of the base case to observe how installing DG will improve the reliability of distribution system and also improve the energy efficiency and voltage profile to the standards.

Table4.10: The reliability indices in case of 7.2 MW DG installed at distribution system

Case II	NO Generation at buses(Mw)	One year Reliability indices
After DG Integration	$P_{DGfeeder\ no1}$=2.7 $P_{DGfeeder\ no4}$=4.5	SAIFI=119.653113 CAIFI=119.653113 SAIDI=103.42 CAIDI=0.864 ASAI=0.9881 ASUI=0.011 ENS=2488.846 AENS=0.037

Case III: integrating DG in MV and LV feeders to improve reliability

In addition, when the capacity of DG is considered SAIFI varies depending on the size of DG installed. It is noticed that, when the capacity of DG is increased, SAIFI tends to decrease so the reliability of distribution system will be improved. This also indicates that capacity of DG and location of DG play an important role in reliability improvement in such a system.

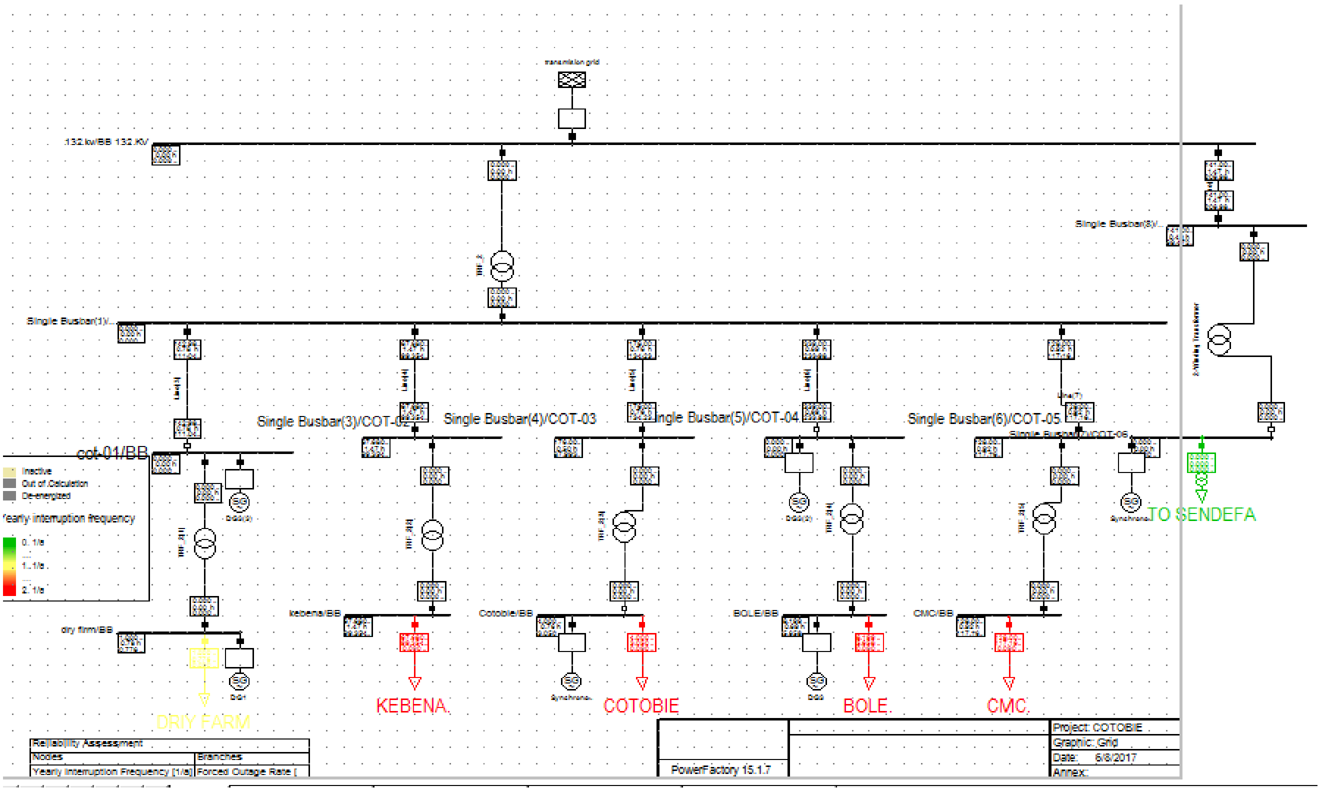
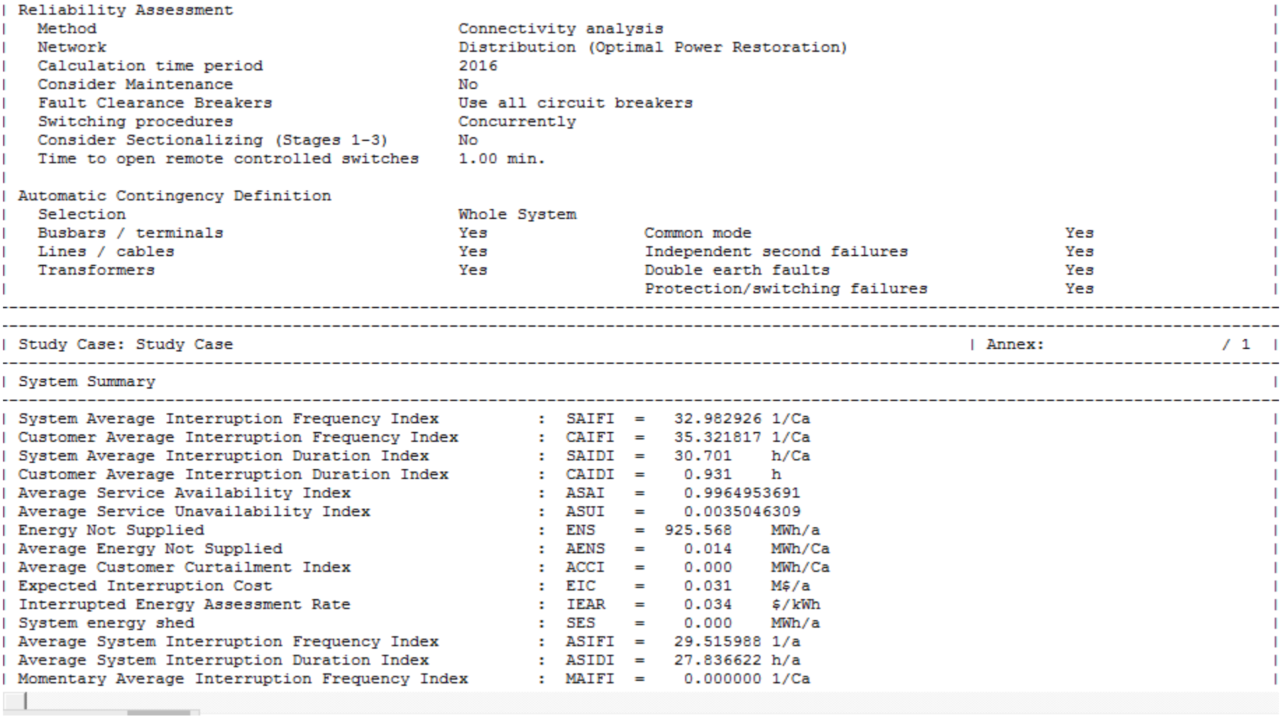


Figure4.12: A radial system integrating DG in MV and LV feeders to improve reliability



```
| Reliability Assessment                                                                                          |
|   Method                                     Connectivity analysis                                              |
|   Network                                    Distribution (Optimal Power Restoration)                           |
|   Calculation time period                    2016                                                               |
|   Consider Maintenance                       No                                                                 |
|   Fault Clearance Breakers                   Use all circuit breakers                                           |
|   Switching procedures                       Concurrently                                                       |
|   Consider Sectionalizing (Stages 1-3)       No                                                                 |
|   Time to open remote controlled switches    1.00 min.                                                          |
|                                                                                                                 |
| Automatic Contingency Definition                                                                                |
|   Selection                                  Whole System                                                       |
|   Busbars / terminals                        Yes                Common mode                          Yes        |
|   Lines / cables                             Yes                Independent second failures          Yes        |
|   Transformers                               Yes                Double earth faults                  Yes        |
|                                                                 Protection/switching failures        Yes        |
-------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                                 | Annex:            / 1   |
-------------------------------------------------------------------------------------------------------------------
| System Summary                                                                                                  |
-------------------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index          :  SAIFI  =   32.982926 1/Ca                               |
| Customer Average Interruption Frequency Index        :  CAIFI  =   35.321817 1/Ca                               |
| System Average Interruption Duration Index           :  SAIDI  =   30.701    h/Ca                               |
| Customer Average Interruption Duration Index         :  CAIDI  =    0.931    h                                  |
| Average Service Availability Index                   :  ASAI   =    0.9964953691                               |
| Average Service Unavailability Index                 :  ASUI   =    0.0035046309                               |
| Energy Not Supplied                                  :  ENS    =  925.568    MWh/a                              |
| Average Energy Not Supplied                          :  AENS   =    0.014    MWh/Ca                             |
| Average Customer Curtailment Index                   :  ACCI   =    0.000    MWh/Ca                             |
| Expected Interruption Cost                           :  EIC    =    0.031    M$/a                               |
| Interrupted Energy Assessment Rate                   :  IEAR   =    0.034    $/kWh                              |
| System energy shed                                   :  SES    =    0.000    MWh/a                              |
| Average System Interruption Frequency Index          :  ASIFI  =   29.515988 1/a                                |
| Average System Interruption Duration Index           :  ASIDI  =   27.836622 h/a                                |
| Momentary Average Interruption Frequency Index       :  MAIFI  =    0.000000 1/Ca                               |
```

Figure4.13: Reliability assessment Simulation result integrating DG in MV and LV feeders

Table4.11: The reliability indices in case of 13.2 MW DG installed at distribution system

Case III	NO Generation at MV and LV buses(Mw)	One year Reliability indices
After DG Integration	$MVP_{DGfeeder\ no1}=2.7$ $MVP_{DGfeeder\ no\ 4}=4.5$ $LVP_{DGfeeder\ no\ 1}=2$ $LVP_{DGfeeder\ no\ 4}=2$ $LVP_{DGfeeder\ no\ 3}=2$	SAIFI=32.9829 CAIFI=35.3218 SAIDI=30.701 CAIDI=0.931 ASAI=0.996 ASUI=0.0035 ENS=925.568 AENS=0.014

SAIFI of base case (no DG) is **190.4044** times/customer/year while for the appropriate size and location on MV and LV feeders the SAIFI decreases to **32.9829** times/customer/year. The results show that when the location of DG is considered by installing at selected buses the reliability of the distribution system decreases but depends on the location of the bus it was installed. For the appropriate size and location, it can be seen that the SAIFI decreases with **82.677%.** This indicates the utilities will be benefited by employing DG.

The following observations can be summarized from reliability analysis:

- ✓ Reliability indices (SAIDI, CAIDI, and ENS) will not be improved if the DG unit is installed at the distribution substation regardless of the DG size. This is because the failures in any section or distributor lateral within the circuit will not be mitigated as the DG unit will just act as an additional source to the distribution substation. However, in case of power interruptions from the main substation, the DG can be used to supply power to the system.
- ✓ Reliability indices (SAIDI, CAIDI, and ENS) improve as the DG is installed away from the substation and closer to the loads.
- ✓ The best improvement is observed when the DG is placed at the end of the line.

CHAPTER FIVE

Conclusions, Recommendations and Future Work

5.1 Conclusions

This thesis has explained the placement and size of DGs to meet the increment in energy demand and reducing the active power loss, for a large scale distribution system. The generalized steps toward deriving the analytic expressions for simultaneous sizing, which also include the impact of the size of one DG on the others, are presented. The optimum power factor required from a DG is also incorporated, resulting in the versatility of the derived expressions to be used for DGs with both active and reactive power generation capabilities. The proposed methodology is the general set of steps which can be applied to any number of DGs, but the case with only two DGs is presented here. The least losses can only be possible with appropriate sized DG, otherwise, the losses may go beyond the value of losses without DG(s).

The analytical method using sensitivity analysis is implemented and tested on the distribution network by DIgSILENT power factory commercial software. Results are presented by determining the appropriate place and capacity of DG for this distribution network. Here bus no 4 and bus no 1 are selected as appropriate place to integrate DG based on TENVDI with a size of 7.2 MW on both feeders and also for LV 6 MW DG is integrated as a backup to Cotobie distribution system to be the maximum size based on active power loss reduction of 71.68% and reactive loss reduction of 61.61%. This thesis also presented the analysis of reliability with the inclusion of DG. The different distribution system reliability indices such as SAIFI, SAIDI, CAIDI CAIFI, before and after DG integration (base case) to the distribution system are compared. It is shown that by installing DG with proper size and location Cotobie distribution system reliability is increased by decreases those indices by 37.08% SAIFI, 32.48% SAIDI, 37.08% CAIFI and 43.61 EENS. It is also shown that distribution system reliability indices depend on both the size and location of DG in the distribution system. Other case installing as a backup 6MW DG source in LV feeders reliability improvement of 82.428% and shown that load demand increases rapidly each year then DG units are able to meet the demand requirements until year-5 more in detail have seen in section 3.2.1. Therefore both the location of DG and its capacity of DG must take into account to reach an appropriate condition in order to create the suitability and fairness for both utility and DG.

5.2 Recommendations

We Ethiopians are mostly using hydroelectric power plant to meet our energy demand and we know that there is high electric interruption which is reported due to the decrease in the level of water used for the power generation. Therefore it is recommend that Ethiopian electric utility may apply the concept of DG integration into distribution system which mostly uses small-scale renewable energy technologies implemented to other substations to solve the problem associated with the increase in energy demand and increase the reliability of distribution systems and the concept of DG integration may also be applicable to many other developing countries worldwide.

5.3 Suggestion for Future Work

The costs of integrating distributed generation and the performance of protection system are not assessed in this thesis. The detailed impact of DG on protection system and its cost analysis benefits of integrating DG into the distribution network may be carried out as further extension of this work.

References

[1]. L. Yuping, Y. Xin, W. Ji'an, L. Xia, “An intelligent islanding technique considering load balance for distribution system with DGs,” Power Engineering Society General Meeting, IEEE, June 18-22, 2006.

[2]. Wallace, A. R., Harrison, G., May 2003. Planning for optimal accommodation of dispersed generation in distribution networks. In: Proc. of CIRED 17th International Conference on Electricity Distribution. Barcelona.

[3]. Dugan, R., McDermott, T., Ball, G., Mar. 2001. Planning for distributed generation. IEEE Industry Applications Magazine 7 (2), 80–88.

[4]. Castronuovo, E. D., Lopes, J. A. P., Aug. 2004. On the optimization of the daily operation of a wind-hydro power plant. IEEE Trans. Power Syst. 19 (3), 1599–1606.

[5]. Zhou, Q., Bialek, J., 2007. Generation curtailment to manage voltage constraints in distribution networks. IEE Proc.-Gener. Transm. Distrib. (in press).

[6]. Liu, J., Salama, M., Mansour, R., Jul. 2005. Identify the impact of distributed resources on congestion management. IEEE Trans. Power Deliv. 20 (3), 1998–2005.

[7] A. J. ovarrubias, “Expansion Planning for Electric Power Systems,” IAEA Bulletin, vol. 21, pp. 55-64, 1979.

[8] K.-H. R. Juergen Schlabbach, Power Systems Engineering Planning, Design and Operation of Power Systems Systems and Equipment, Homburg: WILEY-VCH Verlag GmbH &Co. KGaA, 2008.

[9]. J. M. Nahman and D. M. Peric, "Optimal planning of radial distribution networks by simulated annealing technique," IEEE Transactions on Power Systems, vol. 23, pp.790-795, 2008.

[10]. S. Wong, K. Bhattacharya and J. D. Fuller, "Electric power distribution system design and planning in a deregulated environment," IET Generation Transmission and Distribution, vol. 3, pp. 1061-1078, 2009.

[11]. A. Chowdhury, S. K. Agarwal and D. O. Koval, "Reliability modeling of distributed generation in conventional distribution systems planning and analysis," IEEE Transactions on Industry Applications, vol. 39, pp. 1493-1498, 2003.

[12]. M. R. Haghifam, H. Falaghi and O. P. Malik, "Risk-based distributed generation placement," IET Generation Transmission and Distribution, vol. 2, pp. 252-260, 2008.

[13] W. El-Khattam, Y. G. Hegazy, M. M. A. Salama, “An Integrated Distribution Generation Optimization Model for Distribution System Planning”, IEEE Transactions on Power Systems, Vol. 20, No. 2, May 2005, PP. 1158-1165.

[14] S. Favuzza, G. Graditi, M. G. Ippolito, E. R. Sanseverino, “Optimal Electrical Distribution Systems Reinforcement Planning Using Gas Micro Turbines by Dynamic Ant Colony Search Algorithm”, IEEE Transactions on Power Systems, Vol. 22, No. 2, May 2007, PP. 580-587.

[15] S. Haffner, L. F. A. Pereira, L. A. Pereira, L. S. Barreto, “Multistage Model for Distribution Expansion Planning with Distributed Generation-PartI: Problem Formulation”, IEEE Transactions on Power Delivery, Vol. 23, No. 2, April 2008, PP. 915-923.

[16] S. Haffner, L. F. A. Pereira, L. A. Pereira, L. S. Barreto, “Multistage Model for Distribution Expansion Planning with Distributed Generation-PartII: Numerical Results”, IEEE Transactions on Power Delivery, Vol. 23, No. 2, April 2008, PP. 924-929.

[17] Y. C. Huang, H. T. Yang, C. L. Huang, “Solving the Capacitor Placement Problem in a Radial Distribution System Using Tabu Search Approach”, IEEE Transactions on Power Systems, Vol. 11, No. 4, November 1996, PP. 1868-1873.

[18] C. F. Chang, “Reconfiguration and Capacitor Placement for Loss Reduction of Distribution Systems by Ant Colony Search Algorithm”, IEEE Transactions on Power Systems, Vol. 23, No. 4, November 2008, 1747-1755.

[19] R. H. Liang, C. K. Cheng, “Dispatch of Main Transformer ULTC and Capacitors in a Distribution System”, IEEE Transactions on Power Delivery, Vol. 16, No. 4, October 2001, PP. 625-630.

[20] Z. Hu, X. Wang, H. Chen, G. A. Taylor, “Volt/Var Control in Distribution Systems Using a Time-Interval Based Approach”, IEE Proceedings of Generation, Transmission and Distribution, Vol. 142, No. 1, September 2003, PP. 548-554.

[21] J. Y. Park, S. R. Nam, J. K. Park, “Control of a UTLC Considering the Dispatch Schedule of Capacitors in a Distribution System”, IEEE Transactions on Power Systems, Vol. 22, No. 2, May 2007, PP. 755-761.

[22] I. Ziari, G. Ledwich, A. Ghosh, “Optimal Voltage Support Mechanism in Distribution Networks”, IET Proceedings of Generation, Transmission and Distribution, Vol. 5, No. 1, 2011, PP. 127-135.

[23] M. A. S. Masoum, M. Ladjevardi, A. Jafarian, “Optimal Placement, Replacement and Sizing of Capacitor Banks in Distorted Distribution Networks by Genetic Algorithms”, IEEE Transactions on Power Delivery, Vol. 19, No. 4, November 2008, 1794-1801.

[24] Z. Q. Wu, K. L. Lo, “Optimal Choice of Fixed and Switched Capacitors in Radial Distributors with Distorted Substation Voltae”, IEE Proceedings of Generation, Transmission and Distribution, Vol. 142, No. 1, January 1995, PP. 24-28.

[25] M. E. H. Golshan, S. A. Arefifar, “Distributed Generation, Reactive Sources and Network Configuration Planning for Power and Energy-Loss Reduction”, IEE Proceedings of Generation, Transmission and Distribution, Vol. 153, No. 2, March 2006, PP. 127-136.

[26] G. Celli, E. Ghiani, S. Mocci, and F. Pilo, “A Multi objective Evolutionary Algorithm for The Sizing and Siting of Distributed Generation,” IEEE Transaction on Power System, Vol. 20, No. 2, May 2005, PP. 750–757.

[27] D. Zhu, R. P. Broadwater, K. S. Tam, R. Seguin, H. Asgeirsson, “Impact of DG Placement on Reliability and Efficiency with Time-Varying Loads”, IEEE Transactions on Power Systems, Vol. 21, No. 1, February 2006, PP. 419-427.

[28] L. Wang, C. Singh, “Reliability-Constrained Optimum Placement of Reclosers and Distributed Generators in Distribution Networks Using an Ant Colony System Algorithm”, IEEE Transactions on Systems, Man, And Cybernetics-Part C: Applications and Reviews, Vol. 38, No. 6, November 2008, PP. 757-764.

[29] Distributed generation: Definition, benefits, and issues. *Energy Policy, 33(6),* 787-798 Pepermans.G, Belmans, R. , Driesen, J. , D .haeseleer, W. , & Haeseldonckx, D. 2006.

[30] D. Remic, I. Tatarintsev and P. A. Urena, "Microturbines for distributed power generation," 2007. Available: http://me1065.wikidot.com/microturbines;

[31] H. Zareipour, K. Bhattacharya and C. Canizares, "Distributed generation: Current status and challenges," *Presented at Proc. 36th Annual North American Power Symposium (NAPS),* 2004.

[32]. N. Jenkins, R.Allan, P.Crossley, D.Kirschen, and G. Strbac, Embedded Generation, 1sted. IET Power and Energy Series 31, London: Institute of Engineering and Technology, UK, 2000,pp. 21-230.

Appendixes

Appendix A: Existing loadings and number of customers connected

Supplying Sub Station	Feeder Line	Line Length In K.M.s	Conductor Type & Size	Voltage Level	Number Of Trafo.s	**Total MVA Of The** Trafo.s	**TOTAL NO OF CUSTEMERS**
Eastern A.A	Line 1	10.5	C.S.A 500mm2	15 KV	19	4.575	4,594
>>	Line 2	12	C.S.A 500mm2	15 KV	3	2.23	2,042
>>	Line 3	1	C.S.A 120mm2	15 KV	148	33.015	29,971
>>	Line 4	13	C.S.A 240 mm2	15 KV	71	18.52	12,303
>>	Line 5	6	C.S.A 70 mm2	15 KV	62	13.708	14,718
>>	Line-6	25	C.S.A 240 mm2	33 KV	56	16	4,512

Appendix B: line parameters of MV feeders

	R (ohm)	X (ohm)	I(kA)
Line-1	2.232	1.209	0.208
Line-2	1.74	1.042304	0.056
Line-3	0.72	0.43428	0.291
Line-4	1.8875	1.4375	0.404
Line-5	0.9	0.68	0.282
Line-6	3.625	2.171	0.032

Appendix C: load forecasting using mat lab

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

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

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

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

sizepd = size(past_dem);

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

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

% get the number of years to predict

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

ntotal = np + nf;

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

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

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

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

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

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

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

% solve for the initial value, Po and g

Po = exp(B);

g = exp(A) - 1;

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

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

% calculate the estimated values

est_dem = 0;

for i = 1:ntotal

n = i - 1;

% year = first year + n

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

% load growth equation

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

if i < np

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

else
```

```
fprintf('\t%4d\t-\t\t\t%6.2f\n', est_dem(i,1),est_dem(i,2));
end
end
plot(past_dem(:,1),past_dem(:,2), 'k-s', est_dem(:,1), est_dem(:,2), 'k-+');
xlabel('Year'); ylabel('Demand'); legend('Actual', 'Forecast');
```

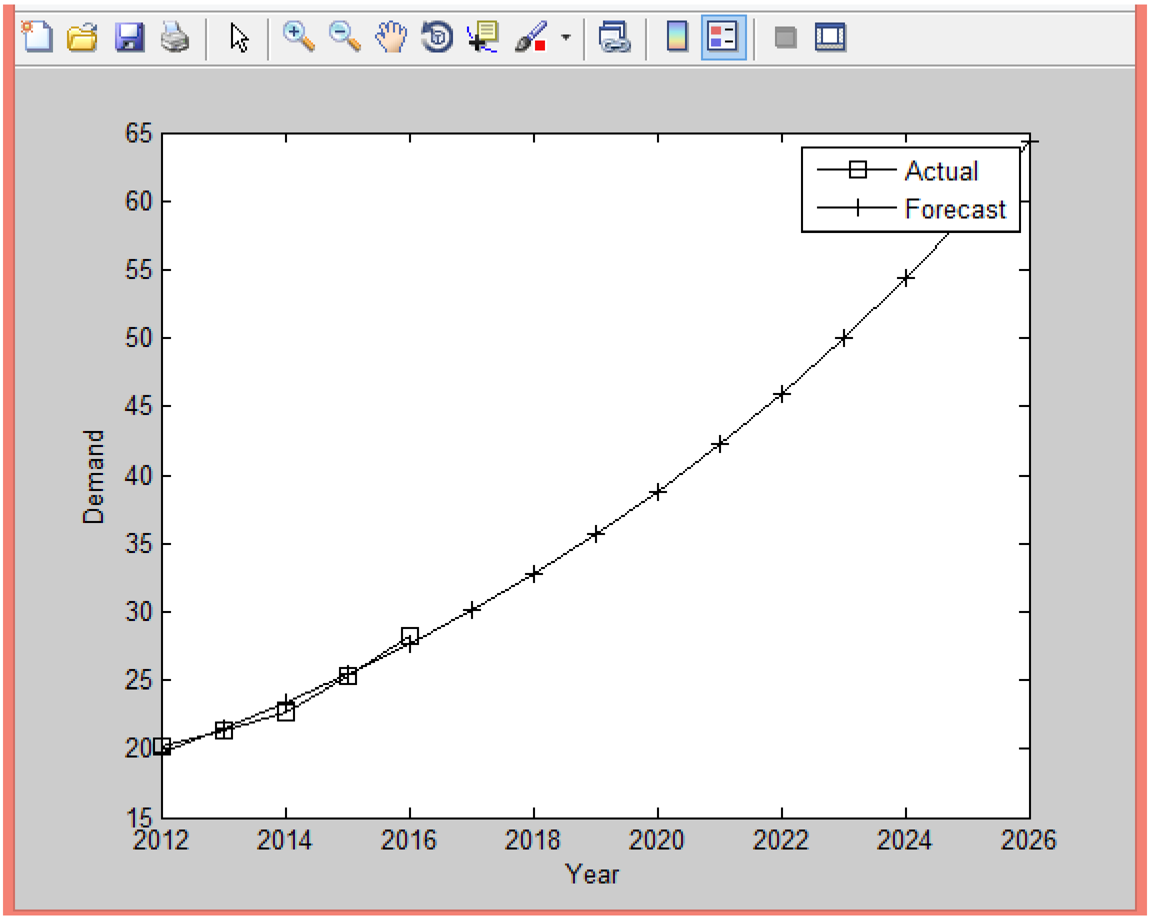
```
 Enter an array of demand values in the form:

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

Enter year/demand values: [2012 20.21; 2013 21.31; 2014 22.66; 2015 25.30; 2016 28.28]

Enter the number of year to predict: 10

            Rate of growth =8.80%
```



```
            YEAR    ACTUAL                  FORECAST

            2012     20.21            19.75
```

2013	**21.31**	**21.49**	
2014	**22.66**	**23.38**	
2015	**25.30**	**25.44**	
2016	**-**		**27.67**
2017	**-**		**30.11**
2018	**-**		**32.76**
2019	**-**		**35.64**
2020	**-**		**38.78**
2021	**-**		**42.19**
2022	**-**		**45.91**
2023	**-**		**49.95**
2024	**-**		**54.35**
2025	**-**		**59.13**
2026	**-**		**64.33>>**

Appendix D: Detail Interruption report of 2016/17 G.C

Table C-1: 15 kV Feeder 1 (DIARY FARM)

DATE - MM/DD/YY		INT. TIME	REC. TIME	DUR TIME	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
E.C	G.C				
6/21/08	2/29/2016	10:41	13:27	3:46	for substation maintenance
6/23/08	3/2/2016	20:41	21:02	0:21	Earth Fault
6/27/08	3/6/2016	16:03	16:51	0:48	
		19:29	20:57	1:28	Short Circuit
		21:53	22:00	0:07	
6/28/08	3/7/2016	9:06	11:19	2:13	Due to system loaded
6/29/08	3/8/2016	18:01	18:19	0:18	Earth Fault
7/1/08	3/10/2016	9:52	13:26	3:34	
		19:30	19:43	0:13	Due to system over loaded
7/4/08	3/13/2016	13:05	14:06	1:01	Short Circuit
		15:32	15:49	0:17	For maintenance
7/10/08	3/19/2016	11:34	12:31	1:01	For maintenance
7/15/08	3/24/2016	7:15	7:18	0:03	
7/18/08	3/27/2016	14:53	15:06	0:13	For maintenance

7/19/08	3/28/2016	13:15	13:38	0:23	
		17:02	17:44	0:42	
7/20/08	3/29/2016	10:10	10:35	0:25	Due to system over loaded
7/26/08	4/4/2016	7:49	10:20	2:31	Short Circuit
		10:58	11:03	0:05	For closing section
7/27/08	4/5/2016	9:30	9:35	0:05	For closing link
7/28/08	4/6/2016	8:16	9:56	1:40	
		16:03	16:24	0:21	For closing link
7/30/08	4/8/2016	19:46	20:22	0:36	Due to system loaded
8/3/08	4/11/2016	6:53	8:11	1:18	
		12:34	12:38	0:04	Earth Fault
		18:04	18:22	0:18	For maintenance
8/5/08	4/13/2016	10:06	11:40	1:36	Short Circuit
		14:05	14:31	0:26	Due to system loaded
		19:03	19:28	0:25	Due to system loaded
8/6/08	4/14/2016	11:30	11:52	0:22	Black out
8/10/08	4/18/2016	16:43	17:12	0:29	For maintenance
8/11/08	4/19/2016	8:17	8:43	0:26	Black out
8/16/08	4/24/2016	5:50	5:56	0:06	For maintenance
8/23/08	5/1/2016	19:08	19:21	0:13	Earth Fault
9/3/08	5/11/2016	12:29	12:44	0:15	Earth Fault
		13:58	14:41	0:43	For maintenance
9/5/08	5/13/2016	11:55	12:02	0:07	For maintenance
9/8/08	5/16/2016	2:15	2:54	0:39	
		4:40	4:59	0:19	Earth Fault
9/10/08	5/18/2016	14:19	14:51	0:32	For safty
		19:11	19:25	0:14	
9/15/08	5/23/2016	7:10	7:42	0:32	
		19:30	20:20	0:50	
9/22/08	5/30/2016	15:05	15:18	0:13	For maintenance
		16:42	18:38	1:56	Short Circuit
		19:32	20:40	1:08	Due to trafo loaded
10/6/08	6/13/2016	6:37	9:04	2:27	
		19:36	20:48	1:12	Due trafo loaded
10/10/08	6/17/2016	12:32	13:21	0:49	
10/12/08	6/19/2016	14:16	15:19	1:03	Short Circuit
10/15/08	6/22/2016	6:25	6:49	0:24	Black out
		15:08	17:02	1:54	for substation maintenance
		18:22	19:59	1:37	
10/16/08	6/23/2016	20:57	21:00	0:03	
10/18/08	6/25/2016	11:19	12:39	1:20	black- out,fincha debremarkos transmission line fault
10/23/08	6/30/2016	16:20	17:26	1:06	
10/25/08	7/2/2016	8:47	12:31	3:44	For maintenance
10/26/08	7/3/2016	8:49	11:24	2:35	For maintenance
		20:23	20:25	0:02	
11/3/08	7/10/2016	7:46	8:15	0:29	
11/6/08	7/13/2016	13:42	13:53	0:11	
11/10/08	7/17/2016	19:26	20:25	0:59	
11/11/08	7/18/2016	8:58	9:52	0:54	Short Circuit
		15:40	16:14	0:34	Black out
11/16/08	7/23/2016	16:57	17:13	0:16	For closing link
11/24/08	7/31/2016	3:53	5:58	0:05	

		14:22	15:22	1:00	
		15:34	15:37	0:03	For closing link
		17:41	17:44	0:03	For opening link
		17:56	18:20	0:24	
11/25/08	8/1/2016	8:43	8:46	0:03	
		8:53	9:18	0:25	for substation maintenance
		10:30	10:31	0:01	
		11:12	11:48	0:36	
		13:05	13:07	0:04	
		13:37	14:14	0:37	
		15:24	16:01	0:37	For closing link
		19:05	19:21	0:16	For connecting tap
		19:48	19:55	0:07	Phase reverse
11/27/08	8/3/2016	11:21	12:21	1:00	Due to TR loaded
		12:52	13:03	0:11	Tafo CB loaded
		14:43	14:58	0:15	Tafo CB loaded
		19:11	19:48	0:37	
11/29/08	8/5/2016	9:52	10:21	0:29	For sefty
		11:31	12:29	0:58	Due to TR loaded
12/3/08	8/9/2016	11:23	12:15	0:52	Due to TR loaded
12/4/08	8/10/2016	19:17	19:32	0:15	Due to TR loaded
12/6/08	8/12/2016	11:07	12:29	1:22	Due to TR loaded
12/12/08	8/18/2016	14:50	15:04	0:14	
		17:33	17:42	0:09	
12/16/08	8/22/2016	15:24	15:58	0:34	For sefty
12/29/08	9/4/2016	12:32	12:35	0:03	
		12:36	13:36	1:00	
		13:46	14:32	0:46	For closing section
		14:33	15:56	1:23	For maintenance
		15:59	16:28	0:29	Tafo CB tripped
12/30/08	9/5/2016	14:11	14:20	0:09	
13/03/08	9/8/2016	11:40	11:46	0:06	Black out
13/05/08	9/10/2016	18:10	19:55	1:45	
1/2/09	9/12/2016	14:59	16:27	1:28	For safty
1/6/09	9/16/2016	9:44	10:26	0:42	
1/29/09	10/9/2016	9:08	10:33	1:25	For maintenance
2/2/09	10/12/2016	14:00	14:08	0:08	
		13:50	13:55	0:05	
		15:21	15:28	0:07	
		15:37	17:38	2:01	
2/15/09	10/25/2016	18:35	19:05	0:30	Black out
2/17/09	10/27/2016	14:13	14:23	0:10	Preventive maintenance
2/19/09	10/29/2016	8:11	12:53	4:42	For connecting tap
		15:34	16:23	0:49	For opening link
2/20/09	10/30/2016	7:30	8:11	0:41	For closing link
		11:14	11:51	0:37	
2/28/09	11/7/2016	2:59	5:42	2:43	
3/06/09	11/15/2016	16:29	16:35	0:06	
3/15/09	11/24/2016	12:01	12:07	0:06	

3/16/09	11/25/2016	12:16	12:25	0:09	
		12:29	12:35	0:06	
3/17/09	11/26/2016	3:51	4:01	0:10	
		4:03	6:11	2:08	
3/19/09	11/28/2016	2:08	2:20	0:12	due to short circuit on cot-01
		8:23	9:22	0:59	
		10:41	11:54	1:13	
3/23/09	12/2/2016	14:17	15:04	0:47	
3/25/09	12/4/2016	12:38	13:50	1:12	
3/27/09	12/6/2016	17:15	17:39	0:24	For filling drop out fuse
4/1/09	12/10/2016	8:32	11:58	3:26	
		17:00	17:27	0:27	
4/5/09	12/14/2016	13:10	13:14	0:04	
4/16/09	12/25/2016	7:06	7:30	0:24	For opening section
		12:20	12:51	0:31	For closing section
4/20/09	12/29/2016	13:47	14:23	0:36	
		16:20	16:25	0:05	For closing section
4/21/09	12/30/2016	8:39	10:27	1:48	Black out
5/4/09	1/12/2017	11:22	11:29	0:07	
		12:50	13:12	0:22	
5/5/09	1/13/2017	2:55	2:58	0:03	
		2:58	9:23	6:25	
		15:14	15:27	0:13	For maintenance
5/9/09	1/17/2017	8:00	8:24	0:24	
5/12/09	1/20/2017	14:36	14:46	0:10	
		16:35	16:41	0:06	
5/20/09	1/28/2017	14:30	14:36	0:06	
		15:31	15:38	0:07	
Total	1 year	No of interruptions=143		6663 min	

Table C-2: 15 kV Feeder 2 (KEBENA)

DATE - MM/DD/YY		INT. TIME	REC. TIME	DUR TIME	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
E.C	G.C				
7/1/08	3/10/2016	10:43	12:08	1:25	For maintenance
8/6/08	4/14/2016	11:30	11:52	0:22	Black out
8/11/08	4/19/2016	8:17	8:43	0:26	Black out
9/1/08	5/9/2016	7:13	7:18	0:05	
9/7/08	5/15/2016	5:34	7:27	1:53	For maintenance
9/8/08	5/16/2016	2:15	2:54	0:39	due to short circuit on cot-01
		4:40	4:59	0:19	
9/13/08	5/21/2016	8:10	8:21	0:11	
9/20/08	5/28/2016	16:18	16:25	0:07	
10/3/08	6/10/2016	13:56	14:10	0:14	For safty
10/15/08	6/22/2016	6:25	6:49	0:24	Black out
10/23/08	6/30/2016	16:20	17:26	1:06	due to short circuit on cot-01
11/11/08	7/18/2016	15:40	16:14	0:34	Black out
11/18/08	7/25/2016	16:49	19:24	2:35	

11/24/08	7/31/2016	3:53	5:58	2:05	Black out
11/27/08	7/3/2016	9:29	9:46	0:17	For safty
		12:52	13:03	0:11	Tafo CB tripped
		14:43	14:58	0:15	Tafo CB tripped
11/29/08	7/5/2016	9:52	10:21	0:29	For sefty
12/12/08	8/18/2016	14:50	15:04	0:14	Black out
12/16/08	8/22/2016	14:14	15:14	1:00	
		15:15	15:58	0:43	
13/03/08	9/8/2016	16:52	16:57	0:05	
13/05/08	9/10/2016	18:10	19:55	1:45	due to short circuit on cot-01
1/2/09	9/12/2016	14:59	16:25	1:26	
1/6/09	9/16/2016	9:44	10:26	0:42	For safty
1/29/09	9/9/2016	9:08	10:33	1:25	For safty
2/15/09	10/25/2016	18:35	19:05	0:30	Black out
2/17/09	10/27/2016	14:13	14:23	0:10	
2/28/09	10/7/2016	2:59	5:42	2:43	Black out
4/1/09	12/10/2016	11:22	11:58	0:36	
		17:00	17:27	0:27	
4/4/09	12/13/2016	9:50	10:00	0:10	
4/21/09	12/30/2016	8:39	10:27	1:48	Black out
5/28/09	1/5/2017	5:04	12:30	7:26	
		12:38	12:43	0:05	For closing link
		18:42	18:52	0:10	For connecting tap
Total	1 year	No of interruptions =38		2102 min	

Table C-3: 15 kV Feeder 3 (COTEBE)

DATE- MM/DD/YY		INT. TIME	REC. TIME	DUR TIME	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
E.C	G.C				
6/21/08	2/29/2016	10:41	13:38	2:57	
6/22/08	3/1/2016	10:30	10:41	0:11	For maintenance
6/23/08	3/2/2016	11:19	11:30	0:11	
		20:41	21:02	0:21	for substation maintenance
6/27/08	3/6/2016	16:03	16:51	0:48	
		19:29	20:57	1:28	
		21:53	22:00	0:07	to energize new trafo
6/28/08	3/7/2016	19:07	20:13	0:56	
6/29/08	3/8/2016	17:38	19:32	1:54	
6/30/08	3/9/2016	9:21	9:44	0:23	For maintenance
		9:45	10:09	0:24	
		10:23	11:01	0:38	For maintenance
7/8/08	3/17/2016	14:30	14:37	0:07	
7/14/08	3/23/2016	11:31	11:35	0:04	
		16:55	17:07	0:12	For maintenance
7/15/08	3/24/2016	6:57	7:05	0:08	
7/16/08	3/25/2016	15:44	15:50	0:06	
7/17/08	3/26/2016	11:31	11:36	0:05	
7/26/08	4/4/2016	13:50	14:03	0:13	For safty
7/30/08	4/8/2016	10:50	10:56	0:06	
8/5/08	4/13/2016	10:06	11:39	1:33	

		14:05	14:31	0:26	Due to system loaded
		14:50	14:55	0:05	
		19:03	19:28	0:25	Due to system loaded
		19:32	20:01	0:29	
8/6/08	4/14/2016	11:30	11:52	0:22	Black out
8/8/08	4/16/2016	3:00	3:04	0:04	
		4:12	9:26	1:14	
		18:15	18:53	0:38	For safty
8/9/08	4/17/2016	8:24	11:06	2:42	
8/10/08	4/18/2016	19:00	20:26	1:26	Due to system loaded
8/11/08	4/19/2016	8:17	8:43	0:26	Black out
8/12/08	4/20/2016	12:56	13:02	0:06	
8/13/08	4/21/2016	11:12	11:24	0:12	Due to system loaded
8/14/08	4/22/2016	8:13	8:15	0:03	
		11:37	11:44	0:07	
8/16/08	4/24/2016	18:29	18:39	0:10	Due to system loaded
8/20/08	4/28/2016	15:53	16:22	0:29	For load sharing
08/21-22/09	4/29-30/2016	23:30	6:31	7:01	
8/22/08	4/30/2016	6:53	8:09	1:16	under frequency
		10:55	11:02	0:07	
		11:20	11:33	0:13	
		15:42	15:50	0:08	For closing link
		16:14	17:22	1:08	
		17:34	19:15	1:41	
		20:17	20:32	0:15	For closing link
		20:40	20:42	0:02	
		20:50	21:13	0:23	
		21:26	21:29	0:03	under frequency
		21:42	22:20	0:38	
8/23/08	5/1/2016	10:46	11:23	0:37	For safty
8/25/08	5/3/2016	8:48	8:57	0:09	
9/3/08	5/11/2016	20:03	20:41	0:38	
9/8/08	5/16/2016	2:15	2:54	0:39	
		4:40	4:59	0:19	
9/11/08	5/19/2016	20:30	21:02	0:32	For safty
9/15/08	5/23/2016	18:28	18:48	0:20	For safty
9/19/08	5/27/2016	8:36	8:47	0:11	
		15:42	15:49	0:07	
9/23/08	5/31/2016	5:54	15:28	9:34	Changed new cable
		19:07	19:17	0:10	
		19:23	20:30	1:07	for substation maintenance
9/25/08	6/2/2016	14:20	14:23	0:03	
9/27/08	6/4/2016	16:54	18:51	1:57	
9/28/08	6/5/2016	5:42	10:27	4:45	Due to system loaded
9/29/08	6/6/2016	14:35	15:10	0:35	Phase reverse
9/30/08	6/7/2016	17:22	17:31	0:09	To connect new load
10/2/08	6/9/2016	16:05	16:08	0:03	
10/11/08	6/18/2016	10:20	12:17	1:57	b/c of trafo loaded
10/14/08	6/21/2016	9:41	9:45	0:04	
10/23/08	6/30/2016	17:58	18:03	0:05	
10/25/08	7/2/2016	14:57	15:24	0:27	For safty
10/27/08	7/4/2016	5:41	6:07	0:26	

11/3/08	7/10/2016	5:32	6:46	1:14	
11/9/08	7/16/2016	11:56	12:07	0:11	For connecting tap
11/11/08	7/18/2016	15:40	16:14	0:34	Black out
11/13/08	7/20/2016	19:20	19:24	0:04	over load
11/14/08	7/21/2016	20:34	20:42	0:08	
11/15/08	7/22/2016	8:48	11:00	2:12	
		11:02	11:05	0:03	For closing link
11/17/08	7/24/2016	4:29	4:34	0:05	
11/18/08	7/25/2016	19:17	19:24	0:07	Over loaded
		19:31	19:58	0:17	Over loaded
11/20/08	7/27/2016	11:31	12:22	0:51	
11/24/08	7/31/2016	3:53	5:58	2:05	Tafo CB loaded
11/27/08	8/3/2016	12:52	13:03	0:11	Tafo CB loaded
		14:43	14:58	0:15	
11/29/08	8/5/2016	22:59	0:58	1:59	
11/30/08	8/6/2016	6:47	6:51	0:04	under frequency
12/1/08	8/7/2016	7:46	7:51	0:05	
		8:11	9:01	0:50	
12/2/08	8/8/2016	19:09	20:29	1:20	For maintenance
12/4/08	8/10/2016	12:34	13:30	0:56	Tafo CB loaded
		19:18	19:19	0:01	
		19:26	21:10	1:44	Over loaded
12/5/08	8/11/2016	18:20	20:53	1:33	Over loaded
12/6/08	8/12/2016	19:23	19:25	0:02	
12/9/08	8/15/2016	18:19	18:25	0:06	
12/10/08	8/16/2016	14:56	15:42	0:46	To decrease load
12/11/08	8/17/2016	14:15	14:33	0:18	Changed fuse box
		15:52	17:24	1:32	
		17:28	17:32	0:04	For closing section
12/12/08	8/18/2016	14:50	15:05	0:15	
12/18/08	8/24/2016	6:36	6:40	0:04	
12/19/08	8/25/2016	15:09	15:31	0:22	
12/20/08	8/26/2016	10:58	11:14	0:16	For closing link
		11:55	12:49	0:54	
12/21/08	8/27/2016	11:28	15:37	4:09	For maintenance
12/22/08	8/28/2016	15:01	16:41	1:40	Removed tree branch
12/26/08	9/1/2016	11:48	12:03	0:15	Due tafo loaded
12/27/08	9/2/2016	11:16	12:02	0:46	For safty
12/29/08	9/4/2016	6:16	6:20	0:04	
12/30/08	9/5/2016	12:57	12:59	0:02	
13/05/08	9/10/2016	12:33	12:35	0:02	To minimize load
		15:01	15:02	0:01	For closing link
		19:03	19:07	0:04	
		19:18	19:33	0:15	
		20:24	20:33	0:09	
		20:53	21:07	0:14	For maintenance
		21:29	21:46	0:17	For maintenance
1/1/09	9/11/2016	19:12	19:23	0:11	
1/2/09	9/12/2016	7:23	7:26	0:03	
		7:29	7:33	0:04	
1/4/09	9/14/2016	6:44	6:47	0:03	
1/6/09	9/16/2016	15:01	15:05	0:04	For maintenance

1/7/09	9/17/2016	7:34	7:39	0:05	
1/8/09	9/18/2016	15:45	15:48	0:03	
1/13/09	9/23/2016	19:17	20:58	1:41	
1/16/09	9/26/2016	14:27	14:38	0:11	For maintenance
1/19/09	9/29/2016	14:58	15:02	0:04	
1/29/09	10/9/2016	6:03	8:03	2:00	For connecting trafo tap
2/1/09	10/11/2016	17:52	17:54	0:02	For closing link
2/3/09	10/13/2016	6:51	7:00	0:09	
2/7/09	10/17/2016	19:47	20:50	1:03	For safty
2/8/09	10/18/2016	10:22	11:31	1:09	For safty
2/9/09	10/19/2016	15:34	15:36	0:02	
2/12/09	10/22/2016	14:32	14:39	0:07	under frequency
2/13/09	10/23/2016	11:30	11:33	0:03	
		15:32	16:01	0:29	Removed tree branch
2/15/09	10/25/2016	14:57	16:15	1:18	
		18:35	19:05	0:30	Black out
2/18/09	10/28/2016	9:57	10:06	0:09	
2/20/09	10/30/2016	18:51	19:07	0:16	
2/21/09	10/31/2016	17:03	18:05	1:02	For safty
2/22/09	11/1/2016	2:32	2:44	0:12	
2/23/09	11/2/2016	5:43	7:03	1:20	To connecting tap
		18:52	19:20	0:28	For safty
2/28/09	11/7/2016	2:59	5:42	2:43	
		12:59	7:32	6:33	For maintenance work
		6:45	9:44	2:59	For maintenance work
2/29/09	11/8/2016	16:42	16:59	0:17	To fill dropped out fuse
3/18/09	11/27/2016	9:30	9:34	0:04	
3/25/09	12/4/2016	11:47	12:24	0:37	
		16:23	16:37	0:14	
3/26/09	12/5/2016	11:21	11:31	0:10	
4/6/09	12/15/2016	13:23	14:52	1:29	
4/8/09	12/17/2016	12:59	13:08	0:09	
4/9/09	12/18/2016	16:12	16:32	0:20	To maintained broken tap
4/14/09	12/23/2016	11:07	11:45	0:37	For changing new trafo
4/21/09	12/30/2016	8:39	13:11	4:32	Black out
4/22/09	12/31/2016	5:25	9:25	4:00	For unknown interruption
4/25/09	1/3/2017	17:32	18:21	0:49	For maintenance
4/28/09	1/6/2017	15:37	15:45	0:08	
		18:42	19:46	1:04	b/c of trafo loaded
		21:32	21:36	0:14	For closing link
5/2/09	1/10/2017	6:38	7:11	0:33	
5/3/09	1/11/2017	16:30	16:34	0:04	
		16:52	18:06	1:14	
5/4/09	1/12/2017	9:38	10:04	0:26	For maintenance
5/5/09	1/13/2017	8:24	9:47	1:23	
		9:51	9:53	0:04	For closing link
5/8/09	1/16/2017	10:42	10:53	0:11	For maintenance
5/10/09	1/18/2017	6:00	6:40	0:40	
5/16/09	1/24/2017	11:15	11:26	0:11	
5/17/09	1/25/2017	15:09	15:29	0:20	For maintenance
Total	1 year	No of interruptions = 176		8,054 min	

Table C-4: 15 kV Feeder 4 (BOLE)

DATE - MM/DD/YY		INT. TIME	REC. TIME	DUR TIME	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
E.C	G.C				
6/21/08	1/29/2016	10:41	13:27	2:46	
6/22/08	2/1/2016	8:49	10:53	2:04	For maintenance
6/23/08	2/2/2016	20:41	21:02	0:21	
6/26/08	2/5/2016	7:14	7:30	0:16	
6/27/08	2/6/2016	16:03	16:51	0:48	for substation mentenance
		19:29	20:57	1:28	
		21:53	22:00	0:07	
6/28/08	2/7/2016	7:06	11:19	4:13	Due to system over loaded
7/1/08	2/10/2016	19:30	19:45	0:15	Due to system over loaded
7/2/08	2/11/2016	17:17	17:35	0:18	
		17:55	18:03	0:08	under frequency
7/5/08	2/14/2016	23:24	23:30	0:06	
7/6/08	2/15/2016	15:33	16:01	0:28	For safty
		17:25	17:29	0:04	
7/15/08	2/24/2016	9:00	9:04	0:04	
7/19/08	2/28/2016	14:49	15:16	0:27	For maintenance
		19:03	20:37	1:34	Due to system over loaded
7/22/08	2/31/2016	14:32	14:36	0:04	
7/25/08	3/3/2016	9:16	9:20	0:04	
		9:59	10:02	0:03	
7/28/08	3/6/2016	7:38	7:40	0:02	
7/30/08	3/8/2016	19:46	20:22	0:36	Due to system loaded
8/1/08	3/9/2016	17:01	17:38	0:37	
8/2/08	3/10/2016	13:42	13:46	0:04	
8/5/08	3/13/2016	10:06	11:39	1:33	under frequency
		19:24	19:30	0:06	
8/6/08	3/14/2016	11:30	11:52	0:22	Black out
		19:58	21:24	1:26	Due to system loaded
8/7/08	3/15/2016	10:17	10:42	0:25	For safty
8/8/08	3/16/2016	12:23	12:36	0:13	
		18:59	19:02	0:03	
8/11/08	3/19/2016	8:17	8:43	0:26	Black out
8/12/08	3/20/2016	10:35	11:15	0:40	Due to system loaded
8/14/08	3/22/2016	6:15	7:10	0:55	
8/16/08	3/24/2016	11:25	11:29	0:04	
8/17/08	3/25/2016	21:14	21:39	0:25	For safty
8/20/08	3/28/2016	15:53	16:22	0:29	For load sharing
8/21/08	3/29/2016	17:10	17:14	0:04	
8/22/08	3/30/2016	12:46	12:49	0:03	For opining link
		17:38	17:46	0:08	For closing link
8/23/08	4/1/2016	0:57	1:33	0:36	
		1:35	1:45	0:10	For closing link
		3:15	3:25	0:10	
		9:25	9:55	0:30	For closing link
		10:46	11:10	0:24	For opining link
		11:32	11:42	0:10	For closing link
		12:08	13:30	1:22	For maintenance
8/24/08	4/2/2016	15:07	15:10	0:03	

8/25/08	4/3/2016	17:39	18:15	0:36	For maintenance
8/28/08	4/6/2016	14:01	14:21	0:20	For maintenance
8/29/08	4/7/2016	8:20	8:37	0:17	
		4:28	4:31	0:03	
9/1/08	4/9/2016	8:08	9:36	1:28	For maintenance
9/3/08	4/11/2016	12:04	14:40	2:36	
		16:37	16:42	0:05	
		20:32	21:26	0:54	For safty
9/4/08	4/12/2016	11:07	11:40	0:33	For safty
		14:30	14:55	0:25	For connecting tap
9/5/08	4/13/2016	9:18	12:03	2:45	
9/6/08	4/14/2016	15:14	15:30	0:16	For closing link
9/8/08	4/16/2016	2:15	2:55	0:40	
		4:40	5:00	0:20	
9/9/08	4/17/2016	1:40	1:46	0:06	
		9:28	10:07	0:39	For maintenance
9/10/08	4/18/2016	11:40	14:50	3:10	
9/11/08	4/19/2016	9:13	9:27	0:14	
9/12/08	4/20/2016	6:20	6:24	0:04	
		18:41	18:53	0:12	For maintenance
9/13/08	4/21/2016	10:28	10:34	0:06	
		10:34	12:21	1:47	
		17:06	17:14	0:08	For closing link
9/15/08	4/23/2016	17:28	17:40	0:12	For filling fuse
9/16/08	4/24/2016	12:11	12:38	0:27	For maintenance
9/17/08	4/25/2016	15:32	15:38	0:06	
9/18/08	4/26/2016	14:15	14:18	0:03	
9/19/08	4/27/2016	7:11	8:28	1:17	
		14:51	15:21	0:30	For maintenance
		19:00	19:31	0:31	For maintenance
9/21/08	4/29/2016	9:29	10:33	1:04	Adding of load
9/22/08	4/30/2016	14:08	14:26	0:18	For maintenance
9/23/08	4/31/2016	11:53	11:59	0:06	For maintenance
9/25/08	5/2/2016	8:39	9:00	0:21	
		21:51	21:57	0:06	For safty
9/27/08	5/4/2016	10:10	10:14	0:04	
9/28/08	5/5/2016	5:43	13:57	8:14	Due to system loaded
		14:57	15:10	0:13	Phase reverse
9/29/08	5/6/2016	9:05	9:22	0:17	For maintenance
		19:25	19:28	0:03	
		19:50	19:58	0:08	under frequency
10/3/08	5/10/2016	8:20	8:27	0:07	
		12:39	14:10	1:31	
10/4/08	5/11/2016	6:36	9:04	2:28	Wire broken
		11:13	11:39	0:26	For maintenance
10/6/08	5/13/2016	17:44	17:47	0:03	
10/7/08	5/14/2016	11:32	11:41	0:09	For passing truck
10/8/08	5/15/2016	16:44	16:48	0:04	
10/9/08	5/16/2016	9:02	9:09	0:07	
		11:35	11:42	0:07	
		16:30	16:35	0:05	
10/10/08	5/17/2016	9:11	9:13	0:02	under frequency

10/11/08	5/18/2016	6:22	6:24	0:02	
		10:33	10:41	0:08	
10/12/08	5/19/2016	18:31	19:48	1:17	Phase unbalance
10/13/08	5/20/2016	9:53	9:57	0:04	For load sharing
10/14/08	5/21/2016	14:57	15:30	0:33	
10/15/08	5/22/2016	5:44	8:42	2:58	Due to system over loaded
		12:24	12:27	0:03	
10/17/08	5/24/2016	9:37	10:00	0:23	For maintenance
		12:08	12:13	0:05	For closing link
10/18/08	5/25/2016	11:19	12:39	1:20	
		16:22	16:41	0:19	
		17:20	17:24	0:04	
10/20/08	5/27/2016	8:25	8:28	0:03	
		14:07	14:24	0:17	For maintenance
		15:58	19:31	3:33	
10/21/08	5/28/2016	11:37	12:37	1:00	For maintenance
		12:38	13:12	0:34	
		14:24	14:38	0:14	b/c of flame occurred
10/23/08	5/30/2016	6:32	6:35	0:03	
		16:10	16:41	0:31	
10/24/08	6/1/2016	9:54	9:57	0:03	due to tree
		14:45	14:53	0:08	
		17:32	18:16	0:44	
10/25/08	6/2/2016	7:35	7:45	0:10	
		14:48	14:50	0:02	
		17:06	17:28	0:22	For connecting tap
10/26/08	6/3/2016	2:23	2:32	0:09	
10/27/08	6/4/2016	7:05	8:41	1:36	For safty
		11:45	11:50	0:05	
		16:33	16:37	0:04	due to tree
10/29/08	6/6/2016	3:47	3:54	0:07	
10/30/08	6/7/2016	10:06	10:08	0:02	
		17:30	17:57	0:27	For maintenance
11/1/08	6/8/2016	9:52	10:32	0:40	New trafo installed
		15:24	15:31	0:07	
		20:32	20:43	0:11	
11/2/08	6/9/2016	6:28	6:33	0:05	
		9:16	9:32	0:16	For maintenance
11/3/08	6/10/2016	5:37	8:36	2:59	
		13:12	13:16	0:04	
		14:52	15:01	0:09	
11/4/08	6/11/2016	6:12	6:17	0:05	
		10:05	10:07	0:02	
11/5/08	6/12/2016	4:45	7:06	2:21	For maintenance
11/6/08	6/13/2016	15:44	15:49	0:05	
		16:47	17:13	0:26	For maintenance
		8:21	18:24	0:03	
11/8/08	6/15/2016	2:06	2:17	0:11	
		2:49	10:07	7:18	
		10:20	10:23	0:01	
		11:18	11:54	0:36	For safty
11/10/08	6/17/2016	7:54	8:00	0:06	

		13:53	14:06	0:13	
		16:10	16:17	0:07	
11/11/08	6/18/2016	15:40	16:14	0:34	Black out
11/13/08	6/20/2016	17:10	17:28	0:18	For maintenance
		18:05	18:11	0:06	
11/16/08	6/23/2016	16:17	16:19	0:02	
11/17/08	6/24/2016	13:52	14:00	0:08	
11/18/08	6/25/2016	7:48	7:59	0:11	
		14:56	15:00	0:04	
11/20/08	6/27/2016	15:58	16:23	0:25	For maintenance
		20:32	20:36	0:04	
11/21/08	6/28/2016	8:37	8:48	0:11	
		22:48	23:04	0:16	For filling fuse
11/22/08	6/29/2016	10:20	10:24	0:04	
		17:12	17:16	0:04	
11/24/08	6/31/2016	3:53	5:58	2:05	
		16:11	16:15	0:04	
11/25/08	7/1/2016	8:07	8:09	0:02	due to tree
		14:44	14:47	0:03	
11/27/08	7/3/2016	7:22	9:46	2:24	
		12:52	13:04	0:12	Incoming load
		14:43	14:58	0:15	Tafo loaded
11/28/08	7/4/2016	16:37	16:56	0:19	For maintenance
11/29/08	7/5/2016	9:52	10:21	0:29	For maintenance
11/30/08	7/6/2016	17:44	19:46	2:02	
12/2/08	7/8/2016	11:30	11:32	0:02	
12/3/08	7/9/2016	16:19	17:02	0:43	b/c of unbalance
12/5/08	7/11/2016	10:44	12:35	1:51	Tafo loaded
		21:28	21:52	0:24	
12/7/08	7/13/2016	11:07	11:12	0:05	
12/8/08	7/14/2016	16:37	16:44	0:07	
12/9/08	7/15/2016	6:44	7:06	0:22	
		11:49	12:09	0:20	For minimizing load
12/10/08	7/16/2016	5:23	6:08	0:45	To connect new load
12/11/08	7/17/2016	9:55	10:05	0:10	
		11:17	11:24	0:07	
12/12/08	7/18/2016	14:50	15:05	0:15	
		6:28	6:31	0:03	
12/17/08	7/23/2016	14:18	14:21	0:03	
12/18/08	7/24/2016	9:22	9:27	0:05	For opening link
		10:35	11:43	1:08	For closing link
12/20/08	7/26/2016	5:38	10:13	4:35	
12/22/08	7/28/2016	15:11	15:18	0:07	
		16:42	16:48	0:06	
12/24/08	7/30/2016	8:44	8:47	0:03	
12/25/08	7/31/2016	13:42	14:48	1:06	
12/26/08	8/1/2016	11:48	12:03	0:15	Tafo CT loaded
		15:11	15:29	0:18	For maintenance
12/28/08	8/3/2016	11:31	11:38	0:07	
		12:30	12:39	0:09	
12/29/08	8/4/2016	6:09	7:20	1:11	Preventive maintenance
		16:18	16:27	0:09	

		16:48	16:56	0:08	
13/05/08	8/10/2016	9:32	12:34	3:02	b/c of trafo loaded
		12:56	13:00	0:04	
		17:35	18:00	0:25	
		18:08	22:19	4:11	
1/1/09	8/11/2016	14:03	14:06	0:03	
1/2/09	8/12/2016	7:18	7:23	0:05	
		7:27	7:33	0:06	
		7:54	9:53	1:59	b/c of unbalance load
		13:51	13:58	0:07	
1/3/09	8/13/2016	11:41	12:06	0:25	To change fuse box
1/4/09	8/14/2016	7:52	7:56	0:04	
		14:04	17:08	3:04	
1/5/09	8/15/2016	18:21	18:25	0:04	
1/6/09	8/16/2016	9:44	10:26	0:42	For maintenance
1/7/09	8/17/2016	16:27	16:33	0:06	
1/13/09	8/23/2016	14:41	14:44	0:03	
		16:49	16:52	0:03	
		19:53	20:59	1:06	Kallit line 2 loaded
1/15/09	8/25/2016	8:17	8:45	0:28	For closing link
		16:41	16:44	0:03	
1/16/09	8/26/2016	11:17	11:20	0:03	For filling drop out fuse
1/21/09	9/1/2016	6:50	6:56	0:06	
		17:06	17:13	0:07	
		17:20	17:27	0:07	
		19:00	19:03	0:03	
		19:08	19:56	0:48	
1/22/09	9/2/2016	15:37	15:48	0:11	
1/23/09	9/3/2016	6:57	7:04	0:07	
1/24/09	9/4/2016	7:42	7:46	0:04	
		11:08	11:14	0:06	
		14:14	14:40	0:26	For opened tap
		17:04	17:17	0:13	
		17:45	18:12	0:27	For connected tap
1/25/09	9/5/2016	4:33	4:43	0:10	
		4:48	5:11	0:23	
		10:39	10:43	0:04	
		15:19	15:23	0:04	
		18:46	19:05	0:19	For closing link
1/26/09	9/6/2016	1:13	7:06	5:53	
		17:05	17:12	0:07	
		22:36	22:42	0:06	
		22:46	22:54	0:08	
1/27/09	9/7/2016	1:39	6:49	5:10	
		17:24	17:28	0:04	
		23:57	0:04	0:07	
1/28/09	9/8/2016	1:48	13:48	12:00	After fault removed
1/29/09	9/9/2016	8:37	12:11	3:34	For maintenance
1/30/09	9/10/2016	15:12	15:37	0:25	To change fuse box
2/1/09	9/11/2016	13:01	13:05	0:04	
		16:54	17:15	0:21	For maintenance
2/6/09	9/16/2016	6:57	7:03	0:06	
2/8/09	9/18/2016	15:40	15:49	0:09	

2/10/09	9/20/2016	16:19	16:24	0:05	
		17:42	17:49	0:07	
2/11/09	9/21/2016	10:15	10:17	0:02	
		14:20	14:31	0:11	For opened link
		14:51	16:10	1:19	
		16:10	16:29	0:19	For closing link
		17:49	18:42	0:53	
2/12/09	9/22/2016	19:26	19:41	0:15	To opened link
2/15/09	9/25/2016	6:15	6:25	0:10	
		18:35	19:06	0:21	Black out
2/18/09	9/28/2016	15:54	17:31	1:37	
		17:32	17:34	0:02	For closing section
2/19/09	9/29/2016	8:32	12:10	3:38	For connecting tap
2/20/09	9/30/2016	8:23	12:46	4:23	For rehabilitation work
2/24/09	10/3/2016	6:43	6:51	0:08	
		14:34	14:56	0:22	
2/25/09	10/4/2016	8:34	8:41	0:07	
2/27/09	10/6/2016	6:41	6:54	0:13	
		12:40	12:44	0:04	
2/28/09	10/7/2016	2:59	5:43	2:44	
2/29/09	10/8/2016	8:05	8:10	0:05	
3/01/09	10/10/2016	7:50	7:56	0:06	
3/03/09	10/12/2016	10:52	11:14	0:22	For maintenance
3/06/09	10/15/2016	8:07	8:11	0:04	
		13:10	13:20	0:10	
		15:45	15:58	0:13	
3/08/09	10/17/2016	17:11	17:21	0:10	
3/09/09	10/18/2016	7:09	7:16	0:07	
3/10/09	10/19/2016	6:05	6:08	0:03	
		7:40	7:50	0:10	
		9:06	9:56	0:50	Due to phase unbalance
		10:31	11:01	0:30	Due to phase unbalance
3/12/09	10/21/2016	17:42	17:48	0:06	
		15:00	15:06	0:06	
3/14/09	10/23/2016	16:16	16:22	0:06	
3/16/09	10/25/2016	8:18	8:23	0:05	
3/17/09	10/26/2016	11:10	11:16	0:06	
3/22/09	10/31/2016	6:08	9:16	3:08	For maintenance
		7:30	7:35	0:05	
3/24/09	11/2/2016	11:17	12:22	1:05	
3/25/09	11/3/2016	11:21	16:02	4:41	
		16:49	17:21	0:32	
3/26/09	11/4/2016	10:53	11:17	0:24	
4/5/09	11/13/2016	12:12	12:36	0:24	For maintenance
4/11/09	11/19/2016	6:28	6:40	0:12	
4/14/09	11/22/2016	9:36	9:44	0:08	
4/15/09	11/23/2016	16:12	16:16	0:04	
4/16/09	11/24/2016	5:47	8:52	3:05	For maintenance
		12:26	12:32	0:06	
4/18/09	11/26/2016	22:33	22:46	0:13	
4/19/09	11/27/2016	8:30	11:32	3:02	
		11:36	13:33	1:57	For closing link
		14:21	15:31	1:10	For maintenance work

4/20/09	11/28/2016	6:31	7:18	0:47	
4/21/09	11/29/2016	8:39	13:11	4:32	Black out
4/22/09	11/30/2016	8:02	8:12	0:10	
4/23/09	11/31/2016	5:57	6:04	0:07	
		13:25	13:45	0:20	For maintenance
4/25/09	12/2/2016	9:58	10:15	0:17	
		12:26	12:32	0:06	
4/26/09	12/3/2016	11:46	11:57	0:11	For maintenance
4/27/09	12/4/2016	14:51	14:55	0:04	
4/28/09	12/5/2016	8:37	8:45	0:08	
5/2/09	12/9/2016	6:56	7:01	0:05	
5/4/09	12/11/2016	9:24	9:29	0:05	
		10:15	10:20	0:05	
5/5/09	12/12/2016	1:25	1:34	0:09	
5/6/09	12/13/2016	7:06	7:09	0:03	
5/7/09	12/14/2016	7:40	7:45	0:05	
		17:54	18:22	0:28	
5/8/09	12/15/2016	7:20	7:23	0:03	
		9:50	10:55	1:05	
5/12/09	12/19/2016	9:00	10:37	1:37	
5/15/09	12/22/2016	11:28	12:04	0:36	
5/16/09	12/23/2016	12:05	12:15	0:10	
5/20/09	12/27/2016	12:20	12:26	0:06	For opening trafo link
5/21/09	12/28/2016	8:00	8:03	0:03	
5/24/09	1/3/2017	17:10	18:00	0:50	
5/25/09	1/4/2017	5:44	8:49	3:05	For maintenance
5/26/09	1/5/2017	14:35	15:04	0:29	
5/28/09	1/7/2017	6:05	12:05	6:00	For relocation
		18:55	19:03	0:08	
Total	1 year	No of interruptions = 339		14,039 minutes	

Table C-5: 15 kV Feeder 5 (CMC)

DATE - MM/DD/YY		INT. TIME	REC. TIME	DUR TIME	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
E.C	G.C				
6/21/08	2/29/2016	10:41	13:27	2:46	
6/23/08	3/2/2016	20:41	21:02	0:21	
6/27/08	3/6/2016	16:03	16:51	0:48	
		19:29	20:57	1:28	
		21:53	22:03	0:10	
6/28/08	3/7/2016	1:48	1:54	0:06	
		1:56	5:12	3:16	
		14:16	14:40	0:24	For maintenance
		15:33	18:38	3:05	
		19:45	20:16	0:31	For maintenance
6/29/08	3/8/2016	16:06	16:54	0:48	
6/30/08	3/9/2016	16:03	16:11	0:08	
7/2/08	3/11/2016	11:13	11:16	0:03	
7/8/08	3/17/2016	14:30	14:37	0:07	
		19:00	20:45	1:45	Due to system over loaded

7/9/08	3/18/2016	6:39	11:18	4:39	
7/14/08	3/23/2016	16:58	17:06	0:08	
		19:10	20:10	1:00	Due to system over loaded
7/16/08	3/25/2016	15:44	15:50	0:06	
7/25/08	4/3/2016	7:06	7:11	0:05	
		9:27	9:51	0:24	For maintenance
7/29/08	4/7/2016	19:03	19:40	0:37	
8/1/08	4/9/2016	16:56	17:38	0:42	
8/2/08	4/10/2016	11:17	11:39	0:22	For maintenance
8/4/08	4/12/2016	19:07	20:17	1:10	Due to system loaded
8/5/08	4/13/2016	10:06	11:39	1:33	
		19:24	19:31	0:07	
		19:32	20:00	0:28	
8/6/08	4/14/2016	11:30	11:52	0:22	Black out
		19:58	21:24	1:26	Due to system loaded
8/7/08	4/15/2016	6:54	9:49	2:55	
8/8/08	4/16/2016	1:10	1:13	0:03	
		18:15	18:50	0:35	For safty
8/9/08	4/17/2016	4:42	6:41	1:59	For maintenance
		8:24	11:08	2:44	
8/11/08	4/19/2016	8:17	8:43	0:25	Black out
		18:55	20:24	1:29	Due to system loaded
8/12/08	4/20/2016	16:30	16:39	0:09	For maintenance
8/13/08	4/21/2016	19:27	20:05	0:38	Due to system loaded
8/14/08	4/22/2016	11:37	11:44	0:07	
8/16/08	4/24/2016	17:00	17:08	0:08	
		17:09	17:26	0:17	
		17:31	18:39	1:08	
8/19/08	4/27/2016	8:29	8:33	0:04	
8/20/08	4/28/2016	15:53	16:22	0:29	For load sharing
9/8/08	5/16/2016	2:15	2:55	0:40	
		4:40	5:00	0:20	
9/15/08	5/23/2016	18:28	18:48	0:20	For maintenance
9/19/08	5/27/2016	8:36	8:47	0:11	
		15:42	15:49	0:07	
9/22/08	5/30/2016	10:28	10:44	0:16	For maintenance
9/23/08	5/31/2016	5:54	7:28	1:34	Changed power cable
10/4/08	6/11/2016	8:24	8:32	0:08	
10/10/08	6/17/2016	15:52	18:31	2:39	
		19:44	20:00	0:16	For closing link
10/11/08	6/18/2016	12:46	12:50	0:04	
		17:45	18:41	0:56	
10/15/08	6/22/2016	6:25	6:49	0:24	Block out
10/18/08	6/25/2016	11:19	11:39	0:20	
10/26/08	7/3/2016	8:44	9:36	0:54	
10/27/08	7/4/2016	5:04	6:07	1:03	
10/28/08	7/5/2016	7:01	7:16	0:15	
10/29/08	7/6/2016	12:51	12:57	0:06	
		14:05	14:15	0:10	
		15:02	15:11	0:09	
11/7/08	7/14/2016	1:43	10:04	8:21	
		17:09	17:29	0:20	For connecting tap

11/11/08	7/18/2016	8:58	9:25	0:27	For opening link
		15:40	16:14	0:34	Black out
		18:35	18:50	0:15	For connecting tap
11/24/08	7/31/2016	3:53	5:58	2:05	Black out
11/25/08	8/1/2016	13:29	13:31	0:02	
11/26/08	8/2/2016	6:09	6:22	0:13	
11/27/08	8/3/2016	12:52	13:04	0:12	Tafo CB tripped (load)
		14:43	14:58	0:15	Tafo CB tripped (load)
11/30/08	8/6/2016	6:47	6:51	0:04	
12/2/08	8/8/2016	19:48	20:29	0:41	For safty (b/c of L-3)
12/3/08	8/9/2016	18:56	19:55	0:59	b/c of tafo loaded
12/4/08	8/10/2016	6:41	6:45	0:04	
		10:16	12:15	1:59	b/c of Tafo loded
12/5/08	8/11/2016	9:50	9:57	0:07	
12/6/08	8/12/2016	19:21	20:24	1:03	b/c of Tafo loded
12/7/08	8/13/2016	14:58	15:20	0:22	For closing link
12/10/08	8/16/2016	6:25	6:28	0:03	
		14:56	15:42	0:46	Load share from L-3
12/12/08	8/18/2016	14:50	15:05	0:15	Black out
12/19/08	8/25/2016	15:09	15:31	0:22	
12/20/08	8/26/2016	11:55	12:49	0:54	
12/21/08	8/27/2016	14:48	15:37	0:49	For safty
12/27/08	9/2/2016	8:42	8:44	0:02	
		9:09	9:54	0:45	
		10:00	10:50	0:50	For closing section
		11:16	12:02	0:46	For maintenance
12/28/08	9/3/2016	16:05	16:08	0:03	
12/30/08	9/5/2016	12:57	12:59	0:02	
13/05/08	9/10/2016	7:56	9:32	1:36	Trafo loaded
		19:22	20:34	1:12	
1/1/09	9/11/2016	19:12	19:23	0:11	
1/4/09	9/14/2016	23:28	0:07	0:39	
1/13/09	9/23/2016	19:17	20:59	1:32	
2/1/09	10/11/2016	10:49	11:13	0:24	
2/7/09	10/17/2016	19:47	20:50	1:03	For maintenance
2/8/09	10/18/2016	10:22	11:31	1:09	For changing tap
2/15/09	10/25/2016	18:35	19:06	0:31	Black out
2/18/09	10/28/2016	5:30	6:31	1:01	For maintenance
		9:57	10:06	0:09	
2/20/09	10/30/2016	18:51	19:07	0:16	
2/21/09	10/31/2016	13:45	13:48	0:03	
		16:26	18:05	1:39	
2/23/09	11/2/2016	15:09	15:30	0:21	For maintenance
		18:51	19:22	0:31	
2/28/09	11/7/2016	2:59	5:43	2:44	
		6:39	7:32	0:53	
		8:52	9:44	0:52	
3/12/09	11/21/2016	0:34	6:58	7:32	
		14:36	15:00	0:24	For maintenance
3/16/09	11/25/2016	11:41	14:14	2:33	
3/25/09	12/4/2016	10:15	10:21	0:06	Changing cable
		11:50	17:43	5:53	

4/1/09	12/10/2016	14:30	14:50	0:20	b/c of phase reverce
		22:15	22:21	0:06	For safty
4/2/09	12/11/2016	14:02	14:41	0:39	
4/13/09	11/22/2016	14:27	14:30	0:03	For maintenance
		14:36	14:39	0:03	
		16:06	16:41	0:35	For maintenance
4/21/09	12/30/2016	8:39	13:11	4:32	Black out
5/2/09	1/10/2017	6:38	7:11	0:33	
5/7/09	1/15/2017	9:52	10:20	0:28	For maintenance
Total	1 year	No of interruptions=128		7,030 minuets	