ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

“RELIABILITY ASSESSMENT OF RADIAL DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION”: (A CASE STUDY OF COTTEBE SUBSTATIONS)

A thesis Submitted to the Addis Ababa Institute of Technology, School of Graduate Studies, Addis Ababa University

In Partial Fulfillment of the Requirement for the Degree of MASTER OF SCIENCE IN ELECTRICAL POWER ENGINEERING

By: Amache Jara

Advisor: Dr. Getachew Bekele

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RELIABILITY ASSESSMENT OF RADIAL DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION: (A CASE STUDY: COTTEBE SUBSTATIONS)

By Amache Jara Godebo

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DECLARATION

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

All examiners' comments are duly incorporated.

Amache Jara

Signature: __________

Place: Addis Ababa

Date of submission: …./…./2016

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

Dr. Getachew Bekele _________________________

Advisor's Name Signature

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ABSTRACT

The utility company, EEP and EEU mission is to transmit, distribute and supply electricity in reliable and efficient manner. The problem facing electric power utilities is that the power demand is increasingly but, power problem in distribution system occurs several times, due to over loading, short circuit, improper allocated distribution transformers, poor maintenance, limited protective devices. Therefore the substation need for more extensive justifications of the system facilities, and improvements in production and use of electricity.

This thesis presents reliability assessment of the 132/15 kV transformer through five 15 kV outgoing feeders. The 15 kV network is operated as radials and the total capacity of 132/15 kV transformer is 31.5 MVA supplying to five 15 kV outgoing feeders and the total connected load to the 15 kV feeders between 14.5 and 19.5 MW. The distribution system consists of 45, 33, 15 and 0.4 kV systems but the case study considered 15 and 0.4 kV outgoing feeders of the distribution system with distributed generation providing support to the system adequacy and security for reliability improvement. The distributed generation (DG) units considered for this assessment are any possible DG units installed at optimal place and size at their site to the customers satisfactions. DG systems have received more attention recently due to their high overall efficiency and increase in reliability. A composite system adequacy assessment, which includes the two main components of the power grid viz., generation and distribution, is done using Monte Carlo simulation. The analytical approach is system reliability using direct numerical solutions. The basic data and the topology used in the analysis are based on the Institution of Electrical and Electronics Engineers - Reliability Test System (IEEE-RTS) and IEEE-Reliability Bus bar Test System (IEEE-RBTS). Integrating DG units in 0.4 kV bus of distribution system improve the overall system reliability indices SAIDI from 206.56 to 2.532, SAIFI form 188.8 to 1.9575, ASAI from 97.64% to 99.971%, ASUI from 2.36% to 0.0289% and also EENS, and EIC of the overall distribution system improved by 97.3%. Therefore a base Cotebe distribution system reliability index is very poor according to the reliability standards.

KEY WORDS: Adequacy, DIgSILENT, ETAP, Distribution system, Expected Energy not supplied**,** Expected Interruption cost, Failure rate, Forced outage, Indices, Interruptions, Reliability, Security.

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ACRONYMS

EEP	Ethiopia Electric Power
EEU	Ethiopia Electric Utility
ETAP	Electrical Transient Analyzer Program
DIgSILENT	Digital Simulation and Electrical Network
RBTS	Reliability Bus bar Test System
kV	kilovolt
MVA	Mega volt ampere
MVAR	Mega VAR
MW	Mega watt
HV	High voltage
MV	Medium voltage
LV	Low voltage
DG	Distributed generator
kW	Kilowatt
CHP	combined heat and power
PV	Photovoltaic
FC	Fuel Cells
WT	Wind Turbine
DFIG	Doubly Fed Induction Generator
SCIG	Squirrel Cage Induction Generator
DC	direct current
AC	alternating current
IEEE	International Electrical and Electronic Engineering
SAIFI	System average interruption frequency index
SAIDI	System average interruption duration index

CAIDI	Customer average interruption duration index
ASAI	Average service availability index
ASUI	Average service unavailability index
EENS	Expected energy not supplied
AENS	Average energy not supplied
EIC	Expected Interruption Cost Index
IEAR	Interruption Energy Assessment Rate
PDF	probability density functions
MCS	Monte Carlo Simulation
$P_L t$	Probability of load demand
P_{Ld}^{min}	Minimum load demand
P_{Ld}^{max}	Maximum load demand
μ_{ld}	Statistical mean of the observed load demand
σld	Statistical standard variance of the observed load demand
$f(v)$	Distribution probability of wind speed
c	Scale factor
k	Shape factor
v	Wind speed
Vci	Cut in wind speed
vco	Cut out wind speed
vm	Mean wind speed
Vr	Rated wind speed
$\alpha, \beta c$	Parameters of Beta distribution function
σ	Standard deviation
P_{rated}	Rated power

$G_{PV}\,t$	the solar radiation incident on the PV array
Ci_t^{sr}	Clearness index
$G_{ex}\,t$	Extra-terrestrial solar radiation in a pre-defined period of time
μ	Mean of clearness index
σ	Standard deviation clearness index
OLTC	Online Load Tap Changing
FOR	Forced Outage Rate
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MTBF	Mean Time between Failures
λ	The expected failure rate,
μ	Expected repair rate
λ_s	System average failure rate
U_s	System average annual outage time
r_s	System average outage time
N_i	The number of customers of load points i.
U_i	The annual outage time
L_{peak}	Peak load
f	The corresponding load factor
$L_{a(i)}$	Average load connected to load point i
C_{hi}	Outage cost ($/KWh) of customer due to contingency h
λ_h	Failure rate of contingency h
r_h	Outage time of contingency h
n_h	Number of contingency

n_i	Total number of load point i
P_k	Active power at bus k
Q_i	Reactive power at bus k
N	Number of buses
Y_{ik}	Element (I, k) in admittance matrix
θ_{ik}	Angle of Y_{ik}
δ_k	Voltage angle at bus k
N_i	Number of feeders
$V_k^{\min}$	Minimum voltage at bus k
$V_k^{\max}$	Maximum voltage at bus k
I_l	Current flow in feeder *l*
$I_l^{\max}$	Maximum current capability of feeder l
N_c	Number of capacity steps of a DG
C_j	Capacity at step j of DG
$DG_{\max}$	Maximum total installed capacity
e_{ik}	Decision variable for installation of a DG at bus k

CHAPTER ONE

INTRODUCTION

1.1 Background

The economic and social effects of loss of electric service in Ethiopia have significant impacts on both the utility supplying electric energy and the customer of electric service. The cost of a major power outage confined to one distribution system can be on the order of millions of dollars. If a major power outage affects multiple distribution systems of customer services, then the expected interruption cost can exceed million dollars. Ethiopia electric power system is vulnerable to system abnormalities such as control failures, protection or communication system failures, transmission line failures, poor maintenances and disturbances, such as lightning, grounding, system overload and human operational errors. Therefore, maintaining a reliable power supply to the customer service is a very important issue for power systems design and operation of EEP and EEU.

With recent advances in technology, use of distributed generation (DG) in the radial distribution system is increasing. Incorporating DG into the radial distribution system poses numerous challenges in terms of interconnection, protection coordination, system losses and voltage regulation. Increased reliability and reduced cost of interruption are the primary incentives of adding DG to an existing distribution network.

This thesis presents a methodology to investigate and simulate the operation of a radial distribution system with optimum placement of DG units to improve the system reliability indices and load flow analysis for voltage regulation and power losses. The proposed method uses a GIgSILENT/ETAP/MATLAB simulation of the power system's stochastic model in combination with either qualitative or quantitative techniques. Qualitative techniques imply that reliability assessment must depend solely upon engineering experience and judgment. Quantitative methodologies use statistical approaches to reinforce engineering judgments. Quantitative techniques describe the historical performance of existing systems and utilize the historical performance to predict the effects of changing conditions on system performance. Thorough assessment of reliability and operating strategy of a distribution network can be performed using this developed technique for preliminary reliability planning studies.

The case study of radial distribution system investigation and simulation is carried out on the COTEBE substation system which consists of 33 kV, 45 kV and 15 kV outgoing feeder network in Addis Ababa. The reliability assessment and load flow analysis through 132/15 kV, 31.5 MVA transformer is done on five 15 kV feeders such as DAIRY FARM (feeder 1), KEBENA (feeder 2), COTEBE (feeder 3), BOLE (feeder 4), and CMC (feeder 5) system to assess the performance of the present system and also proposed DG allocation, and size to reliability analysis for the existing system considering load and system configurations. The alternative which gives low SAIDI, SAIFI, CAIDI, EENS, and Interruption costs are being assessed and considered. The reliability of 15 kV systems could be further improved by installation of Distributed generation, Load tap change transformer, load break switch, auto recloser and connecting with line coming from other.

1.1.1 Distribution Systems

The electric power systems can be divided into generation plant, generation sub-station, transmission system, sub-transmission and distribution sub-stations. Traditionally, generation is to supply the power to the transmission system which can be defined as the carrier of power from the generating stations to the sub-transmission system, at voltage levels of 230 kV or higher. The sub-transmission system then transfers the power at voltage levels between 66 kV to 132 kV to the distribution substation systems. Finally, the distribution substation system, at voltages under 33 kV, delivers electricity to the consumer [1]. Figure **1.1** illustrates a typical electric power system.

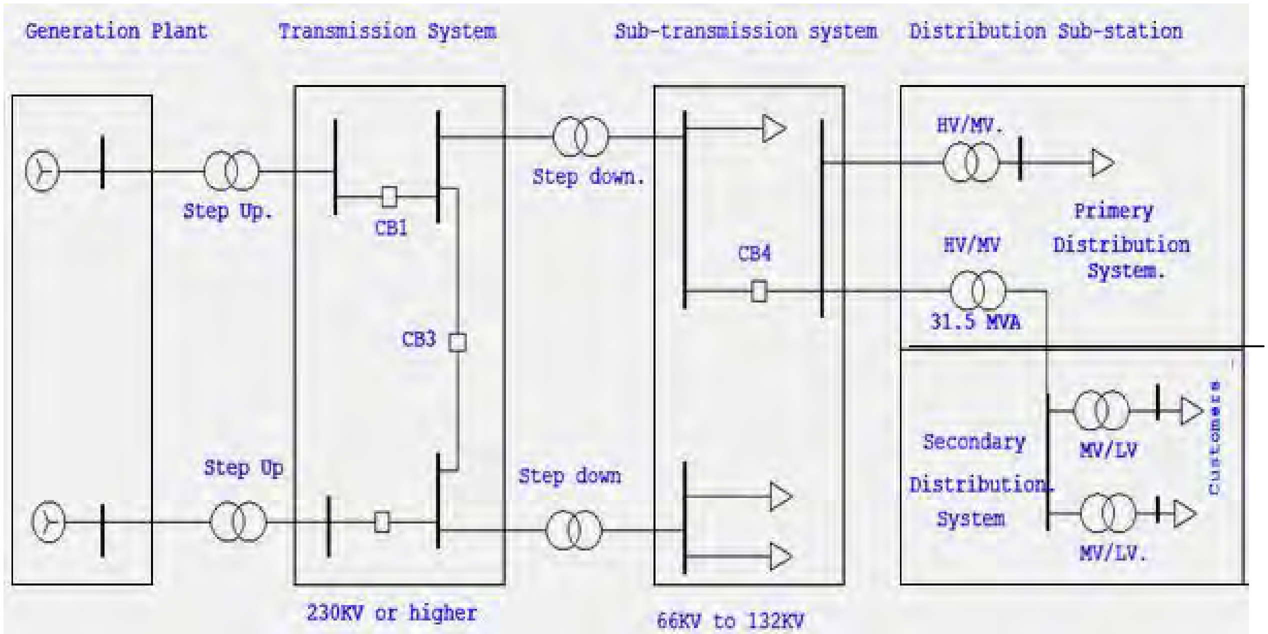

Figure 1.1: Basic power system structure.

The distribution system can be divided into primary and secondary systems. The primary distribution system consists of distribution substations and feeders. The distribution substations step down power from the sub-transmission system to between 45 kV and 11 kV. The primary distribution main feeders branch out from the substation and then lateral feeders to serve local areas. From the lateral, distribution transformers step the voltage down again to the secondary level at which most customers are served, generally at 120/240 V single phase and 400 V three phase.

1.1.2 A typical Configurations of distribution system

An important characteristic of distribution systems is their configuration, or how their lines are connected. There are three common configurations of distribution systems: radial, loop and meshed network [2]. These two types of system are arranged in series or parallel or combinations of the two.

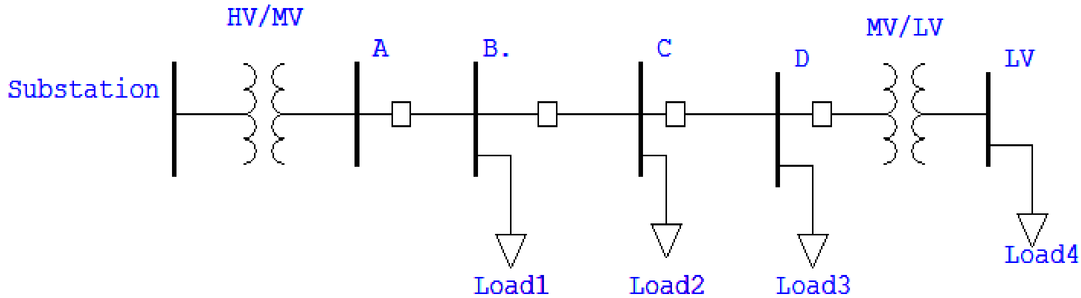

Figure 1.2: Radial Distribution System

Radial configuration of distribution system is the simplest and typical used arrangement for the electric utility company. A radial distribution system consists of a set of components, transformers, lines, protective devices, and buses as shown in Figure 1.2. In this type of system configuration, the distribution feeders leave the substation and passes through all the system area without connection to any other power supply. The simplicity of this type of distribution configuration allows the easy system performance analysis and also the planning issues of related to maintenance, improvement or expansion of the system and it requires the lowest capital cost; however, it also has the lowest reliability, since any faults in the feeders will cause service interruptions at all points downstream.

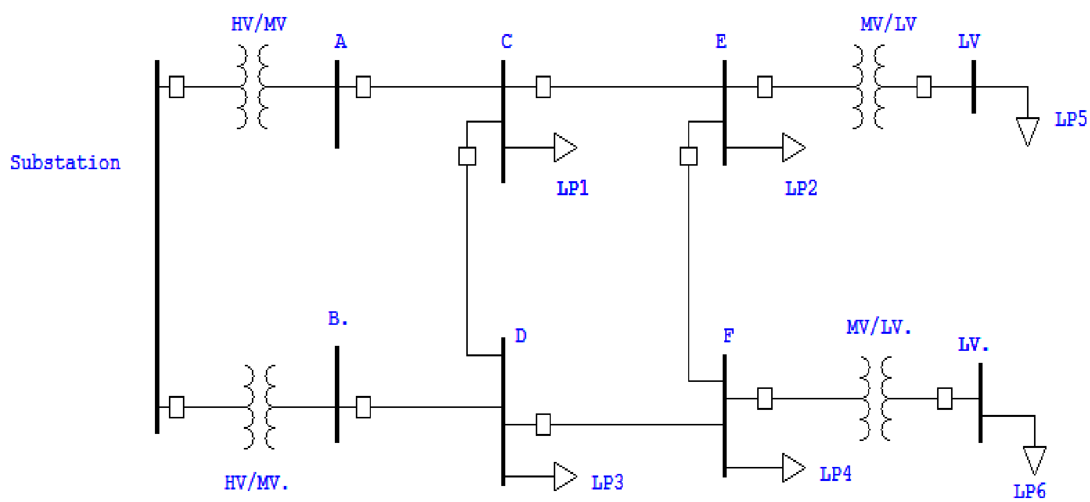

Figure 1.3: Distribution System - Meshed configuration

Meshed distribution system configuration, it is more interconnected meaning that any two points are usually connected by more than one path and some lines form loops within the system. A meshed configuration is generally more reliable because there is exists more than one path for the power to flow, if a line fails. Economically, the cost of a meshed system is the highest because of its numerous feeders with associated protection and control systems. Figure 1.3 shows a meshed configuration of a distribution system. Loop configured distribution systems fall in between the two in terms of cost and reliability. A loop configuration can be described as two radial systems separated by a normally open switch, a failure of one of the two substation transformers the switch can be closed and one section of the distribution system energized through the other.

Distribution system design and planning is facing a major change in paradigm due to deregulation of the power industry, policy changes and advancements in DG technologies. A distribution system design and planning is the key to determine the best expansion strategies to provide reliable and economic services to the customer. In classical planning, the load growth typically is met by adding a new substation or upgrading the existing substation capacity along with their feeders. Today, the rapid advances in DG technology and their numerous benefits have made them an attractive alternative to the distribution companies in their planning tasks [3].

1.2 Statement of the problem

Ethiopian Electricity networks are, and will continue to be a critical part of our energy infrastructure, and they have responsibility to ensure that they are developed consistently and in a manner that meets future demands of society and customers. The process of network development should be directed towards a long term vision aligned with the expectations of the present and future customers. After corporatization and forming as utility company, EEP and EEU mission is to transmit, distribute and supply adequate electricity in a secure, reliable and efficient manner and this has to be accomplished.

The main problem facing the electric power utilities in developing countries today is that the power demand is increasingly rapidly where supply growth is constrained by economical, environmental problems and other societal concerns. This has resulted in a need for more extensive justifications of the new system facilities, and improvements in production and use of electricity. System planning and operation based on reliability assessment approach provides an opportunity to justify one of the scrutinized and vulnerable economic sectors in Ethiopia. It is with this objective to conduct customer surveys to find out the failure occurrences, failure durations, expected energy not supplied and outage cost of interruptions**.**

The study introduces different approaches for investigating the implications of DG interconnection into the distribution system to improve reliability. Therefore the study will contribute to the following aspects:

- More understanding of the reliability assessment of distribution system with DG.
- Incentive for our EEP system to integrate DG unit allocation into distributions as a part of the solution of the increasing the load demand.
- Providing of different aspects regarding planning distribution networks with DG units' allocation and capacity based on the real measured data.

Generally distributed generation may be used as standby units for reliability enhancement at specific load points. If DG capacity is sufficient to meet the load at a load point in the event of failure of supply from substation then the situation at load point is represent. Reliability may be improved for a radial distribution system by modifying failure rate and average repair time of each segment of the system.

1.3 Objectives of the Thesis

The general objective of the thesis is outlined as follows:

- ❖ The reliability assessment of distribution substation system with DG units, by applying analytical and Monte Carlo Simulation method using the DIgSILENT/ETAP /MATLAB software tool.

The specific objectives of the thesis are outlined as follows:

- ❖ Asses the existing distribution network.
- ❖ Study the electrical power reliability assessment of distribution system.

- ❖ Collect the interruption duration, occurrences, causes, number of customers etc.
- ❖ Identify the causes of interruptions.
- ❖ Calculate interruption indices.
- ❖ Examine the local distribution systems performances task taking into account DG unit options.
- ❖ Propose a comprehensive planning framework that will assist in understanding the role of DG and the impact it has on the distribution system.
    - The impact of the DG to the different sections of the systems
    - An analysis of placing DG in at different distances from substation
    - Breakdown of placing more than one DG.

1.4 Methodology

Due to the nature of the study, it is started by reviewing literatures related to the investigation of reliability problems of power systems. Recent and unpublished important information and data have been collected from Cotebe substation and distribution transformers. Interviews with respective professionals at substations have been considered. Distribution reliability information was obtained from actual data for systems operating in Load Dispatch Center (LDC) and COTEBE substation recorded data and online SCADA system. The significance of the results obtained is discussed.

Generally the following methodology has been followed in conducting the research work:

- ➢ Site visit
- ➢ Technical data collection from the Cotebe Distribution Substation system
- ➢ The interruption duration, occurrences of existing system
- ➢ Identifying the causes of interruptions
- ➢ Investigation of reliability problems of the substation
- ➢ Analysis of the technical performance of the distribution system
- ➢ Modeling the existing system with DG
- ➢ Calculating reliability index and comparison base case with the modified system index

This research work considered the five outgoing feeders of the distribution system. This is because the distribution system is the major contributor of the reliability problem in the power system.

CHAPTER TWO

LITERATURE REVIEW

This section gives a detailed overview of the research papers in the area of reliability assessment of radial distribution systems with distributed generation.

2.1 Power System

The system generation, transmission and distribution system is illustrated in Figure 2.1.

Generation Plants: Electricity is produced at central power plants (also referred to as generating stations) by converting mechanical energy into electrical energy. A prime mover such as engines and turbines convert thermal or non thermal sources such as hydraulic, wind and steam turbine that is used to bring the mechanical power to a generator in order to produce electricity. The generation plants are connected to transmissions networks via generation substations which is interconnection node between generation plant and transmission lines, where electric power is stepped up to a higher voltage (normally between 230 kV to 500 kV) to be transported over long distance.

Transmission: The transmission system is divided into two parts: transmission and sub-transmission systems. The transmission system is the bulk power transfers electric power from a generation plant to a sub-transmission system through generation substations at voltage levels of 230 kV or higher. The transmission system is usually part of the electric utility's network. The sub-transmission system then transfers the electrical power at voltage levels between 66 kV to 132 kV to the distribution substation and on to the distribution networks. Sub-transmission stages are used to enable a more practical or economical transition between transmission and distribution systems.

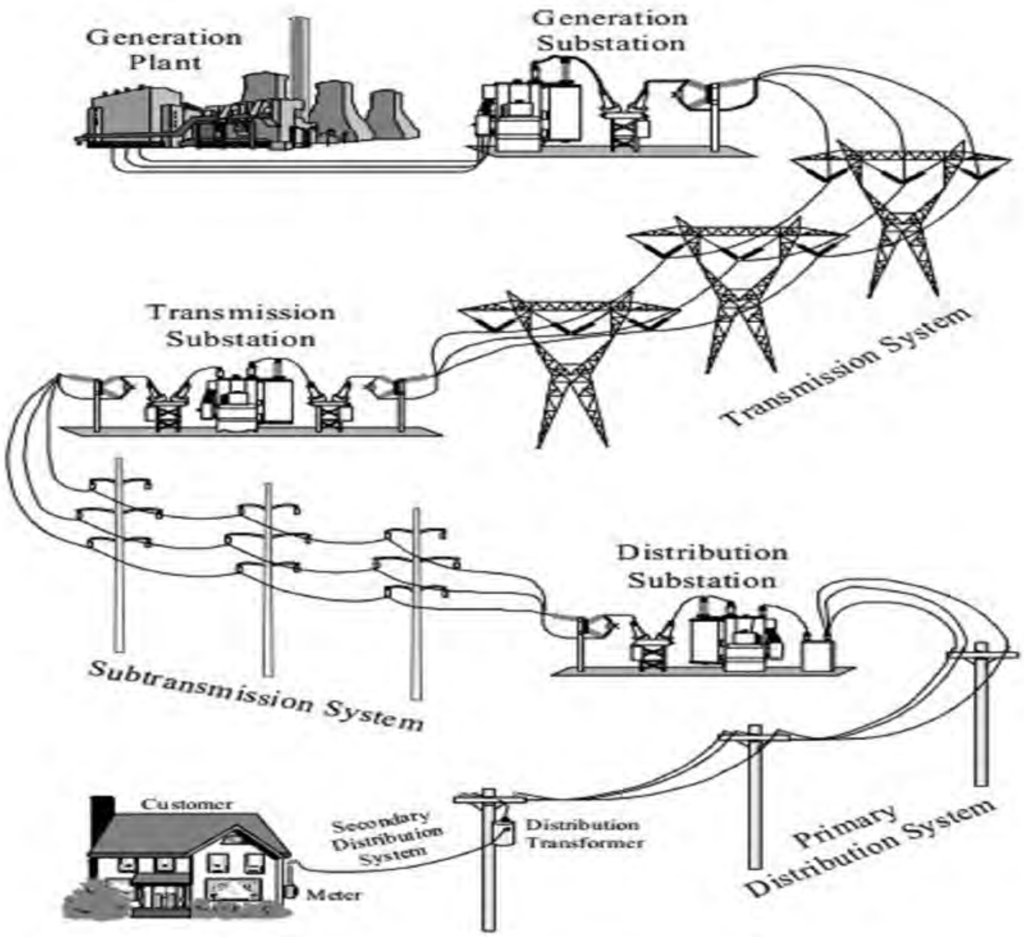

Figure 2.1: Electric power systems [4].

Distribution Substations: Have step-down power transformers, a few incoming high voltage sub-transmission lines and several outgoing medium voltage overhead lines or underground cables. Step down power transformers in the substation step down sub-transmission voltage levels to primary distribution levels. First, the distribution substations step down the voltage from 132 kV to 15 kV. Then, the primary distribution system transfers the electric power from the substation to the distribution transformers. Some industrial customers are served directly from the primary distributions. The distribution transformers step down the voltage again to utilization levels, namely: 120/230 V for single phase, 400 V for three phases. Lastly, the secondary distribution systems distribute the power to the customers' service-entrance equipment. The distribution networks are either overhead lines or underground cables [5].

2.2 Power System Reliability Evaluation

Electric power system reliability evaluation strategy includes three functional zones: generation, transmission and distribution facilities. An overall reliability evaluation is normally not conducted because of the enormity of the problem. Instead, reliability evaluations of generating system, composite generation and transmission systems, and distribution system are conducted independently. Some efforts have been devoted to performing comprehensive reliability evaluation considering impacts of all parts of the power system [6, 7].

Investigation of customer interruption/failure statistics has indicated that the distribution system makes the greatest individual contribution to overall customer supply unavailability [8]. Electric power utilities indicate that the bulk power system contributes only a relatively small component to the overall functional zone C shown in figure 2.3 customer indices, which are performance indices obtained from historical event reporting [9].

The reliability assessments with DG units in distribution systems are evaluated. A method for reliability evaluation that took into account the fluctuating nature of energy produced by renewable energy sources such as wind and solar energy and also reliability assessment evaluated by non renewable energy sources such as diesel generator [10]. The conventional or continuous fuel source units to one subsystem and the fluctuating units to several other subsystems and for each subsystem developed a generation system. The effect of fluctuating energy was included by modifying the generation system of the unconventional unit. The occurrence of capacity deficiency and loss of load expectation for the hour concerned was calculated by combining the generation system.

R. E. Brown, et al., [11], defines the positive impacts of DG units to the distribution network such as reactive power compensation to achieve voltage control, reduction of power losses, regulation and load power consumption tracking to support frequency regulation, spinning reserve to support generation outages and improvement in reliability through backup generation.

A.Chowdhury, et al., backup generator as DG was modeled as a transfer switch and was treated as a voltage source. In an alternate scheme, the DG unit injects power into the system, independent of the system voltage. When a fault occurred, system reliability could be improved in the case where presence of DG in the system. The system analysis consisted of a feeder with DG and feeders connected through normally open tie points. For a certain capacity of DG connected, adjacent feeders experienced improvement of reliability with previously blocked operations now functional since DG reduced loading. However, the DG unit capacity exceeded a certain value; back feed occurred resulting in overloading of the feeder and degradation of reliability.

An optimal placement and size of DG into distribution system improve the system reliability [12]. The determined sittings are performing the analysis of power flow equations. The methodology to specify the generation penetration level and other loading conditions was solved as a security constrained problem.

The reliability assessment method uses a probabilistic model that balanced demand for lower customer rates with improved reliability for a distribution system with DG. The objective is to determine the DG equivalence to a distribution facility with comparable reliability and load requirements. Accordingly, DG installation in the distribution was a better solution since the capital cost for the additional feeder could be avoided, the independent power producers would receive distribution capacity deferral credit and adding DG to the area would also provide voltage control for the network [13].

2.3 Distribution System Reliability

Traditionally, reliability assessment techniques at the distribution level have been far less developed than at the generation level since distribution outages are more localized and less costly than generation or transmission level outages. However, analysis of customer outage data of utilities has shown that the largest individual contribution for unavailability of supply comes from distribution system failure as shown in Table 2.1 [14].

Table 2.1: Typical customer unavailability statistics

Contributor	Minutes	%
Generation/Transmission	0.5	0.5
132KV	2.3	2.4
66KV and 33KV	8	8.3
Distribution	86	88.8

Distribution systems are typically of radial configuration or meshed configurations that are operated as radial systems. Unidirectional energy flows from the supply point to the customer load points through distribution lines, cables and bus bars connected in series. The component reliability indices include failure rates and repair times. The concept of power-system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. There is a reasonable subdivision of the concern designated as “system reliability”, which is shown in Figure 2.2.

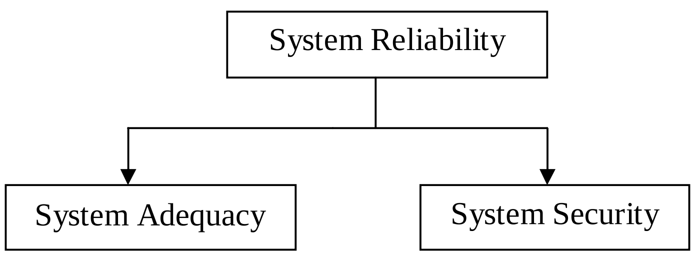

Figure 2.2: Reliability evaluation domains

System security relates to the ability of the system to respond to disturbance arising within the system. Security is therefore associated with the response of the system to whatever disturbances they are subjected. System adequacy relates to the existence of sufficient facilities within the system to satisfy the customer demands within the system operating constraints. This includes the facilities capacity to generate sufficient energy and the associated transmission and distribution facilities to transport the energy to the actual customer load centers.

A power system reliability evaluation is considering three functional zones. The reliability evaluation can be conducted at each of these functional zones or in the combinations that gives the functional zone shown in Fig. 2.3 [15].

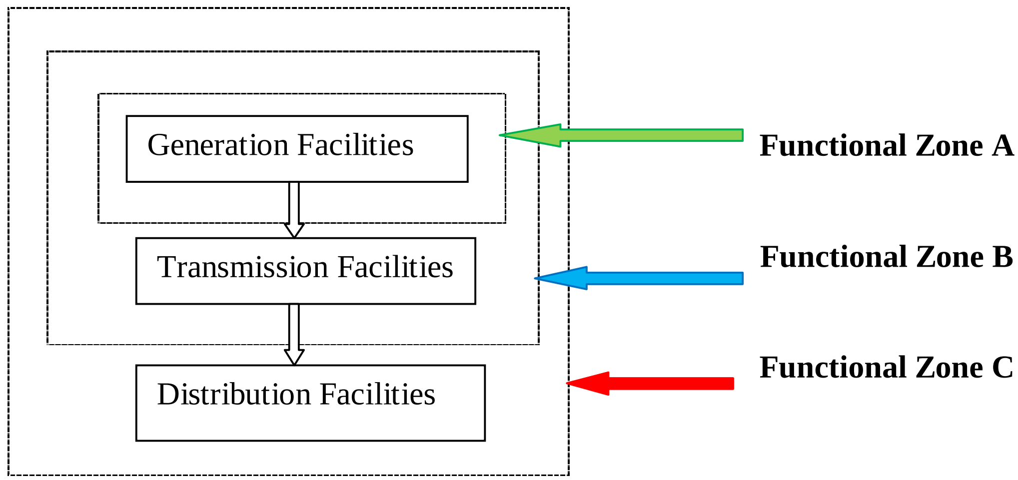

Figure 2.3: The three functional zones for reliability analysis

Reliability assessment at functional zone A is concerned only with the generation facilities and their ability to satisfy the system demand. In a functional zone A study, the total system generation is examined to determine its adequacy to meet the total system load requirement considering random failures, and corrective and protective maintenance of the generation units. The transmission and distribution system and the ability to move the generated power to the consumer load points are not included in this analysis. This activity is usually termed as “generating capacity reliability assessments”.

The second functional zone B refers to the composite assessment includes generation and transmission facilities and the ability to deliver energy to the bulk power points. Functional zone B studies can be used to assess the adequacy of an existing system including the impact of various reinforcement alternatives at both the generation and transmission levels on bulk load point and overall system indices. Adequacy analysis at this level is usually termed as two different set of indices related to the system load point (individual bus) and composite system. The most important indices in this level are failure frequency and its duration.

Finally the functional zone C refers to the complete system assessment includes all three functional zones and starts at the generating point and terminates at the satisfaction of the individual customers in the distribution systems. A practical power system is very complex and therefore it is difficult to optimize the entire power system as a single entity using a completely realistic and exhaustive mechanism. Functional zone C studies are, therefore, not usually done directly. The analysis is usually performed only in the distribution facilities zone and the functional zone B load point indices are used as input values to the zone. The common reliability indices in this level are system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI), the customers' average interruption duration index (CAIDI), Expected Energy not supplied (EENS), and Expected interruption cost (EIC).

Distribution system reliability assessment can be used to obtain quantitative adequacy indices at the actual customer load points. These indices reflect the topology of the network, the components used, protection coordination, the operating strategy and other functions.

Customer interruptions caused by generation and transmission system failure are normally only about 20% of the total load point interruptions. The remaining 80% of customer interruptions occur within distribution system. Power system reliability assessment without considering distribution systems recognizes only a small part of the total outages costs [16]. Therefore this research work is focused on the distribution level reliability assessments.

2.4 Distributed Generation

DG can be defined as "electric power generation within distribution networks or on the customer side of the network" or the process of generating electricity through systems that are located on the distribution network or at the customer side [17]. From an environmental prospective, use of renewable energy reduces emissions as well as help in avoidance of construction of new transmission lines and large power plants. DG units can also have a beneficial impact on power quality and reliability such as improved voltage profile, reduced power losses and network congestion [18]. DGs also have the potential to increase competition in generation which will lead to better service and low energy price. Another incentive for the penetration of renewable energy based DG sources is feed-in- Tariffs (FIT) paid by regulators to achieve their goals of meeting electricity demand with clean or renewable energy resources [18].

The two main classifications of DGs are based on unity capacity and unity technology. The first classification is based on unit capacity which is shown below [18]:

- Micro DG: 1 W - 5 kW
- Small DG: 5 kW - 5 MW
- Medium DG: 5 MW - 50 MW
- Large DG: 50 MW - 300 MW

The second classification is based upon unit technologies which are renewable, modular or combined heat and power (CHP). DG units based on renewable energy resources can be readily replenished and are viewed as 'environmentally friendly'. Modular DG units refers to that can be built and placed within a short time span and can be operated together (as distinct units) to meet larger output requirements.

According to IEEE defines DG as "the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system [22, 23]." IEEE compared the size of the DG to that of a conventional generating plant. A more precise definition is provided by the International Council on Large Electric Systems (CIGRE) and The International Conference on Electricity Distribution (CIRED) [24, 25], which DG based on size, location, and type. CIGRE defines distributed generation as "all generation units with a maximum capacity of 50 MW to 100 MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched." The distributed generation as "the relatively small generation units of 30MW or less that are located to near customer sites to meet specific customer needs, to support economic operation of the distribution grid, or both [26]". Dondi, et al., [27] defines distributed generation as "a small source of electric power generation that is not a part of a large central power system and is located close to the load center." Ackermann [17] defines a distributed generation as "an electric power generation connected directly to the distribution network or on the customer side of the meter." This is most generic one, because there is no limit on the DG size, capacity, and location of the DG.

One aspect investigated here is the effect of Distributed Generators on power system reliability. Standards for connecting DGs into distribution systems are just being developed. An investigation of power utilities and industry interconnection standards was performed to identify the key requirements for a DG connection. The results of this investigation led to the development of a unified approach for determining interconnection requirements [28]. The requirement considers many aspects of DGs in distribution systems, including protection, harmonics, transients, and voltage and frequency control [29].

2.5 Distributed Generation Technologies

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

2.5.1 Fossil-fuel Based DG

The application of fossil-fuel based DG units, such as diesel, micro-turbine and gas turbine generator, and combined heat and power (CHP) has been well important to power industry. Traditionally, the diesel and gas generator units are installed at the load center sites to ensure reliability of sensitive loads, especially in case of system emergencies, whereas CHP units are employed to generate power while providing auxiliary services such as heat to increase the overall efficiency associated with the generation system. Although the name “diesel” is always associated with light fuel, these generators can actually be tuned to use a wide variety of liquid and gaseous fuels, including natural gas, propane, and residual fuel oil.

These technologies are installed as back-up generator, the innovations and improvements in their designs significantly increase their efficiency and make them capable of exporting power to distribution systems for effective system support. The advantages and disadvantages associated with fossil-fuel based DG units are summarized in Table 2.2.

Table 2.2: Advantages and disadvantages of fossil-fuel based DG

Advantages	Disadvantages
➢ Readily reliable with continuous production ➢ Easy to access fuels ➢ Controllable and dispatchable ➢ Relatively low capital investment ➢ Utilization of waste heat (CHP) ➢ Possible export of reactive power for network support	➢ High operation and maintenance cost ➢ High fuel cost ➢ High noise pollution ➢ High emission

2.5.2 Wind Power Generation Based DG

In the last few decades, increasing number of wind turbine generators are getting interconnected in transmission networks. Recently, the wind turbine generators are also being installed in distribution systems due to significant technological development and reduced cost associated with their construction and integration. The wind power generator often is installed in areas of high wind speed that area has the well developed infrastructure of the distribution system, leading to a requirement for careful consideration of the integration of wind to relative weak electrical part of the distribution system.

A wind turbine is characterized by two conversion steps. First the rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft; and in the second step the generation system converts this torque into electricity. The power generated by a wind turbine is proportional to the swept area of the rotor disc and to the cube of wind speed that pass through the mentioned disc. Also the air density and a power coefficient that express the average of extracted energy from the wind by the turbine rotor are implicated [30]. Among these factors, the most important factor is the wind speed, since its impact is cubic.

2.5.3 Photovoltaic Power Generation Based DG

Photovoltaic **(PV)** generation, directly converting sunlight into electricity, is a well established technology for supplying power to sites at a way the distribution substation [31]. It is currently being considered for integration into 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 integration of 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.

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, 41].

2.5.4 Micro Turbine

Micro turbine generator systems are considered as distributed energy resources which are interfaced with the electric power distribution system. They are most suitable for small to medium-sized commercial and industrial loads. The micro turbine provides input mechanical energy for the generator system, which is converted by the generator to electrical energy. The generator nominal frequency is usually in the range of 1.4-4 kHz. This frequency is converted to the supply frequency of 50 Hz by a converter.

There are two types of micro turbine: Recuperated MT and UN recuperated MT. Recuperated micro turbines, which recover the heat from the exhaust gas to boost the temperature of combustion and increase the efficiency. UN recuperated micro turbines, which have lower efficiencies, but also lower capital costs.

Mechanically the MTG is a single shaft, gas turbine with compressor, power turbine and permanent magnet generator being mounted on the same shaft. MTG 's have a high speed gas turbine engine driving an integral electrical generator that produces 20-100 KW power while operating at a high speed generally in the range of 50,000-120,000 rpm. Electric power is produced in the range of 10 kHz converted to high voltage dc and then inverted back to 50 Hz, 400 V ac by an inverter.

2.5.4.1 The Performance of Micro Turbine

Increase in the inlet air temperature will decrease the performance of a micro turbine because of the lower air density.

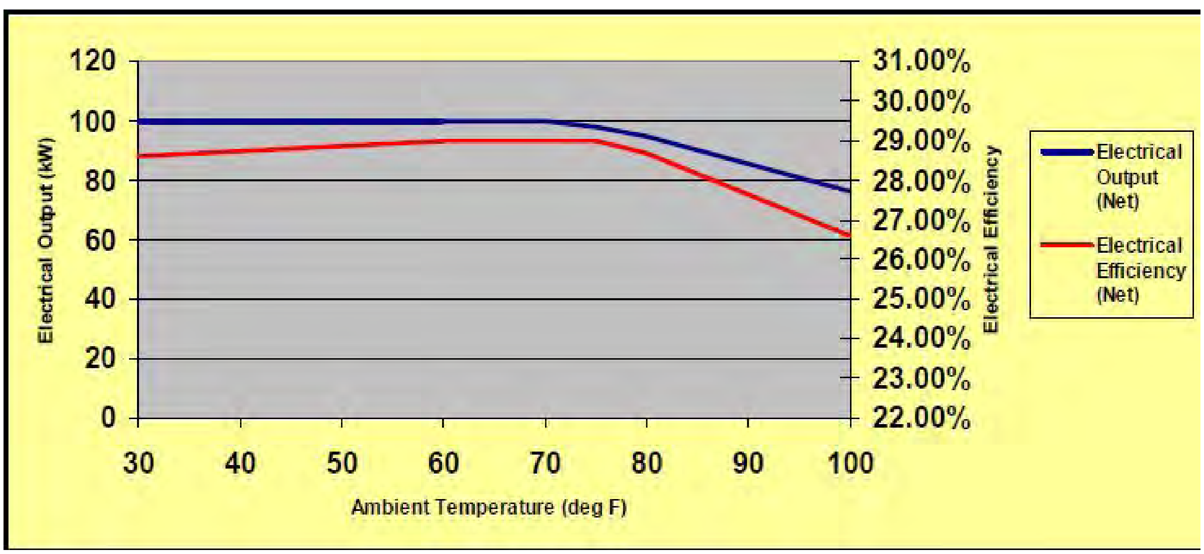

Figure 2.4: Increase air temperature with decrease the performance of microturbine

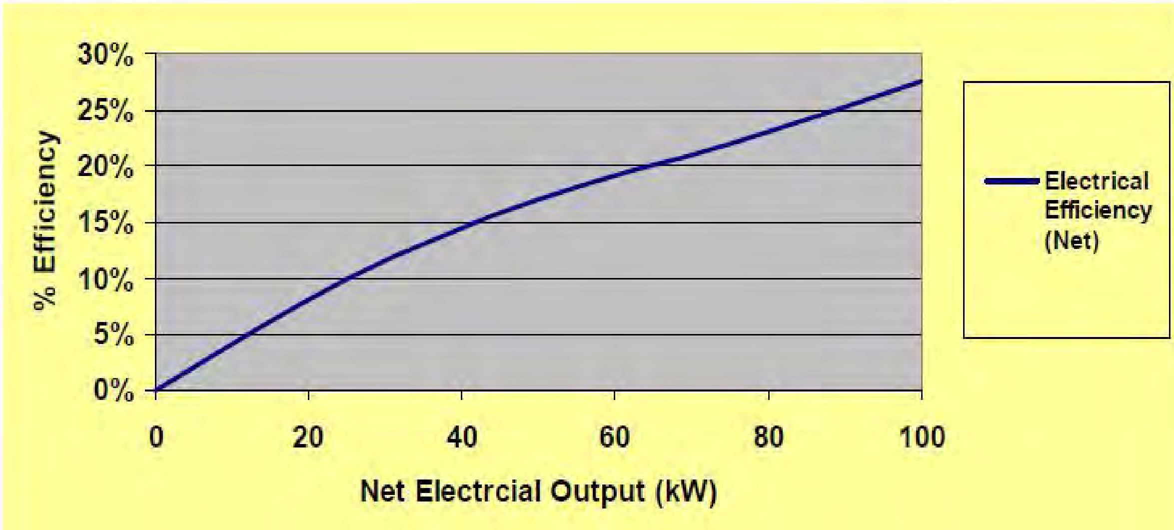

Figure 2.5: Operating micro turbine at part loads decreases the efficiency.

2.6 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 option for distribution system due to the incentives and environmental considerations. Distribution system with DG units demand 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 [33].

S. Wong, et al., in [34], 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 [35].

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 [36].

2.7 Reliability Assessment of Distribution System with DG

Distribution system reliability is one of the important aspects that are of concern to researchers. Incentive research efforts have been devoted to the reliability modeling and assessment of distribution systems encompassing DG due to increasing development of DG units in distribution systems. In the following subsections, reliability indices for quantification of distribution system are introduced. The basic techniques applied for distribution system reliability assessment are covered.

2.7.1 Distribution System Reliability Indices

IEEE Standard 1366 [37], a set of distribution system reliability indices has been suggested for measurement of distribution system reliability. These indices are established based on the average duration and frequency of sustained and momentary interruptions during predefined period of time. A momentary interruption is defined as a single operation of an interrupting device that results in a voltage zero, whereas a sustained interruption is referred to an interruption that lasts more than 5 minutes [37]. The descriptions of these reliability indices are briefly summarized in Table 2.3.

Although various indices are recommended in IEEE Standard 1366, surveys on reliability indices conducted by the IEEE working group on system design [37, 42] have indicated that only some customer-oriented indices, such as system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI), and average service availability index (ASAI) are frequently examined by distribution utilities. The reliability indices in terms of SAIDI and SAIFI are adopted as fundamental parameters in a service target performance incentive scheme proposed in this research works, which provides incentives to distribution network service, provides for maintaining and improving service performance. Therefore, the SAIDI and SAIFI are selected as two main indices for distribution system reliability assessment.

2.7.2 Basic Techniques Applied to Distribution System Reliability Assessment

The basic techniques developed for distribution system reliability assessment are extension of the quantitative techniques, initially established for reliability evaluation of generation and transmission systems [14, 40]. Contingency based methods by means of simulation of short-term system operation, in case of system fault events leading to interruptions, have been dominantly applied to distribution system reliability assessments [38].

Table 2.3: The basic reliability indices for distribution system reliability assessment

Name	Description
SAIFI	System average interruption frequency index indicates the frequency of a sustained interruption experienced by the average customer served in a distribution system during a predefined period of time. It is determined by dividing Total Number of Customers Interruption by Total Number of Customers Served (interruption /Customer. yr).
SAIDI	System average interruption duration index is the average interruption duration per customer served. It is determined by dividing the sum of all customer interruption durations during a year by the number of customers served (hrs /customer year).
CAIDI	Customer average interruption duration index is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption durations by the total number of customer's interruption (hours/customer interruption).

ASAI	Average service availability index indicates the percentage of time in the defined reporting time horizon that the power has been provided to customer. It is determined by dividing Customer hours of available Service by Customers hours service Demands (%)
EENS	Expected energy not supplied is the expected amount of energy not supplied due to capacity deficiency in the period of observation. It is the sum of each load times its outage duration (kWh/yr).
AENS	Average energy not supplied is the total Energy not supplied in system divided by total number of customers served (kWh/yr. customer)
EIC	Expected Interruption Cost Index is the cost of not supplied energy at that load point ($/yr)

In the contingency based approach, it is revealed that the simulation associated with short term system restoration in the interrupted reliability equivalent zones is the most essential aspect of system reliability assessment. The main difficulty associated with the contingency based approach is that the contingencies relevant to all system components such as transformers, transmission lines, and protection devices have to be exhaustively enumerated, which may pose heavy computational burden for reliability evaluation of large-scale distribution systems. In order to reduce the computational burden while ensuring accurate reliability evaluation, a distribution system can be converted to a reliability equivalent zone based network [39, 44].

The approach based on contingency analysis and the concept of reliability equivalent zone provides solid background for distribution system reliability analysis. The methodologies and different perspectives reported in the existing literature, specifically paying attention to the improvement in distribution system reliability assessment using appropriate capacity and place of DG units.

CHAPTER THREE

RELIABILITY IMPROVING TECHNIQUES

3.1 Analyzing of DG in distribution system

The DG in renewable energy relies greatly on renewable resources such as hydro, geothermal, wind speed, solar irradiance, ambient temperature and so forth. Consequently, analyzing the characteristics of renewable resources at the installation location, so as to provide proper models that adequately represent these characteristics, is the very first step to facilitate the deployment of the renewable and non renewable DG into the distribution substation system.

On another aspect, there is no unique model for renewable resources, but different approaches can be used. The selection of the appropriate approaches to model the renewable resources and non renewable is reliant heavily on the application (e.g., long term planning, unit commitment, reliability assessment), as well as the technique utilized to carry out this application (e.g., analytical technique or Mont Carlo Simulation technique).

Therefore, this chapter presents the probabilistic models for describing the characteristics of load demand, the random behavior of distributed generation, accompanied with the application of distribution system. This includes the probabilistically of renewable resources, time-varying load demand and the use of time series and MCS techniques to model them chronologically. Furthermore, a more accurate model is proposed to distributed generation, allocation and sizes through different techniques.

3.2 Modeling of Load Demand

In this thesis, Gaussian distribution with specified minimum and maximum limit is used to represent time varying nature of demand. Figure 3.1 shows a truncated Gaussian distribution and Figure 3.2 shows the existing demand distribution per day. The setting of limits is due to the fact that the Gaussian distribution assumes that the values can vary from $-\infty$ to ∞ which is not realistic for distribution systems with a certain amount of connected load.

By using the condensed Gaussian distribution function, the probability of load demand being $P_L t$ in a specified time period can be obtained as:

$$P_{Ld}(P_{Ld}t) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{(P_{Ld}t-\mu_{Ld})^2}{2(\sigma_{Ld})^2}\right), P_{Ld}\min \le P_{Ld}t \le P_{Ld}\max \quad (3.1)$$

Otherwise the probability of load demand is zero, when

$P_{Ld}t < P_{Ld}\min$ and $P_{Ld}t > P_{Ld}\max$.

where μ_{Ld} and σ_{Ld} are statistical mean and standard variances of the observed load demand in a stipulated time frame respectively, and $P_{Ld}\min$ and $P_{Ld}\max$ are minimum and maximum load demands respectively.

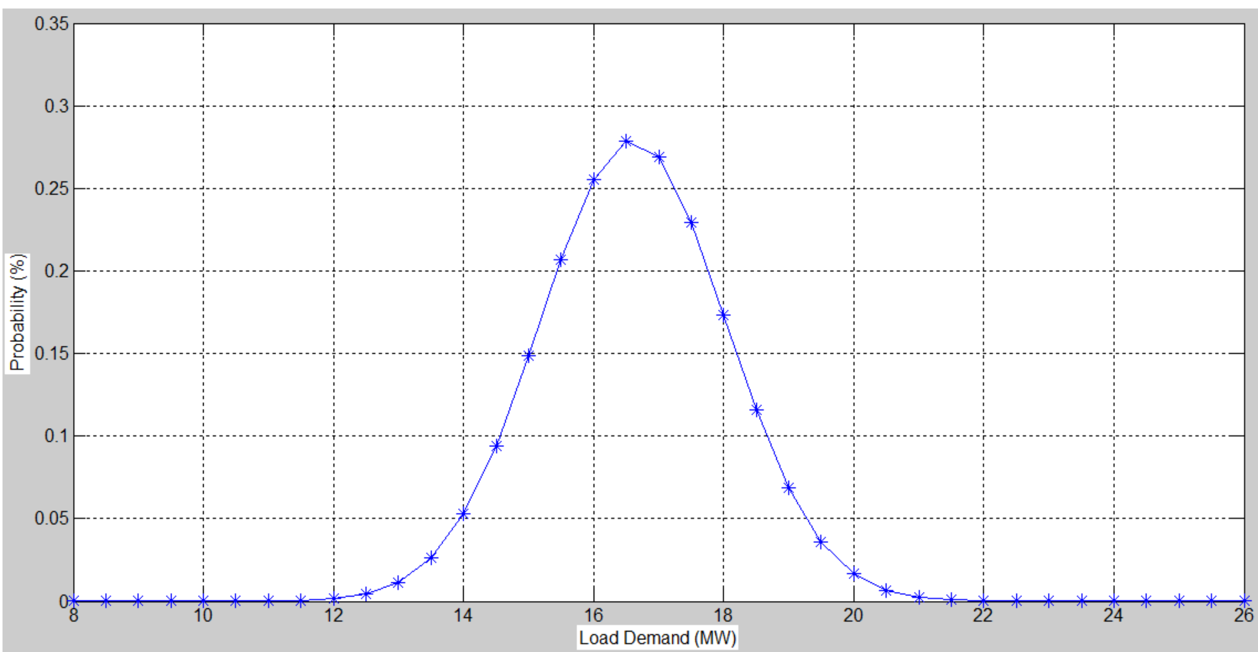

Figure 3.1: A truncated Gaussian distribution of Load profile

The total load modeling on the distribution system and individual customer load for one year at least is required to conduct reliability test studies. A profile for the total hourly load on the distribution system is usually known to the utility for various load zones. This is a sum of all the customer loads on a particular distribution system. The hourly load for customer is also available, usually monitored by the utility. A total 15 kV distribution system load profile curve of the customers is shown in Figure 3.2. This customer is assumed to be connected to each load point through the bus bar 2 of the IEEE-RBTS. The load profiles for all the 32 load points in the bus bar 2 of the IEEE-RBTS are given in Figure A.2 through Figure A.7 of Appendix A.

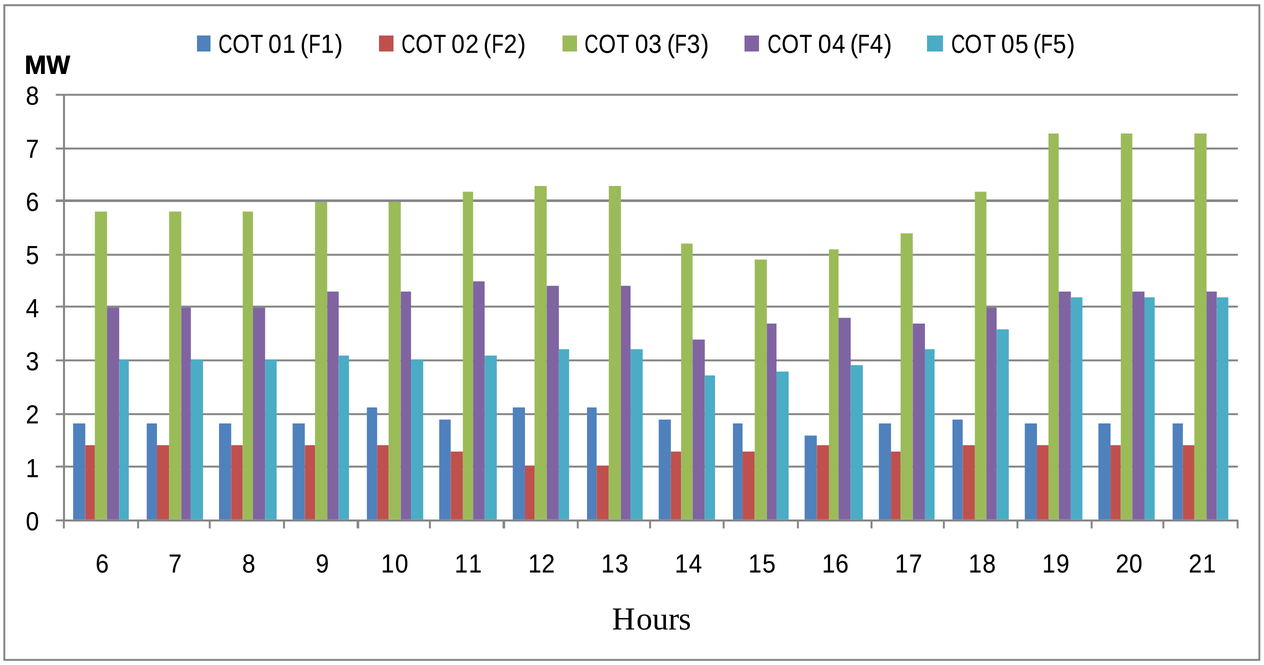

Figure 3.2: Hourly Substation Load profile per day of each feeder

For the purpose of this thesis several real time load data were obtained from a five real out going feeder customers. From this feeder load profiles, 32 load points were chosen for the analysis their peak load and average load are equal to the peak load and average load of the distribution system. These 32 load profiles are considered for reliability assessment.

The load modeling involves system feeder and customer load profile such that for each iteration (or year) the load profiles vary randomly by up to 4.912% from the collected load data. The result of each feeder hourly load curve and the sum of all customer load curves gives the distribution system hourly load curve.

3.3 Characteristics of Wind Power Generation

The wind resource is inherently intermittent and the uncertainty of power availability is one of the biggest challenges associated with their integration. Wind speed is a continuous physical phenomenon that evolves randomly in time space. A random variable can be associated with each value of time.

In order to study the wind availability the use of a probability density function (PDF) is necessary. One of the most regarded of this family of wind speed distribution analysis is the Weibull probability density function [45]. In the following subsections, a probabilistic capable of describing the behavior of wind speed is presented and calculating wind power generation with respect to wind speed.

3.3.1 Wind Speed Characteristics

Wind power is currently one of the most technologically advanced and commercially competitive of the renewable energy technologies. It offers many countries the opportunity to reduce their dependence on fossil fuels, while satisfying the requirements of both energy and the environment. However, the resource is dispersed and intermittent, and providing a proper modeling of wind speed is an important issue, the solution to which will help to appropriately integrate wind-based DG units in distribution systems.

3.3.1.1 Wind Speed Distribution Using Probability Density Function

The wind speed distribution primarily determines the performance and the feasibility of wind power systems. Once the wind speed distribution is known, the potential energy and thus the economic viability can be easily determined. Modeling wind speed using a PDF provides a few key parameters which can illuminate the characteristics of a wide range of wind speed data; this is why it is most desirable to use modeling in the long term planning problems.

Weibull distribution function shown in equation 3.1 is one of the most common PDF used to describe the random behavior of wind speed [46]. Its success derives from the two adjustable parameters, which can provide a great flexibility in fitting the distribution function to the measured values with different behaviors as shown in Figure 3.3. This figure shows that the higher the value of *k*, the more the curve looks like an inverted bell, while as the value of *c* increases, the curve spreads out even more.

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-c} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{3.1}$$

Different methods can be used to calculate the Weibull parameters [47, 48]. Here, the parameters *k* and *c* are calculated, approximately, using the mean wind speed and the standard deviation as follows:

$$k = \left(\frac{\sigma}{V_m}\right)^{-1.086} \tag{3.2}$$

$$c = \frac{V_m}{\Gamma\left(1+\frac{1}{k}\right)} \tag{3.3}$$

$$V_m = \frac{1}{n}\left(\sum_{i=1}^{n} v_i\right) \tag{3.4}$$

$$\sigma = \sqrt{\left[\frac{1}{n-1}\sum_{i=1}^{n}\left(V_i - V_m\right)^2\right]} \tag{3.5}$$

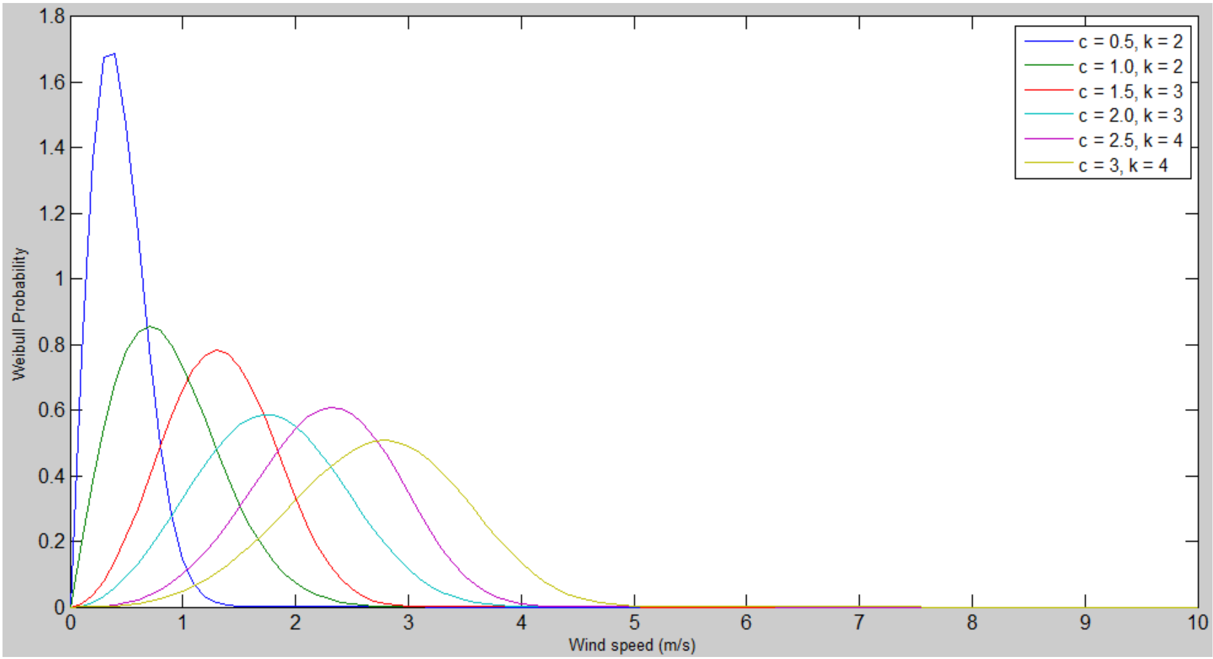

Figure 3.3: Weibull PDF with different values of scale and shape indices.

When the shape index *k* equals to 2, the PDF is called Rayleigh probability density function as given in (3.6) which PDF mimics most wind speed profiles. If the mean value of the wind speed for a site is known, then the scale index *c* can be calculated as in (3.7) and (3.8).

$$f(v) = \left(\frac{2v}{c^2}\right)\exp\left[-\left(\frac{v}{c}\right)^2\right] \tag{3.6}$$

$$Vm = \int_0^\infty v.f(v)dv = \int_0^\infty \left(2\left(\frac{v}{c}\right)^2\right)\exp\left[-\left(\frac{v}{c}\right)^2\right]dv = \frac{\sqrt{\pi}}{2}c \tag{3.7}$$

$$c = \frac{2vm}{\sqrt{\pi}} \tag{3.8}$$

Weibull and Rayleigh functions are usually used to describe the random behavior of the wind speed in a given location over certain period of time, typically annually. Moreover, these two functions can describe wind speed distribution for a typical hour of the year. In the present study, two models are developed to describe the annual wind speed distribution and the wind speed distribution during a typical hour of the year.

3.3.2 Wind Turbine Power Generation

Wind turbines are commonly used today: vertical axis wind turbines and horizontal axis wind turbines. The rated power of a wind turbine is the maximum power allowed for the installed generator and the control system, and it must be ensured that this power is not exceeded in high winds. The number of blades is usually two or three. Two-bladed wind turbines are cheaper since they have one blade fewer, but they rotate faster and appear more flickering to the eyes, whereas three-bladed wind turbines seem calmer and therefore less disturbing in a landscape.

The wind turbines are: the rated power (Pr), cut in speed (V_{ci}), rated speed (Vr), and cut out speed (Vco). The power output curve can be extracted; hence, the output power at any wind speed can be calculated. This power curve of the wind turbine is assumed to be linear with respect to wind speed as shown in equation (3.9) [49, 50]. For example Figure 3.4 shows the power curve of E 0.33 MW wind turbine, where cut-in peed is 3 m/s, rated speed is 13 m/s and cut-out speed is 25 m/s.

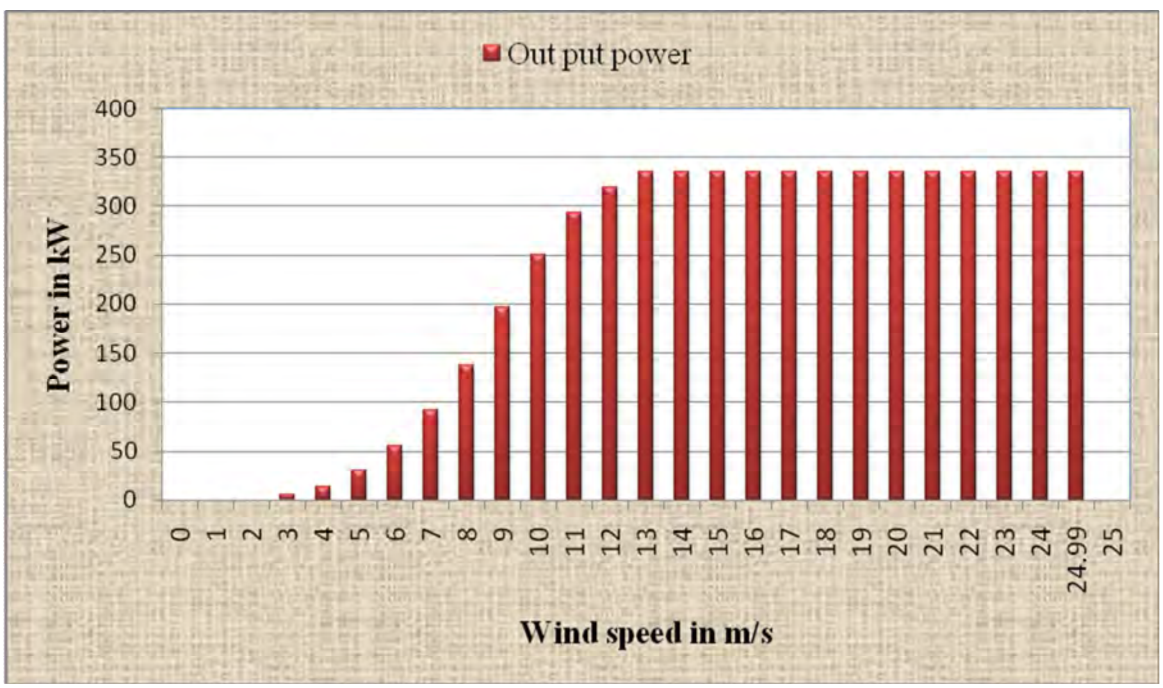

Figure 3.4: Wind turbine power curve

$$
\begin{cases}
0 & 0 \le V < V_{ci} \\
P_{reated} * \dfrac{(V - V_{ci})}{(V_r - V_{ci})} & V_{ci} \le V < V_r \\
P_{reated} & V_r \le V < V_{co} \\
0 & V_{co} < V
\end{cases} \qquad (3.9)
$$

3.4 Characteristics of Solar PV Power Generation

The solar energy generation of a PV system is mostly weather dependent, since the total amount of solar radiation gathered by the module varies with weather conditions. Solar radiation is made up of two components: direct and diffuse. Direct radiation comes directly from the sun, while diffuse radiation is scattered in the atmosphere and approaches the module from all parts of the sky. Energy can be generated during less than half of the day, and total generation varies over the year. On a clear direct radiation may account for 80-90% of the total radiation collected, but on a cloudy day this can drop to zero, leaving a small diffuse component providing 10-20% of the radiation collected on a typical clear day. However, other characteristics such as the type of material used for panel fabrication and the ambient temperature of the module can affect the power output of a PV module. Energy generation is optimized at a 90° angle of light incidence to the module, which can be obtained using a maximum power point tracking circuit. PV cell power output is rated at an ambient temperature of 25°C but, as ambient temperature ruse, power output drops slightly, with current increasing very slightly but voltage dropping more significantly. A probabilistic model capable of capturing the behavior of solar radiation is demonstrated and a model for estimating the amount of power generation from PV array with respect to solar radiation.

3.4.1 Solar Radiation Characteristics

The random behavior of solar irradiance, considering that all the solar irradiance enters the atmosphere and incidence in a given area is collected by the surface of the PV module. The uncertainty in solar radiation cannot be directly modeled by using a probability distribution function due to the fact that the solar radiation has very strong diurnal patterns. The uncertainty in solar radiation incident on a PV array comes from the stochastic nature of weather conditions. A clearness index representing the weather conditions is adopted to address the uncertainty in solar radiation. The clearness index is defined as the ratio of the solar radiation on a horizontal surface to the extra-terrestrial solar radiation [51]. It is assumed that the solar radiation on a horizontal surface fully collected by the PV array, thus the solar radiation incident on the PV array $G_{PV}t$ can be estimated as:

$$G_{pv}t = Ci_t^{sr} G_{ex}t \tag{3.10}$$

Where Ci_t^{sr} is the clearness index, and $G_{ex}t$ is the extra-terrestrial solar radiation in a pre-defined period of time.

The random behavior of the clearness index can be statistically described by using Beta distribution function as shown in Figure 3.5. The probability of clearness being $Ci^{sr}t$ over a specified period of time can be calculated as:

$$P^{sr}\left(Ci_t^{sr}\right) = \frac{\Gamma(\alpha - \beta_c)}{\Gamma(\alpha)\Gamma(\beta_c)}\left(Ci_t^{sr}\right)^{(\alpha - 1)}\left(1 - Ci_t^{sr}\right)^{(\beta_c - 1)} \tag{3.11}$$

Where the Beta parameters α and β_c can be estimated by using the mean (μ) and standard deviation (σ) of clearness index given as follows:

$$\alpha = \frac{(\mu)^2(1-\mu)}{\sigma^2} - \mu \tag{3.12}$$

$$\beta_c = \frac{\alpha(1-\mu)}{\mu} \tag{3.13}$$

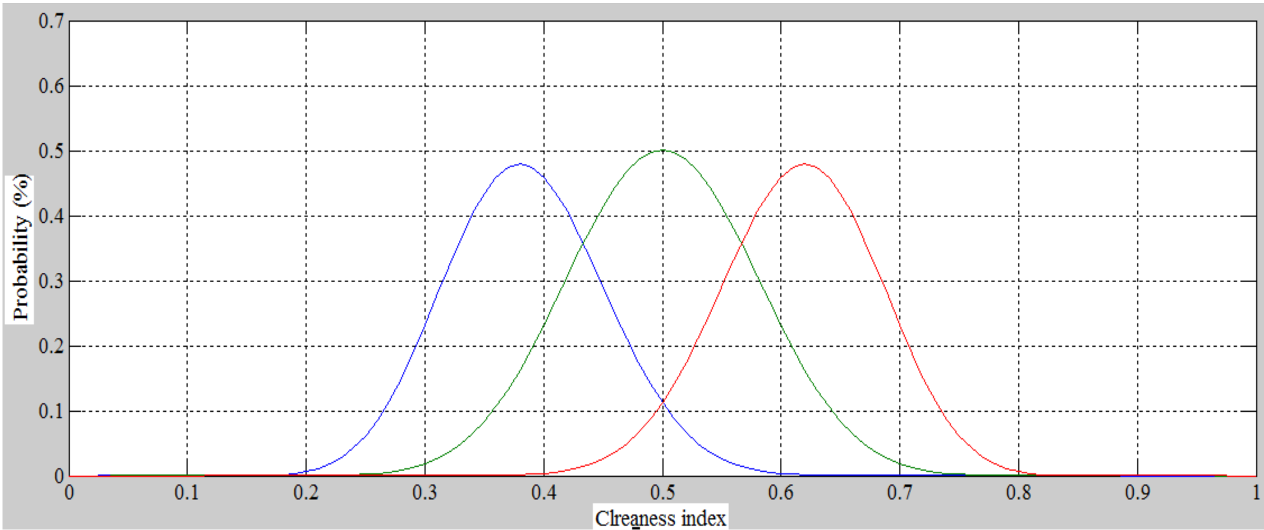

Figure 3.5: Beta PDF with respect to different values of parameters

3.5 Impact of DG on The Power System

Interconnecting a DG to the power system can have significant effects on the system such as power flow, voltage regulation, reliability enhancement, and power loss etc. DG changes traditional characteristics of the distribution system. Most of the distribution systems are that the power flows in one direction. When the DG power is more than the downstream load, it sends power upstream reversing the direction of power flow and at some point between the DG and substation; the real power flow is zero due to back flow of power from DG.

The central power plants are located at specific remote sites and are connected to an extended transmission system which transfers bulk electrical power to the distribution system. This way of power system operation is often called a vertically-operated power system.

The decentralized power generation sources are small in size and mainly connected to the distribution system. Because of the implementation of DG in the distribution system the power is generated closer to the load which will affect the local power flow [52]. An increasing penetration level of DG is expected and the total amount of generated electric power can exceed the total connected load. As a consequence the distribution grid can start exporting electrical power to neighboring distribution grids what converts the power system into a horizontally operated power system [56]. This is shown in Figure 3.6 below.

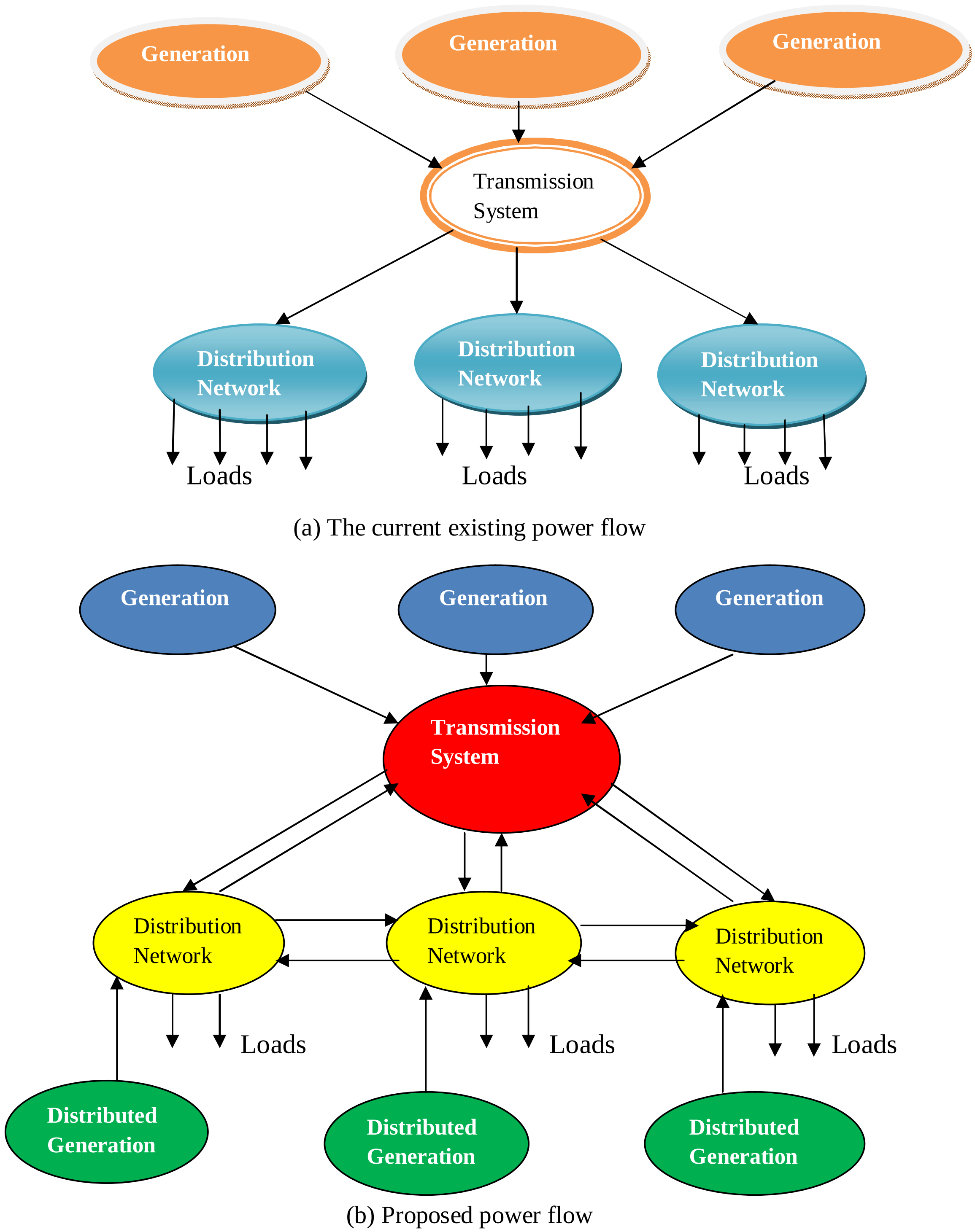

Figure 3.6: Transition from vertically to a horizontally operating power system

As discussed in the following sections, the impacts of DG on voltage regulation, power losses, reliability enhancement, fault level and protection, and congestion alleviation of a distribution network are studied based on various criteria.

3.5.1 Impact of DG on Voltage Regulation

The DG integration can impact the overall voltage profile of the system. DG can improve feeder voltage of distribution networks in areas where voltage dip or blackouts are of concern for utilities. Some techniques to regulate voltage using the optimal DG allocation for minimum losses and proper voltage and reliability support. When the DG causes downstream the system, it can confuse the voltage regulation by setting a voltage lower than the standard value and can cause the voltage to change above or below the permissible range. The impacts of distributed generation on voltage regulation can be balanced by using Online Load Tap Changing (OLTC) transformer controls to avoid under-voltage and over-voltage. A good coordination between the integrated DG and voltage regulator is necessary to improve the voltage profile of the system and improve the power system stability.

The tap changing transformers are adjusted so that the following conditions are satisfied:

- At times of maximum load the most near customer to DG connected bus (C) will receive acceptable voltage (above the minimum acceptable).

At times of minimum load the customers will receive acceptable voltage (below the maximum acceptable the voltage profiles, will change the distribution network. If the DG is exporting, then this will cause the voltage to rise. The degree of voltage rise depends on many factors such as the following:

- Capacity of export relative to the minimum load on the network
- Sitting of the DG (proximity to a bus bar where the voltage is regulated by the distribution company)
- Distribution of load on the network
- The size of DG units
- Magnitude and direction of reactive power flow on the network

If the DG is used onsite, it does not badly affect network voltages (i.e., if a load is connected to bus D consuming most of the power generated by DG).

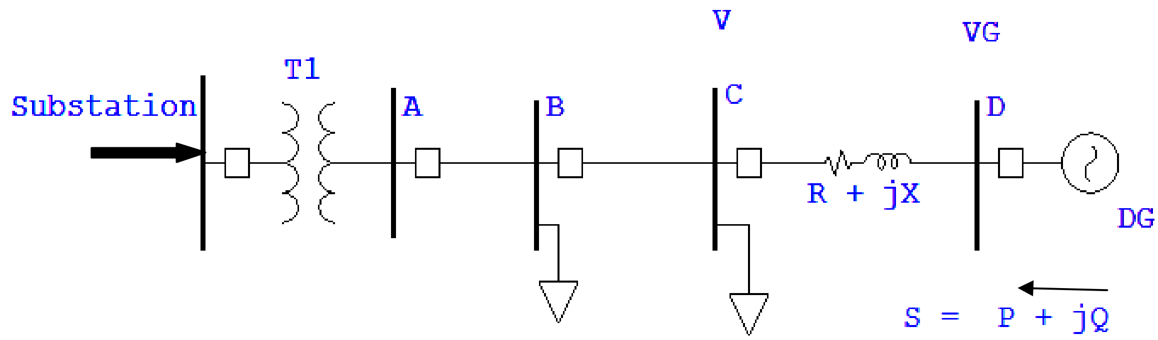

Figure 3.7: A simple radial distribution network with DG

The line between bus C and bus D in Figure 3.7 has an impedance R + jX (in per unit), then the voltage drop $\delta|V|$ (in per unit) can be calculated as follows:

$$\delta|V| \approx \frac{RP + XQ}{V_G} \quad (3.14)$$

Where, $\delta|V| = |V_G| - |V|$

$|V_G|$ is the modulus of voltage V_G in per unit

$|V|$ is the modulus of voltage V in per unit

As a result, the voltage rise may be limited controlling the reactive power Q exported by the DG. In particular, for negative values of Q (i.e., DG importing reactive power), it is possible to achieve $\delta|V|$ = 0. This method can be effective for circuits with high X/R ratio, such as higher voltage overhead circuits. However, for low voltage (LV) distribution circuits with a low X/R ratio, the method does not work. As a result, only very small DG can generally be connected to LV networks.

3.5.2 Impact of DG on Power Losses

One of the major impacts of Distributed generation is on the losses in a feeder. The appropriate location of DG units in the existing system is an important criterion that has to be analyzed to be able to achieve a better reliability of the system with reduced losses. Integration of DG to the system changes traditional radial characteristic of the distribution system, because it introduces power source to the system. When the DG power is more than the downstream load, it sends power upstream reversing the direction of power flow and at some point between the DG and substation; the real power is zero due to reversal flow of power from DG. This is the reason of loss reduction into the distribution feeders. Therefore, the optimum location of DG units in the system reduces the losses.

When the distribution feeders have high losses, integrating a number of small capacity DGs will show an important positive effect on the losses and have a great advantage to the distribution system. On the other hand, if large DG units are integrated, they must be considering the feeder capacity.

3.5.3 Impact of DG on Reliability Enhancement

Distribution system reliability assessment with DG is an important factor in the entire system operations. The optimal allocation of DG can improve the reliability of the system by serving as backup generation for some specific customers in case system interruption from the utility. Therefore, the distribution system reliability assessment with DG should be proper optimized, for example failure rate, energy availability, system component failure rates, the change in load demand and the DG locations. Integration of DG in the distribution system is positive and negative impact on reliability indices and power quality. The positive impacts included faster restoration service to the customer and reduced voltage sags while the negative impacts could be sympathetic tripping, increased fuse blowing etc.

3.5.4 Congestion Alleviation

As load increases, the utility company has to look for different mechanisms to satisfy the customer demand requirement and avoid the distribution substation congestion. Traditionally, the transformer capacity expansion or a new distribution substation is the solution, but it needs high investments and large areas for expansion of construction. Due to different reasons, the existing substation facility expansion options have been restricted by many surrounding communities with high population. Consequently, schedules for installing new facilities to meet demands at certain safety constraints have become difficult to satisfy.

Therefore, integrating DG to the distribution substation is a good option to mitigate the congestion.

3.5.5 DG Impact on Fault Level and Protection Devices.

When the DG connected to the distribution grid changes the fault level. The impact on the fault level depends on the ability of the DG-unit to contribute to the fault current. We might also have back flow in the case fault, i.e.; fault current may also flow from load side to source side. This means that protective devices may see fault currents for a fault in the downstream section and in the upstream section.

A significant contribution to the fault current of the DG-unit affects the protective devices in the distribution system. Because the fault currents are affected by the DG-units, the measured currents used for protection purposes, are affected as well. This can lead to incorrect operation of the protective system and causes fault detection problems and selectivity problems. There are some protection requirements that are established by the utility company. Adequate interconnection protection should consider both parties ensuring the achievement of the utility requirements. Interconnection protection is usually dependent on size, type of generator, interconnection point and interconnecting transformer connection.

3.6 Reliability Evaluation Methodology for Distribution Systems

Power system reliability can be estimated using a variety of methods. There are basically two main approaches for power system reliability evaluation that are widely accepted in the power industry, deterministic and probabilistic method. Deterministic approach known as the N-1 criterion, this traditional approach for reliability states that in a given network, when one of the components fails, the remaining grid will continue to supply all loads without overloading lines or exceeding voltage limits. This approach to security assessment often results in costly operating restrictions that are not justified by the corresponding level of risk. While deterministic approaches have the advantage of simplicity, probabilistic methods produce results that describe better real conditions, although in a more complex manner.

The probabilistic approach assessments are two methods: stochastic and analytic methods. The stochastic approach examined bases itself on the cost of reliability, which is computed using Monte Carlo simulation (MCS). The basic two methods have been extensively utilized for power generation evaluation. Similar techniques have been applied to transmission and distribution systems. Either of them is able to compute reliability indices.

3.6.1 Analytical Method

Analytical techniques assess system reliability using direct numerical solutions. The expected risk of loss of load is calculated using applicable system capacity outage probability combined with the system load characteristic. This approach is based on contingency enumeration and involves the analysis of the adequacy evaluation of the composite system, taking in consideration "all possible contingency states".

The basic generating unit model used in reliability evaluation is a two-state model that represents the probability of finding the unit on forced outage at some distant time in the future. The probability is defined as the unit unavailability, and historically in power system applications it is known as unit Forced Outage Rate (FOR). The concepts of the availability and unavailability are illustrated in Equation (3.15) and Equation (3.16).

$$\text{Unavailability (FOR)} = \frac{r}{m+r} = \frac{\lambda}{\lambda+\mu} = \frac{\sum \text{down time}}{\sum \text{down time} + \sum \text{up time}} \qquad (3.15)$$

$$\text{Availability} = \frac{m}{m+r} = \frac{\mu}{\lambda+\mu} = \frac{\sum \text{up time}}{\sum \text{down time} + \sum \text{up time}} \qquad (3.16)$$

Where, m is Mean Time to Failure (MTTF), r is Mean Time to Repair (MTTR) and m + r is Mean Time Between Failures (MTBF).

FOR is the basic parameter used is the probability of finding the component on forced out at some distant time in the future. FOR in equation is associated with the two-state outage model, in Figure 3.8, that can be directly applicable to a generating unit which is either operating or forced out of service. In Figure 3.8, λ is the expected failure rate, as in Equation (3.17), and μ is expected repair rate, as in Equation (3.18).

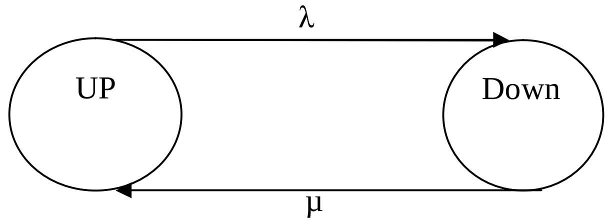

Figure 3.8: Two state model of system availability

$$\lambda = \frac{1}{MTTF} \tag{3.17}$$

$$\mu = \frac{1}{MTTR} \tag{3.18}$$

Modeling of analytical method is based on the treatment of a distribution system as tow state: UP and DOWN state. The UP state indicates that the distribution system is operational and thus the load point is connected to the supply point. The DOWN state implies that one of the components in the distribution system has failed and the load point is not connected to the supply point.

Analytical method generally evaluates expected value of reliability indices utilizing numerical solution from mathematical model that represents the status of the system components. It relies on capacity outage that tells the exact probability of each level of outage capacity of the systems. However, building capacity outage probability for the real power systems is much more complicated due to the huge amount of outage combinations among generators in the system.

3.6.2 Monte Carlo Simulation (MCS) Based Method

Monte Carlo methods are a class of computational method that relies on repeated random sampling to compute the statistics. More broadly, Monte Carlo methods are useful for modeling phenomena with significant uncertainty in the systems. It is used for obtaining numerical solutions to problems which are too complicated to solve analytically. In an analytical method, unfortunately, assumptions are frequently required in order to simplify the problems. When complex systems and complex operating procedures have to be considered, analytical method is not even capable to achieve the correct solution. Therefore, the simulation techniques are very important in the reliability evaluation. MCS is increasingly considered by system planner due to the capability of modeling system behavior more comprehensively and informatively. Sequential Monte Carlo method is typically applied for solving the uncertainty of a system in chronological order. If the operating life of the system is sufficiently simulated using Monte Carlo method, it is possible to conclude the behavior of the system and obtain a clear picture of the type of failure that the system may suffer.

Monte Carlo simulation methods estimate power system reliability indices by simulating the actual operations and random events in the system. The method treats the problem as a series of real experiments. The techniques can take into account virtually all aspects and contingencies inherent in the operation of a power system. The goal of Monte Carlo simulation is to achieve the statistics of the realistic system by making a large amount of trials for the happening in the system. This recorded information permits the expected values of reliability indices together with their frequency distributions to be evaluated.

3.6.3 Distribution System Reliability Indices

The most commonly used reliability indices of distribution systems are statistical aggregations of reliability data for defined loads, components or customers. They are mostly average values of a particular reliability characteristic for an entire system, operating region, distribution service area or other portion of the system. The indices can be categorized as customer based and load based indices.

- Customer based indices

System Average Interruption Frequency Index: (SAIFI) is measure of how many sustained interruptions on average customer will experience over the course of a year. For a fixed number of customers, the only way to improve SAIFI is reduce the number of sustained interruption experienced by customers.

$$SAIFI = \frac{\text{Total number of custemer interruptions}}{\text{Total number of cutemer served}} = \frac{\sum \lambda_i N_i}{\sum N_i} \qquad (3.19)$$

System average interruption duration index: (SAIDI) is a measure of how many interruption hours on average customer will experience over the course of a year. For a fixed number of customers, SAIDI can be improved by decreasing the number of interruptions or by decreasing the duration of these interruptions. Since both of these reflect reliability improvements, a reduction in SAIDI means an improvement in reliability.

$$\text{SAIDI} = \frac{\text{Sum of custemer interruptions durations}}{\text{Total number of customer}} = \frac{\sum U_i N_i}{\sum N_i} \tag{3.20}$$

Customer average interruption duration index: (CAIDI) is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system incidents. CAIDI can be improved by decreasing the length of interruptions, but can also be decreased by increasing the number of short interruptions. As a result, a decrease in CAIDI does not necessarily mean an improvement in reliability.

$$\text{CAIDI} = \frac{\text{Sum of customer interruptions durations}}{\text{Total number of customer interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \tag{3.21}$$

Average service availability index: (ASAI) is the customer-weighted availability of the system and provides the same information as SAIDI. Higher ASAI values means higher level of system reliability, with most us utilities having ASAI greater than 0.999.

$$\text{ASAI} = \frac{\text{Customer hours of available service}}{\text{Customer hours demand}} = \frac{8760 \times \sum N_i - \sum U_i N_i}{8760 \times \sum N_i} \tag{3.22}$$

Average service unavailability index:

$$\text{ASUI} = \frac{\text{Customer hours of unavailable service}}{\text{Customer hours demand}} = \frac{\sum U_i N_i}{8760 \times \sum N_i} \tag{3.23}$$

Where N_i is the number of customers for load point i, U_i is the annual outage duration for load point i, and 8760 is the number of hours in a calendar year.

- Load and Energy Based Indices

One of the important parameters required in the evaluation of load and energy based indices is the average load (L_a) at each load point bus bars, which is given by:

$$L_a = L_{peak} f \tag{3.24}$$

where L_{peak} is the peak load demand f is the corresponding load factor.

Expected Energy Not Supplied Index at Load Point:

$$\text{EENS} = \text{Expected total energy not supplied by the system} = \sum U_i L_{a(i)} \tag{3.25}$$

Average energy not supplied:

$$\text{AENS} = \frac{\text{Total energy not supplied}}{\text{Total number of customers served}} = \frac{\sum U_i L_{a(i)}}{\sum N_i} \qquad (3.26)$$

3.7 Optimal Capacity Allocation Methodology of DG

Objective Function:

The objective is to maximize generation capacity subject to the constraint outlined in equation (3.27) and to minimize the customer outage cost that can be written as follows in (3.28). This methodology ensures optimal use of the existing network assets, thus helping to meet the DG targets in a cost effective manner. Generation capacity should be allocated across the buses such that none of the technical constraints are breached and the capacity maximized. Therefore the proposed objective function is as shown in Equation (3.27).

$$J = \sum_{i=1}^{N} P_{DGi} \qquad (3.27)$$

Where P_{DGi} is the DG capacity at the i^{th} bus and N is the number of buses.

$$\text{Minimize EIC} = \sum_{h=1}^{n_h}\sum_{i=1}^{n_i}\left(L_{a(i)} C_{hi} \lambda_h r_h\right) \qquad (3.28)$$

Where: $L_{a(i)}$ = average load connected to load point i

C_{hi} = outage cost ($/kWh) of customer due to contingency h

λ_h = failure rate of contingency h

r_h = failure time of contingency

n_h = number of contingency

n_i = total number of load point i

The objective function J (MW), given in Equation (3.27) is maximized and EIC ($/kWh), given in Equation (3.28) is minimized subject to the constraints, which are formalized below.

- Power flow constraint:

$$P_k = \sum_{i=1}^{N} \left|Y_{ik} V_i V_k\right| \cos\left(\theta_{ik} + \delta_k - \delta_i\right) \qquad (3.29)$$

$$Q_k = -\sum_{i=1}^{N} |Y_{ik} V_i V_k| \sin(\theta_{ik} + \delta_k - \delta_i) \tag{3.30}$$

- The voltage of each bus k must be within standards limits:

$$V_k^{\min} \le V_k \le V_k^{\max} \tag{3.31}$$

- Current transfer capability of feeder lines:

$$I_l \le I_l^{\max};\ l \in \{1, 2, ..., N_l\} \tag{3.32}$$

- Maximum number of DGs (nDG) to be installed:

$$\sum_{k=1}^{N} e_{jk} \le nDG;\ j \in \{1, 2, ..., N_C\} \tag{3.33}$$

- Maximum installed capacity of DGs:

$$\sum_{k=1}^{N} \sum_{j=1}^{N_C} C_j e_{jk} \le DG_{\max} \tag{3.34}$$

- Decision variables for the installed of a DG:

$$e_{ik} = \begin{Bmatrix} 0 \text{ if the DG is not installed at bus k} \\ 1 \text{ if the DG is installed at bus k with the capacity at step j} \end{Bmatrix} \tag{3.35}$$

3.7.1 Software Implementation Procedure for Reliability Evaluation

DIgSILENT is a computer aided engineering tool for the analysis of industrial, commercial, and residential electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system analysis in order to achieve the main objectives of planning and operation optimization.

The name DIgSILENT stands for "Digital Simulation and Electrical Network calculation program". This software is used mainly for transmission and distribution systems analyses. It includes optimal power flow; short-circuit calculation, harmonic analysis, transient stability, reliability analyses, and protection coordination. DIgSILENT reliability evaluation can be used to provide not only the reliability indices for both the individual load points and the overall power system, but also it can be used to provide the cost of interruptions.

DIgSILENT is based on Monte Carlo simulation and enumeration techniques. Figure 3.9 shows the reliability evaluation procedure taken in DIgSILENT to achieve the reliability indices for both load point and the overall system.

The first step is to analyze all the input data required for power flow analysis and data required for reliability evaluation. After processing the data and solving the power flow program for the system in order to obtain the system characteristics in normal condition, the system will be modeled by applying the MCS. The achieved model will be reduced to the reasonably small model by applying the contingency and ranking. But applying such techniques require a deep understanding over practical systems i.e. it is necessary to know what kind of outages may occur in practical system. In DIgSILENT the predefined outages events are categorized in two groups' i.e. first order and second order contingencies.

The second step is to create a first order and second order outage combinations. First order contingencies deal with single stochastic outages and single deterministic outages. Generally the single deterministic group does not contribute in interruption frequency while it causes no supply interruption to the loads of the system. Single stochastic outages group includes several modes such as independent single outage, common mode outage, ground fault and unintended switch opening. The reliability input data for these categories are failure rate and repair time and the output data are failure frequency and its relevant duration.

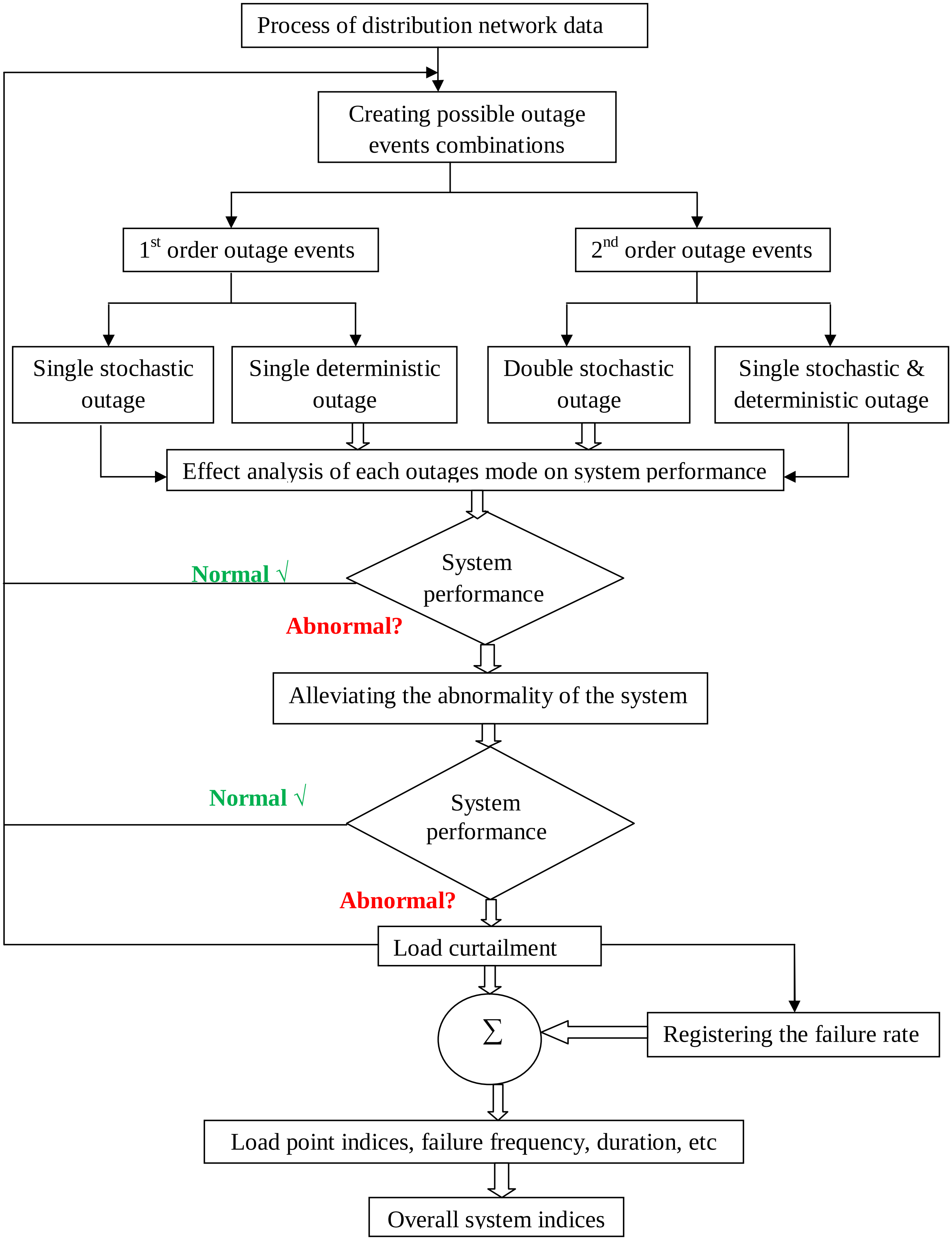

Figure 3.9: Flow chart for reliability evaluation of the system

Second order contingencies can be considered either as two stochastic outages or stochastic and deterministic outages. In the case of overlapping of two stochastic outages the failure frequency is calculated by applying Equation 3.36 or 3.37. The failure frequency for overlapping of stochastic and deterministic outages is obtained through Equation 3.38.

For independent outages:

$$\text{Failure frequency}(FF) = \lambda_A \lambda_B (r_A + r_B) \tag{3.36}$$

Where λ_A and λ_B are failure rate and r_A and r_B are their relavant repair time.

For dependent outages where the second outage may occur with the probability of Pr as a consequent of the first outage, like a second short circuit due to delay in clearing the first short circuit in network, the failure frequency is calculated by applying Equation 3.37.

$$\text{Failure frequency}(FF) = \lambda_A P_r r_B \tag{3.37}$$

The deterministic outage itself may not cause supply interruption in load, but simultaneous occurrence of deterministic and stochastic outages may result in forced outage, which leads to load failure. In such case the failure frequency at load points obtained by applying Equation 3.38.

$$\text{Failure frequency}(FF) = \lambda_A \lambda_B r_B \tag{3.38}$$

where λ_A and λ_B are the failure rate for stochastic and deterministic outage respectively and r_B is the relavant repair time for deterministic outage.

For the appropriate reliability index evaluation, all the possible outages combinations which have been contributed to provide the reliability indices will be analyzed individually to verify their impacts on the system performance. If the created outages result in any variation in system characteristic such as fluctuation in bus voltages, the corrective action such as disconnecting the faulty line and supplying the load in an appropriate way is performed. After performing the corrective action, if the abnormality still exists, the remedial action i.e. load curtailment will be required. The failure frequency of that specific state which results in load curtailment will be calculated. For second order combinations the failure frequency in DIgSILENT is calculated by applying Equations 3.36 to 3.38. The calculated failure frequency will be registered in order to contribute for final reliability calculation. This procedure will be continued to analyze all the possible outage events that may occur within a practical system.

The last step after studying all the possible outage events is to sum up the registered failure frequency relevant to a specific load bus and calculated the relevant indices at each individual load point and overall system.

CHAPTER FOUR

DISTRIBUTION SYSTEM DATA COLLECTION AND ANALYSIS

4.1 Case Study

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 Northern Addis Ababa has been performed. The study is firstly a power flow analysis of the 15 kV and 0.4 kV network which has been created and is maintained by the distribution network operator, and secondly measurements from the supervisory control and data acquisition system (SCADA) of the distribution system.

The substation supplies 63736 customers. The utility owns the distribution lines at 45, 33, 15 and 0.4 kV levels. The grid is connected to the bus bar through the 132/45 kV, 132/33 kV and 132/15 kV transformers, but it can be connected to the neighboring substation system through three 132 kV lines, such as KALLIT I, KALLIT II and Addis East II or Bella substations. There are one 132/33 kV transformer stations, another 132/15 kV transformer stations, and a third three winding 132/45/15 kV transformer stations. This research considers only the 132/15 kV transformer through five 15 kV outgoing feeders and it also 290 low voltage distribution transformers. The 45, 33, and 15 kV system consists of over head and underground transmission lines and cables, but 0.4 kV systems are considered a loads connected point. A general one line diagram of the 45, 33 and 15 kV grid including the neighboring 132 kV lines and the 132 kV in feed is shown in Figure 4-1.

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 between 14.5 and 19.5 MW.

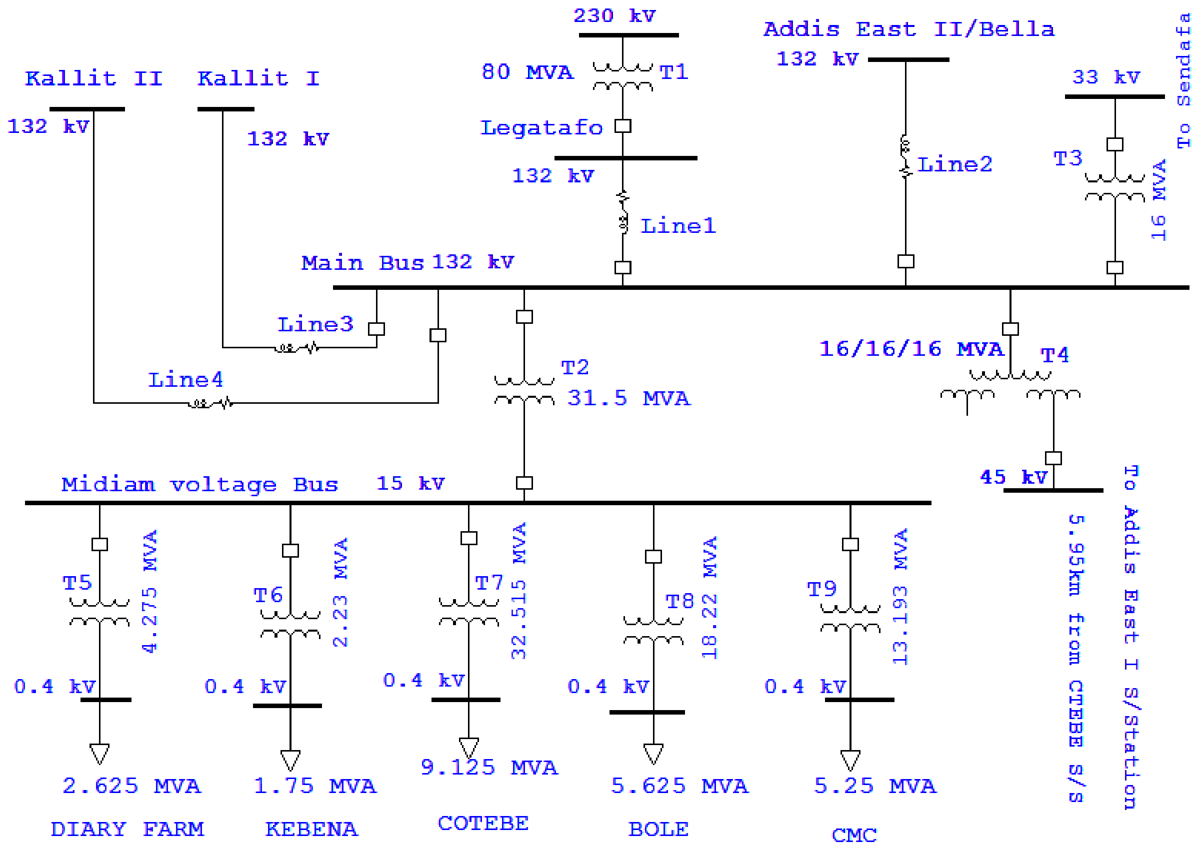

Figure 4.1: A Single line diagram of COTEBE substation

4.2 Distribution Substation Test System

The distribution system modeled with DIgSILENT/ETAP software is shown in Figure 4.1. The peak loading levels of the substation is 19.5 MW and the average load is 16.61 MW. It is assume a 100% of reliability performance from generation and transmission of the RBTS. There is one 132 kV main bus bar that corresponds to substation transformer shown in Figure 4.2: which is connected to 132/15 kV transformer through five 15 kV feeders. Though the 15 kV feeder the power supply is limited by having only one 31.5 MVA, 132/15 kV transformer capacity, there are five feeders that operate as radial system.

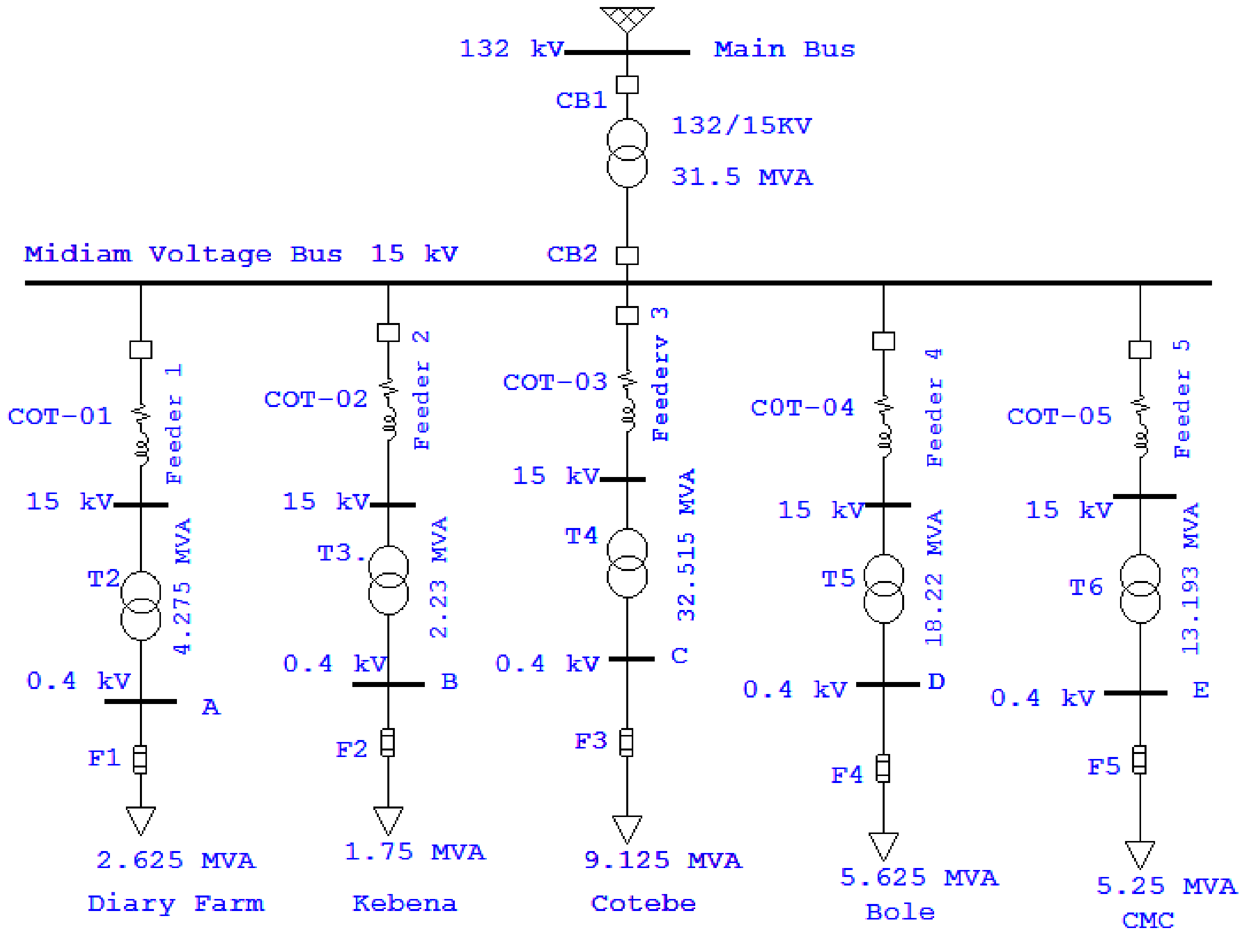

Figure 4.2: The base case distribution substation

The main feeder name, transformers numbers, ratings, connected numbers of customers and remarks of low voltage outgoing feeders are shown in table 4.1. The substation that supplies power to different types of customer's loads, such as residential, commercial and industrial.

Table 4.1: Overview of CTEBE substation Transformers

Substation Feeder name	Transformer Voltage level (KV)	No. of Transformers & Rating (KVA)	No. of Customers (Ni)	Remarks
COT – 01	15/0.4	100 * 3	309	DIATY FARM
		200 * 5	1090	
		300 * 2	618	
		315 * 5	1655	
		800 * 1	872	
Sum		16 (4275KVA)	$\sum_{i=1}^{n} N_i = 4544$	
COT – 02	15/0.4	630 * 1	278	KEBENA
		800 * 2	1744	
Sum		3 (2.23MVA)	$\sum_{i=1}^{n} N_i = 2022$	
COT – 03	15/0.4	25 * 1	25	COTEBE
		50 * 22	1078	
		100 * 45	4410	
		200 * 36	9432	
		315 * 30	9270	
		630 * 8	2224	
		800 * 1	872	
		1250 * 1	1225	
		3150 * 1	1390	
Sum		145 (32.515MVA)	$\sum_{i=1}^{n} N_i = 29926$	
COT – 04	15/0.4	25 * 1	56	BOLE
		50 * 3	306	
		100 * 10	90	
		200 * 27	4050	
		315 * 19	3990	
		630 * 7	2940	
		1250 * 1	834	

Sum		68 (18.22MVA)	$\sum_{i=1}^{n} N_i = 12266$	
COT – 05	15/0.4	50 * 4	408	CMC
		63 * 1	28	
		100 * 8	1616	
		200 * 22	5324	
		300 * 1	309	
		315 * 20	6160	
		500 * 1	515	
		630 * 1	618	
Sum		58 (13.193MVA)	$\sum_{i=1}^{n} N_i = 14978$	
Total		290 (70.433MVA)	$\sum_{i=1}^{n} N_i = 63736$	

From the above substation transformers data the one calendar year and 16 hours per day of medium voltage of five outgoing feeders load obtained. According to this data the load point, the minimum, average and peak load of each feeder is shown in Table 4.2. Also the comparison between the average load and peak load of each feeder and the system is shown in Figure 4.3.

Table 4.2: Number of Costumer, Minimum, Average and Peak Load data of each feeder.

Feeder name	Load point	Number of customers	Minimum load (MW)	Average load (MW)	Peak load (MW)
COT-01	1,2,3,4,5	4544	1.6	1.8625	2.1
COT-02	6,7,8	2022	1	1.325	1.4
COT-03	9,10,11,12,13,14,15,16,17	29926	4.9	6.05625	7.3
COT-04	18,19,20,21,22,23,24	12266	3.7	4.0875	4.5
COT-05	25,26,27,28,29,30,31,32	14978	2.7	3.275	4.2
Total		63736	13.9	16.60625	19.5

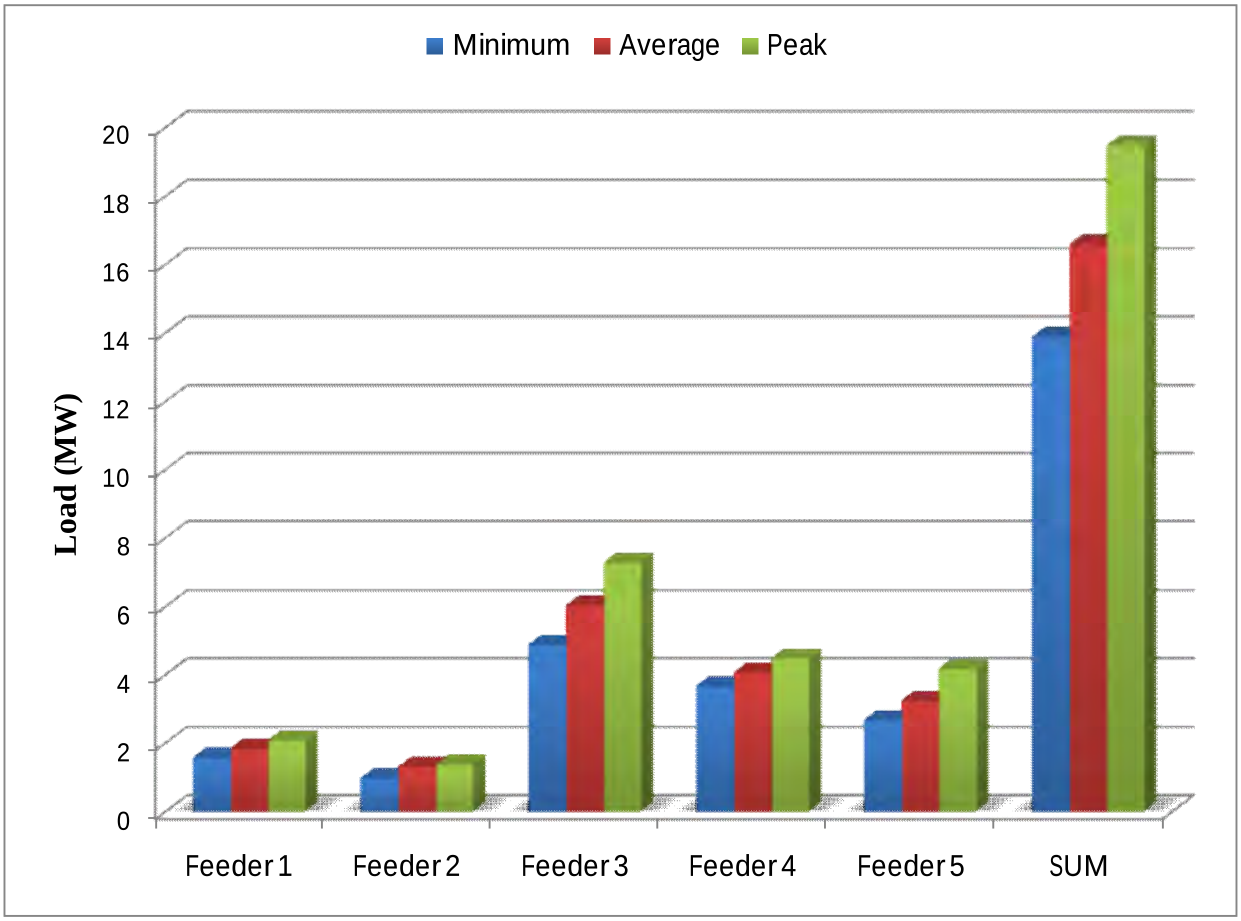

Figure 4.3: Average and Peak load data of each feeder

4.3 Base Case Reliability Analysis

Base case studies provide appropriate information of reliability to obtain the system reliability index. The ETAP/DIgSILENT software calculates several reliability indices and these have been discussed. In the substation test systems reliability analysis is shown in Figure 4.2.

The calculated value of substation reliability indices of each feeders are shown in Table 4.3, as a radial system with no meshed connections the failure rate (λ/yr), the outage durations(hr) and average outage durations(hr/yr) and Figure 4.4 shows outage duration and interruption occurrence of each feeder.

Table 4.3: Radial system reliability indices for main feeders

Substation Feeders	Outage duration (hrs)	Interruption occurrences	Failure rate λ (Failures/year)	Average outage U (hrs/yr)
COT-01	177.76401	119	0.01386585	2.464849
COT-02	61.988141	81	0.009312473	0.577263
COT-03	228.5213833	189	0.0221532525	5.0624919
COT-04	318.423551	290	0.034353773	10.939050
COT-05	246.100444	265	0.031125573	7.66002
Average	206.56	188.8	0.022162184	5.34073478

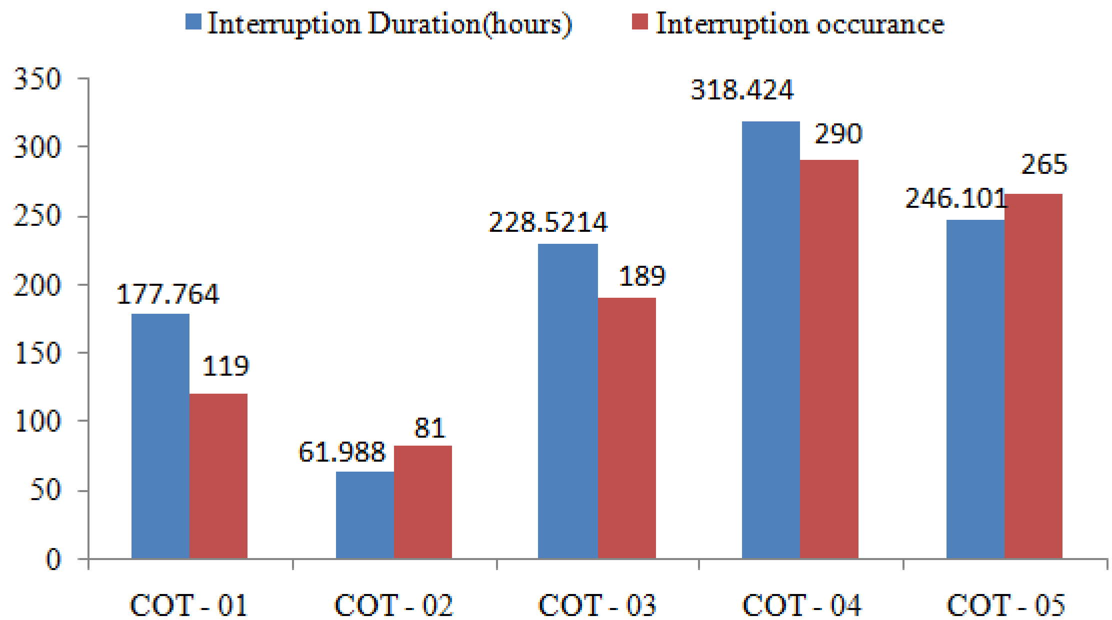

Figure 4.4: Main feeder outage duration and failure occurrence

In the distribution system, there is 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 to 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 power outage for load point since there are no disconnects on the main feeder lines. Then the outage duration r (hours) of each feeder and its failure rate λ (f/yr) is determined. Using the failure rate and outage duration, the annual outage duration U (hrs/yr) for each feeder is obtained.

Secondly, the impact of each lateral distributor's failure on the load point is considered. Since, each lateral is connected to the main feeder through fuse; a fault on any lateral will be introducing impact on the other load point. If there is a fault on the load point, the power from the main feeder is shutdown to repair the fault; its reliability impact will be added to the system.

Adding 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).

$$\lambda_s = \sum_i \lambda_i \tag{4.1}$$

$$U_s = \sum \lambda_i r_i \tag{4.2}$$

$$r_s = \frac{U_s}{\lambda_s} \tag{4.3}$$

From the above equations the other parameters of each feeder were calculated as shown in the Table 4.4.

Table 4.4: The main feeder availability and unavailability indices

Main feeder	N_i	λ_i	r_i	$\lambda_i * N_i$	ASAI (%)	ASUI (%)
COT-01	4544	0.01386585	177.764	63.0064	97.97	2.03
COT-02	2022	0.009312473	61.9881	18.82982	99.29	0.71
COT-03	29926	0.022153252	228.52	662.958	97.37	2.61
COT-04	12266	0.034353773	318.424	421.3834	96.365	3.64
COT-05	14978	0.031125573	246.101	466.1988	97.19	2.81
Sum	63736				97.64	2.36

The load and energy based indices are calculated, using outage duration and average load of each feeders. Those are the expected Energy Not Supplied, the Expected interruption Cost

(EIC) and the Average Energy Not Supplied values are shown in Table 4.5. 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, because a load curtailment at that load point will contribute to higher economic cost.

Table 4.5: Expected Energy not supplied and Interruption Costs indices for each feeder.

Substation Feeders	Expected Energy not supplied (MW hr/yr)	Expected Interruption Cost EIC ($ /yr)	Average Energy Not Supplied (KW hr/yr. ca.)
COT-01	331.085469	290560.922	72.86212
COT-02	82.1342868	72081.1281	40.62032
COT-03	1383.98263	1214584.47	46.24683
COT-04	1301.55626	1142247.01	106.1109
COT-05	805.978954	707327.896	53.81085
Total	3904.7376	3.4268 million$/yr	61.26424

From the table 4.5 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 4.3 and Table 4.4. 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 4.6:

Table 4.6: System indices

Indices	Units	Value
SAIFI	Inter. / customer. yr	188.8
SAIDI	Hrs / customer. yr	206.56
CAIDI	Hrs / customer interruption	1.09407
ASAI	%	97.64
ASUI	%	2.36
EENS	MWh/yr	3904.7376
EIC	m$ /yr	3.4268
AENS	KWh/ ca. yr	61.26424

From Table 4.6, can be concluded that the base case system indices (no DG); SAIDI is 206.56hr/customer yr suggesting that system's average interruption duration for each customer is 206.56 during a year, SAIFI is 188.8 inter./customer yr system's average interruption frequency for each customer during a year, CAIDI is 1.09407 hrs/ customer interruption, suggesting system's average interruption duration for the customers that experience interruption is 1.09407 hrs during a year and system availability and unavailability are 97.64% and 2.36% are respectively. Also, the expected energy not supplied (EENS) of system due to the failures is 3904.7376 MWh/yr and the energy not supplied per customer is 61.26424 kWh/yr. And finally, expected interruption coast of system is 3.426801millions $/yr during a year in the next chapter; it will be observed that how these indices are improved by the installation of DG, proper disconnects, and online tap change transformers.

CHAPTER FIVE

SIMULATION RESULTS AND DISCUSSION

5.1 Modeling of distribution system

The single line diagram of the distribution substation network is shown in Fig. 5.1. The network is formed by five radial feeders, namely Feeder1, Feeder 2, Feeder 3, Feeder 4 and Feeder 5 of 15 kV Cotebe distribution system in Addis Ababa, owned by Ethiopian Electric Utility (EEU).

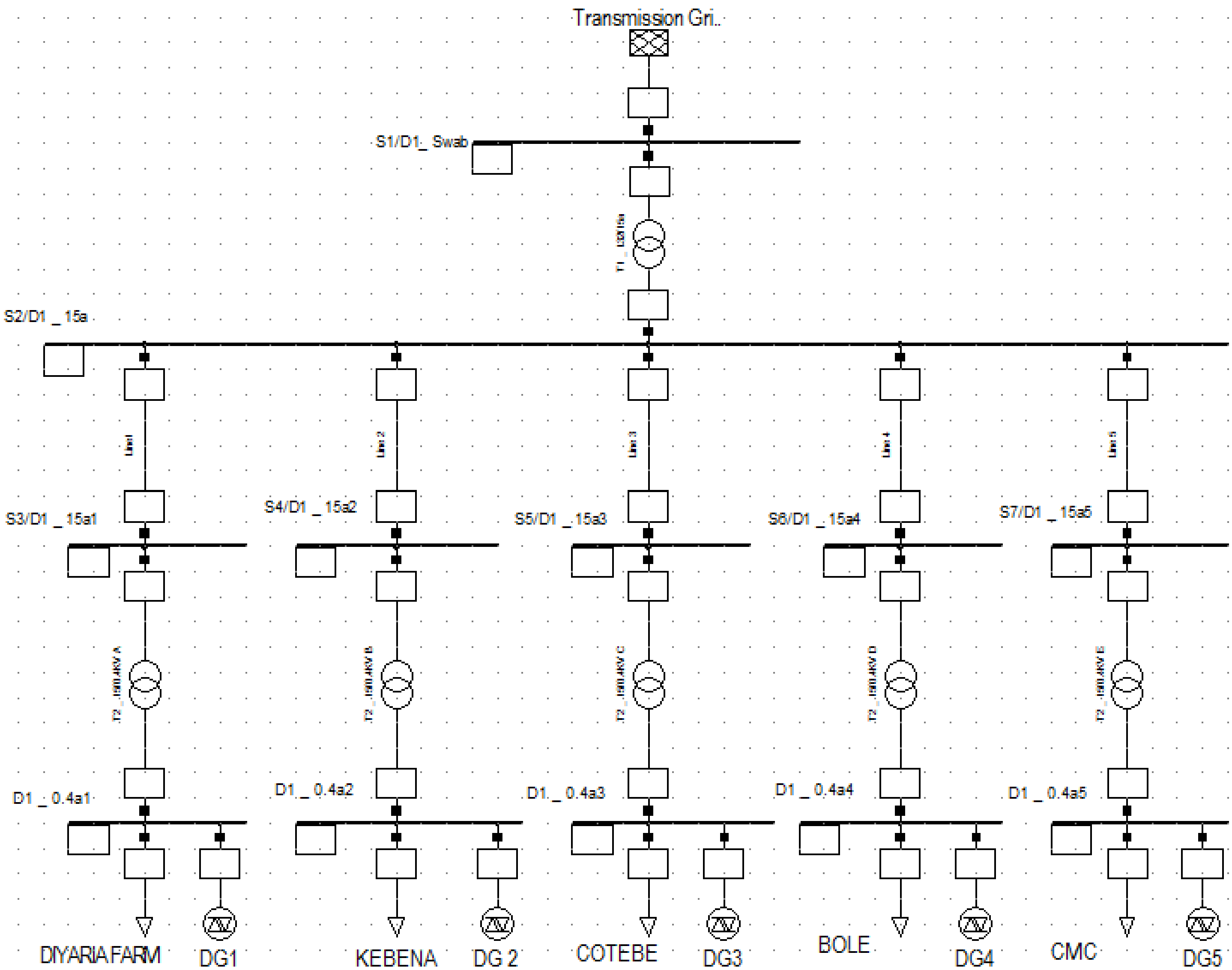

Figure 5.1: Modified Distribution System

5.2 Modified Model Test System

The distribution system Reliability Busbar Test system known as RBTS with some changes in the configuration of the system shown in Fig.5.1 has five outgoing feeders with the voltage level of 15 kV and 0.4 kV. It is assumed that 132 kV and 15 kV circuit breakers are operates successfully when required, disconnects are opened whenever possible to isolate a fault and the supply restored to as many load points as possible using appropriate isolators and the alternative supply is available. The change is that the existing system connected with DG units at the 15 kV bus of outgoing feeders and after low voltage transformers (15/0.4 kV) i.e. 0.4 kV. In this study, there is no restriction in the load transfer, meaning that DG units play a role exactly similar to a power source.

5.3 Case Studies of Reliability Assessments

In this section, three main case studies are discussed. Firstly, as one of the analyses presented is to only consider the benefits at the feeder where DG is placed, this first study case connect DG in 15 kV and evaluates the impact to the rest of the system. Secondly, connect DG at 0.4 kV locations from the supply point and evaluate impact of system reliability. The third study case increasing the value of DG units in 15 kV and 0.4 kV bus. For case the studies, each feeder and system reliability indices will be computed and discussed for DG units installed at proper buses.

5.3.1 Reliability Enhancement of Main Feeders in Different Buses

First, it is studied how adding a generation unit at some point of the main feeders would affect to the other five feeders group configurations. Shows the study case, where a DG units are placed at main feeder of 15 kV shown in Figure 5.2. The system reliability indices SAIFI, CAIDI, SAIDI, EENS and EIC are calculated for DG at all 15 kV feeders with six suggested case feeder group is shown in Table 5.1.

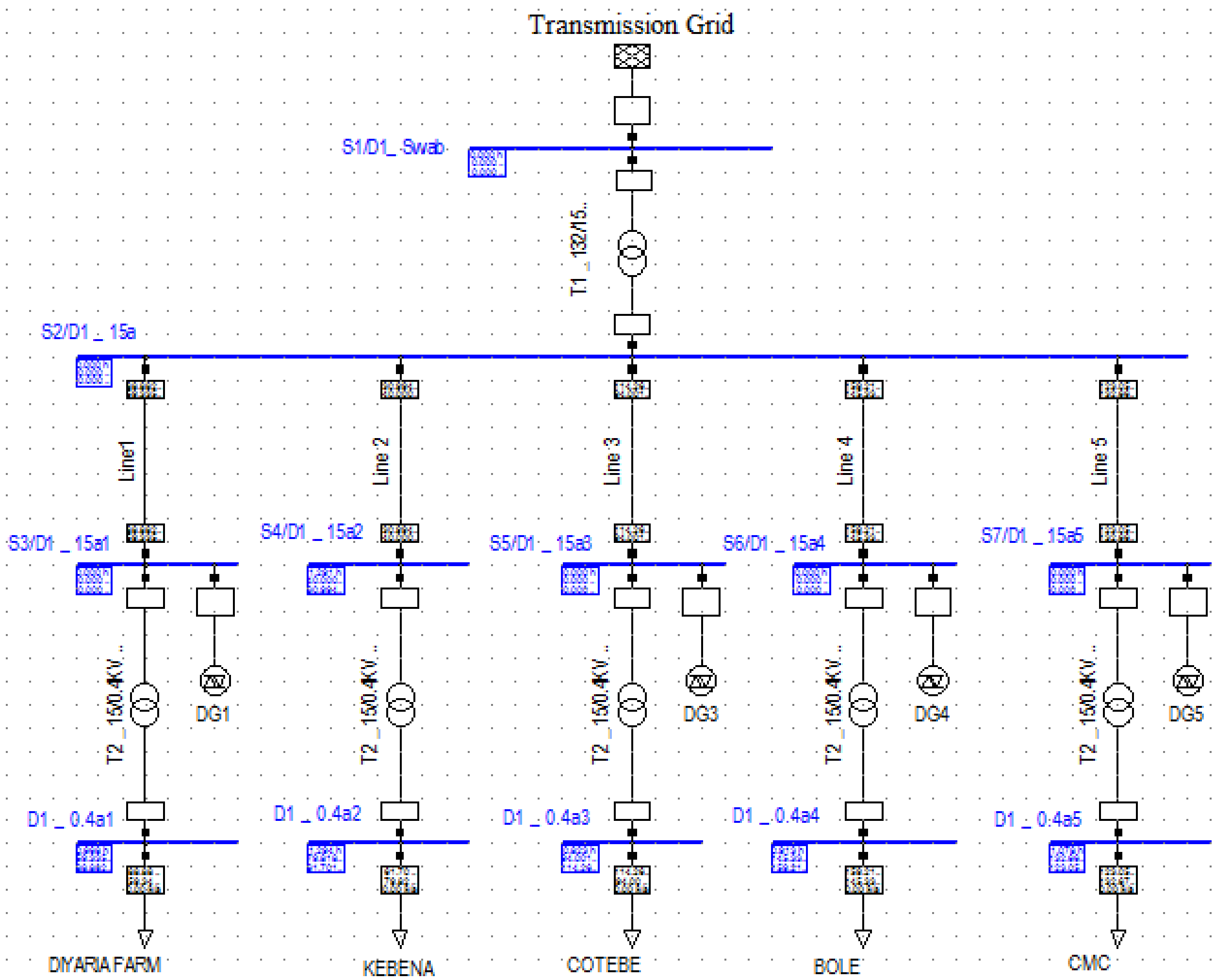

Figure 5.2: DG units are connected with all 15 kV feeders except feeder two

Table 5.1: Reliability indices when more than one DG is placed at different location of 15 kV

DG at 15 kV Bus bars							
DG Connected	SAIFI	SAIDI	CAIDI	ASAI (%)	ASUI (%)	EENS MWh/yr	EIC m$/yr
Except feeder 1	126.78	112.983	0.891	98.7103	1.2898	1871.094	1.6421
Except feeder 2	**121.50**	**110.045**	**0.906**	**98.744**	**1.2562**	**1814.089**	**1.5921**
Except feeder 3	173.07	152.444	0.881	98.2598	1.7402	2324.488	2.03997
Except feeder 4	150.2	136.287	0.907	98.4442	1.556	2345.524	2.05843
Except feeder 5	148.61	139.486	0.939	98.4077	1.5923	2189.235	1.92127
Except feeder 1 & 2	127.75	114.246	0.894	98.6958	1.3042	1923.852	1.6884

From the above Table 5.1 presents the reliability indices of the overall system for six cases of each feeder group configurations. It is concluded that the impact of the distribution generation is at the feeder where it is located in each feeders.

The second case study where DG units are placed at 0.4kV bus of outgoing feeders, shown in Figure 5.3, with six suggested locations feeder group for placing DG. This are DG in F2, F3, F4, F5 (Case 1); F1, F3, F4, F5 (Case 2); F1, F2, F4, F5 (Case 3); F1, F2, F3, F5 (Case 4); F1, F2, F3, F4 (Case 5), and F3, F4, F5 (Case 6). For each case the system reliability indices SAIFI, SAIDI, CAIDI, EENS, AENS and EIC are calculated, which shown in Figure 5.4, 5.5, 5.6, and 5.7 and summarized in Table 5.2.

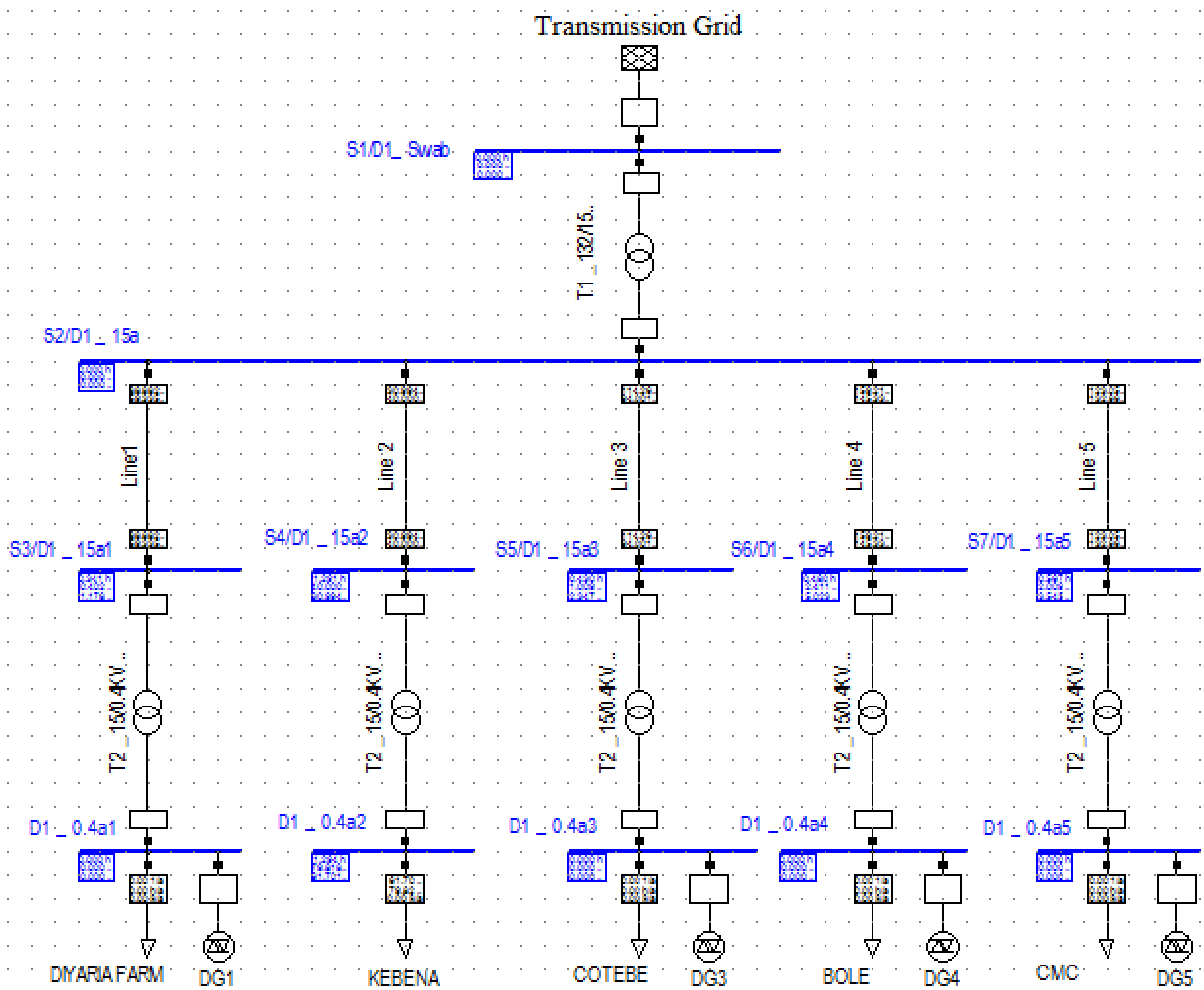

Figure 5.3: DG units are connected with all 0.4 kV feeders except feeder two

Table 5.2: Reliability indices when DG is placed at different location of 0.4 kV bus

DG at 0.4 kV Bus bars							
DG Connected	SAIFI	SAIDI	CAIDI	ASAI (%)	ASUI (%)	EENS MWh/yr	EIC m$/yr
Except feeder 1	12.5895	8.432	0.670	99.90375	0.0963	220.273	0.193
Except feeder 2	**1.95746**	**2.532**	**1.294**	**99.97109**	**0.0289**	**105.758**	**0.0928**
Except feeder 3	106.196	87.799	0.827	98.99773	1.0023	1132.45	0.9938
Except feeder 4	60.3139	55.475	0.920	99.36673	0.6333	1178.24	1.0340
Except feeder 5	57.0007	61.881	1.086	99.29359	0.7064	862.386	0.7568
Except feeder 1 & 2	14.547	10.964	0.754	99.87485	0.1252	326.031	0.2861

While talking about EENS and EIC indices, looking at the difference between base case and DG installed in 0.4 kV bus of all feeders except feeder two cases is shown in Table 5.2 is more than a 97% of EENS and 97.3% EIC improvement than the rest of five feeder group together.

Thus, 97.3% of the economical benefit is located at the main feeder where the DG is installed in 0.4 kV. There is a small impact at SAIFI, SAID, CAIDI, EENS, and EIC indices for DG installed at all feeders except feeder two of 15 kV bus while most of the improvement are considering DG units at all feeders except feeder two of 0.4 kV bus as shown in Table 5.3. For each case configuration simulation results are given in Appendix B.

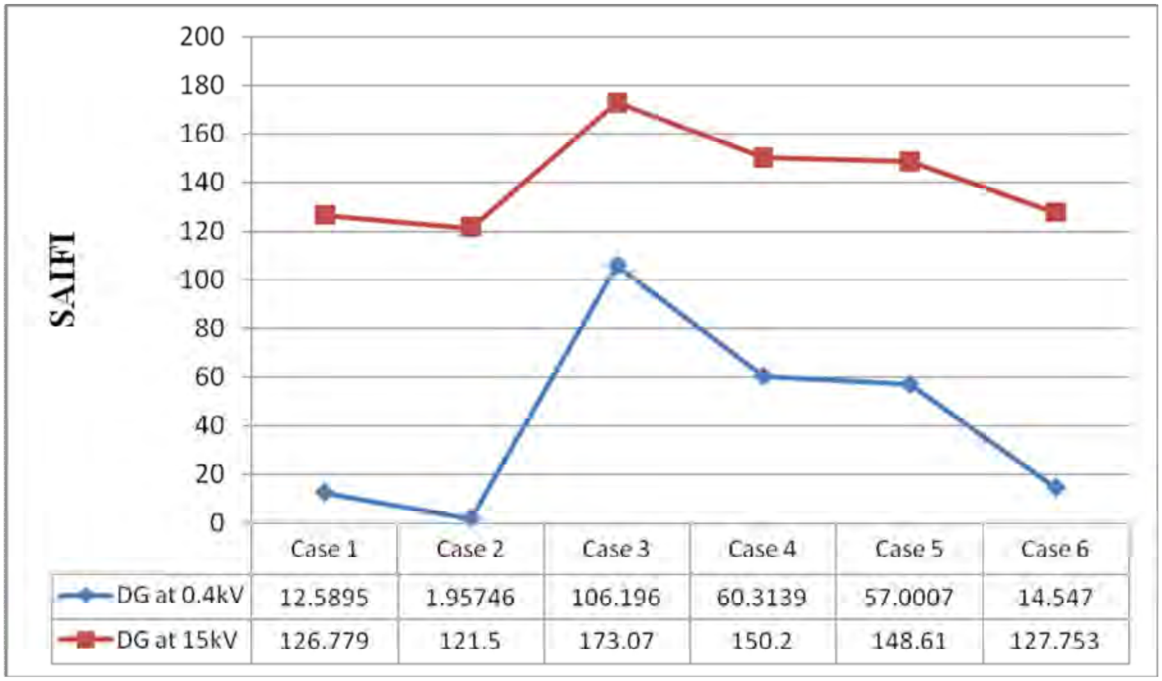

Figure 5.4: System Average Interruption frequency index

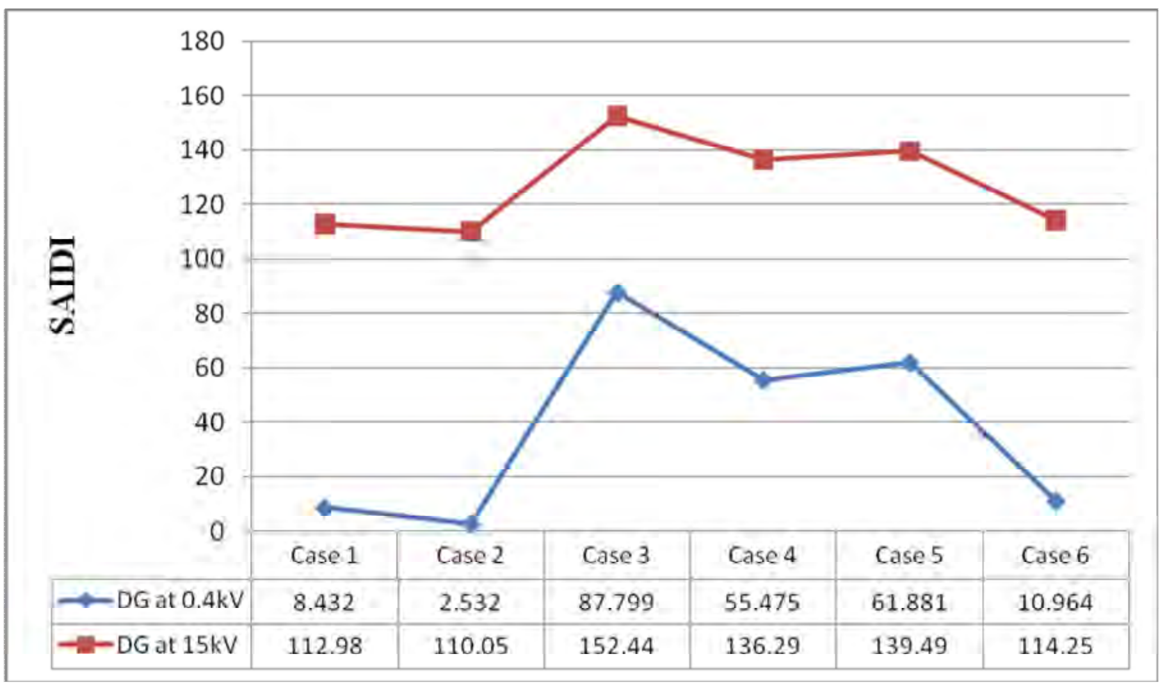

Figure 5.5: System Average Interruption duration index

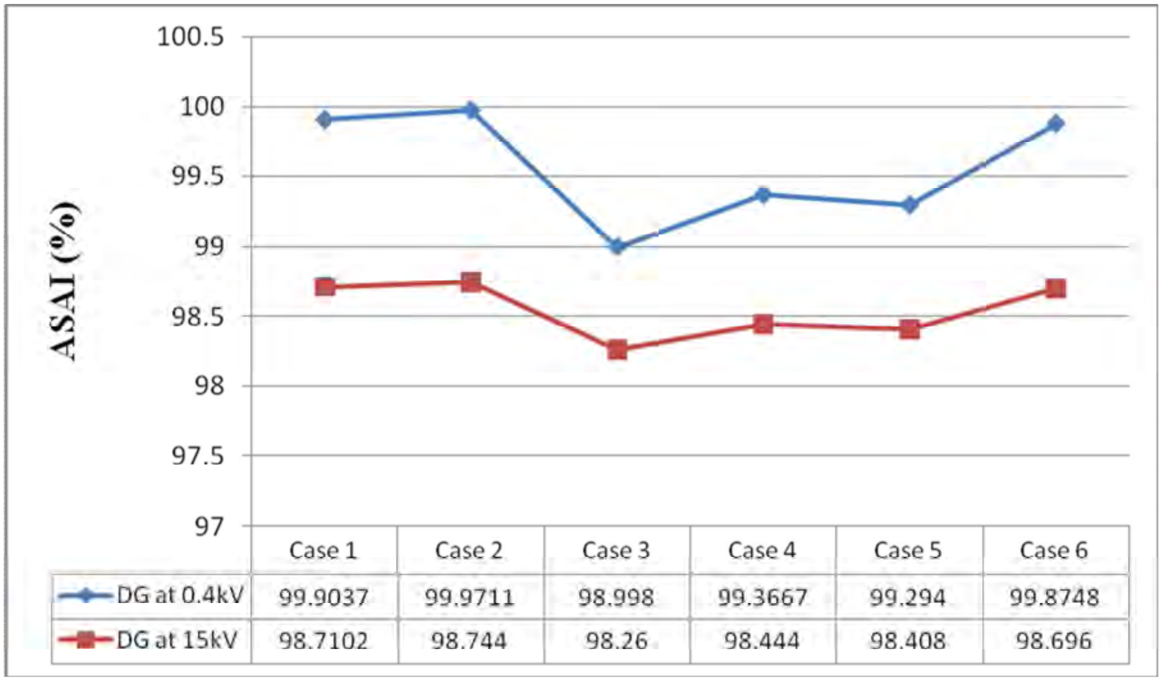

Figure 5.6: Average System Availability Index

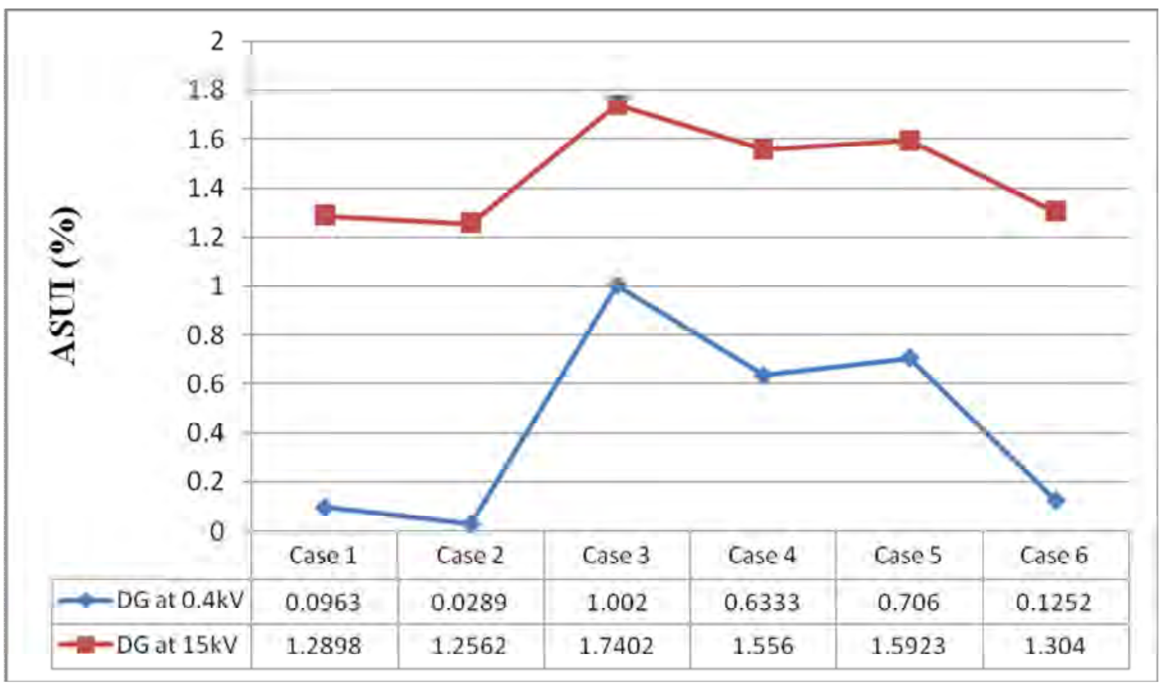

Figure 5.7: Average System Unavailability Index

Table 5.3: System indices for DG at different location from supply point

Indices	Base case (No DG)	(**3.62 MW**) DG at 15 kV bus	(**3.62 MW**) DG at 0.4 kV bus
SAIFI	188.5344	**121.5003**	**1.957456**
SAIDI	206.56	**110.045**	**2.532**
CAIDI	1.09561	**0.906**	**1.294**
ASAI (%)	97.64	**98.74578**	**99.9711**
ASUI (%)	2.36	**1.25622**	**0.0289**
EENS (MWh/yr)	3904.7376	**1814.089**	**105.758**
AENS (MWh/yr. ca.)	61.26424	**0.028**	**0.002**
EIC (million $/yr)	3.4268	**1.592046**	**0.092813**

It can be seen from Table 5.3 that the 3.62 MW DG unit installed at the beginning of the feeder barely improve the reliability indices i.e. in this thesis DG installed at 15 kV the EENS and EIC are 53.54 % improved but DG installed at 0.4 kV the EENS and EIC are 97.3 % and 97.3 % improved respectively, this is because the circuit will be less mitigated as the DG unit at 15 kV just acts as an additional source to the supply bus as the power grid. However, the DG would be used when there is failure of the grid that is why reliability indices are slightly better. There are clearly significantly improved when the DG is placed at any other point distant from the supply point. SAIFI and SAIDI are reduced while DG is further from supply point. On the other hand CAIDI tends to be slightly higher when distance from supply point increases.

EIC index presents the cost due to outages, for this thesis used as reference to choose the best scenario. Figure 5.8 and 5.9 shows that lower EENS and EIC is obtained when the DG units at 0.4 kV bus than DG units at 15 kV bus, and Table 5.3 also shows the reliability index between the base case and mitigated case, this result as the annual worth of placing a DG unit at 15 kV and 0.4 kV buses.

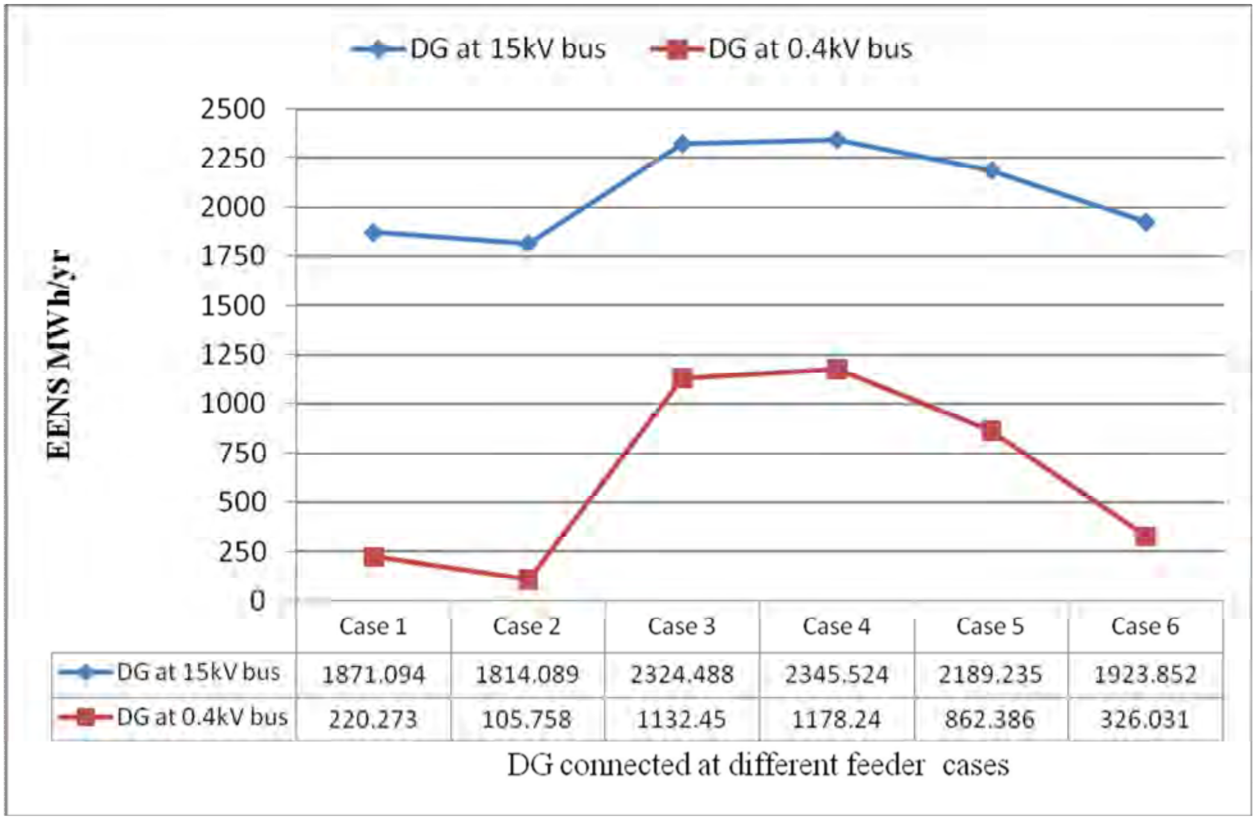

Figure 5.8: Annual EENS in different DG locations

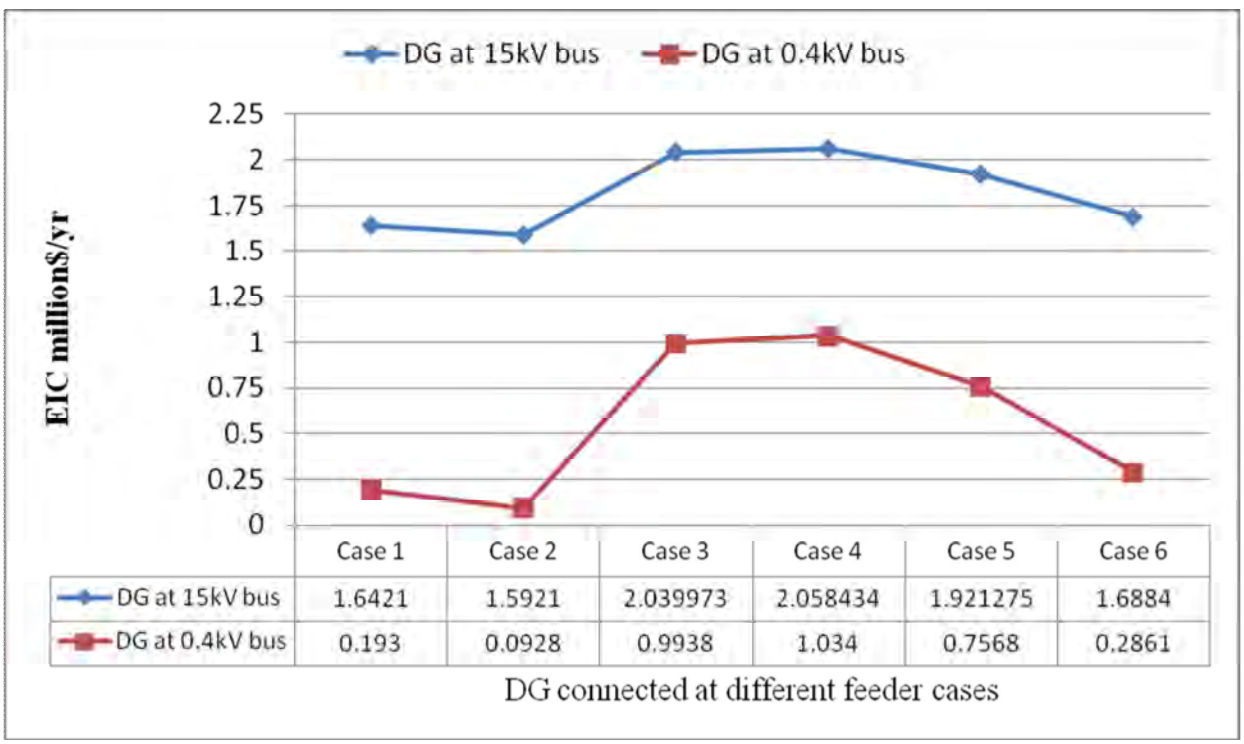

Figure 5.9: Annual EIC in different DG locations

5.3.2 Reliability while Increasing the Capacity of DG units

This case study proposed to evaluate the value of placing different size DG at a location of 15 kV and 0.4 kV buses. In this case there are six different DG sizes are integrated in 15 kV and 0.4 kV buses and twelve cases reliability index analysis are performed. It can be analyzed that increasing the size of DG at the same locations does have a positive effect to the system reliability. For the test system of this thesis locating more than one DG and different sizes in 15 kV and 0.4 kV the impact on reliability index analysis, the protections devices appropriate places are needed to isolate the faults.

Table 5.4 shows a summary of the system indices of a different scenario. Overall system indices for each simulation are given in Appendix B. It is concluded that increasing the size of DG at the locations of 15 kV and 0.4 kV does have decrease the system reliability index and Figure 5.10 and 5.11 are shows the DG size increase with EENS and EIC respectively at 15 kV and 0.4 kV. In this case reliability analyses of increasing the size of DG have a positive effect on reliability index.

Table 5.4: Reliability indices when more than one DG is placed at 15 kV & 0.4 kV buses

	Cases	DG in MW	SAIFI	SAIDI	CAIDI	ASAI (%)	ASUI (%)	EENS MWh/yr	EIC m$/yr
DG at 0.4kV bus	Case 3	2.44	106.196	87.799	0.827	98.998	1.002	1132.445	0.9938
	Case 4	3	60.3139	55.475	0.920	99.3667	0.6333	1178.244	1.0340
	Case 5	3.06	57.0007	61.881	1.086	99.294	0.706	862.386	0.7568
	Case 6	3.2	14.547	10.964	0.754	99.8748	0.1252	326.031	0.2861
	Case 1	3.48	12.5895	8.432	0.670	99.9037	0.0963	220.273	0.193
	Case 2	3.62	1.95746	2.532	1.294	99.9711	0.0289	105.758	0.0928
DG at 15kV	Case 3	2.44	173.07	152.44	0.881	98.26	1.7402	2324.488	2.04
	Case 4	3	150.2	136.29	0.907	98.444	1.556	2345.524	2.0584
	Case 5	3.06	148.61	139.49	0.939	98.408	1.5923	2189.235	1.9213
	Case 6	3.2	127.753	114.25	0.894	98.696	1.304	1923.852	1.6884
	Case 1	3.48	126.779	112.98	0.891	98.7102	1.2898	1871.094	1.6421
	Case 2	3.62	121.50	110.05	0.906	98.744	1.2562	1814.089	1.5921

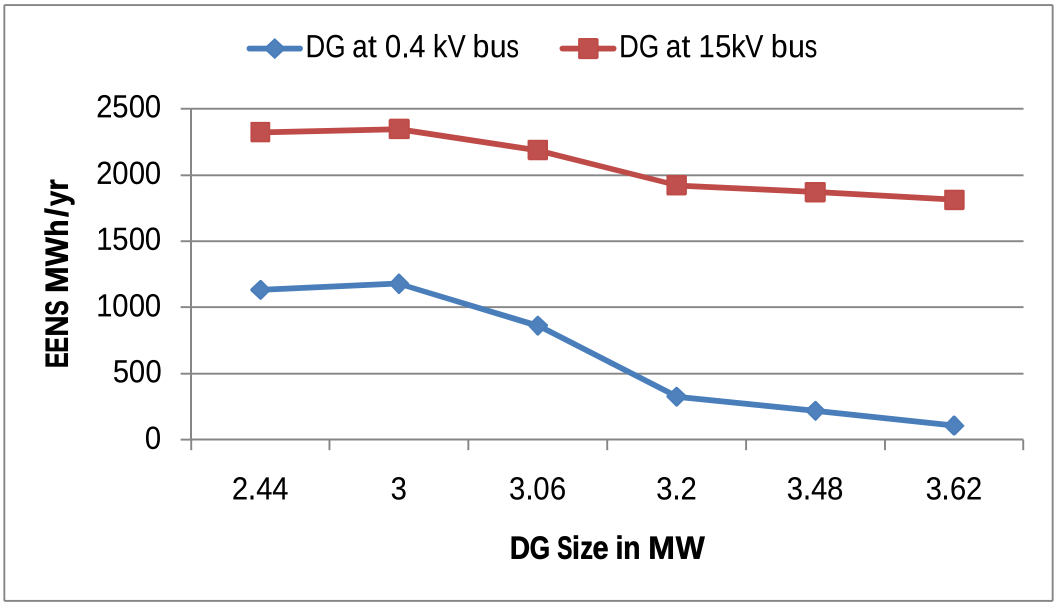

Figure 5.10: Expected Energy Not Supplied with DG Size at different buses

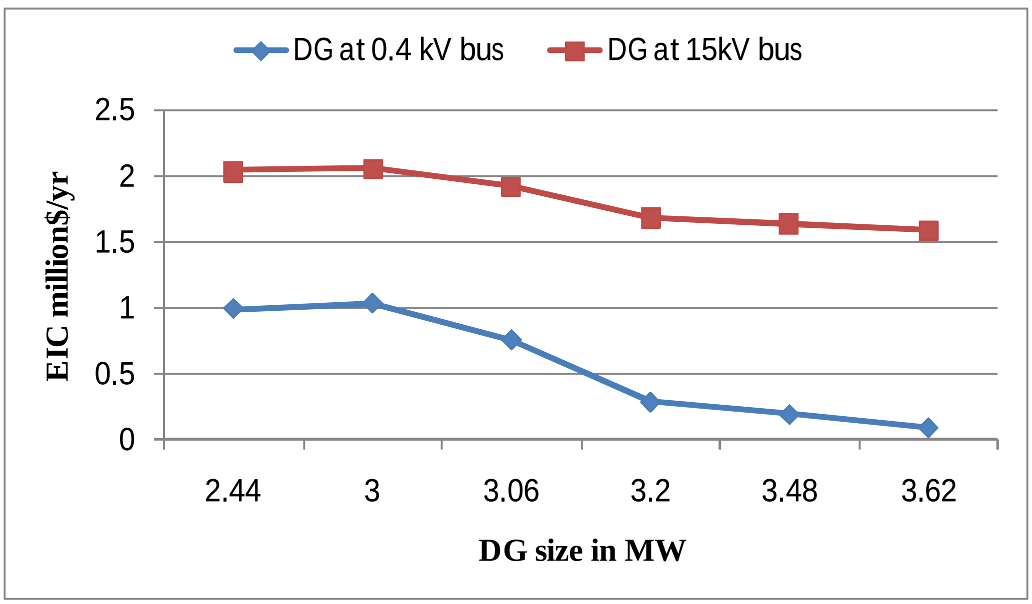

Figure 5.11: Expected Interruption Cost with DG Size at different buses

5.4 Voltage Regulation of Base Case and New Case Studies of System

5.4.1 Case One: DG is Connected with all 15 kV Buses of each Feeder

The proposed method was applied to a 15 kV bus radial distribution system by installing DG at five outgoing feeders. All 15 kV bus feeders are considered as candidate buses in this test and in all subsequent tests. Figure 5.12 shows the voltage deviation level in different bus points without DG and with DG unit. Figure 5.13 shows the corresponding voltage deviation for installing the optimal DG size at 15 kV bus of the system with considering of OLTC transformer. From the figure, we can determine that the voltage deviation level in different bus points of radial distribution systems. Installing the DG at 15 kV buses with a size of 3.62 MW and considering OLTC caused a improve voltage deviation level. Figure 5.13 shows the improvement in the voltage profile after installing the DG unit and considering OLTC transformer.

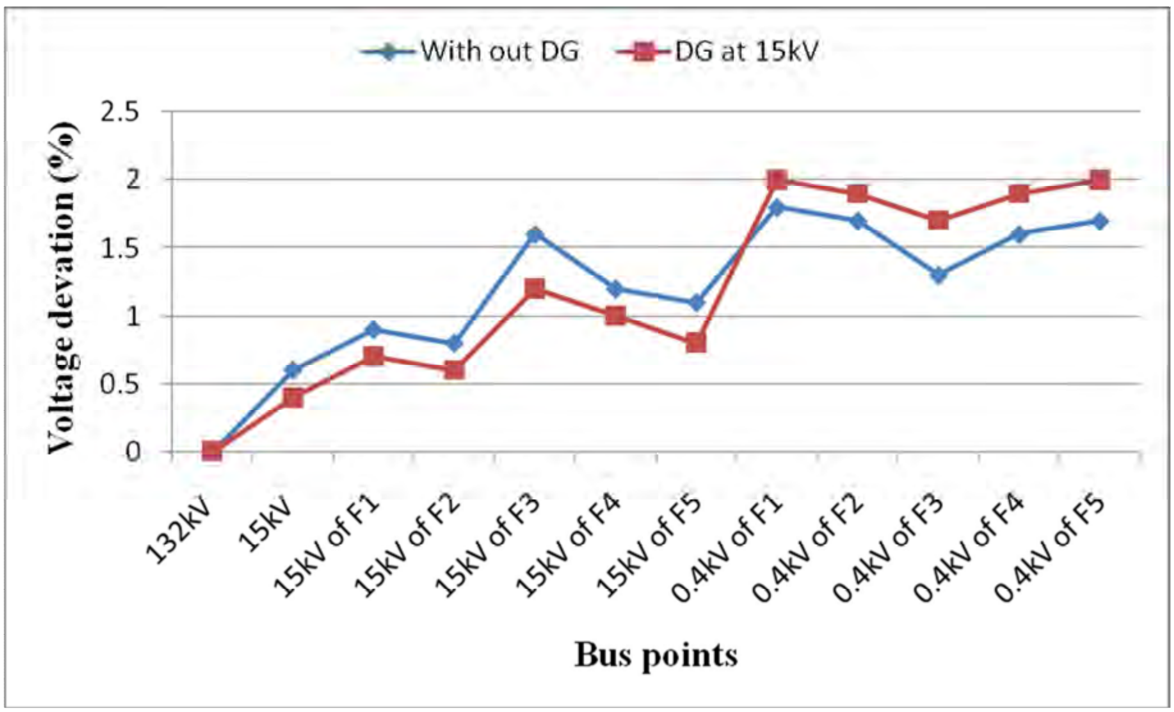

Figure 5.12: Voltage deviations of DG connected in 15 kV buses

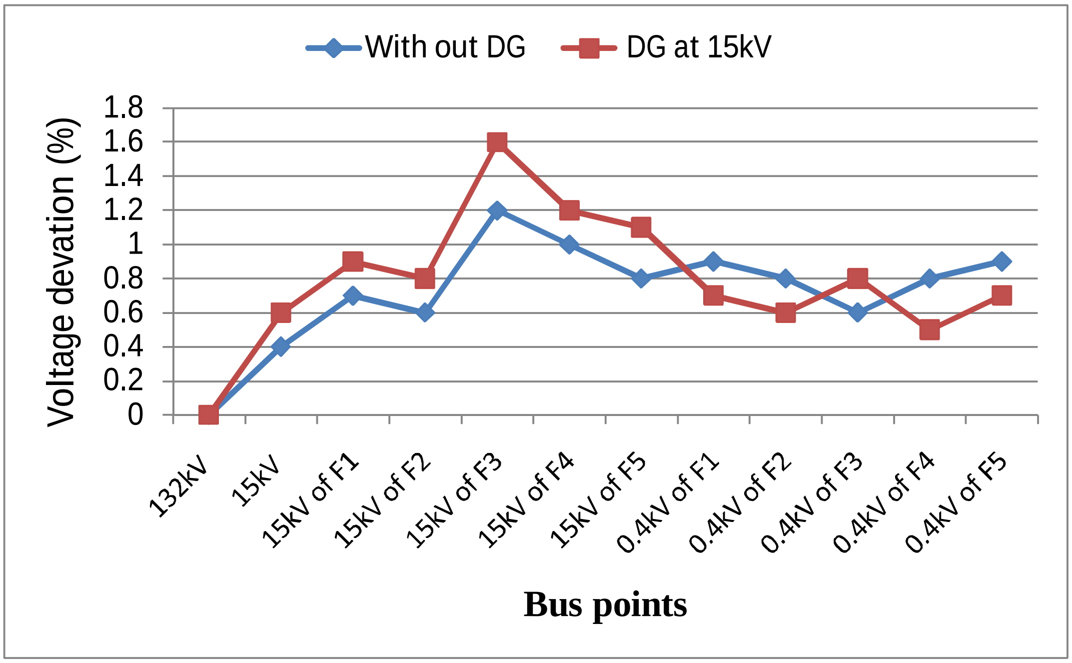

Figure 5.13: Voltage deviations of DG connected in 15 kV buses and OLTC transformer

Figure 5.12 and 5.13 shows the impact of in the profile of each bus, when the DG units integrated in 15 kV the voltage deviation increases because the DG injects the reactive power to the corresponding buses. There for considering OLTC transformer into the corresponding bus is very important to increase or decrease the voltage deviation, where the DG is connected bus.

5.4.2 Case two: DG is connected with all 0.4kV Buses of each Feeder

In this case, all combination of DG units was applied to a 0.4 kV load bus radial distribution system of five outgoing feeders. All 0.4 kV bus low voltage feeders are considered as candidate buses in this test and in all subsequent tests. Figure 5.14 shows the bus points and corresponding voltage deviation at all of the system buses. Figure 5.15 shows the corresponding voltage deviation for installing the optimal DG size at 0.4 kV bus of the system with considering of OLTC transformer. From the figure, we can determine that the voltage deviation level in different bus points of radial distribution systems. Installing the DG near to load connected bus of 0.4 kV and considering OLTC caused an improve voltage deviation level. Figure 5.15 shows the improved voltage profile after installing the DG unit and considering OLTC transformer. Here in that voltage deviation level, when DG units are installed in 0.4 kV load point bus and with considering OLTC transformer.

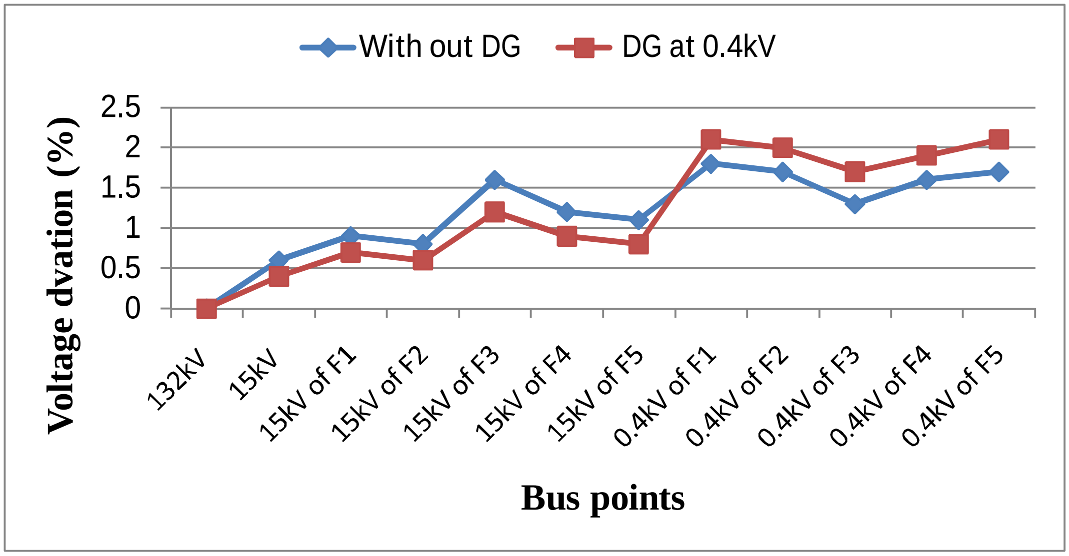

Figure 5.14: Voltage deviation of DG connected in 0.4 kV buses

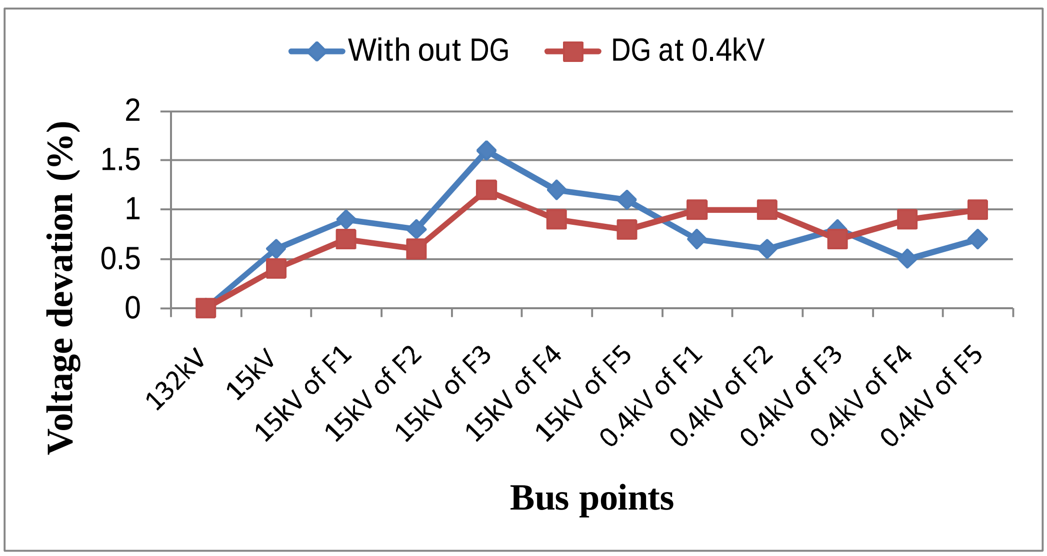

Figure 5.15: Voltage deviation of DG connected in 0.4 kV buses and OLTC transformer

In this case, when the DG units installed at all 0.4kV bus feeders and considering OLTC transformer the voltage deviation in the 15 kV feeder is lower than the original bus voltage deviation and the voltage deviation in the 0.4 kV bus of each feeder is higher than the original bus voltage deviations because DG units more injects reactive power to the corresponding 0.4 kV bus of each feeder.

CHAPTER SIX

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

6.1 Conclusion

This thesis investigates the proper DG location and size for reliability assessments of COTEBE substation distribution system, based on reliability improvement, voltage regulation, power loss minimization and substation alleviation constraints. The reliability assessment and load flow analysis processes, using analytical and Monte Carlo Simulations (MCS) were conducted with radial distribution system of 15 kV five feeders (DIARY FARM, KEBENA, COTEBE, BOLE, and CMC). The integration of DG units into the distribution system significantly affects system operation including voltage deviation, loss reduction, reliability improvement, and congestion alleviation. These impacts were analyzed to determine the contribution of each unit to the improvement of the distribution systems.

The basic objective of the research is to perform reliability assessment of distribution substation system with DG units, by applying analytical approach and Monte Carlo Simulation method using the DIgSILENT/ETAP/MATLAB software tool. The objective is described in detail in system failures are related outages that can propagate to other parts of a system and cause severe damages.

In the base case study it is seen that there is a higher outage as the load point is further from the supply point, therefore there a higher vulnerability in term of reliability worth; EENS (3904.7376) and 3.4268m$/yr are higher at the base case study. And also overall system reliability indices are high.

The proposed solution is chosen for this research as and the option for improving the system reliability indices, Expected energy not supplied and the outage cost of interruptions. From the five 15 kV main feeders it is seen that 15 kV and 0.4 kV buses of different case study is taken into the reliability improvements with higher distribution indices. The installation of a DG at 0.4 kV buses of the feeders will impact for more than a 97% at the 0.4 kV of main feeder that is installed.

From the different case study analysis the installations of DG unit at supply point will barley improve system reliability than DG at near to the load centers. As far the location is from the substation there reliability system indices increase. The case study location for the placement of the DG is at 0.4 kV bus in terms of reliability improvement. In the base case Expected Energy not supplied of the system is 3904.7376 MWh/yr and a cost due to outage of base case is 3.4268m$/yr, while it is EENS of proposed case study is decreased to 105.758 MWh/yr and EIC is 0.092813m$/yr for the case of appropriate DG size installed at 0.4 kV bus.

In the case study scenarios are found for reliability improvement. First one is placing a DG at 0.4 kV bus; second increasing DG size at proposed place (0.4 kV) and DG at different feeder group combinations in that place. There is a high profitability for the case study scenario the EENS is reduced from 3904.7376 MWh/yr to 105.758 MWh/yr and EIC is reduced from 3.426m$/yr to 0.092813m$/yr.

Finally the expected, Case 3 produces the worst set of indices because this system is the most basic and least capital intensive. All the other studies provide facilities for improving system reliability.

It is shown that by adding DG units at proper places and size the system reliability increases more and more the best condition is when the system includes all of the components together.

So that the reduction of SAIDI and SAIFI indicates an improvement in system reliability is shown in Figure 5.4 and 5.5; mean while higher ASAI and lower ASUI values mean higher level of system reliability in figure 5.6 and 5.7 and also this figures are also shown here to simplify the comparison between different cases. As it was supposed, Case 2 has the best reliability and Case 3 has the worst system reliability.

6.2 Recommendations and Future Works

While many aspects of reliability assessment of the distribution system with DG have been covered by this thesis, several other issues are interesting for future investigation. Some of the issues that are believed interesting are listed as follows:

- ✓ This research work only conducted the 15 kV line feeders, future work use the same analysis to improve reliability of the 33 kV and 45 kV line feeders of the substations.
- ✓ When considering installation of DG near to the individual load point, it improves more system reliability indices.
- ✓ Solutions overcoming the issues with a significant presence of DG were briefly described. These solutions could be implemented in DIgSILENT to analyze if the problems found in this thesis persist with the employment of another kind of system´s mitigation mechanisms.
- ✓ The modeling of the distribution system is done by treating the system as a radial network. Other forms of distribution systems such as meshed networks may be considered for reliability evaluation in the future.
- ✓ Distributed generation may cause noticeable voltage flicker and introduce harmonics into the system. Further research could also focus on the impacts of DG on the short circuit levels of the system and the harmonic distortion of the systems.

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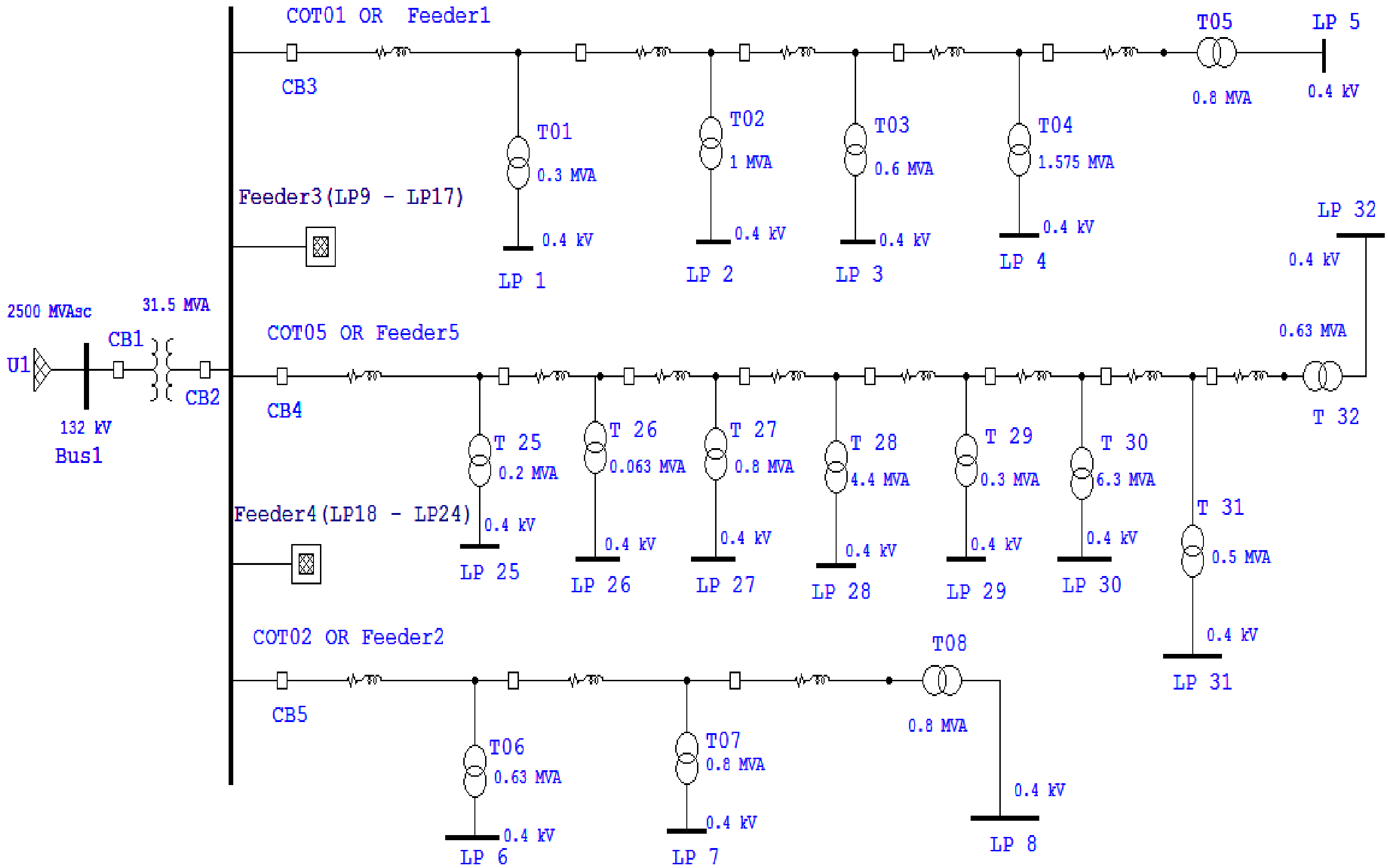
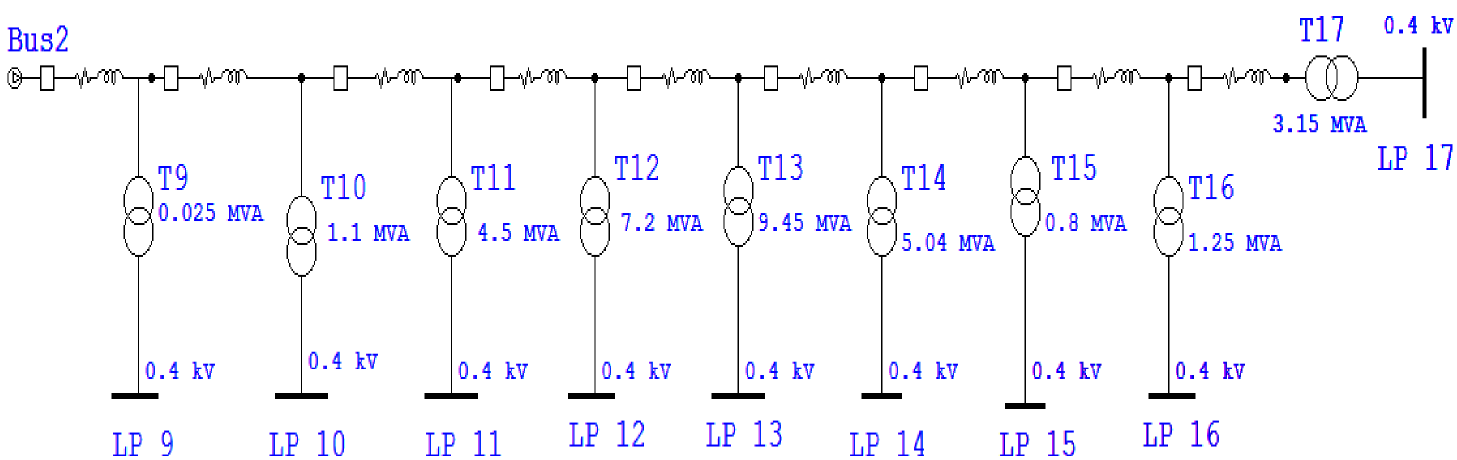
APPENDIX-A

Details of IEEE-Reliability Bus bar Test System of Case Study

The one line diagram of the IEEE-RBTS is shown in Figure A.1.



Feeder3 (Load point 9 - 17) from main Bus bar 2



Feeder4 (Load Point 18 - 24) from main Bus bar 2

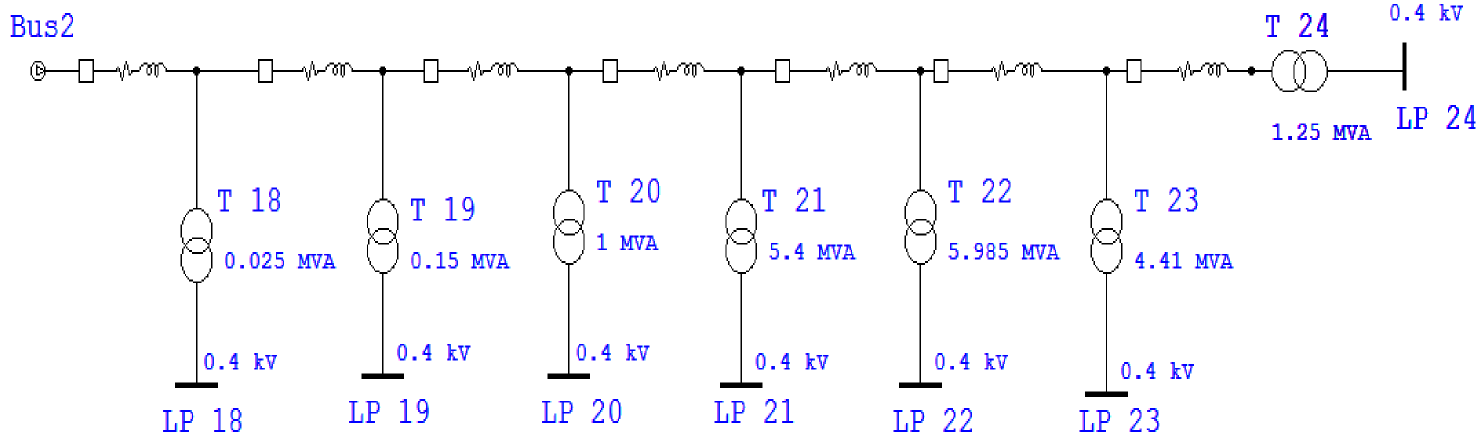


Figure A.1: Case study Distribution System of IEEE–Reliability Bus bar Test System

Table A-1: Reliability Parameters of Distribution System Components

Components	Failure rate (failure/year)	Repair time (hours)
Lines per km	0.065	5
Breaker 15KV	0.006	4
Breaker 132KV	0.0058	8
Transformer 132/15 KV	0.01	168
Transformer 15/0.4 KV	0.015	200
Bus bars 132 KV	0.001	2
Bas bars 15 KV	0.001	2

The following charts, in order, represent the customer hourly load profiles/day for the five feeder points in the bus 2 of IEEE – RBTS.

Feeder1: Peak Load = 2.1 MW; Average Load = 1.8625 MW

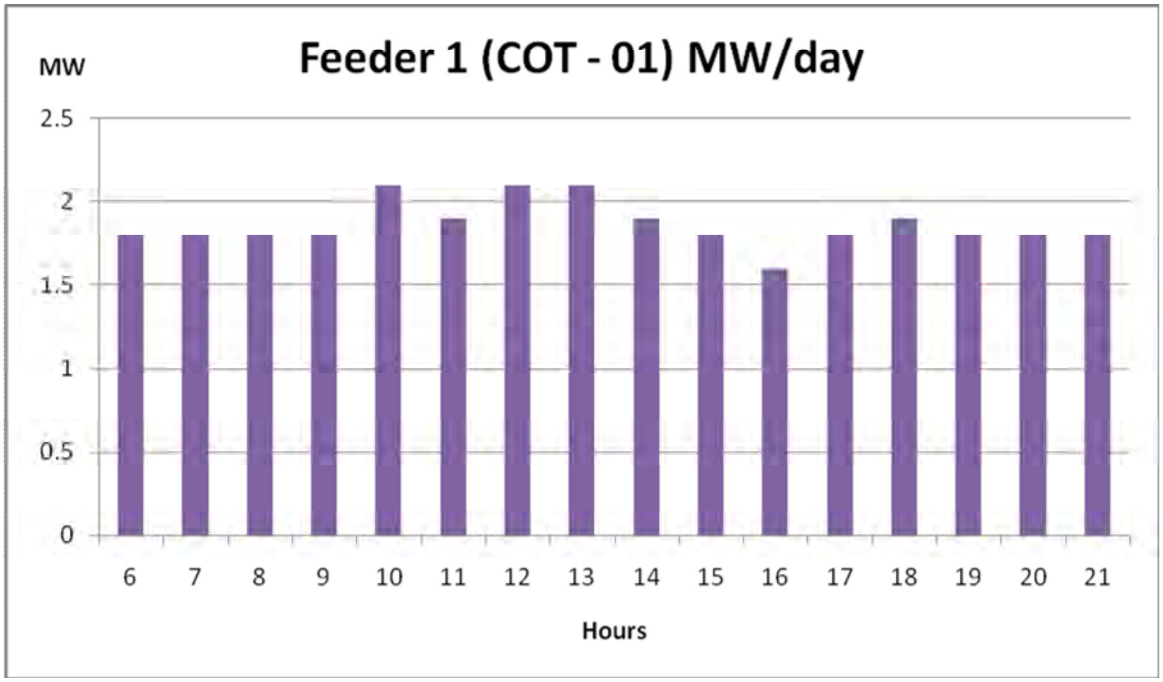


Figure A.2: Hourly Load Profile of Feeder 1

Feeder 2: Peak Load = 1.4 MW; Average Load = 1.325 MW

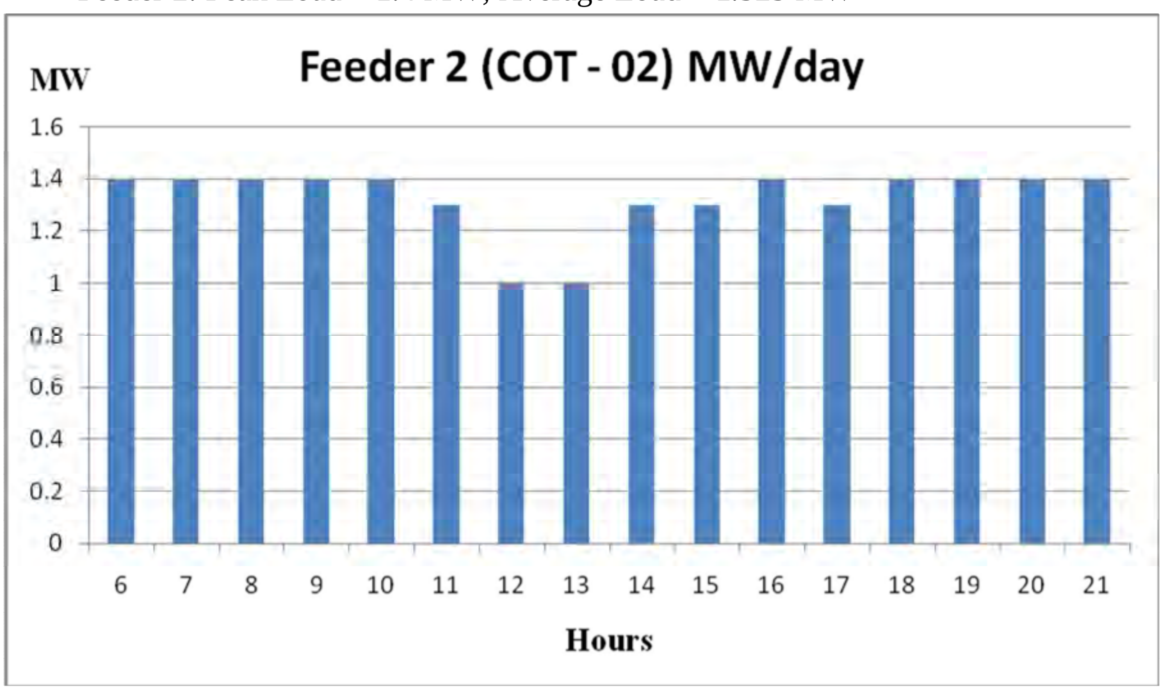


Figure A.3: Hourly Load Profile of Feeder 2

Feeder 3: Peak Load = 7.3 MW; Average Load = 6.05625 MW

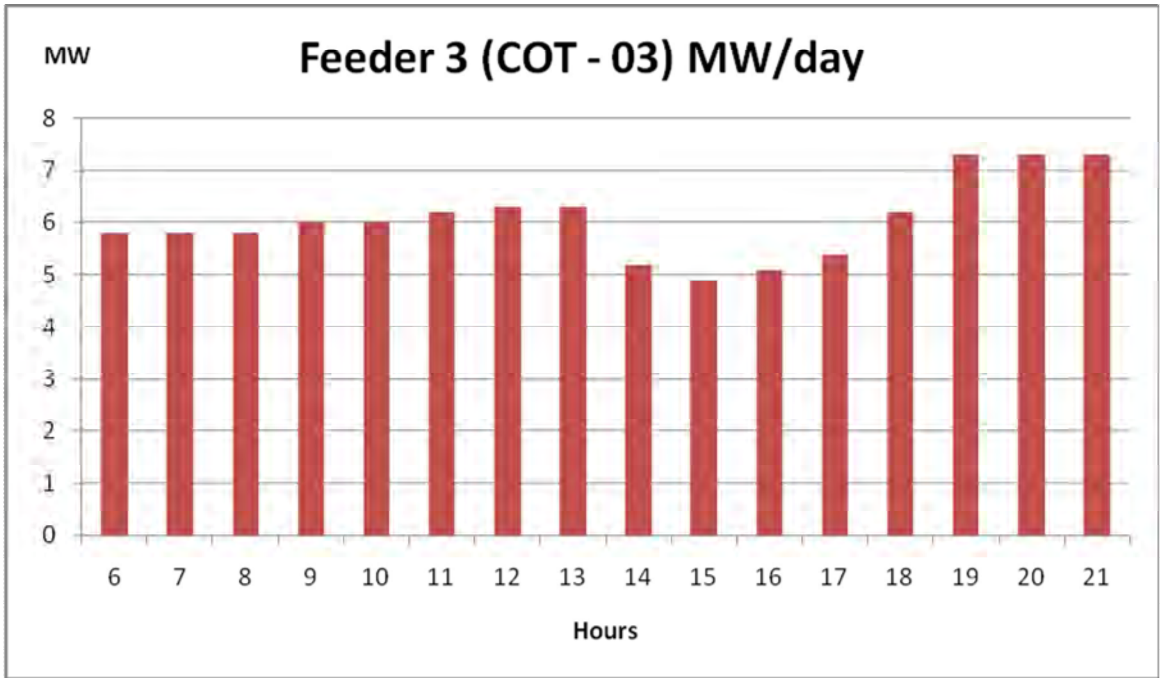


Figure A.4: Hourly Load Profile of Feeder 3

Feeder 4: Peak Load = 4.5 MW; Average Load = 4.0875 MW

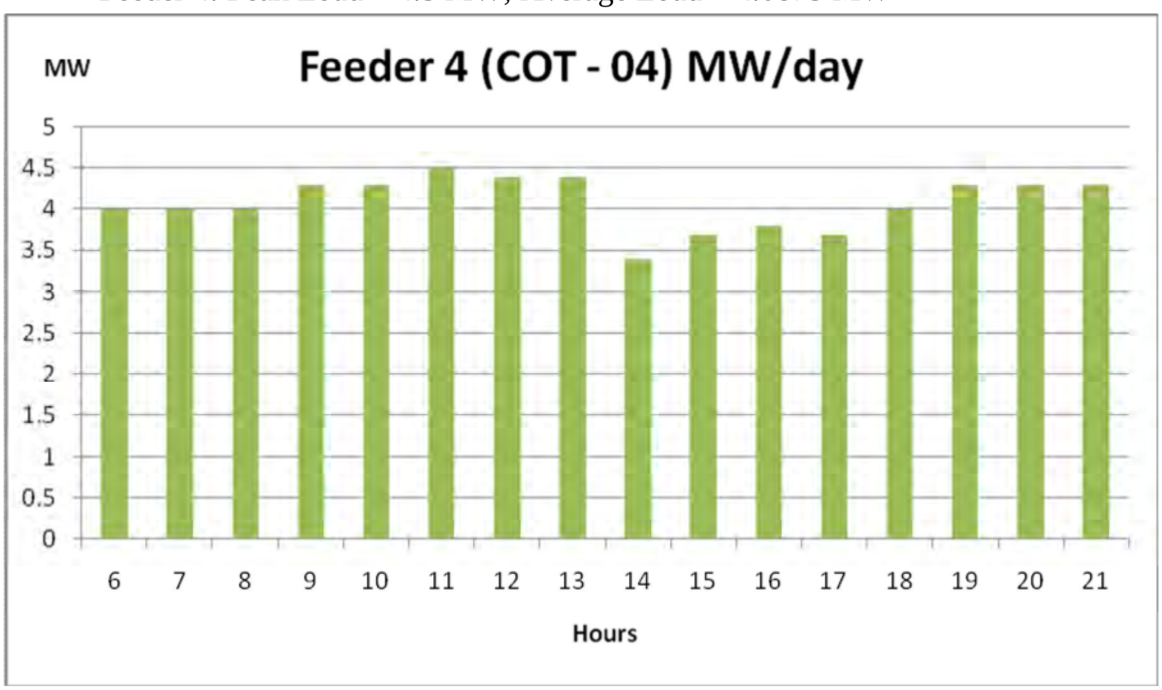


Figure A.5: Hourly Load Profile of Feeder 4

Feeder 5: Peak Load = 4.2 MW; Average Load = 3.275 MW

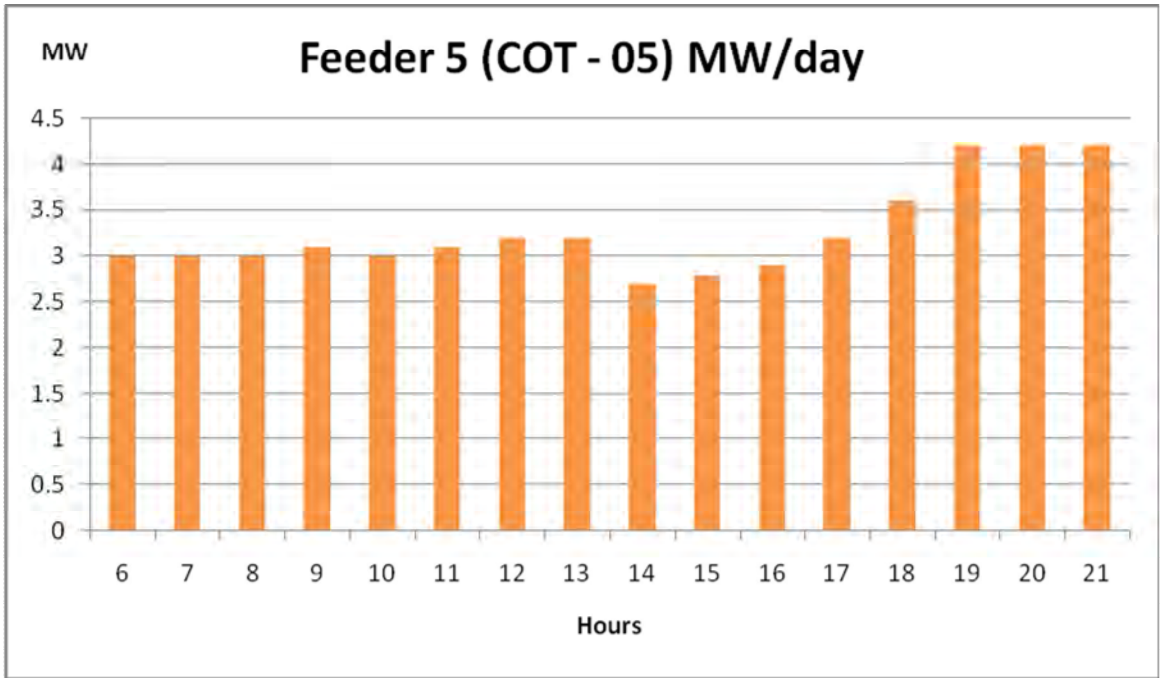


Figure A.6: Hourly Load Profile of Feeder 5

The following figure shows the hourly load profile for the five feeder distribution system.

Total sum of system loads: Peak Load = 19 MW; Average Load = 16.1125 MW

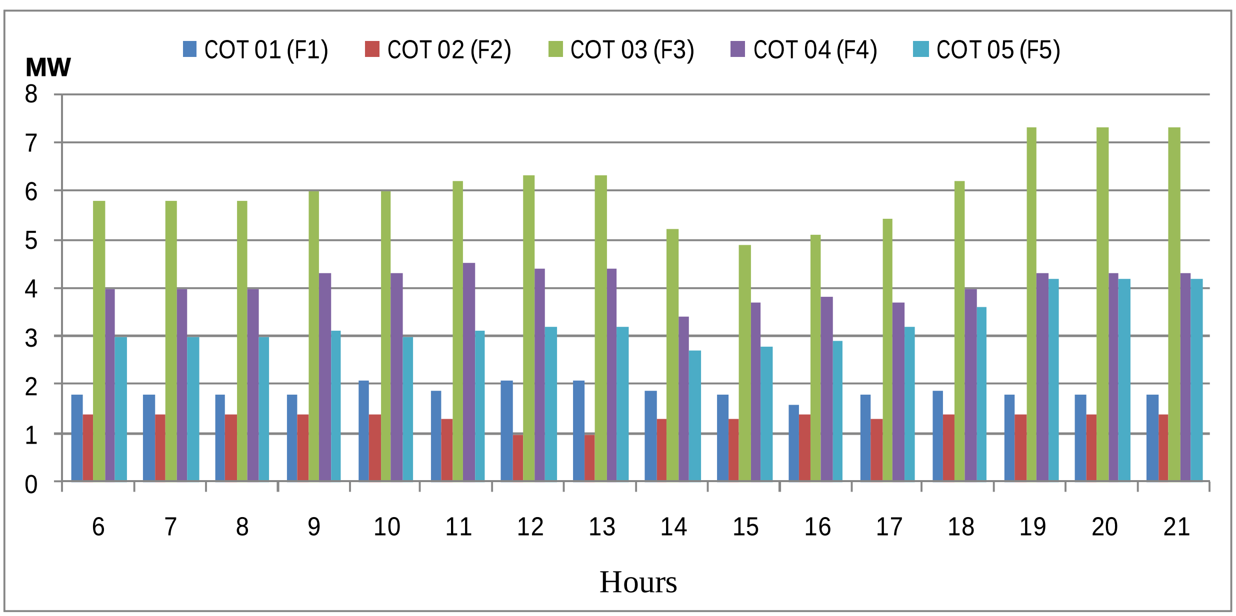


Figure A.7: Hourly Load Profile of all systems

APPENDIX-B

System Reliability Index and Load Flow Analysis Results

When DG is connected at 15kV bus bars

Table B-1: DG is connected except feeder one

```
| Reliability Assessment
| -
| - Network, connectivity analysis
| Selection    = Whole System
| Yes  = Common mode                    | Yes  = Independent second failures
| Yes  = Busbars / terminals            | Yes  = Double earth faults
| Yes  = Lines / cables                 | No   = Maintenance
| Yes  = Transformers                   |
| Study Case: Case1                                         | Annex:           / 1
| System Summary
| System Average Interruption Frequency Index      : SAIFI: =  126.778884 1/Ca
| Customer Average Interruption Frequency Index    : CAIFI: =  126.778884 1/Ca
| System Average Interruption Duration Index       : SAIDI: =  112.983    h/Ca
| Customer Average Interruption Duration Index     : CAIDI: =    0.891    h
| Average Service Availability Index               : ASAI:  =    0.9871023836
| Average Service Unavailability Index             : ASUI:  =    0.0128976164
| Energy Not Supplied                              : ENS:   = 1871.094  MWh/a
| Average Energy Not Supplied                      : AENS:  =    0.029    MWh/Ca
| Load Flow Calculation                   Complete System Report: Voltage Profiles, Grid Interchange
|     AC Load Flow, balanced, positive sequence       |  Automatic Model Adaptation for Convergency    Yes
|     Automatic Tap Adjust of Transformers      Yes   |  Max. Acceptable Load Flow Error for
|     Consider Reactive Power Limits            Yes   |     Nodes                                    1.00 kVA
|                                                     |     Model Equations                          0.10 %
| Grid: Grid            System Stage: Grid       | Study Case: Case1            | Annex:          / 1
```

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
Station 1					
2	132.00	1.000	132.00	0.00	
D1_ Swab	132.00	1.000	132.00	0.00	
Station 2					
D1 _ 15a	15.00	0.995	14.93	-0.72	
Station 3					
D1 _ 15a1	15.00	0.992	14.89	-1.12	
Station 4					
D1 _ 15a2	15.00	0.994	14.91	-0.95	
Station 5					
D1 _ 15a3	15.00	0.988	14.82	-1.72	
Station 6					
D1 _ 15a4	15.00	0.990	14.85	-1.41	
Station 7					
D1 _ 15a5	15.00	0.992	14.87	-1.25	
D1 _ 0.4a1	0.40	1.008	0.40	-1.85	
D1 _ 0.4a2	0.40	1.008	0.40	-1.94	
D1 _ 0.4a3	0.40	1.006	0.40	-2.03	
D1 _ 0.4a4	0.40	1.008	0.40	-1.79	
D1 _ 0.4a5	0.40	1.009	0.40	-1.66	

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/[Mvar]	Motor Load [MW]/[Mvar]	Load [MW]/[Mvar]	Compen-sation [MW]/[Mvar]	External Infeed [MW]/[Mvar]	Interchange to	Power Interchange [MW]/[Mvar]	Total Losses [MW]/[Mvar]	Load Losses [MW]/[Mvar]	Noload Losses [MW]/[Mvar]
0.40	0.00	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-16.61	0.00	0.00	0.00
							-5.46	0.15	0.15	0.00
15.00	3.48	0.00	0.00	0.00	0.00			0.01	0.01	-0.00
	1.14	0.00	0.00	0.00	0.00			0.17	0.18	-0.01
						0.40 kV	16.61	0.00	0.00	0.00
							5.60	0.15	0.15	0.00
						132.00 kV	-13.14	0.00	0.00	0.00
							-4.63	0.19	0.19	0.00
132.00	0.00	0.00	0.00	0.00	13.14			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.81			0.00	0.00	0.00
						15.00 kV	13.14	0.00	0.00	0.00
							4.81	0.19	0.19	0.00
Total:	3.48	0.00	16.61	0.00	13.14		0.00	0.01	0.01	-0.00
	1.14	0.00	5.46	0.00	4.81		0.00	0.50	0.51	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/[Mvar]	Motor Load [MW]/[Mvar]	Load [MW]/[Mvar]	Compen-sation [MW]/[Mvar]	External Infeed [MW]/[Mvar]	Inter Area Flow [MW]/[Mvar]	Total Losses [MW]/[Mvar]	Load Losses [MW]/[Mvar]	Noload Losses [MW]/[Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.48	0.00	16.61	0.00	13.14	0.00	0.01	0.01	-0.00
	1.14	0.00	5.46	0.00	4.81	0.00	0.50	0.51	-0.01
Total:									
	3.48	0.00	16.61	0.00	13.14		0.01	0.01	-0.00
	1.14	0.00	5.46	0.00	4.81		0.50	0.51	-0.01

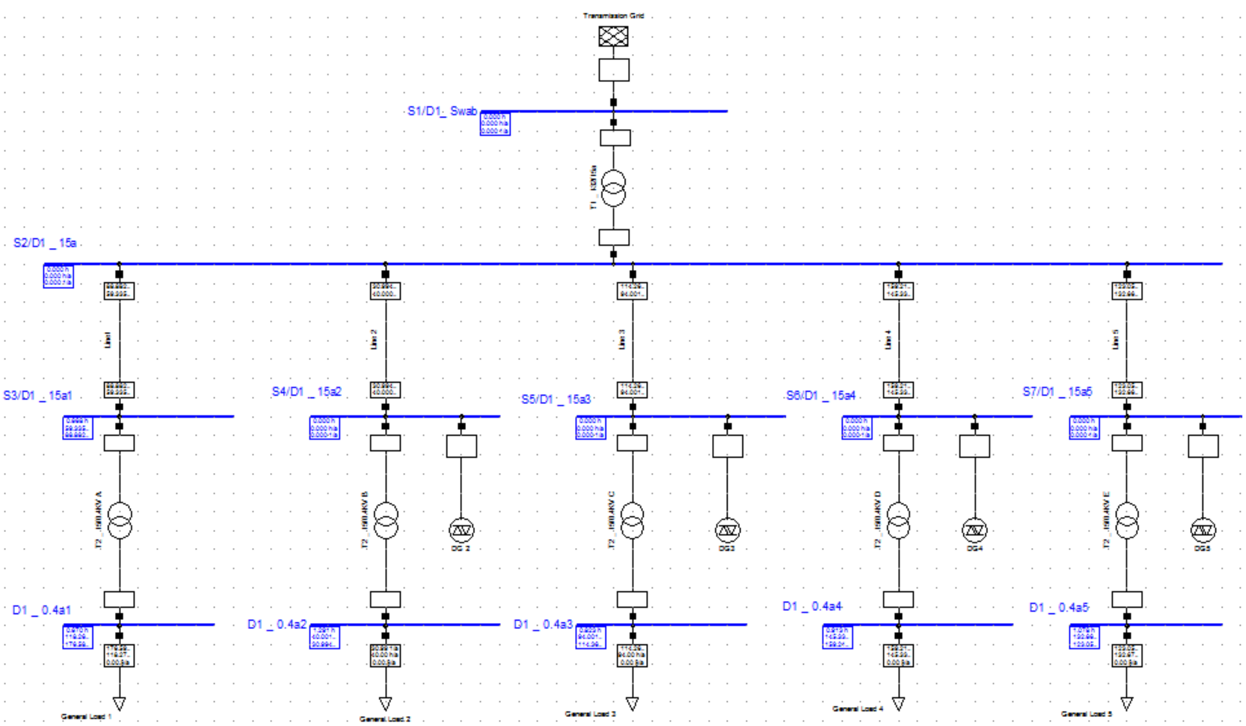


Figure B.1: DG is connected except feeder one

Table B-2: DG is connected except feeder two

Reliability Assessment

-

- Network, connectivity analysis

Selection	= Whole System		
Yes	= Common mode	Yes	= Independent second failures
Yes	= Busbars / terminals	Yes	= Double earth faults
Yes	= Lines / cables	No	= Maintenance
Yes	= Transformers		

Study Case: Case1 | Annex: / 1

System Summary

System Average Interruption Frequency Index	: SAIFI: =	121.500311 1/Ca
Customer Average Interruption Frequency Index	: CAIFI: =	121.500311 1/Ca
System Average Interruption Duration Index	: SAIDI: =	110.045 h/Ca
Customer Average Interruption Duration Index	: CAIDI: =	0.906 h
Average Service Availability Index	: ASAI: =	0.9874378147
Average Service Unavailability Index	: ASUI: =	0.0125621853
Energy Not Supplied	: ENS: =	1814.089 MWh/a
Average Energy Not Supplied	: AENS: =	0.028 MWh/Ca

Load Flow Calculation — Complete System Report: Voltage Profiles, Grid Interchange

AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergency	Yes
Automatic Tap Adjust of Transformers	Yes	Max. Acceptable Load Flow Error for	
Consider Reactive Power Limits	Yes	Nodes	1.00 kVA
		Model Equations	0.10 %

Grid: Grid | System Stage: Grid | Study Case: Case1 | Annex: / 1

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] (-10, -5, 0, +5, +10)
Station 1					
2	132.00	1.000	132.00	0.00	
D1_ Swab	132.00	1.000	132.00	0.00	
Station 2					
D1 _ 15a	15.00	0.996	14.93	-0.71	
Station 3					
D1 _ 15a1	15.00	0.993	14.90	-1.02	
Station 4					
D1 _ 15a2	15.00	0.993	14.90	-1.00	
Station 5					
D1 _ 15a3	15.00	0.988	14.82	-1.71	
Station 6					
D1 _ 15a4	15.00	0.990	14.86	-1.40	
Station 7					
D1 _ 15a5	15.00	0.992	14.87	-1.24	
D1 _ 0.4a1	0.40	1.009	0.40	-1.76	
D1 _ 0.4a2	0.40	1.008	0.40	-2.00	
D1 _ 0.4a3	0.40	1.006	0.40	-2.02	
D1 _ 0.4a4	0.40	1.008	0.40	-1.78	
D1 _ 0.4a5	0.40	1.009	0.40	-1.66	

Grid: Grid			System Stage: Grid			Study Case: Case1			Annex:	/ 2
Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	0.00	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-16.61	0.00	0.00	0.00
							-5.46	0.15	0.15	0.00
15.00	3.62	0.00	0.00	0.00	0.00			0.01	0.01	0.00
	1.19	0.00	0.00	0.00	0.00			0.16	0.18	-0.01
						0.40 kV	16.61	0.00	0.00	0.00
							5.60	0.15	0.15	0.00
						132.00 kV	-13.00	0.00	0.00	0.00
							-4.58	0.18	0.18	0.00
132.00	0.00	0.00	0.00	0.00	13.00			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.76			0.00	0.00	0.00
						15.00 kV	13.00	0.00	0.00	0.00
							4.76	0.18	0.18	0.00
Total:	3.62	0.00	16.61	0.00	13.00		0.00	0.01	0.01	0.00
	1.19	0.00	5.46	0.00	4.76		0.00	0.49	0.51	-0.01

Total System Summary					Study Case: Case1			Annex:	/ 3
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.62	0.00	16.61	0.00	13.00	0.00	0.01	0.01	0.00
	1.19	0.00	5.46	0.00	4.76	0.00	0.49	0.51	-0.01
Total:									
	3.62	0.00	16.61	0.00	13.00		0.01	0.01	0.00
	1.19	0.00	5.46	0.00	4.76		0.49	0.51	-0.01

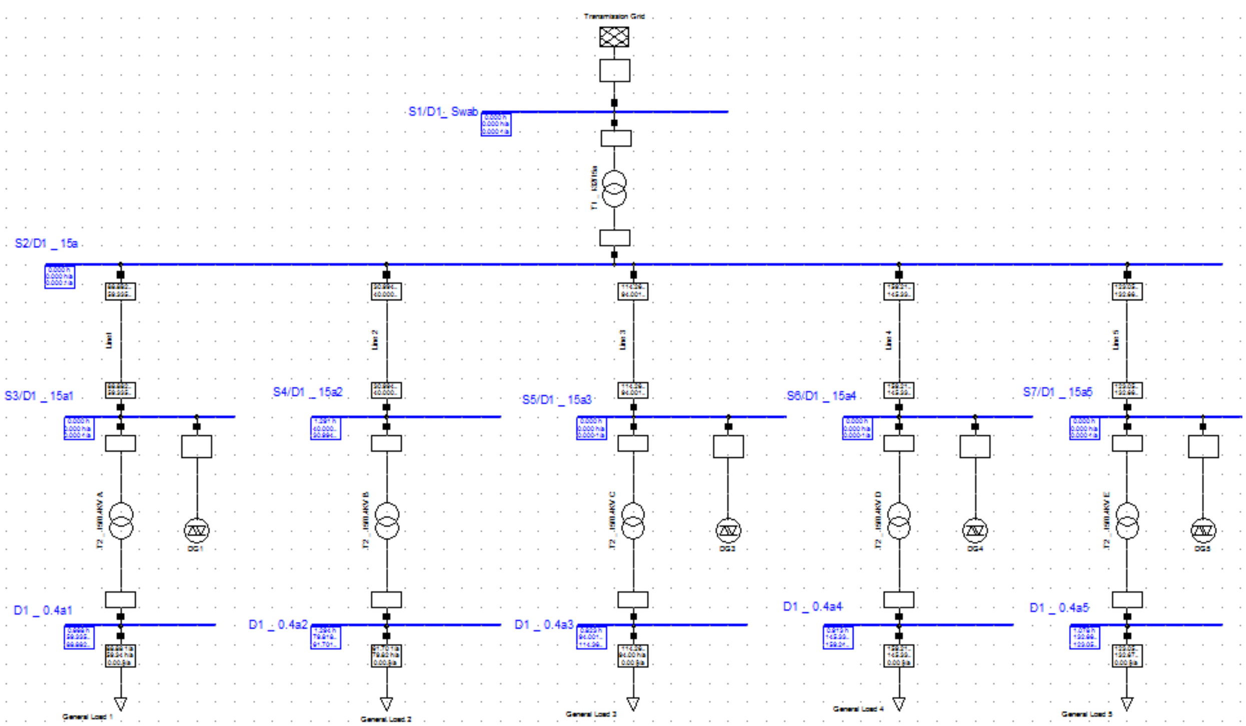


Figure B.2: DG is connected except feeder two

Table B-3: DG is connected except feeder three

Reliability Assessment
-
- Network, connectivity analysis

Selection	= Whole System		
Yes	= Common mode	Yes	= Independent second failures
Yes	= Busbars / terminals	Yes	= Double earth faults
Yes	= Lines / cables	No	= Maintenance
Yes	= Transformers		

Study Case: Case1 | Annex: / 1

System Summary

System Average Interruption Frequency Index	: SAIFI: =	173.073094 1/Ca
Customer Average Interruption Frequency Index	: CAIFI: =	173.073094 1/Ca
System Average Interruption Duration Index	: SAIDI: =	152.444 h/Ca
Customer Average Interruption Duration Index	: CAIDI: =	0.881 h
Average Service Availability Index	: ASAI: =	0.9825977124
Average Service Unavailability Index	: ASUI: =	0.0174022876
Energy Not Supplied	: ENS: =	2324.488 MWh/a
Average Energy Not Supplied	: AENS: =	0.036 MWh/Ca

Load Flow Calculation — Complete System Report: Voltage Profiles, Grid Interchange

AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergency	Yes
Automatic Tap Adjust of Transformers	Yes	Max. Acceptable Load Flow Error for	
Consider Reactive Power Limits	Yes	Nodes	1.00 kVA
		Model Equations	0.10 %

Grid: Grid | System Stage: Grid | Study Case: Case1 | Annex: / 1

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] (-10 -5 0 +5 +10)
Station 1					
2	132.00	1.000	132.00	0.00	
D1_ Swab	132.00	1.000	132.00	0.00	
Station 2					
D1 _ 15a	15.00	0.995	14.93	-0.78	
Station 3					
D1 _ 15a1	15.00	0.993	14.89	-1.09	
Station 4					
D1 _ 15a2	15.00	0.993	14.90	-1.00	
Station 5					
D1 _ 15a3	15.00	0.985	14.78	-2.09	
Station 6					
D1 _ 15a4	15.00	0.990	14.85	-1.47	
Station 7					
D1 _ 15a5	15.00	0.991	14.87	-1.30	
D1 _ 0.4a1					
	0.40	1.009	0.40	-1.82	
D1 _ 0.4a2					
	0.40	1.008	0.40	-2.00	
D1 _ 0.4a3					
	0.40	1.003	0.40	-2.41	
D1 _ 0.4a4					
	0.40	1.008	0.40	-1.85	
D1 _ 0.4a5					
	0.40	1.009	0.40	-1.72	

Grid: Grid	System Stage: Grid					Study Case: Case1			Annex:	/ 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	0.00	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-16.61	0.00	0.00	0.00
							-5.46	0.15	0.15	0.00
15.00	2.44	0.00	0.00	0.00	0.00			0.02	0.02	-0.00
	0.80	0.00	0.00	0.00	0.00			0.23	0.24	-0.01
						0.40 kV	16.61	0.00	0.00	0.00
							5.60	0.15	0.15	0.00
						132.00 kV	-14.19	0.00	0.00	0.00
							-5.03	0.22	0.22	0.00
132.00	0.00	0.00	0.00	0.00	14.19			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	5.25			0.00	0.00	0.00
						15.00 kV	14.19	0.00	0.00	0.00
							5.25	0.22	0.22	0.00
Total:	2.44	0.00	16.61	0.00	14.19		0.00	0.02	0.02	-0.00
	0.80	0.00	5.46	0.00	5.25		0.00	0.59	0.61	-0.01

Total System Summary						Study Case: Case1		Annex:	/ 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	2.44	0.00	16.61	0.00	14.19	0.00	0.02	0.02	-0.00
	0.80	0.00	5.46	0.00	5.25	0.00	0.59	0.61	-0.01
Total:									
	2.44	0.00	16.61	0.00	14.19		0.02	0.02	-0.00
	0.80	0.00	5.46	0.00	5.25		0.59	0.61	-0.01

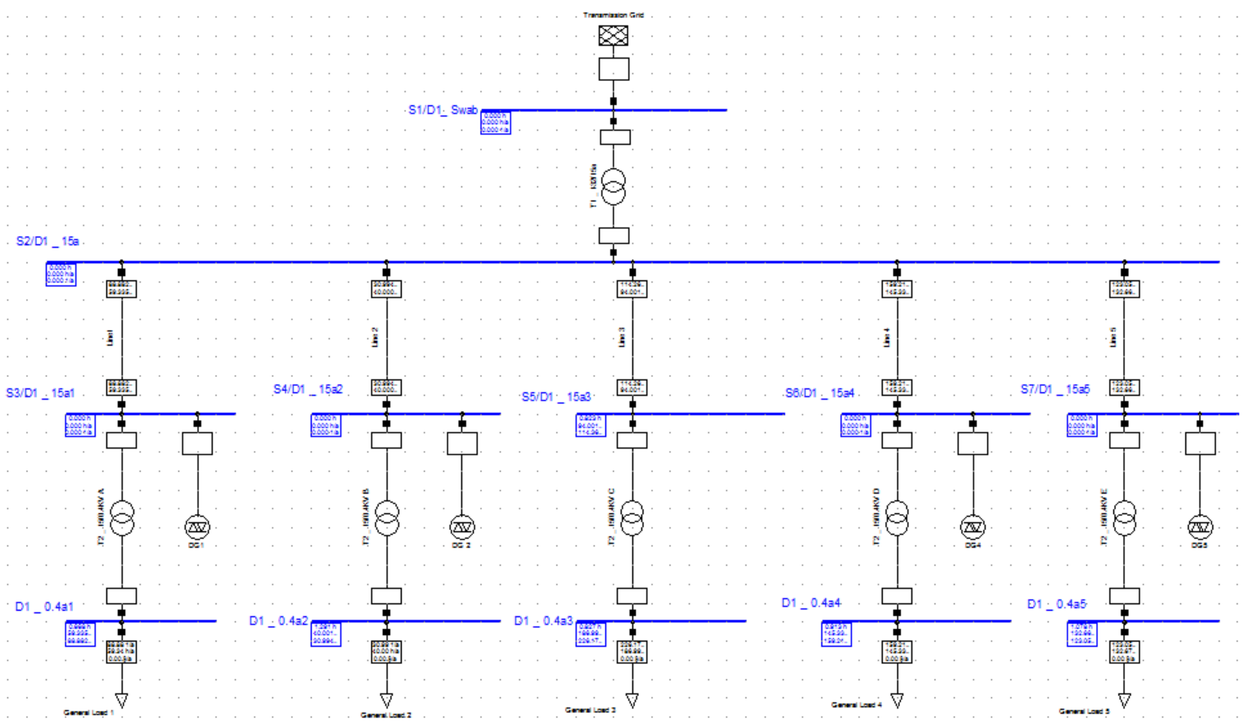


Figure B.3: DG is connected except feeder three

Table B-4: DG is connected except feeder four

```
| Reliability Assessment
| -
| - Network, connectivity analysis

| Selection    = Whole System
| Yes  = Common mode                        | Yes  = Independent second failures
| Yes  = Busbars / terminals                | Yes  = Double earth faults
| Yes  = Lines / cables                     | No   = Maintenance
| Yes  = Transformers                       |

| Study Case: Case1                                                        | Annex:          / 1  |

| System Summary

| System Average Interruption Frequency Index       :  SAIFI: =  150.199699 1/Ca
| Customer Average Interruption Frequency Index     :  CAIFI: =  150.199699 1/Ca
| System Average Interruption Duration Index        :  SAIDI: =  136.287    h/Ca
| Customer Average Interruption Duration Index      :  CAIDI: =    0.907    h
| Average Service Availability Index                :  ASAI:  =    0.9844421276
| Average Service Unavailability Index              :  ASUI:  =    0.0155578724
| Energy Not Supplied                               :  ENS:   = 2345.524    MWh/a
| Average Energy Not Supplied                       :  AENS:  =    0.037    MWh/Ca

| Load Flow Calculation                             Complete System Report: Voltage Profiles, Grid Interchange |

|     AC Load Flow, balanced, positive sequence              |  Automatic Model Adaptation for Convergency     Yes      |
|     Automatic Tap Adjust of Transformers          Yes      |  Max. Acceptable Load Flow Error for                     |
|     Consider Reactive Power Limits                Yes      |     Nodes                                   1.00 kVA  |
|                                                            |     Model Equations                         0.10 %    |

| Grid: Grid              System Stage: Grid          | Study Case: Case1              | Annex:          / 1  |

|                   rtd.V     Bus - voltage                          Voltage - Deviation [%]                 |
|                   [kV]  [p.u.]     [kV]  [deg]       -10       -5         0        +5        +10           |

|Station 1
|  2               132.00  1.000   132.00   0.00
|  D1_ Swab        132.00  1.000   132.00   0.00
|Station 2
|  D1 _ 15a         15.00  0.995    14.93  -0.75
|Station 3
|  D1 _ 15a1        15.00  0.993    14.89  -1.06
|Station 4
|  D1 _ 15a2        15.00  0.994    14.90  -0.97
|Station 5
|  D1 _ 15a3        15.00  0.988    14.82  -1.74
|Station 6
|  D1 _ 15a4        15.00  0.989    14.83  -1.63
|Station 7
|  D1 _ 15a5        15.00  0.991    14.87  -1.27
|D1 _ 0.4a1
|                    0.40  1.009     0.40  -1.79
|D1 _ 0.4a2
|                    0.40  1.008     0.40  -1.97
|D1 _ 0.4a3
|                    0.40  1.006     0.40  -2.06
|D1 _ 0.4a4
|                    0.40  1.007     0.40  -2.01
|D1 _ 0.4a5
|                    0.40  1.009     0.40  -1.69
```

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	0.00	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-16.61	0.00	0.00	0.00
							-5.46	0.15	0.15	0.00
15.00	3.00	0.00	0.00	0.00	0.00			0.02	0.02	-0.00
	0.99	0.00	0.00	0.00	0.00			0.19	0.20	-0.01
						0.40 kV	16.61	0.00	0.00	0.00
							5.60	0.15	0.15	0.00
						132.00 kV	-13.62	0.00	0.00	0.00
							-4.81	0.20	0.20	0.00
132.00	0.00	0.00	0.00	0.00	13.62			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	5.01			0.00	0.00	0.00
						15.00 kV	13.62	0.00	0.00	0.00
							5.01	0.20	0.20	0.00
Total:	3.00	0.00	16.61	0.00	13.62		0.00	0.02	0.02	-0.00
	0.99	0.00	5.46	0.00	5.01		0.00	0.54	0.55	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.00	0.00	16.61	0.00	13.62	0.00	0.02	0.02	-0.00
	0.99	0.00	5.46	0.00	5.01	0.00	0.54	0.55	-0.01
Total:									
	3.00	0.00	16.61	0.00	13.62		0.02	0.02	-0.00
	0.99	0.00	5.46	0.00	5.01		0.54	0.55	-0.01

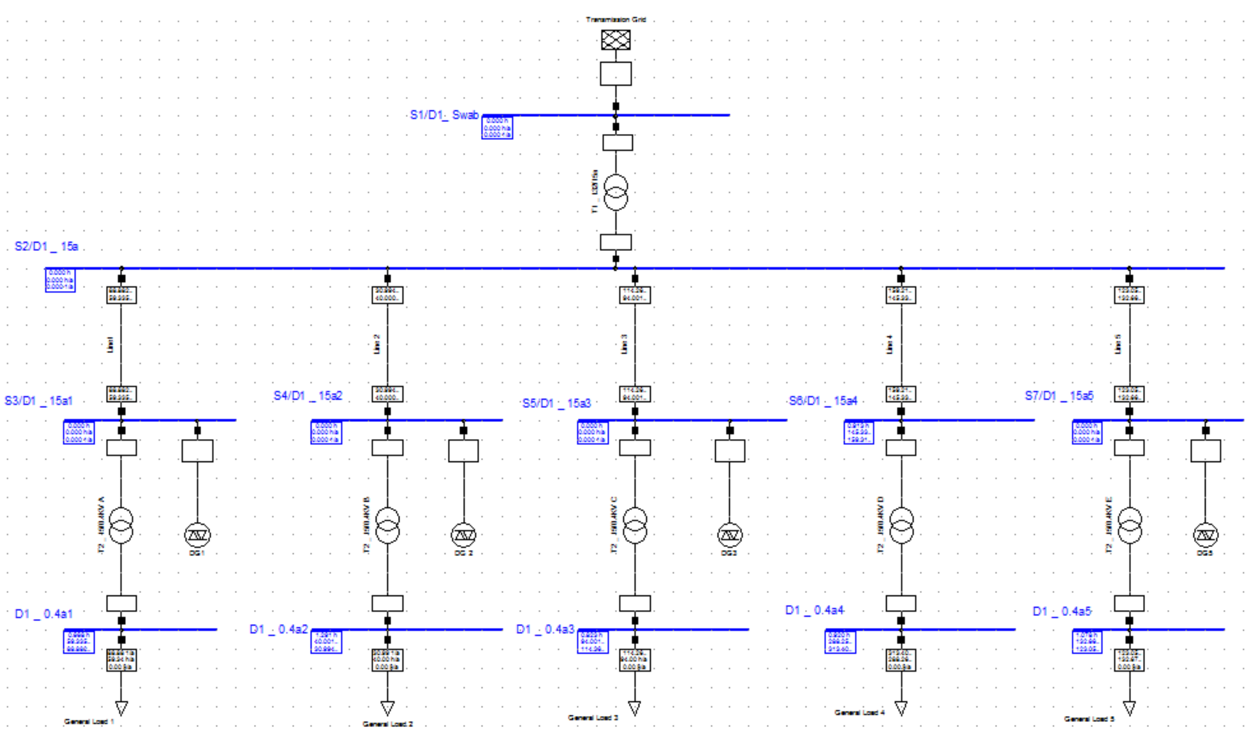


Figure B.4: DG is connected except feeder four

Table B-5: DG is connected except feeder five

Reliability Assessment

- Network, connectivity analysis

Selection = Whole System

Yes = Common mode	Yes = Independent second failures
Yes = Busbars / terminals	Yes = Double earth faults
Yes = Lines / cables	No = Maintenance
Yes = Transformers	

Study Case: Case1 | Annex: / 1

System Summary

System Average Interruption Frequency Index	SAIFI: =	148.609943	1/Ca
Customer Average Interruption Frequency Index	CAIFI: =	148.609943	1/Ca
System Average Interruption Duration Index	SAIDI: =	139.486	h/Ca
Customer Average Interruption Duration Index	CAIDI: =	0.939	h
Average Service Availability Index	ASAI: =	0.9840769267	
Average Service Unavailability Index	ASUI: =	0.0159230733	
Energy Not Supplied	ENS: =	2189.235	MWh/a
Average Energy Not Supplied	AENS: =	0.034	MWh/Ca

Load Flow Calculation — Complete System Report: Voltage Profiles, Grid Interchange

AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergency	Yes
Automatic Tap Adjust of Transformers	Yes	Max. Acceptable Load Flow Error for	
Consider Reactive Power Limits	Yes	Nodes	1.00 kVA
		Model Equations	0.10 %

Grid: Grid | System Stage: Grid | Study Case: Case1 | Annex: / 1

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
Station 1				
2	132.00	1.000	132.00	0.00
D1_ Swab	132.00	1.000	132.00	0.00
Station 2				
D1 _ 15a	15.00	0.995	14.93	-0.74
Station 3				
D1 _ 15a1	15.00	0.993	14.89	-1.05
Station 4				
D1 _ 15a2	15.00	0.994	14.90	-0.97
Station 5				
D1 _ 15a3	15.00	0.988	14.82	-1.74
Station 6				
D1 _ 15a4	15.00	0.990	14.85	-1.43
Station 7				
D1 _ 15a5	15.00	0.990	14.85	-1.45
D1 _ 0.4a1	0.40	1.009	0.40	-1.79
D1 _ 0.4a2	0.40	1.008	0.40	-1.97
D1 _ 0.4a3	0.40	1.006	0.40	-2.05
D1 _ 0.4a4	0.40	1.008	0.40	-1.81
D1 _ 0.4a5	0.40	1.008	0.40	-1.87

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

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex:	/ 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	0.00	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-16.61	0.00	0.00	0.00
							-5.46	0.15	0.15	0.00
15.00	3.06	0.00	0.00	0.00	0.00			0.02	0.02	-0.00
	1.01	0.00	0.00	0.00	0.00			0.18	0.20	-0.01
						0.40 kV	16.61	0.00	0.00	0.00
							5.60	0.15	0.15	0.00
						132.00 kV	-13.56	0.00	0.00	0.00
							-4.78	0.20	0.20	0.00
132.00	0.00	0.00	0.00	0.00	13.56			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.98			0.00	0.00	0.00
						15.00 kV	13.56	0.00	0.00	0.00
							4.98	0.20	0.20	0.00
Total:	3.06	0.00	16.61	0.00	13.56		0.00	0.02	0.02	-0.00
	1.01	0.00	5.46	0.00	4.98		0.00	0.53	0.54	-0.01

Total System Summary	Study Case: Case1	Annex:	/ 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.06	0.00	16.61	0.00	13.56	0.00	0.02	0.02	-0.00
	1.01	0.00	5.46	0.00	4.98	0.00	0.53	0.54	-0.01
Total:									
	3.06	0.00	16.61	0.00	13.56		0.02	0.02	-0.00
	1.01	0.00	5.46	0.00	4.98		0.53	0.54	-0.01

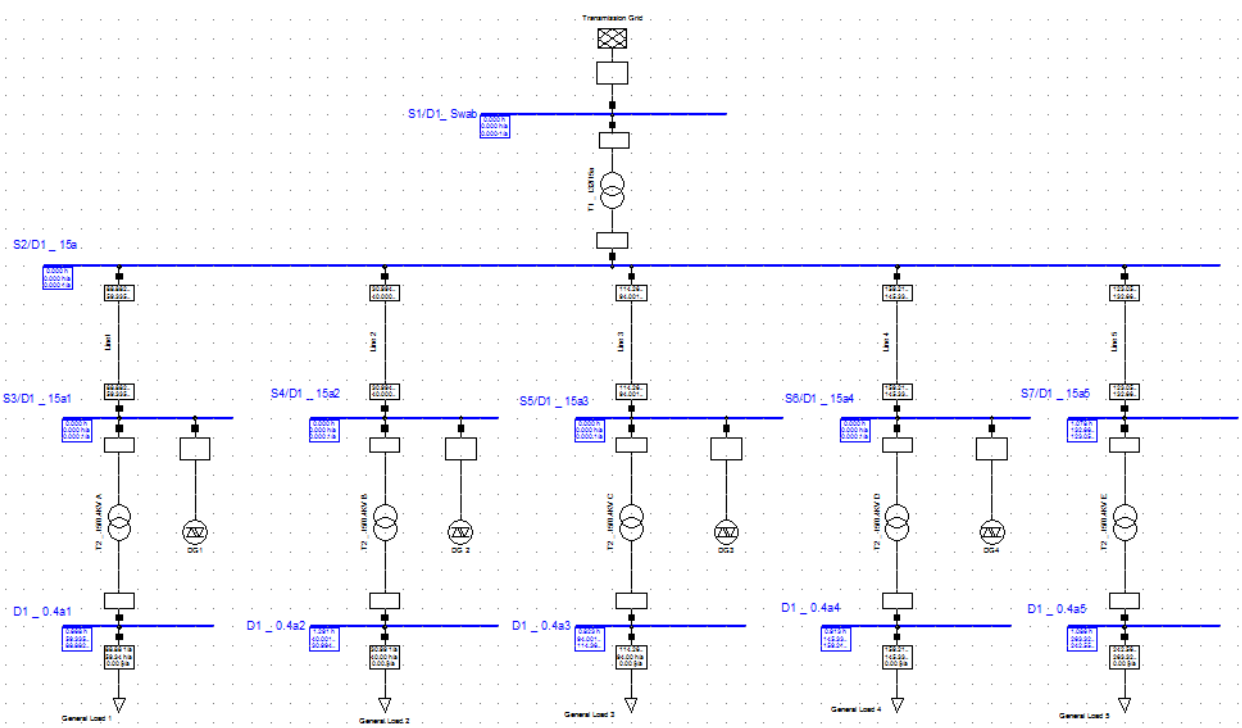


Figure B.5: DG is connected except feeder five

Table B-6: DG is connected except feeder one and two

Reliability Assessment
-
- Network, connectivity analysis

Selection	= Whole System		
Yes	= Common mode	Yes	= Independent second failures
Yes	= Busbars / terminals	Yes	= Double earth faults
Yes	= Lines / cables	No	= Maintenance
Yes	= Transformers		

Study Case: Case1 | Annex: / 1

System Summary

System Average Interruption Frequency Index	: SAIFI: =	127.753065 1/Ca
Customer Average Interruption Frequency Index	: CAIFI: =	127.753065 1/Ca
System Average Interruption Duration Index	: SAIDI: =	114.246 h/Ca
Customer Average Interruption Duration Index	: CAIDI: =	0.894 h
Average Service Availability Index	: ASAI: =	0.9869581820
Average Service Unavailability Index	: ASUI: =	0.0130418180
Energy Not Supplied	: ENS: =	1923.852 MWh/a
Average Energy Not Supplied	: AENS: =	0.030 MWh/Ca

Load Flow Calculation — Complete System Report: Voltage Profiles, Grid Interchange

AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergency	Yes
Automatic Tap Adjust of Transformers	Yes	Max. Acceptable Load Flow Error for	
Consider Reactive Power Limits	Yes	Nodes	1.00 kVA
		Model Equations	0.10 %

Grid: Grid System Stage: Grid | Study Case: Case1 | Annex: / 1

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
Station 1				
2	132.00	1.000	132.00	0.00
D1_ Swab	132.00	1.000	132.00	0.00
Station 2				
D1 _ 15a	15.00	0.995	14.93	-0.74
Station 3				
D1 _ 15a1	15.00	0.992	14.89	-1.14
Station 4				
D1 _ 15a2	15.00	0.993	14.90	-1.02
Station 5				
D1 _ 15a3	15.00	0.988	14.82	-1.73
Station 6				
D1 _ 15a4	15.00	0.990	14.85	-1.42
Station 7				
D1 _ 15a5	15.00	0.991	14.87	-1.26
D1 _ 0.4a1	0.40	1.008	0.40	-1.87
D1 _ 0.4a2	0.40	1.008	0.40	-2.02
D1 _ 0.4a3	0.40	1.006	0.40	-2.05
D1 _ 0.4a4	0.40	1.008	0.40	-1.80
D1 _ 0.4a5	0.40	1.009	0.40	-1.68

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

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	0.00	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.00	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-16.61	0.00	0.00	0.00
							-5.46	0.15	0.15	0.00
15.00	3.20	0.00	0.00	0.00	0.00			0.01	0.01	-0.00
	1.05	0.00	0.00	0.00	0.00			0.17	0.18	-0.01
						0.40 kV	16.61	0.00	0.00	0.00
							5.60	0.15	0.15	0.00
						132.00 kV	-13.42	0.00	0.00	0.00
							-4.72	0.19	0.19	0.00
132.00	0.00	0.00	0.00	0.00	13.42			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.92			0.00	0.00	0.00
						15.00 kV	13.42	0.00	0.00	0.00
							4.92	0.19	0.19	0.00
Total:	3.20	0.00	16.61	0.00	13.42		0.00	0.01	0.01	-0.00
	1.05	0.00	5.46	0.00	4.92		0.00	0.51	0.52	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.20	0.00	16.61	0.00	13.42	0.00	0.01	0.01	-0.00
	1.05	0.00	5.46	0.00	4.92	0.00	0.51	0.52	-0.01
Total:									
	3.20	0.00	16.61	0.00	13.42		0.01	0.01	-0.00
	1.05	0.00	5.46	0.00	4.92		0.51	0.52	-0.01

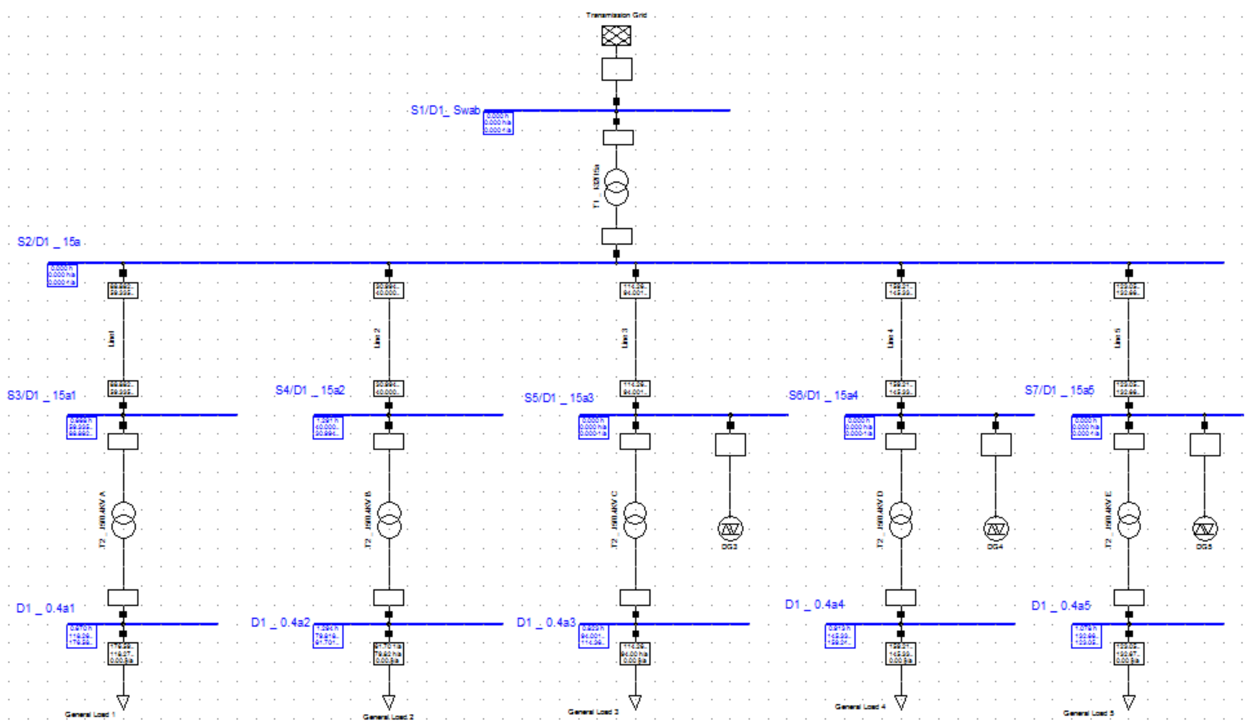


Figure B.6: DG is connected except feeder one and two

When DG is connected at 0.4kV bus bars

Table B-7: DG is connected except feeder one

```
-------------------------------------------------------------------------------------------------------------
|                 |                                                      |   DIgSILENT    | Project:         |
|                 |                                                      | PowerFactory   |------------------|
|                 |                                                      |    14.0.524    | Date:  3/2/2016  |
-------------------------------------------------------------------------------------------------------------
| Reliability Assessment                                                                                    |
| -                                                                                                         |
| - Network, connectivity analysis                                                                          |
-------------------------------------------------------------------------------------------------------------
| Selection    = Whole System                                                                               |
| Yes  = Common mode                            |  Yes  = Independent second failures                       |
| Yes  = Busbars / terminals                    |  Yes  = Double earth faults                               |
| Yes  = Lines / cables                         |  No   = Maintenance                                       |
| Yes  = Transformers                           |                                                           |
-------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------
| Study Case: Case1                                                              | Annex:            / 1  |
-------------------------------------------------------------------------------------------------------------
| System Summary                                                                                            |
-------------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index       :  SAIFI: =   12.589516 1/Ca                             |
| Customer Average Interruption Frequency Index     :  CAIFI: =  176.585690 1/Ca                             |
| System Average Interruption Duration Index        :  SAIDI: =    8.432    h/Ca                             |
| Customer Average Interruption Duration Index      :  CAIDI: =    0.670    h                                |
| Average Service Availability Index                :  ASAI:  =    0.9990374639                               |
| Average Service Unavailability Index              :  ASUI:  =    0.0009625361                               |
| Energy Not Supplied                               :  ENS:   =  220.273    MWh/a                            |
| Average Energy Not Supplied                       :  AENS:  =    0.003    MWh/Ca                           |
-------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                        Complete System Report: Voltage Profiles, Grid Interchange |
-------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence           |   Automatic Model Adaptation for Convergency  Yes  |
|    Automatic Tap Adjust of Transformers         Yes    |   Max. Acceptable Load Flow Error for              |
|    Consider Reactive Power Limits               Yes    |      Nodes                              1.00 kVA   |
|                                                        |      Model Equations                    0.10 %     |
-------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------
| Grid: Grid            System Stage: Grid        | Study Case: Case1              | Annex:          / 1  |
-------------------------------------------------------------------------------------------------------------
|                   rtd.V     Bus - voltage                           Voltage - Deviation [%]               |
|                   [kV]  [p.u.]     [kV]  [deg]        -10       -5        0        +5        +10         |
-------------------------------------------------------------------------------------------------------------
|Station 1                                                                                                  |
|  2               132.00   1.000  132.00   0.00                                                            |
|  D1_ Swab        132.00   1.000  132.00   0.00                                                            |
|Station 2                                                                                                  |
|  D1 _ 15a         15.00   0.996   14.93  -0.72                                                            |
|Station 3                                                                                                  |
|  D1 _ 15a1        15.00   0.992   14.89  -1.12                                                            |
|Station 4                                                                                                  |
|  D1 _ 15a2        15.00   0.994   14.91  -0.95                                                            |
|Station 5                                                                                                  |
|  D1 _ 15a3        15.00   0.988   14.82  -1.72                                                            |
|Station 6                                                                                                  |
|  D1 _ 15a4        15.00   0.990   14.86  -1.41                                                            |
|Station 7                                                                                                  |
|  D1 _ 15a5        15.00   0.992   14.87  -1.25                                                            |
|D1 _ 0.4a1                                                                                                 |
|                    0.40   1.008    0.40  -1.85                                                            |
|D1 _ 0.4a2                                                                                                 |
|                    0.40   1.009    0.40  -1.73                                                            |
|D1 _ 0.4a3                                                                                                 |
|                    0.40   1.007    0.40  -1.96                                                            |
|D1 _ 0.4a4                                                                                                 |
|                    0.40   1.009    0.40  -1.70                                                            |
|D1 _ 0.4a5                                                                                                 |
|                    0.40   1.010    0.40  -1.56                                                            |
-------------------------------------------------------------------------------------------------------------
```

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	3.48	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	1.14	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.13	0.00	0.00	0.00
							-4.31	0.10	0.10	0.00
15.00	0.00	0.00	0.00	0.00	0.00			0.01	0.01	-0.00
	0.00	0.00	0.00	0.00	0.00			0.17	0.18	-0.01
						0.40 kV	13.13	0.00	0.00	0.00
							4.41	0.10	0.10	0.00
						132.00 kV	-13.14	0.00	0.00	0.00
							-4.58	0.19	0.19	0.00
132.00	0.00	0.00	0.00	0.00	13.14			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.76			0.00	0.00	0.00
						15.00 kV	13.14	0.00	0.00	0.00
							4.76	0.19	0.19	0.00
Total:	3.48	0.00	16.61	0.00	13.14		0.00	0.01	0.01	-0.00
	1.14	0.00	5.46	0.00	4.76		0.00	0.45	0.46	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.48	0.00	16.61	0.00	13.14	0.00	0.01	0.01	-0.00
	1.14	0.00	5.46	0.00	4.76	0.00	0.45	0.46	-0.01
Total:									
	3.48	0.00	16.61	0.00	13.14		0.01	0.01	-0.00
	1.14	0.00	5.46	0.00	4.76		0.45	0.46	-0.01

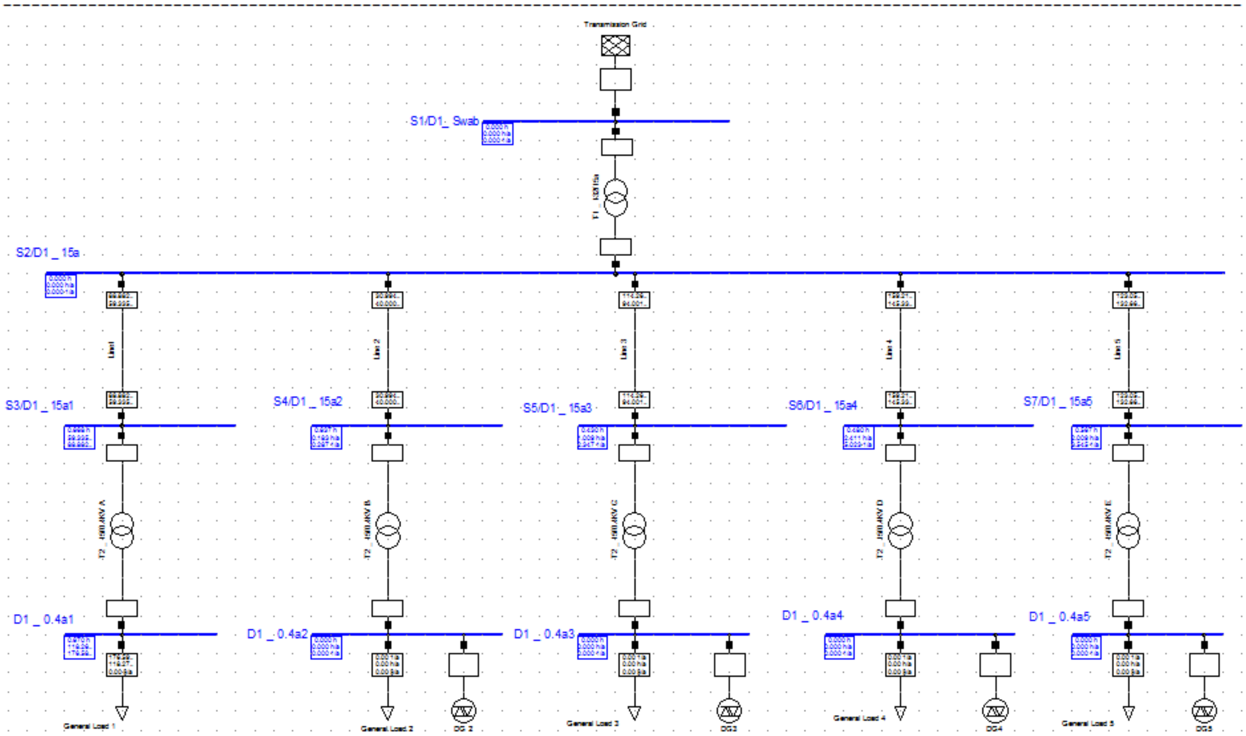


Figure B.7: DG is connected except feeder one

Table B-8: DG is connected except feeder two

Reliability Assessment	
-	
- Network, connectivity analysis	
Selection = Whole System	
Yes = Common mode	Yes = Independent second failures
Yes = Busbars / terminals	Yes = Double earth faults
Yes = Lines / cables	No = Maintenance
Yes = Transformers	

Study Case: Case1	Annex: / 1

System Summary		
System Average Interruption Frequency Index	SAIFI: =	1.957456 1/Ca
Customer Average Interruption Frequency Index	CAIFI: =	61.701495 1/Ca
System Average Interruption Duration Index	SAIDI: =	2.532 h/Ca
Customer Average Interruption Duration Index	CAIDI: =	1.294 h
Average Service Availability Index	ASAI: =	0.9997109354
Average Service Unavailability Index	ASUI: =	0.0002890646
Energy Not Supplied	ENS: =	105.758 MWh/a
Average Energy Not Supplied	AENS: =	0.002 MWh/Ca

Load Flow Calculation		Complete System Report: Voltage Profiles, Grid Interchange	
AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergency	Yes
Automatic Tap Adjust of Transformers	Yes	Max. Acceptable Load Flow Error for	
Consider Reactive Power Limits	Yes	Nodes	1.00 kVA
		Model Equations	0.10 %

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 1

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
Station 1					
2	132.00	1.000	132.00	0.00	
D1_ Swab	132.00	1.000	132.00	0.00	
Station 2					
D1 _ 15a	15.00	0.996	14.93	-0.71	
Station 3					
D1 _ 15a1	15.00	0.993	14.90	-1.02	
Station 4					
D1 _ 15a2	15.00	0.993	14.90	-1.00	
Station 5					
D1 _ 15a3	15.00	0.988	14.82	-1.71	
Station 6					
D1 _ 15a4	15.00	0.990	14.86	-1.40	
Station 7					
D1 _ 15a5	15.00	0.992	14.88	-1.24	
D1 _ 0.4a1					
	0.40	1.010	0.40	-1.59	
D1 _ 0.4a2					
	0.40	1.008	0.40	-2.00	
D1 _ 0.4a3					
	0.40	1.007	0.40	-1.95	
D1 _ 0.4a4					
	0.40	1.009	0.40	-1.70	
D1 _ 0.4a5					
	0.40	1.010	0.40	-1.55	

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	3.62	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	1.19	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-12.99	0.00	0.00	0.00
							-4.27	0.10	0.10	0.00
15.00	0.00	0.00	0.00	0.00	0.00			0.01	0.01	-0.00
	0.00	0.00	0.00	0.00	0.00			0.16	0.18	-0.01
						0.40 kV	12.99	0.00	0.00	0.00
							4.36	0.10	0.10	0.00
						132.00 kV	-13.00	0.00	0.00	0.00
							-4.53	0.18	0.18	0.00
132.00	0.00	0.00	0.00	0.00	13.00			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.71			0.00	0.00	0.00
						15.00 kV	13.00	0.00	0.00	0.00
							4.71	0.18	0.18	0.00
Total:	3.62	0.00	16.61	0.00	13.00		0.00	0.01	0.01	-0.00
	1.19	0.00	5.46	0.00	4.71		0.00	0.44	0.46	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.62	0.00	16.61	0.00	13.00	0.00	0.01	0.01	-0.00
	1.19	0.00	5.46	0.00	4.71	0.00	0.44	0.46	-0.01
Total:									
	3.62	0.00	16.61	0.00	13.00		0.01	0.01	-0.00
	1.19	0.00	5.46	0.00	4.71		0.44	0.46	-0.01

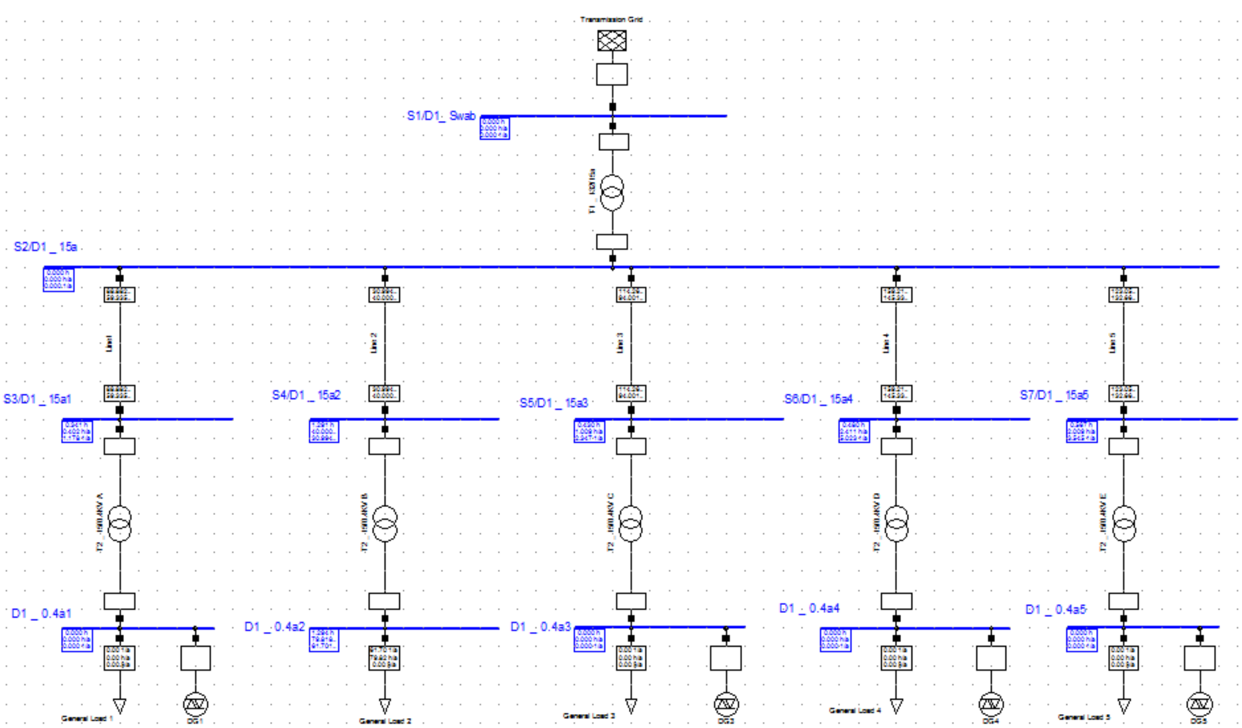


Figure B.8: DG is connected except feeder two

Table B-9: DG is connected except feeder three

```
------------------------------------------------------------------------------------------------------------------------------
| Reliability Assessment                                                                                                      |
| -                                                                                                                           |
| - Network, connectivity analysis                                                                                            |
------------------------------------------------------------------------------------------------------------------------------
| Selection    = Whole System                                                                                               |
| Yes  = Common mode                              |  Yes  = Independent second failures                                         |
| Yes  = Busbars / terminals                      |  Yes  = Double earth faults                                                 |
| Yes  = Lines / cables                           |  No   = Maintenance                                                         |
| Yes  = Transformers                             |                                                                             |
------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------------
| Study Case: Case1                                                                        | Annex:              / 1  |
------------------------------------------------------------------------------------------------------------------------------
| System Summary                                                                                                              |
------------------------------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index        :  SAIFI: =  106.195854 1/Ca                                             |
| Customer Average Interruption Frequency Index      :  CAIFI: =  226.174529 1/Ca                                             |
| System Average Interruption Duration Index         :  SAIDI: =   87.799    h/Ca                                             |
| Customer Average Interruption Duration Index       :  CAIDI: =    0.827    h                                                |
| Average Service Availability Index                 :  ASAI:  =    0.9899773277                                                 |
| Average Service Unavailability Index               :  ASUI:  =    0.0100226723                                                 |
| Energy Not Supplied                                :  ENS:   = 1132.445    MWh/a                                            |
| Average Energy Not Supplied                        :  AENS:  =    0.018    MWh/Ca                                           |
------------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                        Complete System Report: Voltage Profiles, Grid Interchange |
------------------------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence              |   Automatic Model Adaptation for Convergency          Yes   |
|    Automatic Tap Adjust of Transformers           Yes     |   Max. Acceptable Load Flow Error for                       |
|    Consider Reactive Power Limits                 Yes     |     Nodes                                          1.00 kVA |
|                                                           |     Model Equations                                0.10 %   |
------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------------
| Grid: Grid               System Stage: Grid           | Study Case: Case1                  | Annex:              / 1  |
------------------------------------------------------------------------------------------------------------------------------
|                       rtd.V       Bus - voltage                           Voltage - Deviation [%]                          |
|                        [kV]  [p.u.]      [kV]  [deg]         -10         -5          0          +5         +10             |
------------------------------------------------------------------------------------------------------------------------------
|Station 1                                                                                                                    |
|  2                    132.00   1.000   132.00   0.00                                                                        |
|  D1_ Swab             132.00   1.000   132.00   0.00                                                                        |
|Station 2                                                                                                                    |
|  D1 _ 15a              15.00   0.995    14.93  -0.78                                                                        |
|Station 3                                                                                                                    |
|  D1 _ 15a1             15.00   0.993    14.89  -1.09                                                                        |
|Station 4                                                                                                                    |
|  D1 _ 15a2             15.00   0.993    14.90  -1.00                                                                        |
|Station 5                                                                                                                    |
|  D1 _ 15a3             15.00   0.985    14.78  -2.09                                                                        |
|Station 6                                                                                                                    |
|  D1 _ 15a4             15.00   0.990    14.85  -1.47                                                                        |
|Station 7                                                                                                                    |
|  D1 _ 15a5             15.00   0.991    14.87  -1.30                                                                        |
|D1 _ 0.4a1                                                                                                                   |
|                         0.40   1.010     0.40  -1.66                                                                        |
|D1 _ 0.4a2                                                                                                                   |
|                         0.40   1.009     0.40  -1.79                                                                        |
|D1 _ 0.4a3                                                                                                                   |
|                         0.40   1.003     0.40  -2.41                                                                        |
|D1 _ 0.4a4                                                                                                                   |
|                         0.40   1.008     0.40  -1.76                                                                        |
|D1 _ 0.4a5                                                                                                                   |
|                         0.40   1.010     0.40  -1.61                                                                        |
------------------------------------------------------------------------------------------------------------------------------
```

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	2.44	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.80	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-14.17	0.00	0.00	0.00
							-4.66	0.10	0.10	0.00
15.00	0.00	0.00	0.00	0.00	0.00			0.02	0.02	-0.00
	0.00	0.00	0.00	0.00	0.00			0.23	0.24	-0.01
						0.40 kV	14.17	0.00	0.00	0.00
							4.76	0.10	0.10	0.00
						132.00 kV	-14.19	0.00	0.00	0.00
							-4.99	0.22	0.22	0.00
132.00	0.00	0.00	0.00	0.00	14.19			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	5.21			0.00	0.00	0.00
						15.00 kV	14.19	0.00	0.00	0.00
							5.21	0.22	0.22	0.00
Total:	2.44	0.00	16.61	0.00	14.19		0.00	0.02	0.02	-0.00
	0.80	0.00	5.46	0.00	5.21		0.00	0.55	0.56	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	2.44	0.00	16.61	0.00	14.19	0.00	0.02	0.02	-0.00
	0.80	0.00	5.46	0.00	5.21	0.00	0.55	0.56	-0.01
Total:									
	2.44	0.00	16.61	0.00	14.19		0.02	0.02	-0.00
	0.80	0.00	5.46	0.00	5.21		0.55	0.56	-0.01

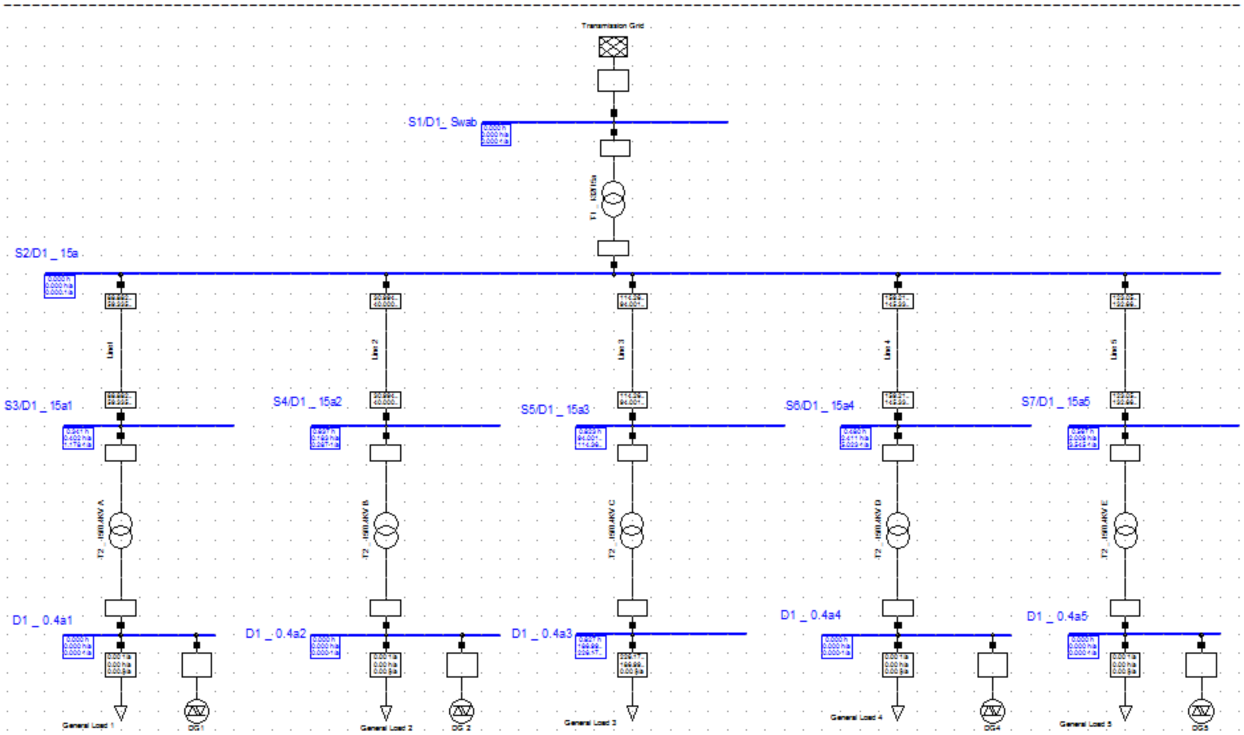


Figure B.9: DG is connected except feeder three

Table B-10: DG is connected except feeder four

```
-----------------------------------------------------------------------------------------------------------
| Reliability Assessment                                                                                  |
| -                                                                                                       |
| - Network, connectivity analysis                                                                        |
-----------------------------------------------------------------------------------------------------------
| Selection    = Whole System                                                                             |
| Yes   = Common mode                               |  Yes  = Independent second failures                  |
| Yes   = Busbars / terminals                       |  Yes  = Double earth faults                          |
| Yes   = Lines / cables                            |  No   = Maintenance                                  |
| Yes   = Transformers                              |                                                      |
-----------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------
| Study Case: Case1                                                                 | Annex:          / 1 |
-----------------------------------------------------------------------------------------------------------
| System Summary                                                                                          |
-----------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index       :  SAIFI: =   60.313899 1/Ca                          |
| Customer Average Interruption Frequency Index     :  CAIFI: =  313.400187 1/Ca                          |
| System Average Interruption Duration Index        :  SAIDI: =   55.475    h/Ca                          |
| Customer Average Interruption Duration Index      :  CAIDI: =    0.920    h                             |
| Average Service Availability Index                :  ASAI:  =    0.9936672520                            |
| Average Service Unavailability Index              :  ASUI:  =    0.0063327480                            |
| Energy Not Supplied                               :  ENS:   = 1178.244    MWh/a                         |
| Average Energy Not Supplied                       :  AENS:  =    0.018    MWh/Ca                        |
-----------------------------------------------------------------------------------------------------------
| Load Flow Calculation                          Complete System Report: Voltage Profiles, Grid Interchange |
-----------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence            |  Automatic Model Adaptation for Convergency   Yes      |
|    Automatic Tap Adjust of Transformers       Yes       |  Max. Acceptable Load Flow Error for                   |
|    Consider Reactive Power Limits             Yes       |     Nodes                                    1.00 kVA  |
|                                                         |     Model Equations                          0.10 %    |
-----------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------
| Grid: Grid              System Stage: Grid        | Study Case: Case1              | Annex:          / 1 |
-----------------------------------------------------------------------------------------------------------
|                     rtd.V      Bus - voltage                              Voltage - Deviation [%]       |
|                      [kV]  [p.u.]     [kV]  [deg]         -10        -5         0         +5        +10 |
-----------------------------------------------------------------------------------------------------------
|Station 1                                                                                                |
|  2                 132.00   1.000  132.00   0.00                                                        |
|  D1_ Swab          132.00   1.000  132.00   0.00                                                        |
|Station 2                                                                                                |
|  D1 _ 15a           15.00   0.995   14.93  -0.75                                                        |
|Station 3                                                                                                |
|  D1 _ 15a1          15.00   0.993   14.90  -1.06                                                        |
|Station 4                                                                                                |
|  D1 _ 15a2          15.00   0.994   14.90  -0.97                                                        |
|Station 5                                                                                                |
|  D1 _ 15a3          15.00   0.988   14.82  -1.74                                                        |
|Station 6                                                                                                |
|  D1 _ 15a4          15.00   0.989   14.83  -1.63                                                        |
|Station 7                                                                                                |
|  D1 _ 15a5          15.00   0.991   14.87  -1.27                                                        |
|D1 _ 0.4a1                                                                                               |
|                      0.40   1.010    0.40  -1.62                                                        |
|D1 _ 0.4a2                                                                                               |
|                      0.40   1.009    0.40  -1.76                                                        |
|D1 _ 0.4a3                                                                                               |
|                      0.40   1.007    0.40  -1.98                                                        |
|D1 _ 0.4a4                                                                                               |
|                      0.40   1.007    0.40  -2.01                                                        |
|D1 _ 0.4a5                                                                                               |
|                      0.40   1.010    0.40  -1.58                                                        |
-----------------------------------------------------------------------------------------------------------
```

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	3.00	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	0.99	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.61	0.00	0.00	0.00
							-4.47	0.10	0.10	0.00
15.00	0.00	0.00	0.00	0.00	0.00			0.02	0.02	0.00
	0.00	0.00	0.00	0.00	0.00			0.19	0.20	-0.01
						0.40 kV	13.61	0.00	0.00	0.00
							4.57	0.10	0.10	0.00
						132.00 kV	-13.62	0.00	0.00	0.00
							-4.76	0.20	0.20	0.00
132.00	0.00	0.00	0.00	0.00	13.62			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.96			0.00	0.00	0.00
						15.00 kV	13.62	0.00	0.00	0.00
							4.96	0.20	0.20	0.00
Total:	3.00	0.00	16.61	0.00	13.62		0.00	0.02	0.02	0.00
	0.99	0.00	5.46	0.00	4.96		0.00	0.49	0.50	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.00	0.00	16.61	0.00	13.62	0.00	0.02	0.02	0.00
	0.99	0.00	5.46	0.00	4.96	0.00	0.49	0.50	-0.01
Total:									
	3.00	0.00	16.61	0.00	13.62		0.02	0.02	0.00
	0.99	0.00	5.46	0.00	4.96		0.49	0.50	-0.01

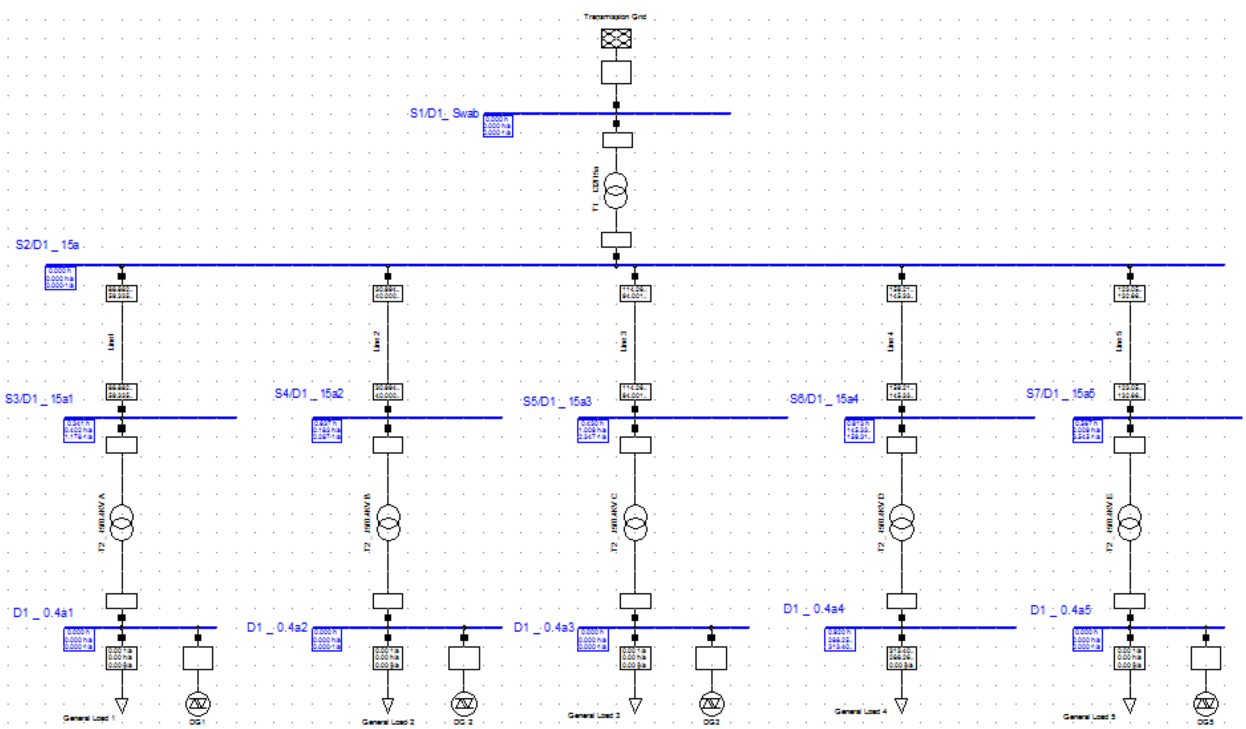


Figure B.10: DG is connected except feeder four

Table B-11: DG is connected except feeder five

```
-----------------------------------------------------------------------------------------------------------
| Reliability Assessment                                                                                  |
| -                                                                                                       |
| - Network, connectivity analysis                                                                        |
-----------------------------------------------------------------------------------------------------------
| Selection   = Whole System                                                                              |
| Yes  = Common mode                               | Yes  = Independent second failures                   |
| Yes  = Busbars / terminals                       | Yes  = Double earth faults                           |
| Yes  = Lines / cables                            | No   = Maintenance                                   |
| Yes  = Transformers                              |                                                      |
-----------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------
| Study Case: Case1                                                              | Annex:          / 1  |
-----------------------------------------------------------------------------------------------------------
| System Summary                                                                                          |
-----------------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index       :  SAIFI: =   57.000689 1/Ca                          |
| Customer Average Interruption Frequency Index     :  CAIFI: =  242.555474 1/Ca                          |
| System Average Interruption Duration Index        :  SAIDI: =   61.881    h/Ca                          |
| Customer Average Interruption Duration Index      :  CAIDI: =    1.086    h                             |
| Average Service Availability Index                :  ASAI:  =    0.9929359212                            |
| Average Service Unavailability Index              :  ASUI:  =    0.0070640788                            |
| Energy Not Supplied                               :  ENS:   =  862.386    MWh/a                          |
| Average Energy Not Supplied                       :  AENS:  =    0.014    MWh/Ca                         |
---------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                               Complete System Report: Voltage Profiles, Grid Interchange |
---------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence            |   Automatic Model Adaptation for Convergency      Yes      |
|    Automatic Tap Adjust of Transformers         Yes     |   Max. Acceptable Load Flow Error for                      |
|    Consider Reactive Power Limits               Yes     |      Nodes                                      1.00 kVA  |
|                                                         |      Model Equations                            0.10 %    |
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------
| Grid: Grid               System Stage: Grid         | Study Case: Case1              | Annex:          / 1  |
---------------------------------------------------------------------------------------------------------------
|                    rtd.V      Bus - voltage                           Voltage - Deviation [%]              |
|                     [kV]  [p.u.]     [kV]  [deg]          -10         -5          0          +5         +10  |
---------------------------------------------------------------------------------------------------------------
|Station 1                                                                                                    |
|  2                132.00   1.000   132.00   0.00                                                            |
|  D1_ Swab         132.00   1.000   132.00   0.00                                                            |
|Station 2                                                                                                    |
|  D1 _ 15a          15.00   0.995    14.93  -0.74                                                            |
|Station 3                                                                                                    |
|  D1 _ 15a1         15.00   0.993    14.90  -1.05                                                            |
|Station 4                                                                                                    |
|  D1 _ 15a2         15.00   0.994    14.91  -0.97                                                            |
|Station 5                                                                                                    |
|  D1 _ 15a3         15.00   0.988    14.82  -1.74                                                            |
|Station 6                                                                                                    |
|  D1 _ 15a4         15.00   0.990    14.85  -1.43                                                            |
|Station 7                                                                                                    |
|  D1 _ 15a5         15.00   0.990    14.85  -1.45                                                            |
|D1 _ 0.4a1                                                                                                   |
|                     0.40   1.010     0.40  -1.62                                                            |
|D1 _ 0.4a2                                                                                                   |
|                     0.40   1.009     0.40  -1.76                                                            |
|D1 _ 0.4a3                                                                                                   |
|                     0.40   1.007     0.40  -1.98                                                            |
|D1 _ 0.4a4                                                                                                   |
|                     0.40   1.009     0.40  -1.73                                                            |
|D1 _ 0.4a5                                                                                                   |
|                     0.40   1.008     0.40  -1.87                                                            |
---------------------------------------------------------------------------------------------------------------
```

Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	3.06	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	1.01	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.55	0.00	0.00	0.00
							-4.45	0.10	0.10	0.00
15.00	0.00	0.00	0.00	0.00	0.00			0.02	0.02	-0.00
	0.00	0.00	0.00	0.00	0.00			0.18	0.20	-0.01
						0.40 kV	13.55	0.00	0.00	0.00
							4.55	0.10	0.10	0.00
						132.00 kV	-13.56	0.00	0.00	0.00
							-4.73	0.20	0.20	0.00
132.00	0.00	0.00	0.00	0.00	13.56			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.93			0.00	0.00	0.00
						15.00 kV	13.56	0.00	0.00	0.00
							4.93	0.20	0.20	0.00
Total:	3.06	0.00	16.61	0.00	13.56		0.00	0.02	0.02	-0.00
	1.01	0.00	5.46	0.00	4.93		0.00	0.48	0.49	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.06	0.00	16.61	0.00	13.56	0.00	0.02	0.02	-0.00
	1.01	0.00	5.46	0.00	4.93	0.00	0.48	0.49	-0.01
Total:									
	3.06	0.00	16.61	0.00	13.56		0.02	0.02	-0.00
	1.01	0.00	5.46	0.00	4.93		0.48	0.49	-0.01

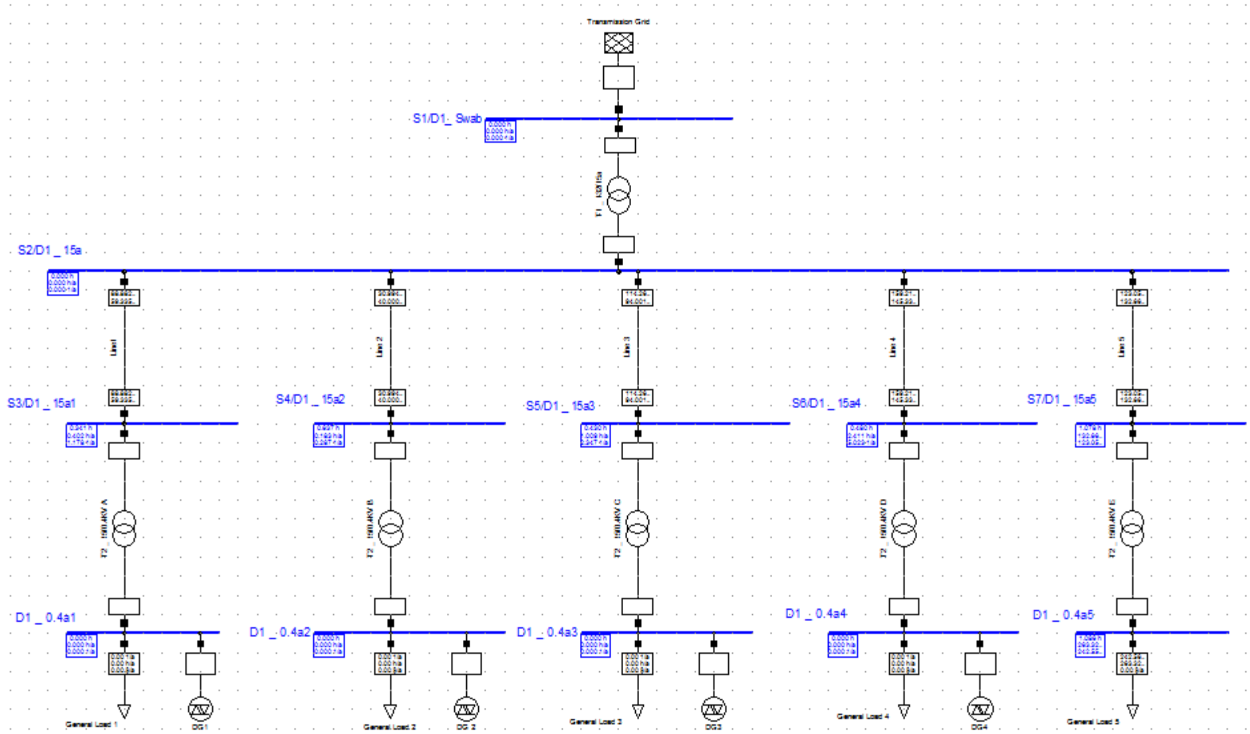
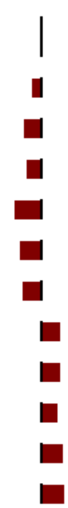


Figure B.11: DG is connected except feeder five

Table B-12: DG is connected except feeder one and two

```
----------------------------------------------------------------------------------------------------
| Reliability Assessment                                                                            |
| -                                                                                                 |
| - Network, connectivity analysis                                                                  |
----------------------------------------------------------------------------------------------------
| Selection   = Whole System                                                                        |
| Yes  = Common mode                        |  Yes  = Independent second failures                    |
| Yes  = Busbars / terminals                |  Yes  = Double earth faults                            |
| Yes  = Lines / cables                     |  No   = Maintenance                                    |
| Yes  = Transformers                       |                                                        |
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
| Study Case: Case1                                                        | Annex:          / 1  |
----------------------------------------------------------------------------------------------------
| System Summary                                                                                    |
----------------------------------------------------------------------------------------------------
| System Average Interruption Frequency Index      : SAIFI: =   14.546972 1/Ca                      |
| Customer Average Interruption Frequency Index    : CAIFI: =  141.207097 1/Ca                      |
| System Average Interruption Duration Index       : SAIDI: =   10.964    h/Ca                      |
| Customer Average Interruption Duration Index     : CAIDI: =    0.754    h                         |
| Average Service Availability Index               : ASAI:  =    0.9987483992                        |
| Average Service Unavailability Index             : ASUI:  =    0.0012516008                        |
| Energy Not Supplied                              : ENS:   =  326.031    MWh/a                     |
| Average Energy Not Supplied                      : AENS:  =    0.005    MWh/Ca                    |
--------------------------------------------------------------------------------------------------------
| Load Flow Calculation                      Complete System Report: Voltage Profiles, Grid Interchange |
--------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence          |   Automatic Model Adaptation for Convergency      Yes     |
|    Automatic Tap Adjust of Transformers         Yes   |   Max. Acceptable Load Flow Error for                     |
|    Consider Reactive Power Limits               Yes   |     Nodes                                       1.00 kVA  |
|                                                       |     Model Equations                             0.10 %    |
--------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------
| Grid: Grid               System Stage: Grid          | Study Case: Case1              | Annex:       / 1 |
--------------------------------------------------------------------------------------------------------
|                    rtd.V     Bus - voltage                            Voltage - Deviation [%]          |
|                    [kV]  [p.u.]     [kV]   [deg]            -10        -5         0        +5       +10  |
--------------------------------------------------------------------------------------------------------
|Station 1                                                                                             |
|  2                132.00  1.000   132.00   0.00                                                     |
|  D1_ Swab         132.00  1.000   132.00   0.00                                                     |
|Station 2                                                                                             |
|  D1 _ 15a          15.00  0.995    14.93  -0.74                                                     |
|Station 3                                                                                             |
|  D1 _ 15a1         15.00  0.992    14.89  -1.14                                                     |
|Station 4                                                                                             |
|  D1 _ 15a2         15.00  0.993    14.90  -1.02                                                     |
|Station 5                                                                                             |
|  D1 _ 15a3         15.00  0.988    14.82  -1.73                                                     |
|Station 6                                                                                             |
|  D1 _ 15a4         15.00  0.990    14.85  -1.42                                                     |
|Station 7                                                                                             |
|  D1 _ 15a5         15.00  0.992    14.87  -1.26                                                     |
|D1 _ 0.4a1                                                                                            |
|                     0.40  1.008     0.40  -1.87                                                     |
|D1 _ 0.4a2                                                                                            |
|                     0.40  1.008     0.40  -2.02                                                     |
|D1 _ 0.4a3                                                                                            |
|                     0.40  1.007     0.40  -1.97                                                     |
|D1 _ 0.4a4                                                                                            |
|                     0.40  1.009     0.40  -1.72                                                     |
|D1 _ 0.4a5                                                                                            |
|                     0.40  1.010     0.40  -1.57                                                     |
--------------------------------------------------------------------------------------------------------
```



Grid: Grid	System Stage: Grid	Study Case: Case1	Annex: / 2

Volt. Level [kV]	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Interchange to	Power Interchange [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
0.40	3.20	0.00	16.61	0.00	0.00			0.00	0.00	0.00
	1.05	0.00	5.46	0.00	0.00			0.00	0.00	0.00
						15.00 kV	-13.41	0.00	0.00	0.00
							-4.41	0.11	0.11	0.00
15.00	0.00	0.00	0.00	0.00	0.00			0.01	0.01	0.00
	0.00	0.00	0.00	0.00	0.00			0.17	0.18	-0.01
						0.40 kV	13.41	0.00	0.00	0.00
							4.51	0.11	0.11	0.00
						132.00 kV	-13.42	0.00	0.00	0.00
							-4.68	0.19	0.19	0.00
132.00	0.00	0.00	0.00	0.00	13.42			0.00	0.00	0.00
	0.00	0.00	0.00	0.00	4.88			0.00	0.00	0.00
						15.00 kV	13.42	0.00	0.00	0.00
							4.88	0.19	0.19	0.00
Total:	3.20	0.00	16.61	0.00	13.42		0.00	0.01	0.01	0.00
	1.05	0.00	5.46	0.00	4.88		0.00	0.47	0.48	-0.01

Total System Summary	Study Case: Case1	Annex: / 3

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\Amache\Project amache\Network Model\Network Data\Grid									
	3.20	0.00	16.61	0.00	13.42	0.00	0.01	0.01	0.00
	1.05	0.00	5.46	0.00	4.88	0.00	0.47	0.48	-0.01
Total:									
	3.20	0.00	16.61	0.00	13.42		0.01	0.01	0.00
	1.05	0.00	5.46	0.00	4.88		0.47	0.48	-0.01

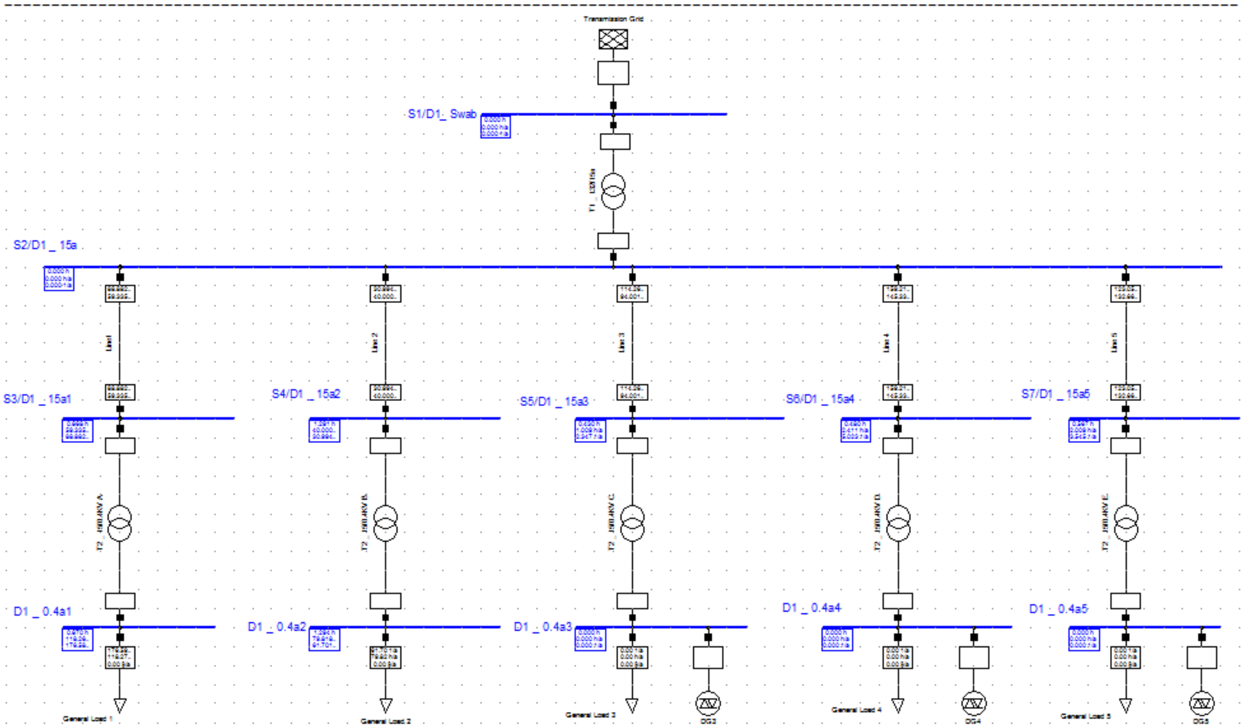


Figure B.12: DG is connected except feeder one and two

APPENDIX-C

Detail Interruption report

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

DATE	INT. TIME	REC. TIME	DUR TIME	Duration (Hr)	TYPE OF FAULT	FAULT REASON	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
1/11/2005	10:30	10:32	0:02	0.0333333	TRANSIENT	EARTH FAULT	
1/11/2005	14:35	14:37	0:02	0.0333333	TRANSIENT	EARTH FAULT	
1/11/2005	13:54	20:00	6:06	6.1	PERMANENT	EARTH FAULT	
3/11/2005	6:10	6:58	0:48	0.8	GUP	GUP	TO OPEN DEBREMARKOSE
15/11/2005	7:20	7:22	0:02	0.03333	TRANSIENT	EARTH FAULT	
15/11/2005	7:58	10:17	2:19	2.316667	PERMANENT	SHORT CIRCUIT	
16/11/2005	15:55	16:18	0:23	0.38333	OPERATION	BY REQUEST	TO CONNECT TAP
16/11/2005	18:40	19:30	0:50	0.83333	SOL	SOL	NO-43
19/11/2005	6:21	9:20	2:59	2.98333	OPERATION	BY REQUEST	
20/11/2005	15:00	17:20	2:20	2.33333	UF	UNDER FRIQUANCY	BLACK OUT
21/11/2005	16:05	16:35	0:30	0.5	OPERATION	BY REQUEST	FOR MENTENANCE
1/3/2006	20:25	22:05	1:40	1.66667	BLACKOUT	BLACKOUT	
1/4/2006	13:59	14:20	0:21	0.35	OPERATION	BYREQUEST	DUE TO BROKEN TAP
1/4/2006	15:55	18:13	2:18	2.3	SOL	SOL	NO-43
1/8/2006	11:20	20:05	8:45	8.75	OVERLOAD	OVERLOAD	
1/9/2006	7:10	10:55	3:45	3.75	UF	UNDER FRIQUANCY	BLACK OUT
1/9/2006	11:40	13:00	1:20	1.3333333	OVERLOAD	OVERLOAD	
1/10/2006	10:55	12:40	1:45	1.75	UF	UNDER FRIQUANCY	BLACK OUT
1/19/2006	6:45	7:18	0:33	0.55	OPERATION	BYREQUEST	FOR SUBSTATION MENTENANCE
1/21/2006	15:40	16:15	0:35	0.58333	OPERATION	BYREQUEST	DUE TO BROKEN TAP
1/26/2006	0:15	2:05	1:50	1.83333	UF	UNDER FRIQUANCY	BLACK OUT
1/27/2006	20:10	20:38	0:28	0.46667	UF	UNDER FRIQUANCY	BLACK OUT
2/1/2006	16:45	17:30	0:45	0.75	OPERATION	BYREQUEST	
2/7/2006	6:25	6:27	0:02	0.03333	TRANSIENT	SHORT CIRCUIT	
2/8/2006	5:55	10:55	5:00	5	PERMANENT	SHORT CIRCUIT	
2/15/2006	0:00	1:43	1:43	1.716667	UF	UNDER FRIQUANCY	BLACK OUT
2/23/2006	16:50	17:20	0:30	0.5	OPERATION	BYREQUEST	
2/25/2006	17:35	17:37	0:02	0.03333	TRANSIENT	EARTHFAULT	
30/2/2006	19:15	19:55	0:40	0.66667	TRAFO	OVER LOAD	
2/3/2006	16:55	18:30	1:35	1.5833333	UNDER FRIQUANCY	BLACK OUT	
2/3/2006	19:10	20:45	1:35	1.5833333	OUTGOING FEEDER	OVER LOAD	
3/8/2006	11:25	12:35	1:10	1.1666667	OPERATION	BYREQUEST	FOR MENTENANCE

3/8/2006	15:10	16:30	1:20	1.3333333	UNDER FRIQUANCY	BLACK OUT	
3/10/2006	18:35	19:50	1:15	1.25	OUTGOING FEEDER	OVER LOAD	
3/20/2006	10:45	11:15	0:30	0.5	UNDER FRIQUANCY	BLACK OUT	
3/20/2006	16:10	16:30	0:20	0.3333333	SOL	SOL	NO-43
3/22/2005	18:55	20:35	1:40	1.6666667	SOL	SOL	NO-43
3/25/2006	8:40	9:42	1:02	1.0333333	UNDER FRIQUANCY	BLACK OUT	
3/26/2006	18:55	19:55	1:00	1	OUTGOING FEEDER	OVER LOAD	
3/27/2006	8:20	10:20	2:00	2	UNDER FRIQUANCY	BLACK OUT	
3/29/2006	18:45	18:55	0:10	0.1666667	SOL	SOL	NO-43
3/30/2006	0:50	0:52	0:02	0.0333333	TRANSIENT	EARTHFAULT	
4/5/2006	17:35	18:00	0:25	0.416667	PERMANENT	SHORT CIRCUIT	
4/9/2006	19:15	19:50	0:35	0.58333	OUTGOING FEEDER	OVER LOAD	
4/12/2006	3:45	4:40	0:55	0.916667	UNDER FRIQUANCY	BLACK OUT	
4/15/2006	19:03	20:10	1:07	1.116667	TRAFO	OVER LOAD	
4/15/2006	19:03	20:10	1:07	1.116667	TRAFO	OVER LOAD	
4/18/2006	19:43	20:20	0:37	0.616667	TRAFO	OVERLOAD	
4/18/2006	19:43	20:20	0:37	0.616667	TRAFO	OVERLOAD	
4/28/2006	11:05	11:55	0:50	0.83333	PERMANENT	SHORT CIRCUIT	
5/22/2006	13:20	13:22	0:02	0.033	TRANSIENT	EARTHFAULT	
5/24/2006	18:45	18:47	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/25/2006	19:55	21:35	1:40	1.667	TLP	TLP	BLACKOUT,DUE TO TANABELES TO DEBERMARKOS 400KV TRANSMISSION LINE PROBLEM
6/2/2006	7:30	7:32	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/9/2006	3:20	3:22	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/15/2006	7:10	13:27	6:17	6.283	OPERATION	BYREQUEST	BY AA SEB STATION &AND OPRATION TEAM TO AJUST CT
6/15/2006	12:40	13:09	0:29	0.483	TLP	TLP	DUE TO PROBLEM ON 132KV MUGER LINE
6/15/2006	19:20	19:55	0:35	0.583	OPERATION	BYREQUEST	WORK ON LEG SUBSTATION BY SEBSTATION OPRATION TEAM
6/28/2006	7:10	8:40	1:30	1.500	TLP	TLP	BLACKOUT,LEGETAFO KOMBOLCHA TRANSMISSION LINE EARTH FAULT
6/28/2006	18:55	20:25	1:30	1.500	SOL	SOL	75A
6/29/2006	19:15	21:25	2:10	2.167	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/29/2006	21:30	23:35	2:05	2.083	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	8:25	10:45	2:20	2.333	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	9:45	11:00	1:15	1.25	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT

7/1/2006	3/10/2014	18:30	21:50	3:20	3.333	SOL	SOL	34A
7/3/2006	3/12/2014	10:45	12:35	1:50	1.833	SOL	SOL	81A
7/6/2006	3/15/2014	18:47	20:00	1:13	1.217	SOL	SOL	64A
7/9/2006	3/18/2014	15:45	15:47	0:02	0.033	TRANSIENT	EARTHFAULT	

7/9/2006	3/18/2014	19:30	20:10	0:40	0.667	SOL	SOL	
7/13/2006	3/22/2014	14:40	14:42	0:02	0.033	TRANSIENT	EARTHFAULT	
7/13/2006	3/22/2014	19:05	20:50	1:45	1.750	SOL	SOL	71A
7/15/2006	3/24/2014	18:25	20:55	2:30	2.500	SOL	SOL	100A
7/16/2006	3/25/2014	9:50	10:50	1:00	1.000	SOL	SOL	47A
20/07/2006	29/03/2014	12:00	14:00	2:00	2.000	SOL	SOL	
23/07/2006	1/4/2014	16:05	19:40	3:35	3.58	PERMANENT	SHORT CIRCUIT	NOTHING FOUND ON THE LINE BY TRACING & RECONNECTED
26/07/2006	4/4/2014	10:00	12:15	2:15	2.250	SOL	SOL	FEEDER-80A, BY " 43 (LDC)REQUEST,DUE TO SULULTA MARKOS TRANSMISSION LINE PROBLEM
27/07/2006	5/4/2014	9:30	12:05	2:35	2.583	TLP	TLP	BLACK OUT (SEBETA ,KALITY GEFERSA& SULULTA TRANSMITION LINE EARTH FAULT)
29/07/2006	7/4/2014	10:12	13:25	3:13	3.217	SOL	SOL	FEEDER-97A, BY " 43 (LDC)REQUEST,
2/8/2006	10/4/2014	9:45	12:30	2:45	2.750	SOL	SOL	FEEDER-88A, BY " 43 (LDC)REQUEST,
3/8/2006	11/4/2014	18:55	20:25	1:30	1.500	SOL	SOL	FEEDER-91A, BY " 43 (LDC)REQUEST,
5/8/2006	13/4/2014	12:00	13:55	1:55	1.917	TLP	TLP	BLACKOUT, DUE TO BROKEN TRANSMSION LINE FROM GEF TO ADN

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

DATE	INT. TIME	REC. TIME	DUR TIME	Duration (Hr)	TYPE OF FAULT	FAULT REASON	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
3/11/2005	6:10	6:58	0:48	0.8	GUP	GUP	TO OPEN DEBREMARKOSE
13/11/2005	11:20	11:22	0:02	0.0333333	TRANSIENT	EARTH FAULT	
15/11/2005	10:42	11:13	0:31	0.5166667	OPERATION	BY REQUEST	FOR SAFTY
16/11/2005	18:45	19:30	0:45	0.75	SOL	SOL	NO-43
20/11/2005	15:00	16:43	1:43	1.7166667	UF	UNDER FRIQUANCY	BLACK OUT
1/3/2006	20:25	22:40	2:15	2.25	BLACKOUT	BLACKOUT	
1/4/2006	15:55	16:45	0:50	0.8333333	SOL	SOL	NO-43
1/9/2006	13:00	13:45	0:45	0.75	OVERLOAD	OVERLOAD	
1/10/2006	10:55	12:40	1:45	1.75	UF	UNDER FRIQUANCY	BLACK OUT
1/19/2006	6:45	7:00	0:15	0.25	OPERATION	BYREQUEST	FOR SUBSTATION MENTENANCE
1/21/2006	13:00	13:02	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/26/2006	0:15	2:05	1:50	1.8333333	UF	UNDER FRIQUANCY	BLACK OUT
1/27/2006	20:10	20:38	0:28	0.4666667	UF	UNDER FRIQUANCY	BLACK OUT
2/10/2006	6:50	7:00	0:10	0.1666667	OPERATION	BYREQUEST	
2/15/2006	0:00	1:40	1:40	1.6666667	UF	UNDER FRIQUANCY	BLACK OUT
2/24/2006	17:05	17:07	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	
2/3/2006	16:55	17:48	0:53	0.883333	UNDER FRIQUANCY	BLACK OUT	
2/3/2006	19:10	19:15	0:05	0.083333	OUTGOING FEEDER	OVER LOAD	

3/8/2006	7:00	9:55	2:55	2.9166667	TRANSIENT	SHORT CIRCUIT	
3/8/2006	15:10	16:00	0:50	0.833333	UNDER FRIQUANCY	BLACK OUT	
3/20/2006	11:30	11:55	0:25	0.4166667	OUTGOING FEEDER	OVER LOAD	
3/20/2006	12:05	12:09	0:04	0.0666667	OUTGOING FEEDER	OVER LOAD	
3/20/2006	10:45	11:15	0:30	0.5	UNDER FRIQUANCY	BLACK OUT	
3/24/2006	20:45	20:47	0:02	0.033333	PERMANENT	SHORT CIRCUIT	
3/25/2006	8:40	9:42	1:02	1.033333	UNDER FRIQUANCY	BLACK OUT	
3/27/2006	8:20	9:32	1:12	1.2	UNDER FRIQUANCY	BLACK OUT	
4/4/2006	8:15	8:17	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/12/2006	3:45	4:40	0:55	0.9166667	UNDER FRIQUANCY	BLACK OUT	
4/18/2006	19:10	19:12	0:02	0.033333	OUTGOING FEEDER	OVERLOAD	
4/22/2006	19:10	19:55	0:45	0.75	TRAFO	OVERLOAD	60A
4/28/2006	11:05	11:13	0:08	0.133333	PERMANENT	SHORT CIRCUIT	DUE TO SHORT CIRCUIT ON COT-01
4/28/2006	19:20	20:35	1:15	1.25	OUTGOING FEEDER	OVERLOAD	61A
4/28/2006	21:00	21:02	0:02	0.033333	OUTGOING FEEDER	OVERLOAD	100A
4/28/2006	21:30	21:32	0:02	0.033333	OUTGOING FEEDER	OVERLOAD	100A
4/28/2006	22:00	22:40	0:40	0.666667	OUTGOING FEEDER	OVERLOAD	100A
4/28/2006	22:00	22:40	0:40	0.666667	OUTGOING FEEDER	OVERLOAD	100A
5/22/2006	13:20	13:22	0:02	0.033	TRANSIENT	EARTHFAULT	
5/25/2006	19:55	21:35	1:40	1.667	TLP	TLP	BLACKOUT,DUE TO TANABELES TO DEBERMARKOS 400KV TRANSMISSION LINE PROBLEM
5/30/2006	12:10	12:12	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/9/2006	3:20	3:22	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/15/2006	7:10	7:25	0:15	0.250	OPERATION	BYREQUEST	BY AA SEB STATION &AND OPRATION TEAM TO AJUST CT
6/15/2006	12:40	13:26	0:46	0.767	TLP	TLP	DUE TO PROBLEM ON 132KV MUGER LINE
6/15/2006	19:20	19:55	0:35	0.583	OPERATION	BYREQUEST	WORK ON LEG SUBSTATION BY SEBSTATION OPRATION TEAM
6/28/2006	7:10	8:40	1:30	1.500	TLP	TLP	BLACKOUT,LEGETAFO KOMBOLCHA TRANSMISSION LINE EARTH FAULT
6/28/2006	8:55	8:57	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/29/2006	19:15	21:25	2:10	2.167	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/29/2006	21:30	23:35	2:05	2.083	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	8:25	10:45	2:20	2.333	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	9:45	11:00	1:15	1.25	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT

7/15/2006	3/24/2014	12:30	12:32	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
7/15/2006	3/24/2014	12:50	12:52	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
7/15/2006	3/24/2014	13:55	13:57	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
27/07/2006	5/4/2014	9:30	10:50	1:20	1.333	TLP	TLP	BLACK OUT (SEBETA ,KALITY GEFERSA& SULULTA TRANSMITION LINE EARTH FAULT)
5/8/2006	13/4/2014	12:00	13:55	1:55	1.917	TLP	TLP	BLACKOUT, DUE TO BROKEN TRANSMSION LINE FROM GEF TO ADN

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

DATE	INT. TIME	REC. TIME	DUR TIME	Duration (Hr)	TYPE OF FAULT	FAULT REASON	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
1/11/2005	10:30	10:32	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
3/11/2005	6:10	6:58	0:48	0.8	GUP	GUP	TO OPEN DEBREMARKOSE
3/11/2005	20:50	21:06	0:16	0.2666667	OPERATION	BY REQUEST	TO CLOSE TAP
5/11/2005	21:10	21:23	0:13	0.2166667	OPERATION	BY REQUEST	REPLACEMENT DROP OUT FUSE
10/11/2005	11:05	12:00	0:55	0.9166667	PERMANENT	EARTH FAULT	
10/11/2005	18:15	18:25	0:10	0.1666667	OPERATION	BY REQUEST	
14/11/2005	10:00	10:02	0:02	0.0333333	TRANSIENT	EARTH FAULT	
16/11/2005	18:45	19:30	0:45	0.75	SOL	SOL	NO-43
18/11/2005	15:10	15:12	0:02	0.0333333	TRANSIENT	EARTH FAULT	
20/11/2005	3:15	3:17	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
20/11/2005	15:00	17:20	2:20	2.3333333	UF	UNDER FRIQUANCY	BLACK OUT
24/11/2005	16:50	17:15	0:25	0.4166667	OPERATION	BY REQUEST	TO CLOSED DROPOUT FUSE
28/11/2005	20:17	20:30	0:13	0.2166667	OPERATION	BY REQUEST	TO CLOSED LINK
29/11/2005	12:10	12:30	0:20	0.3333333	OPERATION	BY REQUEST	TO CONNECT BROKEN HT LINE
29/11/2005	18:25	18:50	0:25	0.4166667	OPERATION	BY REQUEST	FOR MENTENANCE
30/11/2005	12:20	15:40	3:20	3.3333333	PERMANENT	EARTH FAULT	
30/11/2005	17:54	18:00	0:06	0.1	OPERATION	BY REQUEST	TO CLOSED F4
1/4/2006	20:25	2:58	6:33	6.55	BLACKOUT	BLACKOUT	
1/4/2006	4:44	7:05	2:21	2.35	OPERATION	BYREQUEST	
1/4/2006	9:45	10:15	0:30	0.5	OPERATION	BYREQUEST	TO CONNECT TAP
1/4/2006	15:55	16:25	0:30	0.5	SOL	SOL	NO-43
1/8/2006	18:10	23:55	5:45	5.75	OVERLOAD	OVERLOAD	
1/9/2006	5:01	10:55	5:54	5.9	UF	UNDER FRIQUANCY	BLACK OUT
1/10/2006	10:55	12:55	2:00	2	UF	UNDER FRIQUANCY	BLACK OUT
1/15/2006	13:50	14:15	0:25	0.4166667	PERMANENT	SHORT CIRCUIT	
1/16/2006	17:10	17:12	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/17/2006	11:25	11:27	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
1/19/2006	9:25	11:00	1:35	1.5833333	SOL	SOL	NO-43
1/26/2006	0:15	2:05	1:50	1.8333333	UF	UNDER FRIQUANCY	BLACK OUT
1/27/2006	18:20	18:22	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
1/27/2006	20:10	20:38	0:28	0.46666667	UF	UNDER FRIQUANCY	BLACK OUT
1/28/2006	18:35	19:50	1:15	1.25	SOL	SOL	NO-43
1/29/2006	10:05	10:50	0:45	0.75	OPERATION	BYREQUEST	DUE TO BROKEN TAP
2/1/2006	18:45	19:55	1:10	1.166667	SOL	SOL	NO-43
2/3/2006	9:35	9:44	0:09	0.15	OPERATION	BYREQUEST	
2/6/2006	11:30	12:05	0:35	0.583333	OPERATION	BYREQUEST	DUE TO BROKEN TAP
2/15/2006	0:00	1:43	1:43	1.716667	UF	UNDER FRIQUANCY	BLACK OUT
2/16/2006	6:20	6:22	0:02	0.033333	TRANSIENT	EARTHFAULT	

2/18/2006	8:35	8:37	0:02	0.033333	TRANSIENT	EARTHFAULT	
2/18/2006	18:25	18:45	0:20	0.333333	SOL	SOL	NO-43
2/20/2006	10:35	11:56	1:21	1.35	SOL	SOL	NO-43
2/21/2006	11:57	12:10	0:13	0.216667	OPERATION	BYREQUEST	FOR SAFTY
2/22/2006	18:25	19:40	1:15	1.25	SOL	SOL	NO-43
2/27/2006	6:25	7:20	0:55	0.916667	SOL	SOL	NO-43
2/28/2006	8:00	10:25	2:25	2.416667	OPERATION	BYREQUEST	
3/1/2006	9:35	11:35	2:00	2	PERMANENT	EARTHFAULT	DUE TO BROKEN CONDUCTOR
3/1/2006	13:45	13:48	0:03	0.05	OPERATION	BYREQUEST	TO CLOSED LINK
2/3/2006	16:55	18:30	1:35	1.583333	UNDER FRIQUANCY	BLACK OUT	
2/3/2006	19:10	19:15	0:05	0.083333	OUTGOING FEEDER	OVER LOAD	
3/4/2006	18:20	19:50	1:30	1.5	TRAFO	OVER LOAD	
3/9/2006	7:35	10:28	2:53	2.883333	PERMANENT	EARTHFAULT	
3/9/2006	20:06	20:28	0:22	0.366667	SOL	SOL	NO-43
3/10/2006	10:20	11:15	0:55	0.9166667	PERMANENT	SHORT CIRCUIT	
3/20/2006	10:45	11:15	0:30	0.5	UNDER FRIQUANCY	BLACK OUT	
3/25/2006	8:05	8:07	0:02	0.033333	TRANSIENT	EARTHFAULT	
3/25/2006	8:40	9:42	1:02	1.033333	UNDER FRIQUANCY	BLACK OUT	
3/26/2006	9:25	11:30	2:05	2.083333	PERMANENT	SHORT CIRCUIT	
3/26/2006	17:20	17:30	0:10	0.166667	OPERATION	BYREQUEST	TO CONNECT TAP
3/27/2006	8:20	10:20	2:00	2	UNDER FRIQUANCY	BLACK OUT	
3/29/2006	13:48	17:25	3:37	3.616667	PERMANENT	EARTHFAULT	
3/30/2006	10:55	12:20	1:25	1.416667	SOL	SOL	NO-43
4/3/2006	10:35	10:50	0:15	0.25	OPERATION	BYREQUEST	TO CHANGE RELAY
4/12/2006	3:45	4:40	0:55	0.9166667	UNDER FRIQUANCY	BLACK OUT	
4/12/2006	18:45	20:20	1:35	1.583333	OUTGOING FEEDER	OVER LOAD	
4/13/2006	16:20	16:30	0:10	0.1666667	OPERATION	BYREQUEST	TO ENERGIZE NEW TRAFO
4/14/2006	23:00	23:05	0:05	0.083333	OPERATION	BYREQUEST	DUE TO BROKEN TAP ABOVE LINK
4/15/2006	17:05	17:25	0:20	0.333333	OPERATION	BYREQUEST	DUE TO BROKEN TAP ABOVE LINK
4/18/2006	16:30	16:38	0:08	0.133333	OPERATION	BYREQUEST	FOR MANTAIN CONNDUCTOR ABOVE A LINK
4/18/2006	17:45	18:55	1:10	1.1666667	PERMANENT	EARTHFAULT	
4/18/2006	19:05	19:43	0:38	0.633333	TRAFO	OVERLOAD	
4/24/2006	10:55	10:57	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/24/2006	16:15	16:17	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/28/2006	11:05	11:13	0:08	0.133333	PERMANENT	SHORT CIRCUIT	DUE TO SHORT CIRCUIT ON COT-01
4/28/2006	11:55	12:15	0:20	0.333333	OUTGOING FEEDER	OVERLOAD	257A, PARTIALLY, OPENNING SECTION AT MERETAB
5/8/2006	7:15	7:17	0:02	0.033	TRANSIENT	EARTHFAULT	

5/9/2006	9:58	10:02	0:04	0.067	OPERATION	BYREQUEST	BY CENTRAL EMERGENCY TOOPEN SECTION ATMEHRETAB HOTEL
5/11/2006	3:10	11:25	8:15	8.250	PERMANENT	PERMANENT	CT PROBLEM IN PRIMARY SUBSTATION THE SUPLY GIVENE FROM ADJASENT FEEDER(COT-05, LEG-03, LEG-08)
5/15/2006	18:40	18:46	0:06	0.100	OPERATION	BYREQUEST	TO CLOSE LINK AT KARA
5/15/2006	19:15	19:35	0:20	0.333	OUTGOING FEEDER	OVERLOAD	280A (PARTIALLY BY OPENNING SECTION AT MEHRETEAB HOTEL)
5/22/2006	13:20	14:55	1:35	1.583	PERMANENT	EARTHFAULT	WIRE CUT AT MESALEMYA MAINTAINED & RECONNECTED
5/23/2006	9:30	9:32	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/24/2006	9:20	10:45	1:25	1.417	OPERATION	BYREQUEST	TO SHARE LOAD
5/25/2006	19:55	21:55	2:00	2.000	TLP	TLP	BLACKOUT,DUE TO TANABELES TO DEBERMARKOS 400KV TRANSMISSION LINE PROBLEM
5/28/2006	11:45	11:47	0:02	0.033	OPERATION	BYREQUEST	TO CLOSE SECTION SWTICH BY EASTERN AA TECHINIC
5/28/2006	12:40	12:42	0:02	0.033	OPERATION	BYREQUEST	TO CLOSE SECTION SWTICH BY EASTERN AA TECHINIC
6/9/2006	3:20	7:40	4:20	4.333	PERMANENT	SHORT CIRCUIT	MAINTEN BRPKEN CONDUCTOR
6/9/2006	9:50	10:30	0:40	0.667	OPERATION	BYREQUEST	FOR SEFTY TO MAINTEN BROKEN CONDUCTOR ON COT -05
6/10/2006	0:48	6:55	6:07	6.117	OPERATION	BYREQUEST	FOR LINE RELOCATION WORK BY A.A. CONSTRUCTION
6/12/2006	19:40	20:20	0:40	0.667	OPERATION	BYREQUEST	TO MAINTEN BROKEN TAP NEAR TO SUBSTATION
6/13/2006	16:20	16:50	0:30	0.500	SOL	SOL	179A
6/15/2006	7:10	12:29	5:19	5.317	OPERATION	BYREQUEST	BY AA SEB STATION &AND OPRATION TEAM TO AJUST CT
6/15/2006	12:40	13:26	0:46	0.767	TLP	TLP	DUE TO PROBLEM ON 132KV MUGER LINE
6/15/2006	16:10	19:45	3:35	3.583	TLP	TLP	DUE TO PROBLEM ON 132KV MUGER LINE
6/15/2006	19:20	19:45	0:25	0.417	OPERATION	BYREQUEST	WORK ON LEG SUBSTATION BY SEBSTATION OPRATION TEAM
6/15/2006	20:36	20:38	0:02	0.033	OUTGOING FEEDER	OVERLOAD	
6/22/2006	14:20	14:40	0:20	0.333	OPERATION	BYREQUEST	FOR LOAD TRANSFER FROM COT 03 TO LEG 05
6/22/2006	18:20	18:25	0:05	0.083	PERMANENT	SHORT CIRCUIT	BY MAINTENING BROKEN CONDUCTOR BY EASTERN EMERGENCY SERVICE
6/24/2006	19:10	20:00	0:50	0.833	SOL	SOL	274A
6/27/2006	7:15	7:19	0:04	0.067	TRANSIENT	SHORT CIRCUIT	
6/27/2006	9:00	9:15	0:15	0.250	OPERATION	BYREQUEST	TO ISOLAT LV BOX
6/28/2006	7:10	8:40	1:30	1.500	TLP	TLP	BLACKOUT,LEGETAFO KOMBOLCHA TRANSMISSION LINE EARTH FAULT
6/29/2006	9:30	10:05	0:35	0.583	OPERATION	BYREQUEST	TO CONNECT BROKEN TAP
6/29/2006	19:15	21:15	2:00	2.000	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/29/2006	21:30	23:35	2:05	2.083	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	6:10	6:45	0:35	0.583	SOL	SOL	154A
6/30/2006	8:25	10:45	2:20	2.333	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	9:45	11:00	1:15	1.25	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT

7/1/2006	3/10/2014	16:15	17:35	1:20	1.333	SOL	SOL	178A
7/2/2006	3/11/2014	9:54	13:00	3:06	3.100	SOL	SOL	194A
7/2/2006	3/11/2014	18:55	20:55	2:00	2.000	SOL	SOL	274A
7/4/2006	3/13/2014	10:45	12:05	1:20	1.333	SOL	SOL	254A
7/4/2006	3/13/2014	18:40	21:15	2:35	2.583	SOL	SOL	254A
7/10/2006	3/19/2014	6:40	9:10	2:30	2.500	SOL	SOL	225A

7/11/2006	3/20/2014	13:10	13:12	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
7/15/2006	3/24/2014	15:50	16:06	0:16	0.267	SOL	SOL	UNDER FREQUENCY
7/15/2006	3/24/2014	16:20	17:40	1:20	1.333	SOL	SOL	183A
7/16/2006	3/25/2014	19:00	21:20	2:20	2.333	SOL	SOL	FEEDER-249A
19/7/2006	28/3/2014	13:35	15:05	1:30	1.500	PERMANENT	SHORT CIRCUIT	NOTHING FOUND ON THE LINE BY TRACING & RECONNECTED
20/07/2006	29/3/2014	16:00	16:50	0:50	0.833	SOL	SOL	
24/07/2006	2/4/2014	15:30	17:15	1:45	1.75	PERMANENT	EARTHFAULT	NOTHING FOUND ON THE LINE BY TRACING & RECONNECTED
25/07/2006	3/4/2014	11:00	11:20	0:20	0.33	OPERATION	BYREQUEST	DUE TO FIRE ACCSIDENT ON DISTREBUTION TRAFO
25/07/2006	3/4/2014	21:00	21:30	0:30	0.50	SOL	SOL	FEEDER-240A, BY " 43 (LDC)REQUEST
27/07/2006	5/4/2014	9:30	10:50	1:20	1.333	TLP	TLP	BLACK OUT (SEBETA ,KALITY GEFERSA & SULULTA TRANSMITION LINE EARTH FAULT)
27/07/2006	5/4/2014	19:20	19:55	0:35	0.583	SOL	SOL	
29/07/2006	7/4/2014	18:50	21:40	2:50	2.833	SOL	SOL	
1/8/2006	9/4/2014	9:35	12:05	2:30	2.500	SOL	SOL	FEEDER-220A, BY " 43 (LDC)REQUEST,
1/8/2006	9/4/2014	15:00	18:33	3:33	3.550	PERMANENT	SHORT CIRCUIT	BY MAINTEING BROKEN CONDUCTOR
1/8/2006	9/4/2014	19:40	19:42	0:02	0.033	OUTGOING FEEDER	OVERLOAD	
2/8/2006	10/4/2014	18:45	21:35	2:50	2.833	SOL	SOL	FEEDER-249A, BY " 43 (LDC)REQUEST,
4/8/2006	12/4/2014	18:55	19:55	1:00	1.000	SOL	SOL	FEEDER-265A, BY " 43 (LDC)REQUEST,
5/8/2006	13/4/2014	12:00	13:55	1:55	1.917	TLP	TLP	BLACKOUT, DUE TO BROKEN TRANSMSION LINE FROM GEF TO ADN

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

DATE	INT. TIME	REC. TIME	DUR TIME	Duration (Hr)	TYPE OF FAULT	FAULT REASON	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
3/11/2005	6:10	6:58	0:48	0.8	GUP	GUP	TO OPEN DEBREMARKOSE
9/11/2005	9:55	9:57	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
9/11/2005	15:50	15:53	0:03	0.05	TRANSIENT	SHORT CIRCUIT	
9/11/2005	16:42	18:05	1:23	1.3833333	PERMANENT	SHORT CIRCUIT	DUE TO BROKEN TAP
10/11/2005	7:20	7:22	0:02	0.0333333	TRANSIENT	EARTH FAULT	
10/11/2005	14:52	14:54	0:02	0.0333333	TRANSIENT	EARTH FAULT	
10/11/2005	16:08	19:35	3:27	3.45	PERMANENT	SHORT CIRCUIT	DUE TO BROKEN CONDUCTOR
10/11/2005	6:25	6:27	0:02	0.0333333	TRANSIENT	EARTH FAULT	
10/11/2005	10:45	10:58	0:13	0.2166667	PERMANENT	SHORT CIRCUIT	
10/11/2005	11:35	11:37	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
13/11/2005	10:25	10:27	0:02	0.0333333	TRANSIENT	EARTH FAULT	
14/11/2005	2:43	7:45	5:02	5.0333333	PERMANENT	EARTH FAULT	
16/11/2005	14:45	14:55	0:10	0.1666667	OPERATION	BY REQUEST	TO CONNECT TAP
18/11/2005	10:40	11:55	1:15	1.25	PERMANENT	EARTH FAULT	
18/11/2005	14:30	14:33	0:03	0.05	OPERATION	BY REQUEST	TO PUT TRAFO
19/11/2005	14:55	14:57	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
20/11/2005	3:15	13:50	10:35	10.583333	PERMANENT	EARTH FAULT	DUE TO TREE

20/11/2005	15:00	16:40	1:40	1.6666667	UF	UNDER FRIQUANCY	BLACK OUT
22/11/2005	9:40	9:42	0:02	0.0333333	TRANSIENT	EARTH FAULT	
25/11/2005	18:40	19:45	1:05	1.0833333	PERMANENT	EARTH FAULT	
1/3/2006	20:25	22:05	1:40	1.6666667	BLACKOUT	BLACKOUT	
1/4/2006	6:35	7:05	0:30	0.5	OPERATION	BYREQUEST	
1/4/2006	15:55	16:25	0:30	0.5	SOL	SOL	NO-43
1/5/2006	18:00	18:02	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/8/2006	11:20	18:10	6:50	6.8333333	OVERLOAD	OVERLOAD	
1/8/2006	11:50	11:52	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
1/9/2006	6:05	7:10	1:05	1.0833333	UF	UNDER FRIQUANCY	BLACK OUT
1/9/2006	10:55	10:57	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
1/9/2006	15:40	15:42	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/10/2006	10:55	12:40	1:45	1.75	UF	UNDER FRIQUANCY	BLACK OUT
1/14/2006	16:05	16:08	0:03	0.05	TRANSIENT	EARTHFAULT	
1/17/2006	15:10	18:10	3:00	3	PERMANENT	EARTHFAULT	
1/17/2006	16:38	16:40	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/18/2006	14:20	14:22	0:02	0.0333333	OPERATION	BYREQUEST	TO OPEN SECTION
1/19/2006	6:45	7:00	0:15	0.25	OPERATION	BYREQUEST	FOR SUBSTATION MENTENANCE
1/19/2006	7:25	7:27	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/23/2006	18:12	18:20	0:08	0.1333333	OPERATION	BYREQUEST	
1/23/2006	18:35	18:52	0:17	0.2833333	OVERLOAD	OVERLOAD	
1/24/2006	9:20	9:40	0:20	0.3333333	OPERATION	BYREQUEST	TO OPEN LINK
1/24/2006	9:50	11:31	1:41	1.6833333	OVERLOAD	OVERLOAD	
1/24/2006	17:57	19:45	1:48	1.8	OVERLOAD	OVERLOAD	
1/26/2006	0:15	2:05	1:50	1.8333333	UF	UNDER FRIQUANCY	BLACK OUT
1/26/2006	8:45	12:15	3:30	3.5	PERMANENT	SHORT CIRCUIT	
1/27/2006	20:10	20:38	0:28	0.466667	UF	UNDER FRIQUANCY	BLACK OUT
2/4/2006	13:55	16:30	2:35	2.58333	OPERATION	BYREQUEST	TO CONNECT TAP
2/4/2006	18:40	7:20	12:40	12.6667	PERMANENT	SHORT CIRCUIT	
2/5/2006	8:12	8:14	0:02	0.03333	TRANSIENT	EARTHFAULT	
2/5/2006	8:35	16:22	7:47	7.78333	PERMANENT	EARTHFAULT	
2/6/2006	11:40		12:20	12.3333			
2/7/2006	17:00	17:02	0:02	0.03333	TRANSIENT	EARTHFAULT	
2/9/2006	7:30	7:32	0:02	0.03333	TRANSIENT	EARTHFAULT	
2/10/2006	6:50	7:00	0:10	0.166667	OPERATION	BYREQUEST	
2/15/2006	0:00	1:58	1:58	1.96667	UF	UNDER FRIQUANCY	BLACK OUT
2/16/2006	7:45	7:47	0:02	0.03333	TRANSIENT	EARTHFAULT	
2/20/2006	6:15	6:35	0:20	0.33333	OPERATION	BYREQUEST	

2/23/2006	6:45	8:05	1:20	1.33333	PERMANENT	SHORT CIRCUIT	
3/2/2006	17:54	17:56	0:02	0.03333	TRANSIENT	SHORT CIRCUIT	
2/3/2006	3:10	3:12	0:02	0.033333	TRANSIENT	EARTHFAULT	
2/3/2006	16:55	17:45	0:50	0.83333	UNDER FRIQUANCY	BLACK OUT	
2/3/2006	19:10	19:15	0:05	0.08333	OUTGOING FEEDER	OVER LOAD	
3/8/2006	15:10	16:00	0:50	0.83333	UNDER FRIQUANCY	BLACK OUT	
3/11/2006	7:45	7:47	0:02	0.03333	TRANSIENT	EARTHFAULT	
3/12/2006	8:10	8:12	0:02	0.03333	TRANSIENT	SHORT CIRCUIT	
3/15/2006	6:40	6:42	0:02	0.03333	TRANSIENT	EARTHFAULT	
3/18/2006	14:50	15:15	0:25	0.416667	PERMANENT	EARTHFAULT	
3/18/2006	15:30	15:32	0:02	0.03333	TRANSIENT	EARTHFAULT	
3/20/2006	6:20	7:40	1:20	1.33333	PERMANENT	SHORT CIRCUIT	
3/20/2006	10:45	11:15	0:30	0.5	UNDER FRIQUANCY	BLACK OUT	
3/21/2006	12:55	12:57	0:02	0.03333	TRANSIENT	EARTHFAULT	
3/21/2006	14:20	16:20	2:00	2	OPERATION	BYREQUEST	
3/24/2006	9:50	11:00	1:10	1.166667	PERMANENT	SHORT CIRCUIT	DISCONNECT TAP &CONNECT PARCIALLY
3/25/2006	8:40	9:42	1:02	1.03333	UNDER FRIQUANCY	BLACK OUT	
3/27/2006	8:20	9:50	1:30	1.5	UNDER FRIQUANCY	BLACK OUT	
4/1/2006	7:25	9:50	2:25	2.416667	PERMANENT	SHORT CIRCUIT	
4/8/2006	14:35	15:10	0:35	0.583333	OPERATION	BYREQUEST	TO OPEN LINK
4/8/2006	15:10	15:15	0:05	0.083333	OPERATION	BYREQUEST	TO CLOSED LINK
4/9/2006	17:50	17:52	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/10/2006	14:50	16:20	1:30	1.5	OPERATION	BYREQUEST	
4/11/2006	10:50	10:52	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	
4/11/2006	19:30	20:05	0:35	0.583333	PERMANENT	SHORT CIRCUIT	
4/11/2006	20:10	20:25	0:15	0.25	OPERATION	BYREQUEST	TO MAINTAIN LINK
4/12/2006	2:58	4:50	1:52	1.866667	OPERATION	BYREQUEST	TO CONNECT TRAFO
4/12/2006	17:53	17:55	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	
4/13/2006	15:40	15:42	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	
4/13/2006	15:45	18:15	2:30	2.5	PERMANENT	EARTHFAULT	
4/15/2006	7:40	11:10	3:30	3.5	PERMANENT	SHORT CIRCUIT	
4/15/2006	11:42	11:44	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/15/2006	19:10	19:12	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	
4/16/2006	10:52	12:50	1:58	1.966667	PERMANENT	SHORT CIRCUIT	DUE TO CONNDUCTOR BROKEN
4/16/2006	19:04	20:03	0:59	0.983333	PERMANENT	SHORT CIRCUIT	
4/17/2006	8:25	8:27	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/17/2006	8:55	8:57	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/18/2006	21:30	7:35	10:05	10.08333	PERMANENT	SHORT CIRCUIT	
4/19/2006	8:55	12:10	3:15	3.25	PERMANENT	SHORT CIRCUIT	
4/24/2006	14:17	14:19	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	

4/24/2006	16:15	16:18	0:03	0.05	TRANSIENT	EARTHFAULT	
4/25/2006	9:05	9:07	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	
4/28/2006	11:05	11:13	0:08	0.133333	PERMANENT	SHORT CIRCUIT	DUE TO SHORT CIRCUIT ON COT-01
4/28/2006	16:00	16:02	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/28/2006	16:30	16:32	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/29/2006	9:45	9:47	0:02	0.033333	TRANSIENT	EARTHFAULT	
5/2/2006	16:50	16:52	0:02	0.033	TRANSIENT	EARTHFAULT	
5/2/2006	17:45	17:47	0:02	0.033	TRANSIENT	EARTHFAULT	
5/3/2006	8:18	8:20	0:02	0.033	TRANSIENT	EARTHFAULT	
5/6/2006	10:10	10:12	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/6/2006	15:55	15:57	0:02	0.033	TRANSIENT	EARTHFAULT	
5/6/2006	17:50	17:52	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/7/2006	9:25	9:27	0:02	0.033	TRANSIENT	SHORT CIRCUIT	ONE TIME TRIAL
5/8/2006	16:55	16:57	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/9/2006	16:30	16:32	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/10/2006	17:05	17:07	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/11/2006	8:58	9:00	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/11/2006	18:00	18:02	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/11/2006	18:15	18:20	0:05	0.083	TRANSIENT	SHORT CIRCUIT	
5/12/2006	7:38	7:40	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/12/2006	8:40	8:42	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/12/2006	17:25	17:27	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/12/2006	18:10	18:12	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/13/2006	16:55	16:57	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/14/2006	9:20	10:05	0:45	0.750	PERMANENT	SHORT CIRCUIT	CONDACTOR BROKEN MAINTEND BY EASTERN TECHINIC
5/14/2006	13:40	13:42	0:02	0.033	TRANSIENT	EARTHFAULT	45 KV LIEN BROKEN CONDACTOR MAINTENED BY AA OPRATION TEAM
5/14/2006	17:10	17:12	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/15/2006	7:10	7:12	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/15/2006	15:50	15:52	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/15/2006	16:45	18:25	1:40	1.667	PERMANENT	SHORT CIRCUIT	SAG WIRE AT JACROS ROBERA COFFEE , MAINTAINED AND RECONNECTED
5/16/2006	10:20	10:22	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/22/2006	13:20	13:23	0:03	0.050	TRANSIENT	EARTHFAULT	
5/22/2006	13:50	13:52	0:02	0.033	TRANSIENT	EARTHFAULT	
5/24/2006	8:35	8:37	0:02	0.033	TRANSIENT	EARTHFAULT	
5/25/2006	12:47	13:05	0:18	0.300	OPERATION	BYREQUEST	TO DISCONNECT TRAFO TAP
5/25/2006	19:55	21:55	2:00	2.000	TLP	TLP	BLACKOUT,DUE TO TANABELES TO DEBERMARKOS 400KV TRANSMISSION LINE PROBLEM
5/28/2006	11:50	11:52	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/28/2006	14:20	14:22	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/29/2006	10:02	10:04	0:02	0.033	TRANSIENT	SHORT CIRCUIT	

5/29/2006	10:25	10:27	0:02	0.033	TRANSIENT	EARTHFAULT	
5/29/2006	10:47	11:40	0:53	0.883	PERMANENT	SHORT CIRCUIT	BY OPENNING LINK AND CLOSING
5/30/2006	9:23	9:25	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/30/2006	10:15	12:50	2:35	2.583	OUTGOING FEEDER	OVERLOAD	
5/30/2006	12:55	13:10	0:15	0.250	OUTGOING FEEDER	OVERLOAD	
5/30/2006	13:12	14:25	1:13	1.217	OUTGOING FEEDER	OVERLOAD	
5/30/2006	14:25	18:50	4:25	4.417	OUTGOING FEEDER	OVERLOAD	PARTALLY BY OPENING SECTION AT JACROS
6/1/2006	10:20	10:22	0:02	0.033	OUTGOING FEEDER	OVERLOAD	
6/1/2006	15:30	15:32	0:02	0.033	TRANSIENT	EARTHFAULT	
6/2/2006	10:05	10:20	0:15	0.250	OPERATION	BYREQUEST	BY EASTERN TECHNIC PARTALLY BY DISCONNECTING TAP TO RE-ERECT TILTED HT POLE
6/2/2006	10:20	12:00	1:40	1.667	OPERATION	BYREQUEST	BY EASTREN TECHNIC PARTALLY TO RE-CONNECT TAP
6/2/2006	10:05	10:20	0:15	0.250	OPERATION	BYREQUEST	BY EASTERN TECHNIC PARTALLY BY DISCONNECTING TAP TO RE-ERECT TILTED HT POLE
6/2/2006	10:20	12:00	1:40	1.667	OPERATION	BYREQUEST	BY EASTREN TECHNIC PARTALLY TO RE-CONNECT TAP
6/5/2006	11:35	11:37	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/5/2006	19:20	20:35	1:15	1.250	PERMANENT	SHORT CIRCUIT	BY DISCONNECTING TAP AT ATLETICSE FEDERATION DUE TRAFO FAIL TO GROUND BY EAST EMERGENCY
6/5/2006	20:35	20:45	0:10	0.167	PERMANENT	SHORT CIRCUIT	PARTALLY TO CONNECT TAP AT ATLETICSE FEDERATION (ONLY ONE TRAFO)
6/6/2006	11:25	11:40	0:15	0.250	OPERATION	BYREQUEST	TO CONNECT BROKEN TAP BY EASTERN AA TECHNIC
6/6/2006	14:45	17:45	3:00	3.000	OPERATION	BYREQUEST	TO CONNECT TAP AT ARARAT HOTEL BY EASTERN TECHNIC
6/7/2006	11:00	11:02	0:02	0.033	OUTGOING FEEDER	OVERLOAD	
6/8/2006	15:15	15:17	0:02	0.033	TRANSIENT	EARTHFAULT	
6/9/2006	3:20	3:22	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/10/2006	0:48	6:55	6:07	6.117	OPERATION	BYREQUEST	FOR LINE RELOCATION WORK BY A.A. CONSTRUCTION
6/10/2006	10:35	10:37	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/10/2006	10:55	10:57	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/10/2006	11:30	11:32	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/10/2006	19:45	20:15	0:30	0.500	OPERATION	BYREQUEST	TO CHANGE DAMEGE TRAFO
6/11/2006	0:10	10:30	10:20	10.333	PERMANENT	SHORT CIRCUIT	BY MAINTENING BROKEN CONDUCTOR
6/11/2006	10:52	10:54	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/12/2006	11:20	11:22	0:02	0.033	TRANSIENT	EARTHFAULT	
6/12/2006	16:40	16:42	0:02	0.033	TRANSIENT	EARTHFAULT	
6/15/2006	7:10	7:45	0:35	0.583	OPERATION	BYREQUEST	BY AA SEB STATION &AND OPRATION TEAM TO AJUST CT
6/15/2006	12:40	19:45	7:05	7.083	TLP	TLP	DUE TO PROBLEM ON 132KV MUGER LINE
6/21/2006	11:31	11:33	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
6/24/2006	11:00	11:02	0:02	0.033	OUTGOING FEEDER	OVERLOAD	
6/24/2006	11:20	11:22	0:02	0.033	OUTGOING FEEDER	OVERLOAD	
6/24/2006	11:50	12:20	0:30	0.500	OUTGOING FEEDER	OVERLOAD	
6/26/2006	10:35	10:37	0:02	0.033	OUTGOING FEEDER	OVERLOAD	
6/26/2006	11:00	11:02	0:02	0.033	OUTGOING FEEDER	OVERLOAD	

6/26/2006	11:25	11:40	0:15	0.250	OPERATION	BYREQUEST	TO SHARE THE LOAD FROM COT-04 TO WER-12
6/27/2006	9:15	9:17	0:02	0.033	OPERATION	BYREQUEST	TO CLOSE LINE
6/27/2006	9:50	10:00	0:10	0.167	OPERATION	BYREQUEST	FOR LOAD SHARING
6/28/2006	7:10	8:40	1:30	1.500	TLP	TLP	BLACKOUT,LEGETAFO KOMBOLCHA TRANSMISSION LINE EARTH FAULT
6/29/2006	19:15	20:30	1:15	1.250	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/29/2006	20:45	20:55	0:10	0.167	SOL	SOL	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/29/2006	21:30	23:35	2:05	2.083	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	8:25	10:45	2:20	2.333	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	9:45	11:00	1:15	1.25	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT

7/1/2006	3/10/2014	9:30	9:32	0:02	0.033	TRANSIENT	EARTHFAULT	
7/2/2006	3/11/2014	14:55	15:25	0:30	0.500	PERMANENT	SHORT CIRCUIT	NOTHING FOUND ON THE LINE BY TRACING
7/2/2006	3/11/2014	16:20	17:50	1:30	1.500	PERMANENT	EARTHFAULT	DUE TO BIG BILBORD FALLEN ON THE LINE
7/4/2006	3/13/2014	17:20	17:22	0:02	0.033	TRANSIENT	EARTHFAULT	
7/5/2006	3/14/2014	18:55	19:55	1:00	1.000	SOL	SOL	219A
7/6/2006	3/15/2014	22:10	0:02	1:52	1.867	PERMANENT	SHORT CIRCUIT	PARTALLY BYOPENING LINK AT COTEBE CHAINA COLLEGE
7/6/2006	3/15/2014	0:02	10:40	10:38	10.633	PERMANENT	SHORT CIRCUIT	PATALLY BY MAINTEING BROKEN CONDUCTOR
7/12/2006	3/21/2014	16:50	16:52	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
7/14/2006	3/23/2014	10:40	10:42	0:02	0.033	TRANSIENT	EARTHFAULT	
23/07/2006	1/4/2014	19:05	19:35	0:30	0.50	SOL	SOL	FEEDER-201A
25/07/2006	3/4/2014	10:45	12:30	1:45	1.75	SOL	SOL	FEEDER-250A, BY " 43 (LDC)REQUEST
27/07/2006	5/4/2014	9:30	10:50	1:20	1.333	TLP	TLP	BLACK OUT (SEBETA ,KALITY GEFERSA& SULULTA TRANSMITION LINE EARTH FAULT)
30/07/2006	8/4/2014	10:55	13:35	2:40	2.667	SOL	SOL	FEEDER-244A, BY " 43 (LDC)REQUEST,
30/07/2006	8/4/2014	14:40	14:42	0:02	0.033	TRANSIENT	EARTHFAULT	
30/07/2006	8/4/2014	18:45	20:00	1:15	1.250	SOL	SOL	FEEDER-203A, BY " 43 (LDC)REQUEST,
3/8/2006	11/4/2014	11:00	12:15	1:15	1.250	SOL	SOL	FEEDER-245A, BY " 43 (LDC)REQUEST,
5/8/2006	13/4/2014	12:00	13:55	1:55	1.917	TLP	TLP	BLACKOUT, DUE TO BROKEN TRANSMSION LINE FROM GEF TO ADN
5/8/2006	13/4/2014	17:35	18:00	0:25	0.417	OPERATION	BYREQUEST	FOR MAINTANANCE WORK
8/8/2006	16/4/2014	19:00	21:25	2:25	2.417	SOL	SOL	FEEDER-190A, BY " 43 (LDC)REQUEST,

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

DATE	INT. TIME	REC. TIME	DUR TIME	Dur (Hr)	TYPE OF FAULT	FAULT REASON	IDENTIFIED CAUSE/WORK & MEASURE TAKEN
1/11/2005	10:30	10:32	0:02	0.0333333	TRANSIENT	EARTH FAULT	
1/11/2005	14:35	14:37	0:02	0.0333333	TRANSIENT	EARTH FAULT	
1/11/2005	13:54	20:00	6:06	6.1	PERMANENT	EARTH FAULT	

3/11/2005	6:10	6:58	0:48	0.8	GUP	GUP	TO OPEN DEBREMARKOSE
5/11/2005	12:35	12:37	0:02	0.033333	TRANSIENT	EARTH FAULT	
6/11/2005	8:42	8:44	0:02	0.0333333	TRANSIENT	EARTH FAULT	
7/11/2005	11:30	11:32	0:02	0.0333333	TRANSIENT	EARTH FAULT	
7/11/2005	13:10	13:12	0:02	0.0333333	TRANSIENT	EARTH FAULT	
10/11/2005	7:20	7:22	0:02	0.0333333	TRANSIENT	EARTH FAULT	
10/11/2005	11:05	12:15	1:10	1.1666667	PERMANENT	EARTH FAULT	
10/11/2005	14:38	14:47	0:09	0.15	OPERATION	BY REQUEST	TO CONNECT TAP
10/11/2005	6:25	6:27	0:02	0.0333333	TRANSIENT	EARTH FAULT	
10/11/2005	10:35	10:40	0:05	0.0833333	PERMANENT	SHORT CIRCUIT	DECRESE LOAD F4 TRIP/CLOSE IT
14/11/2005	8:50	8:52	0:02	0.0333333	TRANSIENT	EARTH FAULT	
14/11/2005	10:00	10:02	0:02	0.0333333	TRANSIENT	EARTH FAULT	
15/11/2005	7:20	7:22	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
15/11/2005	7:58	11:13	3:15	3.25	PERMANENT	SHORT CIRCUIT	
15/11/2005	10:35	10:37	0:02	0.0333333	TRANSIENT	EARTH FAULT	
16/11/2005	18:45	19:30	0:45	0.75	SOL	SOL	NO-43
16/11/2005	17:15	20:40	3:25	3.4166667	OPERATION	BY REQUEST	
18/11/2005	10:40	10:42	0:02	0.0333333	TRANSIENT	EARTH FAULT	
18/11/2005	15:10	15:12	0:02	0.0333333	TRANSIENT	EARTH FAULT	
20/11/2005	19:25	22:05	2:40	2.6666667	OVER LOAD	OVER LOAD	
20/11/2005	11:10	11:45	0:35	0.5833333	PERMANENT	SHORT CIRCUIT	DECRESE LOAD F5 TRIP/CLOSE IT
20/11/2005	17:15	17:17	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
20/11/2005	18:17	18:19	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
20/11/2005	19:03	19:06	0:03	0.05	TRANSIENT	SHORT CIRCUIT	
20/11/2005	15:00	17:20	2:20	2.3333333	UF	UNDER FRIQUANCY	BLACK OUT
26/11/2005	10:25	11:00	0:35	0.5833333	OPERATION	BY REQUEST	FOR SAFTY
30/11/2005	18:30	18:32	0:02	0.0333333	OVER LOAD	OVER LOAD	
30/11/2005	18:30	18:35	0:05	0.0833333	OVER LOAD	OVER LOAD	
30/11/2005	18:45	18:47	0:02	0.0333333	OVER LOAD	OVER LOAD	
30/11/2005	19:00	19:50	0:50	0.8333333	OVER LOAD	OVER LOAD	
30/11/2005	23:05	23:10	0:05	0.0833333	OPERATION	BY REQUEST	TO CLOSED LINK
1/3/2006	20:25	22:10	1:45	1.75	BLACKOUT	BLACKOUT	
1/4/2006	5:10	7:05	1:55	1.9166667	OPERATION	BYREQUEST	
1/4/2006	15:55	17:16	1:21	1.35	SOL	SOL	NO-43
1/5/2006	14:00	14:30	0:30	0.5	PERMANENT	EARTHFAULT	DUE TO RAIN
1/5/2006	15:55	15:57	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/5/2006	18:00	18:02	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/8/2006	18:10	23:32	5:22	5.3666667	OVERLOAD	OVERLOAD	
1/9/2006	5:13	10:55	5:42	5.7	UF	UNDER FRIQUANCY	BLACK OUT

1/9/2006	15:40	15:42	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/9/2006	22:50	23:15	0:25	0.4166667	OPERATION	BYREQUEST	FOR SAFTY
1/10/2006	10:55	12:40	1:45	1.75	UF	UNDER FRIQUANCY	BLACK OUT
1/10/2006	17:15	17:30	0:15	0.25	SOL	SOL	NO-43
1/11/2006	7:15	7:17	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/12/2006	19:05	19:10	0:05	0.0833333	PERMANENT	SHORT CIRCUIT	DECRESE LOAD F4 TRIP/CLOSE IT
1/13/2006	6:55	6:57	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/14/2006	13:45	13:55	0:10	0.1666667	PERMANENT	EARTHFAULT	
1/14/2006	16:05	16:08	0:03	0.05	TRANSIENT	EARTHFAULT	
1/15/2006	13:50	14:10	0:20	0.3333333	PERMANENT	SHORT CIRCUIT	
1/16/2006	17:10	17:12	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/17/2006	15:10	18:10	3:00	3	PERMANENT	EARTHFAULT	
1/19/2006	6:45	7:00	0:15	0.25	OPERATION	BYREQUEST	FOR SUBSTATION MENTENANCE
1/19/2006	7:25	7:27	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/21/2006	13:00	13:02	0:02	0.0333333	TRANSIENT	EARTHFAULT	
1/23/2006	18:20	18:25	0:05	0.0833333	OPERATION	BYREQUEST	
1/23/2006	18:40	19:15	0:35	0.5833333	OVERLOAD	OVERLOAD	OPEN THE LINK &CONNECT PARTIALLY
1/24/2006	7:00	8:41	1:41	1.6833333	OPERATION	BYREQUEST	
1/24/2006	17:00	17:25	0:25	0.4166667	OPERATION	BYREQUEST	DUE TO BROKEN TAP ON THE LINK
1/24/2006	19:10	19:30	0:20	0.3333333	OPERATION	BYREQUEST	TO CLOSED SECTION
1/26/2006	0:15	2:05	1:50	1.8333333	UNDER FRIQUANCY	UNDER FRIQUANCY	BLACK OUT
1/27/2006	20:10	20:38	0:28	0.4666667	UNDER FRIQUANCY	UNDER FRIQUANCY	BLACK OUT
1/29/2006	12:00	12:02	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
2/1/2006	11:30	11:32	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/5/2006	8:12	8:14	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/6/2006	8:13	8:15	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/6/2006	11:30	12:05	0:35	0.5833333	OPERATION	BYREQUEST	DUE TO BROKEN TAP
2/7/2006	17:00	17:02	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/9/2006	7:30	7:32	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/10/2006	6:50	7:00	0:10	0.1666667	OPERATION	BYREQUEST	
2/10/2006	18:40	18:42	0:02	0.0333333	TRANSIENT	SHORT CIRCUIT	
2/10/2006	18:50	18:53	0:03	0.05	OVERLOAD	OVER LOAD	
2/10/2006	18:58	20:55	1:57	1.95	OVERLOAD	OVER LOAD	
2/15/2006	0:00	1:40	1:40	1.6666667	UNDER FRIQUANCY	UNDER FRIQUANCY	BLACK OUT
2/16/2006	6:20	6:22	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/16/2006	7:45	7:47	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/18/2006	8:35	8:37	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/18/2006	18:45	20:03	1:18	1.3	PERMANENT	SHORT CIRCUIT	

2/21/2006	12:25	12:32	0:07	0.1166667	OPERATION	BYREQUEST	
2/25/2006	17:35	17:37	0:02	0.0333333	TRANSIENT	EARTHFAULT	
2/27/2006	9:40	10:10	0:30	0.5	OPERATION	BYREQUEST	FOR SAFTY
3/1/2006	14:55	14:57	0:02	0.033333	TRANSIENT	EARTHFAULT	
2/3/2006	3:10	3:12	0:02	0.033333	TRANSIENT	EARTHFAULT	
2/3/2006	16:55	17:45	0:50	0.833333	UF	BLACK OUT	
2/3/2006	19:10	19:15	0:05	0.083333	OUTGOING FEEDER	OVER LOAD	
3/4/2006	13:50	13:52	0:02	0.033333	TRANSIENT	EARTHFAULT	
3/8/2006	15:10	16:00	0:50	0.833333	UNDER FRIQUANCY	BLACK OUT	
3/8/2006	15:10	16:35	1:25	1.416667	UNDER FRIQUANCY	BLACK OUT	
3/10/2006	11:00	13:15	2:15	2.25	OPERATION	BYREQUEST	PARCIALLY CONNECTED
3/10/2006	15:20	15:50	0:30	0.5	OPERATION	BYREQUEST	
3/10/2006	17:40	17:50	0:10	0.166667	OPERATION	BYREQUEST	TO CONNECT TAP
3/11/2006	7:45	7:47	0:02	0.033333	TRANSIENT	EARTHFAULT	
3/12/2006	9:00	9:02	0:02	0.033333	TRANSIENT	EARTHFAULT	
3/15/2006	6:40	6:42	0:02	0.033333	TRANSIENT	EARTHFAULT	
3/18/2006	14:50	15:15	0:25	0.416667	PERMANENT	EARTHFAULT	
3/18/2006	15:30	15:32	0:02	0.033333	TRANSIENT	EARTHFAULT	
3/20/2006	10:45	11:15	0:30	0.5	UNDER FRIQUANCY	BLACK OUT	
3/21/2006	12:55	12:57	0:02	0.033333	TRANSIENT	EARTHFAULT	
3/25/2006	8:40	9:42	1:02	1.033333	UNDER FRIQUANCY	BLACK OUT	
3/27/2006	8:20	9:50	1:30	1.5	UNDER FRIQUANCY	BLACK OUT	
4/3/2006	10:07	10:35	0:28	0.4666667	OPERATION	BYREQUEST	TO CHANGE RELAY
4/4/2006	11:45	12:20	0:35	0.583333	OPERATION	BYREQUEST	
4/6/2006	14:55	15:05	0:10	0.1666667	OPERATION	BYREQUEST	FOR MENTENANCE
4/7/2006	16:40	16:42	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/12/2006	3:45	4:40	0:55	0.9166667	UNDER FRIQUANCY	BLACK OUT	
4/12/2006	17:43	18:05	0:22	0.366667	OPERATION	BYREQUEST	FOR SAFTY
4/12/2006	19:15	19:30	0:15	0.25	UNDER FRIQUANCY	BLACK OUT	1ST &2ND STAGE
4/17/2006	8:25	8:27	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/18/2006	17:45	18:56	1:11	1.183333	PERMANENT	EARTHFAULT	
4/22/2006	19:35	19:37	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/22/2006	21:00	22:10	1:10	1.166667	OPERATION	BYREQUEST	FOR LEG-08 MAINTENANCE
4/23/2006	4:40	6:25	1:45	1.75	OPERATION	BYREQUEST	BY EASTERN TECHNIQUE, FOR MAINTENANCE AT 02 HEALTH CENTER
4/24/2006	10:55	10:58	0:03	0.05	TRANSIENT	EARTHFAULT	
4/25/2006	15:05	15:10	0:05	0.083333	OPERATION	BYREQUEST	FOR LOAD SHARING TO COT-05
4/28/2006	11:05	11:13	0:08	0.133333	PERMANENT	SHORT CIRCUIT	DUE TO SHORT CIRCUIT ON COT-01
4/28/2006	16:05	16:07	0:02	0.033333	TRANSIENT	EARTHFAULT	
4/29/2006	9:45	9:47	0:02	0.033333	TRANSIENT	EARTHFAULT	

4/30/2006	16:05	16:07	0:02	0.033333	TRANSIENT	SHORT CIRCUIT	
5/2/2006	16:50	16:53	0:03	0.050	TRANSIENT	EARTHFAULT	
5/3/2006	8:18	8:21	0:03	0.050	TRANSIENT	EARTHFAULT	
5/3/2006	14:15	14:17	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
5/4/2006	17:25	17:27	0:02	0.033	TRANSIENT	EARTHFAULT	
5/6/2006	11:45	12:20	0:35	0.583	OPERATION	BYREQUEST	FIRE ACCIDENT RECONNECTED AFTER CLEARANCE
5/6/2006	15:55	16:30	0:35	0.583	PERMANENT	EARTHFAULT	
5/7/2006	15:15	15:17	0:02	0.033	TRANSIENT	EARTHFAULT	ONE TIME TRIAL
5/7/2006	16:00	18:48	2:48	2.800	PERMANENT	SHORT CIRCUIT	LOAD DECREMENT ON F4 OF LEG01-ST2 SWITCHING STATION FEEDER IS CLOSED
5/11/2006	10:40	10:45	0:05	0.083	OUTGOING FEEDER	OVERLOAD	
5/12/2006	6:40	9:20	2:40	2.667	PERMANENT	SHORT CIRCUIT	TWIST OF CONDUCTORS
5/22/2006	13:20	13:23	0:03	0.050	TRANSIENT	EARTHFAULT	
5/25/2006	19:55	21:55	2:00	2.000	TLP	TLP	BLACKOUT,DUE TO TANABELES TO DEBERMARKOS 400KV TRANSMISSION LINE PROBLEM
6/9/2006	3:20	7:40	4:20	4.333	PERMANENT	SHORT CIRCUIT	CONDUCTOR BROKEN
6/9/2006	9:50	10:30	0:40	0.667	OPERATION	BYREQUEST	MAINTEN BRPKEN CONDUCTOR
6/10/2006	0:48	6:55	6:07	6.117	OPERATION	BYREQUEST	FOR LINE RELOCATION WORK BY A.A. CONSTRUCTION
6/11/2006	0:25	12:10	11:45	11.750	PERMANENT	SHORT CIRCUIT	BY MAINTENING BROKEN CONDUCTOR
6/11/2006	20:00	20:05	0:05	0.083	OPERATION	BYREQUEST	TO CLOSE LIKE AT COTEBEBRETABRET BY EASTREN TECHNIC
6/12/2006	19:55	20:20	0:25	0.417	OPERATION	BYREQUEST	SEFTY FOR MAINTEN COT 03
6/15/2006	7:10	7:45	0:35	0.583	OPERATION	BYREQUEST	BY AA SEB STATION &AND OPRATION TEAM TO AJUST CT
6/15/2006	12:40	19:45	7:05	7.083	TLP	TLP	DUE TO PROBLEM ON 132KV MUGER LINE
6/15/2006	19:20	20:03	0:43	0.717	OPERATION	BYREQUEST	WORK ON LEG SUBSTATION BY SEBSTATION OPRATION TEAM
6/19/2006	11:19	12:55	1:36	1.600	PERMANENT	SHORT CIRCUIT	DUETO TREES FALLING ON THE MV LINE
6/28/2006	7:10	8:40	1:30	1.500	TLP	TLP	BLACKOUT,LEGETAFO KOMBOLCHA TRANSMISSION LINE EARTH FAULT
6/29/2006	19:15	20:35	1:20	1.333	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/29/2006	20:45	20:55	0:10	0.167	SOL	SOL	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/29/2006	21:30	23:35	2:05	2.083	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	8:25	10:45	2:20	2.333	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT
6/30/2006	9:45	11:00	1:15	1.25	TLP	TLP	BLACK- OUT,FINCHA DEBREMARKOS TRANSMISSION LINE FAULT

7/1/2006	3/10/2014	19:05	22:25	3:20	3.333	SOL	SOL	340A
7/3/2006	3/12/2014	19:15	21:20	2:05	2.083	SOL	SOL	128A
7/6/2006	3/15/2014	22:15	22:17	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
7/6/2006	3/15/2014	22:20	22:45	0:25	0.417	PERMANENT	SHORT CIRCUIT	RECONNECTED AFTER TRIAL A WHILE
7/6/2006	3/15/2014	22:50	0:05	1:15	1.250	PERMANENT	EARTHFAULT	PARTALLY BY OPENING LIMK AT DEHININET
7/6/2006	3/15/2014	0:05	10:55	10:50	10.833	PERMANENT	EARTHFAULT	PARTALLY BY CLOSING LIMK AT DEHININET & MAINTEING BROKEN CONDUCTOR
7/8/2006	3/17/2014	9:20	9:22	0:02	0.033	TRANSIENT	EARTHFAULT	
7/10/2006	3/19/2014	6:40	9:05	2:25		SOL	SOL	96A

					2.417			
7/15/2006	3/24/2014	11:15	11:17	0:02	0.033	TRANSIENT	EARTHFAULT	
7/15/2006	3/24/2014	11:20	11:22	0:02	0.033	TRANSIENT	SHORT CIRCUIT	
7/15/2006	3/24/2014	15:50	16:10	0:20	0.333	SOL	SOL	UNDER FREQUENCY
7/17/2006	3/26/2014	19:05	20:00	0:55	0.917	SOL	SOL	FEEDER-117A
7/18/2006	3/27/2014	13:25	14:45	1:20	1.333	PERMANENT	SHORT CIRCUIT	BY ISOLATING ONE TRAFO, ARRANGING TWISTED CONDUCTOR, MAINTAINING BROKEN CONDUCTOR
19/7/2006	28/3/2014	10:25	10:30	0:05	0.083	OPERATION	BYREQUEST	TO STRAIGHTEN TILTED MV POLE
25/07/2006	3/4/2014	19:00	21:30	2:30	2.50	SOL	SOL	FEEDER-115A, BY " 43 (LDC)REQUEST
27/07/2006	5/4/2014	9:30	12:25	2:55	2.917	TLP	TLP	BLACK OUT (SEBETA ,KALITY GEFERSA& SULULTA TRANSMITION LINE EARTH FAULT)
27/07/2006	5/4/2014	13:15	13:30	0:15	0.250		SOL	FEEDER-123A, BY " 43 (LDC)REQUEST,
29/07/2006	7/4/2014	18:35	21:25	2:50	2.833	SOL	SOL	FEEDER-100A, BY " 43 (LDC)REQUEST,
1/8/2006	9/4/2014	16:35	18:35	2:00	2.000	OPERATION	BYREQUEST	SEFTY TO MAINTAINING COT 03
2/8/2006	10/4/2014	19:10	20:58	1:48	1.800	SOL	SOL	FEEDER-87A, BY " 43 (LDC)REQUEST,
5/8/2006	13/4/2014	12:00	13:55	1:55	1.917	TLP	TLP	BLACKOUT, DUE TO BROKEN TRANSMSION LINE FROM GEF TO ADN

*TLP = Transmission line problem

*SOL = System over load

*UF = under frequency