



**Mekelle University**  
**Ethiopian Institute of Technology-Mekelle**  
School of Electrical and Computer Engineering

A Thesis on “**Medium Voltage Distributed Network Performance Optimization by Reliability Centered Maintenance Prioritization of Distributed Feeders and DG Integration**”.

Submitted to the School of Electrical and Computer Engineering at the Ethiopian Institute of Technology of Mekelle, Mekelle University in partial fulfillment of the requirement of **Master of Science in Electrical Power Engineering**.

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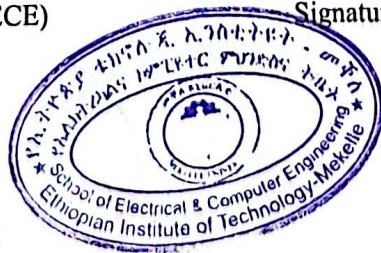
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## Declaration

I hereby declare that the work in this thesis entitled “Optimize medium voltage distributed network performance by reliability-centered maintenance feeder prioritization of distribution feeders and DG integration – in the case of Mekelle City Distribution Network”, submitted to Ethiopian Institute of Technology, Mekelle under the supervision of Dr.ir. Leake Enquay, is a presentation of my original work and no part of the thesis has been submitted for any other degree except where indicated by special reference in the text. Moreover, all sources of other materials used in this work have been fully acknowledged. This thesis has been carried out in accordance with the regulations of Ethiopian Institute of Technology, Mekelle (EIT-M).

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## **Acknowledgment**

I am greatly indebted to my Almighty **GOD** on His mercy and blessing for making this work successful.

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## **Abstract**

In today's world, virtually every human activity relies on electricity, either directly or indirectly. Reliable electric power is essential for our daily activities, and this power is delivered through a distribution network. However, numerous issues prevent the continuous supply of electricity to end-users. The main problem on the distribution network are lack of planned preventive maintenance, improper feeder size selection, over load and lack of DG. To address these issues, this work employs a reliability-centered prioritization of feeders for maintenance and integrate a solar PV system to the distribution network using the Electrical Transient Analyzer Program (ETAP) to improve the reliability and availability of electric power.

A comprehensive reliability analysis for identifying a feeder R5 as a case study sample, making it the case study for Reliability improvement. By integrating, a DG in the selected feeder results a significant improvement in reliability indices. The System Average Interruption Duration Index (SAIDI) was reduced from 735.43 hours/customer/year to 369.413 hours/customer/year, and the System Average Interruption Frequency Index (SAIFI) decreased from 293.259 per year to 200.30 per year. These reductions represent decreases of 49.77% and 31.7%, respectively. Furthermore, the Expected Energy Not Supplied (EENS) dropped from 46,107.5 MWh to 23106.71 MWh, and the Expected Outage Cost (ECOST) decreased from \$2,019,508.5 to \$1,012,073.898, indicating an improvement in cost-worth reliability indices and the network's revenue. The reduced reliability indices demonstrate the enhanced performance of the distribution network from a reliability perspective. Implementing a reliability-centered maintenance for the feeders in the conventional distribution network would also improve the reliability of Mekelle city distribution network.

**Keywords:** ETAP, DG, Reliability-centered maintenance

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# Chapter 1 - Introduction

## 1.1 Background

Ensuring optimal asset performance stands as a primary objective for managers overseeing power distribution systems. Achieving this demands a keen focus on maintenance optimization, which seeks to strike a balance between reliability, cost-efficiency, and meeting customer and regulatory demands. Central to this endeavor is the efficient alignment of maintenance with reliability, and the quest to determine the most advantageous ratio between preventive and corrective maintenance measures.

The concept of cost-effective maintenance through reliability analysis for power system networks dates back to the 1960s, with the advent of computer-driven reliability models [1] and [2]. However, evolving tools and evolving needs within electric power systems require ongoing methodological advancements, including the improvement of maintenance optimization frameworks. Noteworthy strides have been made in developing methods to underpin economically viable maintenance strategies, exemplified in [3], which outlines a quantitative approach to crafting Reliability Centered Maintenance (RCM) plans. While yielding the best solution from a set of policies rather than the ultimate optimal solution, this technique involves comparing various maintenance policies. This thesis extends this methodology, detailing an optimization approach that yields a singular optimal policy, drawing on component reliability importance methods elucidated in [4].

The pursuit of an optimal maintenance solution is not novel, as evidenced by references like [5] and [6]. Nevertheless, the intricate interplay between maintenance, reliability, and costs remains partially unresolved. Pressing demands from stakeholders—owners, authorities, and customers—underscore the imperative for continued innovation in maintenance methodologies, particularly in effectively addressing evolving needs and preferences. Establishing a nexus between component and system reliability performance, with a focus on assessing system performance across multiple load and supply points simultaneously, emerges as pivotal.

Moreover, the dynamics of reregulation have kept the motivation for studying power system performance through a multi objective lens, considering both customer satisfaction and the total network maintenance cost. This broader perspective equips decision-makers with a spectrum of solutions to deliberate upon.

The distribution system domain takes the responsibility to deliver the electricity from the transmission system to end-users in the customer domain. About 80% of customer interruptions are attributed to distribution component failure at the feeder level [7]. In today's environment, the distribution network operator is forced to increase investments due to increasing the pressures from energy regulators and customers to maintain the optimal level of reliability of their network and increase the quality of supply. The reliability-centered maintenance is the key answer to many challenges facing electrical distribution networks.

Mekelle city distribution network is found in the northern part of Ethiopia in which The Ethiopian Electric Utility owns it. The conventional distribution system in the Mekelle city distribution network is a radial network. When a fault happens at any point of a feeder, the upstream circuit breaker opens and interrupts the whole customers, who are connected to it. Currently, the distribution network is under rehabilitation. In addition to rehabilitation of the distribution network, it needs to have preventive maintenance schedule and reliability-centered maintenance prioritization of feeders improves its operating system in terms of reliability, voltage regulation, feeder loading, etc.

## **1.2 Statement of the Problem**

The primary network responsible for delivering power to end-users is the distribution system. Because it is in close proximity to customers, it requires robust protection and control, regular preventive maintenance, and rapid corrective maintenance measures. Ensuring reliable and high-quality power delivery is crucial for profitability and customer satisfaction. Ethiopia Electric Utility (EEU) struggles to provide such quality and reliability. However, the distribution networks in Ethiopia have not; a regular preventive maintenance schedule, regular inspection schedule, feeder prioritization for maintenance and its radial erection of the feeders are unmanageable to reliability of it. Typically, feeders are equipped with only basic circuit breakers at the substation for fault management. When faults occur and breakers trip, downstream customers experience power interruptions. Identifying and rectifying faults also takes considerable time. Consequently, the reliability of the distribution network is compromised and significantly affecting its overall performance.

Similarly, the Mekelle City Distribution Network encounters reliability and efficiency challenges. While the network has undergone rehabilitation with the introduction of switching stations, preventive maintenance, reliability centered maintenance (RCM), feeder prioritization for maintenance were not

adequately addressed in the process. Despite an increase in the number of switching stations, the network remains radial without integrated any alternative supply to improve the reliability of the distribution network. These issues significantly undermine the reliability and operational efficiency of the distribution network. To address these challenges, this work-study on reliability centered maintenance prioritization of distribution feeders and integrated DG on the highly affected feeders to improve the reliability of the distribution network.

## **1.3 Objective**

### **1.3.1 General Objective**

The general objective of this research is to optimize medium voltage distributed network performance by reliability-centered maintenance prioritization of distribution feeders and DG integration. In the case of Mekelle city distribution network.

### **1.3.2 Specific Objectives**

- ❖ To evaluate the reliability of the existing distribution network and identify the weakest Critical Feeder.
  
- ❖ To determine the size of distributed generation DG and integrate the DG to the critical weak feeder of the distribution system to achieve the optimal reliability solutions.
  
- ❖ Cost benefit Analysis of the Mitigation Technique.

## **1.4 Methodology**

The main goal of this work is to improve the reliability of a radial distribution network by integrating distribution generation to the conventional distribution network. The formal methodology followed to achieve the objectives of the thesis work is listed below.

**Data Collection:** - this is the primary task, which is performed in this research. The necessary data that has been collected are monthly interruption duration and number of interruption frequency, number of transformers and its rating, and feeder peak load, length and type of conductor.

**Data Analysis:** - the data are analyzed to identify the main cause of interruption on the feeders. It is manipulated using Microsoft excel.

**System Modelling:** - the Mekelle city distribution network is modelled in ETAP 19.0.1 version software. Reliability analysis of the distribution network is manipulated using this model and the reliability indices are calculated.

## **1.5 Organization of the thesis**

Including the introductory chapter, the thesis consists of five chapters. Chapter 2 provides a literature review and theoretical frameworks. It explains the theory that helped to clarify the systems in this thesis, the reliability indices benchmarks, and system components and review related kinds of literature.

The third chapter deals with data analysis and system modeling. In this chapter the collected data, the distribution network model, and reliability analysis activity are articulated.

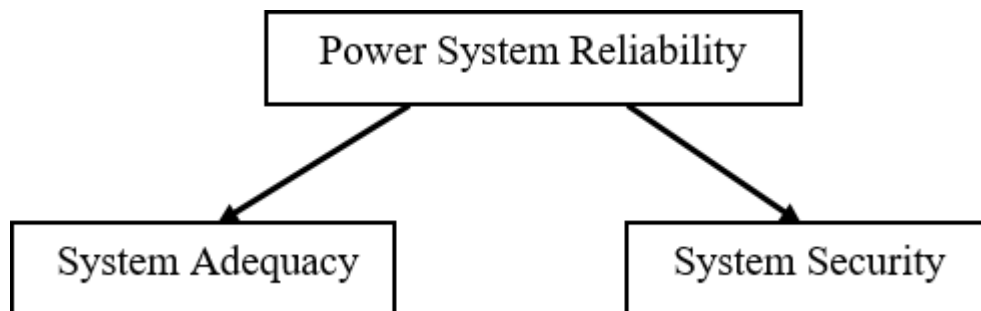
The fourth chapter deals with the overall result and discussion. The results, which are achieved from ETAP software, are discussed in this chapter. Finally, the last chapter consists of the conclusion and recommendation of the thesis.

## Chapter 2 - Literature Review and Conceptual Framework

### 2.1 Power System Reliability

An electric power system must be designed, operated, and maintained to provide reliable power to its customers at a reasonable cost. The electricity generated at production facilities is transmitted to customers via transmission and distribution networks. The random failures of these components pose reliability challenges for the power system. Enhancing system reliability involves reliability-focused planning, operations, system upgrades, and maintenance practices, which often require significant investment. Such investments must be justified by the value of reliability to both electricity consumers and society. Quantitative assessments of power system reliability offer valuable insights for planning and operations to maintain the desired level of supply reliability at an acceptable cost.

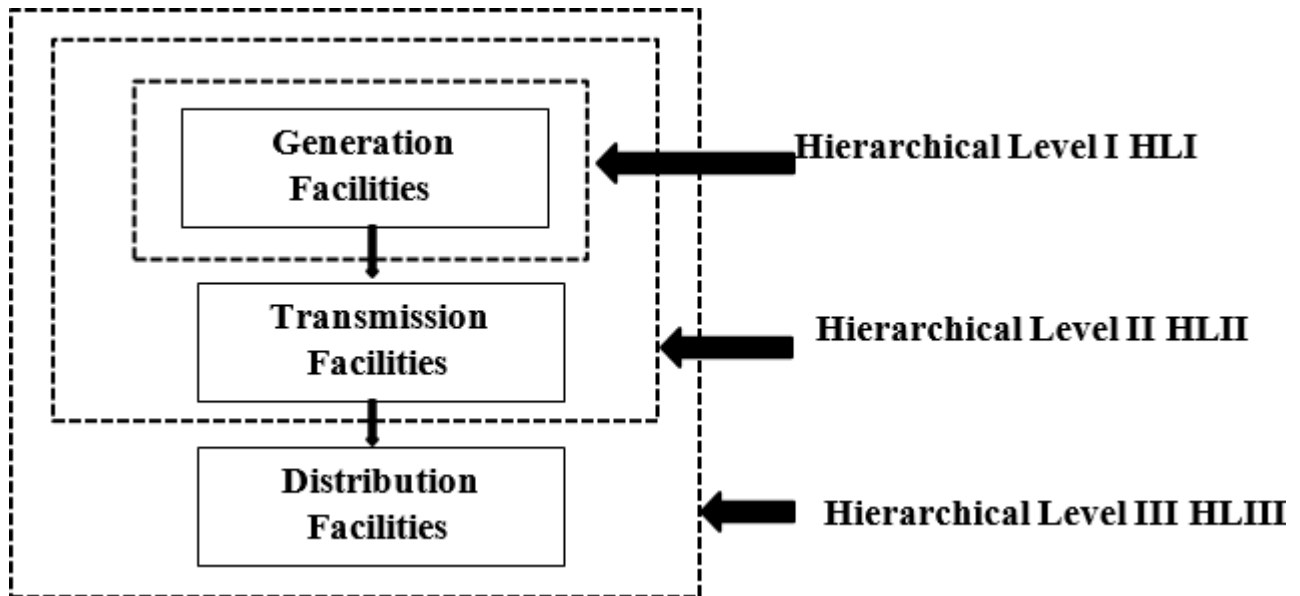
Power system reliability assessment can be divided into two main areas: system adequacy and system security, as illustrated in Fig 1.1 [8]. System adequacy refers to the system's ability to provide sufficient energy to its customers within operational constraints, ensuring there are enough generation, transmission, and distribution resources to meet demand. In contrast, system security pertains to the system's ability to withstand disturbances while maintaining the quality and continuity of the power supply to customer.



*Figure 1 Domains of power system reliability.*

Generation, transmission, and distribution facilities form the three primary functional zones of a power system. Reliability assessments can be conducted at various hierarchical levels, integrating these functional zones as illustrated in Figure 1.2 [8]. At Hierarchical Level I (HLI), the assessment focuses on whether the generation facilities alone can meet the system's load, disregarding transmission and distribution facilities. This level's adequacy evaluation is known as "generation capacity reliability

evaluation." At Hierarchical Level II (HLII), both generation and transmission, facilities are considered. Unlike HLI, HLII assesses the impact of transmission line constraints and the locational aspects of generation facilities on supply reliability at different transmission nodes and the overall system. This level's adequacy assessment is termed "bulk system or composite system reliability evaluation." Hierarchical Level III (HLIII) encompasses all three functional zones, evaluating reliability at individual load points. However, due to the practical power system's complexity, size, diversity, and ownership issues, reliability analysis is typically performed at the distribution system level using inputs from HLII evaluations, making HLIII assessments challenging to conduct.



*Figure 2 Functional zones and hierarchical levels in reliability assessment.*

Historically, distribution system reliability has received considerably less focus compared to generation and bulk system reliability. This is primarily because inadequacies in generation and transmission can have wide-reaching impacts on the overall power system, while unreliability in the distribution network tends to have more localized effects. However, studies have shown that distribution systems contribute significantly (approximately 80%) to the unavailability statistics, regarding supply to load points [8]. Consequently, distribution system reliability indices are crucial for evaluating network integrity, load supply capability, and infrastructure upgrade priorities.

Recent trends in deregulation and privatization have placed distribution utilities in a competitive environment, leading to re-regulation to ensure reliable customer supply and efficient system operation. Additionally, the integration of micro grids and distributed energy resources (DERs), such as distributed generation and energy storage technologies, into distribution networks has transformed their operation. This integration also impacts the business models of distribution utilities, customer supply reliability, and tariff structures. As a result, distribution system reliability is gaining more attention due to these ongoing changes in modern power systems.

Moreover, the growing importance of distribution system reliability assessment is driven by financial incentives and penalties imposed on distribution system owners based on their reliability performance. This thesis focuses on the reliability assessment of modern distribution system

## **2.2 Modern Distribution Systems and Reliability Concerns**

The distribution system connects the transmission system to customer load points and consists of sub-transmission lines, feeders, substations, protection systems, and other power switchgear. Typically operated as radial systems, distribution grids are equipped with sectionalizing and tie switches to link circuits for maintenance and outage restoration. High-reliability electricity customers are served by "network" type distribution systems with multiple interconnected feeders.

Distribution networks are prone to failures and often cover large geographical areas, resulting in various reliability events such as voltage sags, momentary interruptions, and sustained interruptions. According to IEEE Std. 1159 [9], a voltage sag is a drop in root mean square voltage below the nominal value (between 10% and 90%). IEEE Std. 1366 [10] defines a momentary interruption as a brief loss of supply continuity due to the short-term opening and closing of a protective device, generally lasting one to five minutes. Interruptions longer than this are classified as sustained interruptions [8], [10].

Modern distribution systems increasingly employ digital and power electronic equipment, like adjustable speed drives, computers, and automated manufacturing lines, which require high reliability and power quality. These systems are vulnerable to even short-duration reliability events such as voltage sags and momentary interruptions [11], leading to significant financial losses for both industrial/commercial customers and the network [12].

Reliability indices for distribution systems can be assessed at both the system level and individual load points. At the load point level, basic indices include the failure frequency ( $\lambda$ ), average outage duration

(r), and outage probability or unavailability (U), typically expressed as the average annual outage time in hours per year. These indices help calculate other load and energy-based indices, such as the expected energy not supplied (EENS) at each load point. Aggregating load point indices provides system indices like the system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), and EENS, calculated using the following formulas:

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \quad (2.1)$$

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \quad (2.2)$$

$$EENS = \sum L_{a,i} U_i \quad (2.3)$$

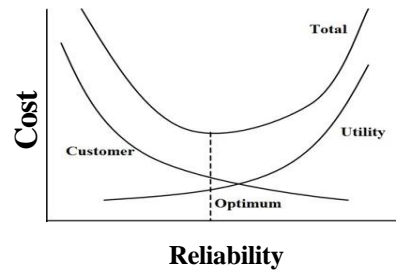
Where,  $\lambda_i$ ,  $U_i$ ,  $L_{a,i}$ , and  $N_i$  denote the failure frequency, average annual outage time, average load connected, and the number of customers of load point  $i$ , respectively.

These indices are primarily based on sustained interruptions. Utility planning and regulatory compliance often focus on the frequency and duration of sustained interruptions [12]. However, short-duration reliability events (voltage sags and momentary interruptions) significantly impact modern industrial/commercial customers with sensitive equipment. The momentary average interruption frequency index (MAIFI) measures the frequency of momentary interruptions [10], [12], and network performance related to voltage sag is reported annually as a function of sag magnitude and duration [11].

Electric power utilities aim to optimize system investments to provide energy at the lowest possible cost while maintaining acceptable reliability levels. Investments must be justified by the reliability worth to electricity consumers. Customer outage cost analysis is a valuable input for assessing the reliability worth, evaluated through the expected cost of interruption (ECOST) in dollars per year, both at load point and system levels. The cost depends on customer type, load curtailed, interruption duration, and timing [8].

Public-owned or vertically integrated utilities often adopt a value-based reliability approach, balancing investment costs (reliability cost) and societal benefits (reliability worth) from improved reliability. As illustrated in Fig 1.3 [8], increased utility costs for system upgrades reduce customer financial losses from interruptions, minimizing the total societal cost, which is the sum of reliability and interruption

costs. This value-based framework identifies the optimal reliability point where societal cost is minimized.



*Figure 3 Reliability cost worth concept.*

In the past, most distribution systems operated as part of a vertically integrated system where the utility owned all three functional zones: generation, transmission, and distribution. Today, modern distribution systems are owned by separate entities and managed by individual distribution system operators (DSOs) in a deregulated environment. Many jurisdictions worldwide are implementing various forms of incentive/performance-based regulation (PBR) [13] to encourage DSOs to enhance economic efficiency within the competitive market. To ensure that the quality of electric supply remains high while utilities pursue economic incentives under PBR, regulators set mandatory reliability standards.

The reliability of supply provided by a distribution system significantly influences the socio-economic development of modern society. Consequently, utilities prioritize customer reliability concerns in distribution system planning and operations. The introduction of new participants, entities, and technologies—such as distributed generations (DG), energy storage systems (ESS), micro grids, load aggregators and the market participation of Distributed Energy Resources (DERs) /micro grids has notably transformed traditional operation and planning practices. The following subsections offer a brief discussion on the major changes and reliability concerns associated with modern distribution systems.

### **2.2.1 Integration of Distributed Energy Resources**

The integration of renewable energy sources (RES), such as solar PV and wind power, into the power system is on the rise, as shown in Fig 1.5 [14], [15], primarily driven by environmental concerns. A significant portion of these resources is connected to medium and low voltage distribution networks as distributed generation (DG). Common DG technologies include cogeneration, solar PV, and wind-based resources. Emission constraints set by regulators in many regions have encouraged the substantial

growth of renewable energy-based DGs. However, the intermittency and variability of renewable resources introduce additional uncertainty, negatively impacting the reliability of power distribution systems. As shown in Fig 1.5, the trend of penetration of solar PV to the power system increases greatly from year to year.

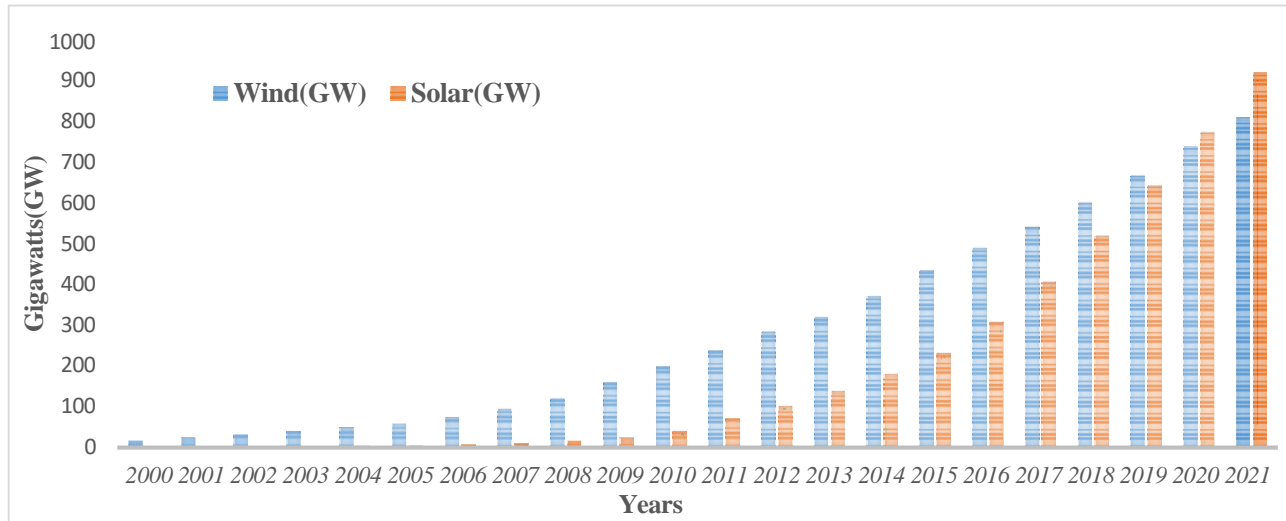


Figure 4 Trend of penetration of renewable energy into power systems [15].

### 2.2.2 Solar PV System

Recently, PV systems have garnered significant attention due to several key advantages, including the infinite availability of their primary energy source and the absence of pollutant emissions. This popularity is attributed to the inherent benefits of using PV systems for distributed generation (DG) in electric utilities. One major advantage is the proximity of PV generators to customers, which significantly reduces transmission and distribution costs. Additionally, PV systems can help level the system load curve, improve voltage profiles, and reduce line losses and transformer loading. Utilities benefit economically from deferring investments in transformer and transmission line upgrades and reducing maintenance costs. However, to achieve these benefits, PV generators must have appropriate penetration levels and be located suitably. Moreover, the so-called infinite source of PV energy is variable, with the injected output power to the distribution system fluctuating significantly based on daily weather conditions. Therefore, there is no guarantee that the anticipated benefits will be fully realized. The operation of PV grid-connected systems and their responses to disturbances or distribution system conditions have increasingly raised concerns, especially with high penetration levels of PV systems. Despite the unpredictable nature of the generated output power, PV systems can still improve

system reliability for radial distribution networks. However, it is important to note that traditional reliability indices are controversial, as most depend on service interruptions, which are not uniformly defined. Extensive research has been conducted on reliability evaluation of interconnected power systems. Hierarchical Markov modeling has been proposed to assess distribution system reliability, and switch placement with DG consideration has shown to improve system reliability in terms of load servicing during faults. Reliability modeling techniques for DG on distribution systems and methods to analyze them are developed using predictive reliability assessment tools. Additionally, network restoration sequences and constraints have been used to evaluate system reliability, and optimal utilization of PV and wind energy sources has been shown to increase the capacity of isolated power systems. The solar irradiance of the selected location is presented in the table shown below. The solar radiation is required to design the solar power at the worst case. In this case, the worst month for solar irradiance is on July. Then the power is design based on that months solar irradiance.

*Table 1 Monthly and daily solar irradiance in KWh/m<sup>2</sup> of Mekelle city*

Month	Solar irradiance in (KWh/m <sup>2</sup> /mo.)	Solar irradiance in (KWh/m <sup>2</sup> /day)
Jan	187.72	6.06
Feb	189.37	6.76
Mar	213.66	6.89
Apr	196.77	6.56
May	195.23	6.30
Jun	164.88	5.50
Jul	125.56	4.05
Aug	148.16	4.78
Sep	194.96	6.50
Oct	204.62	6.60
Nov	184.97	6.17
Dec	187.47	8.93

### 2.3 Reliability Index Benchmark

The most commonly used reliability indices SAIDI and SAIFI of Ethiopian Electric Agency (EEA), European Countries and the United State are presented in *Table 2*. These countries have a great consideration of electric power quality and reliability. Hence, using these standards as a reference would be helpful to improve the reliability of the Mekelle city distribution network.

*Table 2 Bench marking standard practice of some countries [16]*

Country	SAIDI (hr/cust./yr)	SAIFI (Number/cust./yr)
United State	4	1.5
Australia	1.2	0.9
France	1.03	1.0
Germany	0.383	0.5
Italy	0.967	2.2
Spain	1.73	2.2
United Kingdom	1.5	0.8
Ethiopia	<b>25</b>	<b>20</b>

## Chapter 3 - DATA ANALYSIS AND SYSTEM MODELING

### 3.1 Introduction

The data collected for this study include the monthly frequency and duration of interruptions in the existing network configuration, the type and length of medium voltage overhead distribution feeders, transformer type and rating, network component failure rates, and energy costs for the Mekelle city distribution network. Annual interruption frequency and duration are analyzed using Microsoft Excel to identify the most frequently interrupted feeders. Detailed reliability analyses are then performed using ETAP 16.0.0 software to evaluate reliability indices and measure the distribution network's reliability.

Due to the diversity of electrical loads, the nature of electricity must be kept dynamic. It is challenging to generalize the causes of failure history; however, the current scenario provides some clues for determining the causes. The case study highlights issues such as weak planning, network extension problems, and the loading and length of feeders.

From the study area's background, feeders Ko6 to Ko10 were installed after 2013 G.C., with the feeder names corresponding to their installation periods. Feeders with smaller numbers are older, and those with larger numbers are newer. The feeder lengths and peak loads are detailed in *Table 3*.

*Table 3 Feeder installed kVA and length in Km*

Feeder Name	Installed Capacity in kVA	Length(km)
Ko-00	14375	8.89
Ko-3	20290	15
Ko-4	19230	10
Ko-5	830	5.58
Ko-6	40200	6.68
Ko-8	16710	23
Ko-9	7975	31.79
Ko-10	19505	9
Ko-11	13010	13
Ko-12	13350	16.25
R2	5010	5.20
R3	35685	26.88

R4	40365	16.25
R5	32840	20.50
R6	1250	5.20

The necessary data for reliability evaluation, including interruption duration and frequency, were collected from the Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP). The failure rate of each component is sourced from previously conducted research studies [17] [18] because there has not been a national-level study on the failure rates of distribution network components. However, the case studies in these papers have the same distribution network configuration and conductor size as the Mekelle city distribution network. Both networks feature a larger cross-section conductor of 200mm<sup>2</sup> for the main feeder, and both operate with a radial configuration. The failure rates are provided in *Table 4*.

*Table 4 Failure Rate of Distribution Network Components [17] [18]*

Component	Failure Rate	Repair Time(h)
Feeder(per km)	1.4	5
Transformer (per component )	0.015	15
Breaker (per component)	0.006	4
Bus Bar (per component)	0.001	2

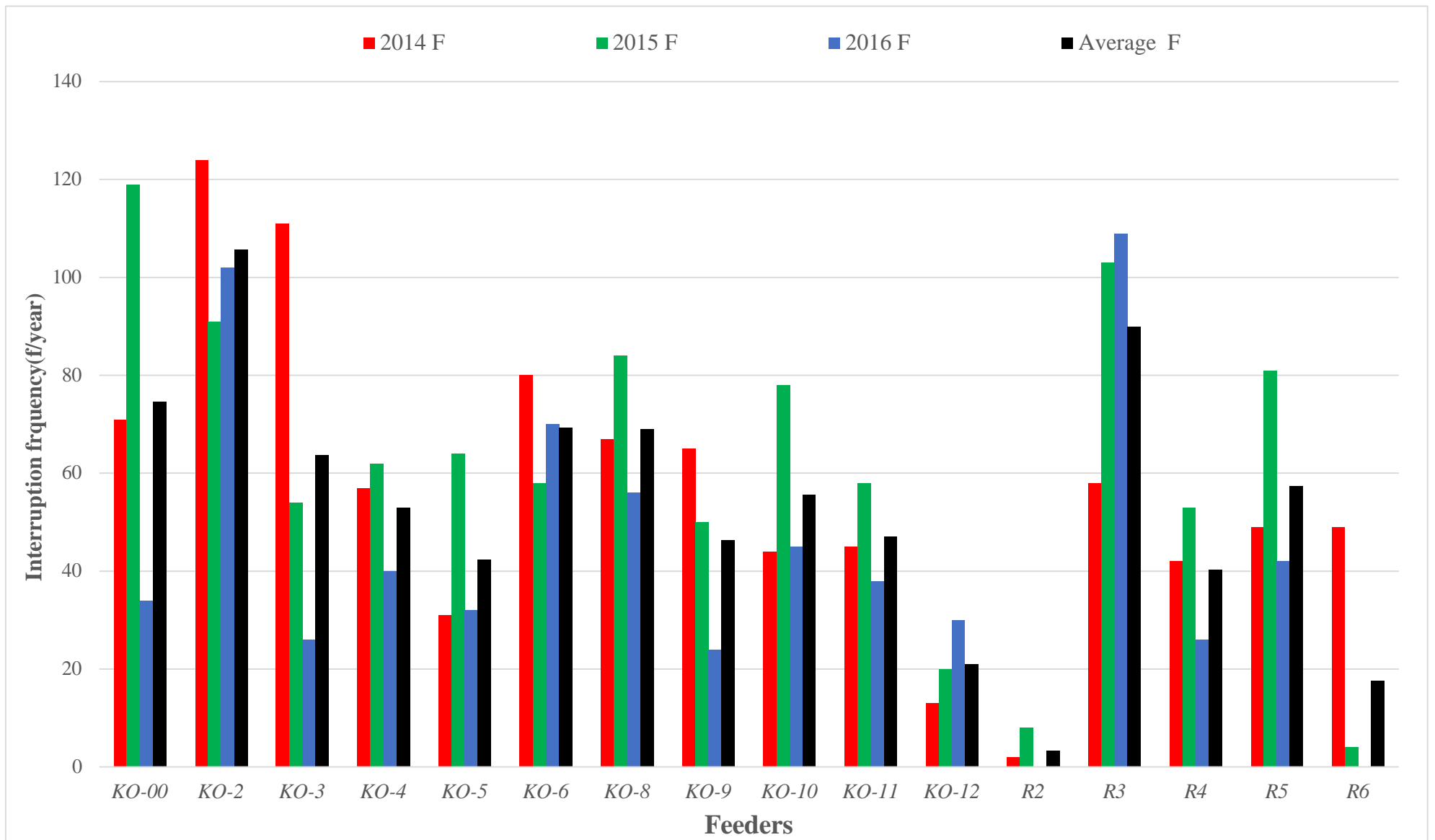
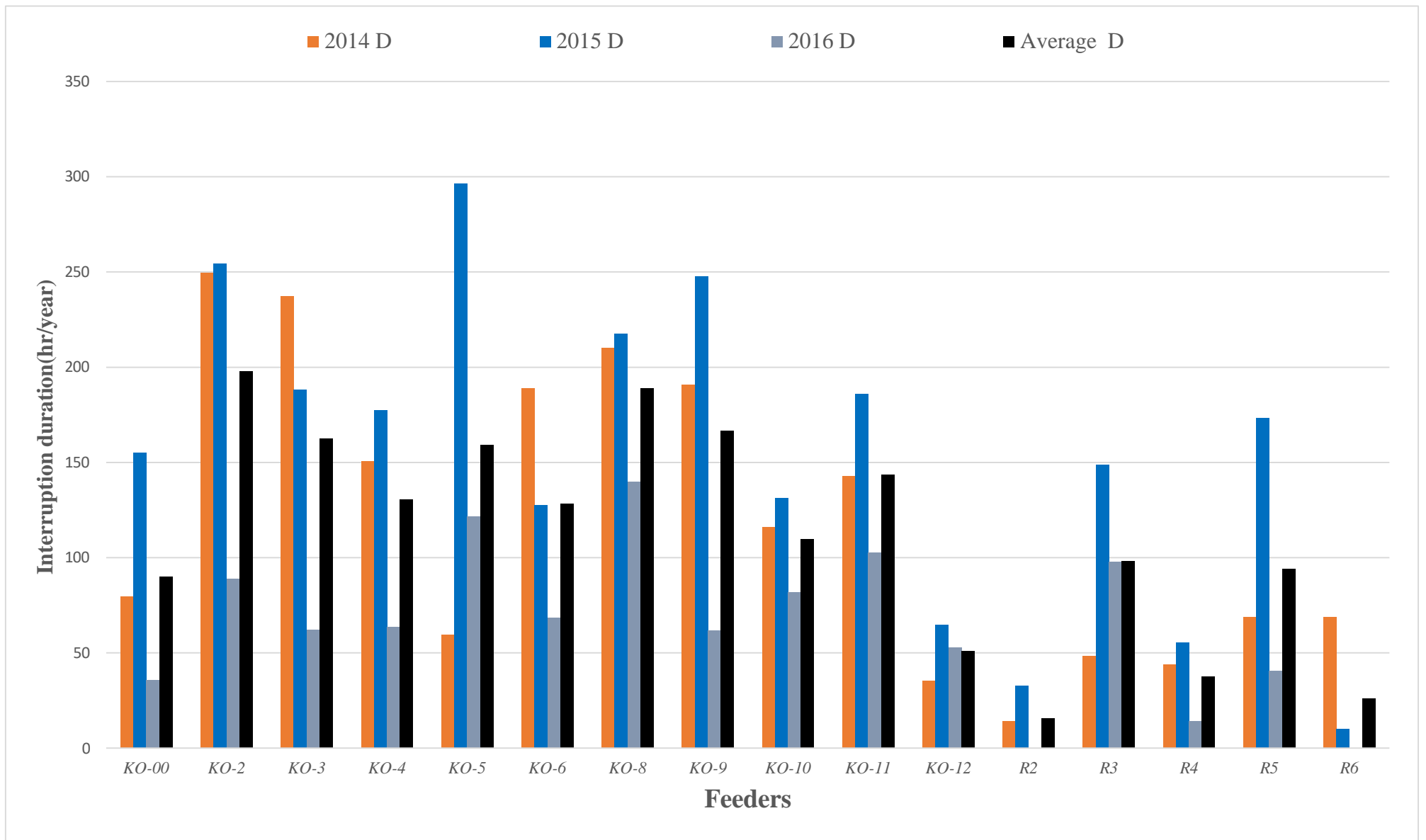


Figure 5 Interruption frequency per year of the feeders in Mekelle distribution network

As illustrated in *Figure 5* feeder, R3 and R2 recorded a highest and lowest number of annual average interruption respectively. Interruption frequency heavily depends on the protection system, which is triggered by fault issues. According to the real data, R3 is the longest feeder, and R2 is the shortest feeder, indicating that feeder length significantly affects interruption frequency. In addition, when a load comparison is taken feeder R3 is load than feeder R2. Thus, the load is also another constraint for the cause of interruption frequency.

*Figure 6* shows that interruption duration per year recorded in 2014 and 2015 are long for most of the feeders. This is likely due to the deficiency of power. This is because during those two years the only power supply was Tekeze Hydroelectric Power Plant (THEPP). However, since 2016, most of the feeders have lower interruption duration. Because during this year Mekelle city receives power from the national grid. Conversely, feeder R2 consistently recorded short annual interruption durations, which can be attributed to its shorter length and lower load. The longer a feeder is, the more time is required to fix faults due to transportation and fault location challenges.

In this study, the researcher considered the four-year average values instead of the longest and shortest annual values, providing a more reasonable basis for determining the causes of interruption durations. On average, the longest and shortest annual average interruption durations were recorded for feeders Ko8 and R2, respectively. As shown in Table 3.1, Ko8 serves a high load at long distance and R2 serves low loads at shortest distance. Then the installed load and distance influences interruption duration.



*Figure 6 Interruption duration [hour per year] of the feeders in Mekelle distribution network*

### **3.2 System Model for Simulation**

To analyze network reliability using simulation, the distribution network under study is modeled in the Electrical Transient Analyzer Program (ETAP) version 19.0.1. This software adheres to the International Electro-technical Commission (IEC) and American National Standards Institute (ANSI) standards, which are widely recognized globally. Data from EEU is used as input parameters for modeling, including line type and length, transformer type and rating, and the failure rate and repair time of overhead distribution network lines, transformers, loads, and other components. The model is illustrated in *Figure 7*.

The model includes a substation that serves as an external grid, synchronized with the national grid through the Alamata Substation and supplemented by power from the Tekeze Hydroelectric Power Plant (THPP). Electric power is transmitted from the substation to Mekelle city via 15 kV overhead feeders, which are supplied by two 37.5 MVA and one 50 MVA mobile substations. The Upstream circuit breakers manage the outgoing feeders.

In Mekelle city, switching stations and old feeders are modeled, each containing numerous transformers and loads. As shown in the model the rectangular boxes are composite networks, which are holding a numerous lines, transformers and loads. This is one important feature of ETAP software in addition to the good analysis techniques. The reliability indices are manipulated in ETAP to understand the performance of the distribution network. Because the reliability indices are the measurable performance improvement of any distribution network reliability.

The reliability indices are also important to prioritize the feeders in the distribution network for preventive maintenance (PM). PM is a crucial maintenance activity in distribution network. Regularly inspect transformers, overhead lines, poles and controlling devices protect from different faults in power system. However, the cost is very high may be beyond the capacity of the utility. Thus, prioritize the feeders for inspection is necessary for cost and saving balance.

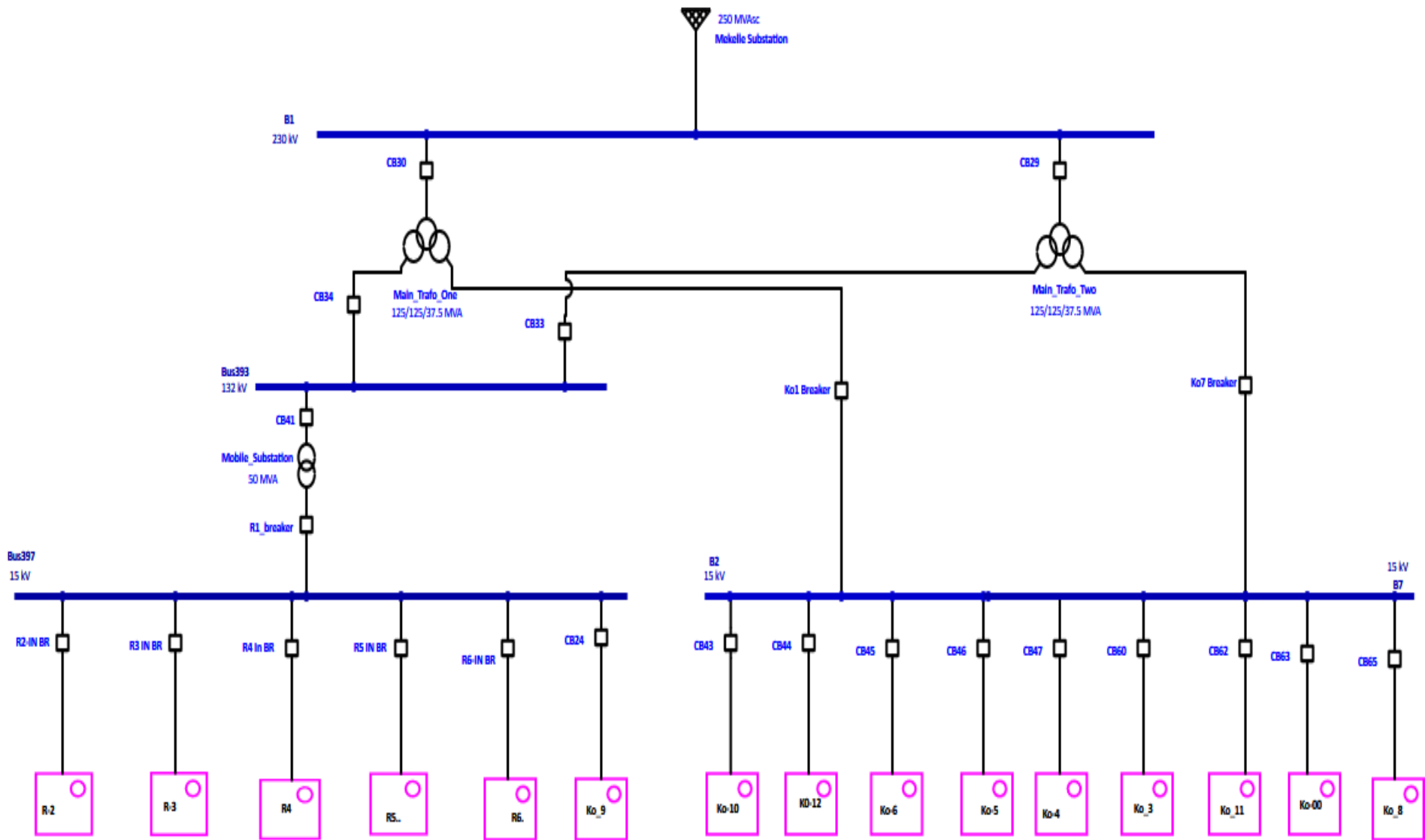
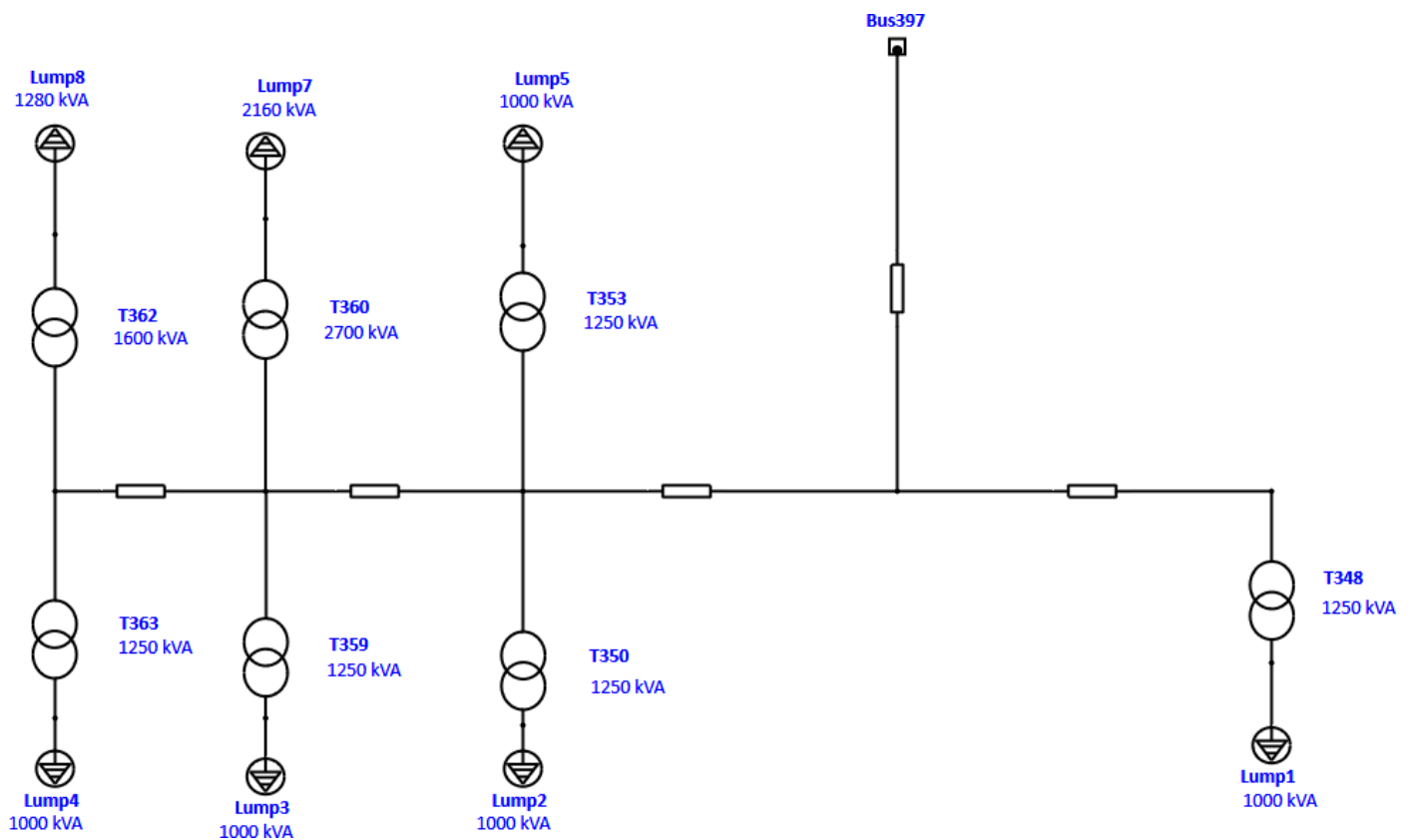


Figure 7 the network model of Mekelle distribution network feeders in ETAP software

The Mekelle distribution network is modeled in ETAP software as shown in the *Figure 7* above. The power flow is starting from the grid (in this case the Mekelle substation is considered as a grid) to the 230kV bus bar and to the three winding transformers. The transformers has two secondary windings, which are 132kV and 15kV. Besides, there is a mobile substation feeding from the 132kV bus bar and it feeds to six 15kV out going feeders. The remaining feeders are energizing from the 15kV bus bar directly from the three winding transformers. The outgoing feeders have a low voltage transformers and lamped loads inside. For instance, the network shown in *Figure 8* below is transformers and their respective loads connected to feeder R2. All the feeders shown in *Figure 7* has different branch circuits in side like R2. Thus, the reliability analysis of the whole network is executed using ETAP software and the result is presented and discussed in the next chapter.



*Figure 8* Line, Transformer and load model of R2 feeder in ETAP software

## Chapter 4 - Result and Discussion

### 4.1 Introduction

This chapter presents the results and provides brief description of each result. The result comprises reliability assessment and economic aspects.

### 4.2 Reliability assessment without DG application

The reliability analysis is executed in ETAP 16.0.0 version and the reliability indices result are discussed herewith. For the distribution network under study, the SAIDI of all feeders are compared as presented in *Figure 9*.

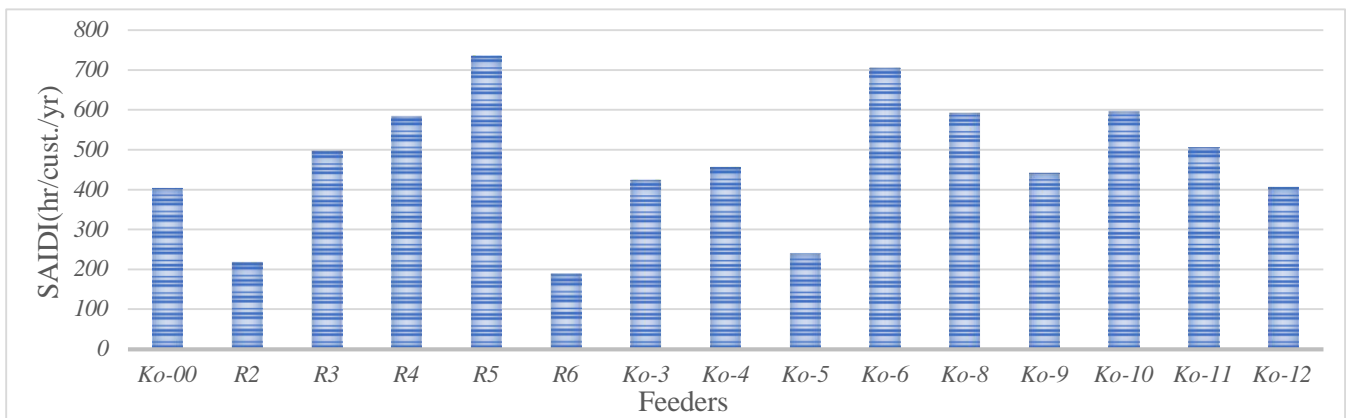


Figure 9 SAIDI value for the existing distribution network feeders

As shown in, R5 has the highest value and feeder R6 has the lowest value. It can be noticed that, all feeders have a SAIDI value much higher than the benchmark reference values. These figures indicated that the SAIDI value is 491 – 1920 times as compared to the benchmark stated by Germany and 8 – 29 times as compared to the benchmark stated by the Ethiopian Electric Agency. Besides, it reveals the distribution network reliability is very bad and needs to be amended. The higher value of SAIDI directs the worst reliability and the lower value of SAIDI points toward better reliability.

The all feeders in the same distribution network, the annual system average interruption frequency index are presented in *Figure 10*.

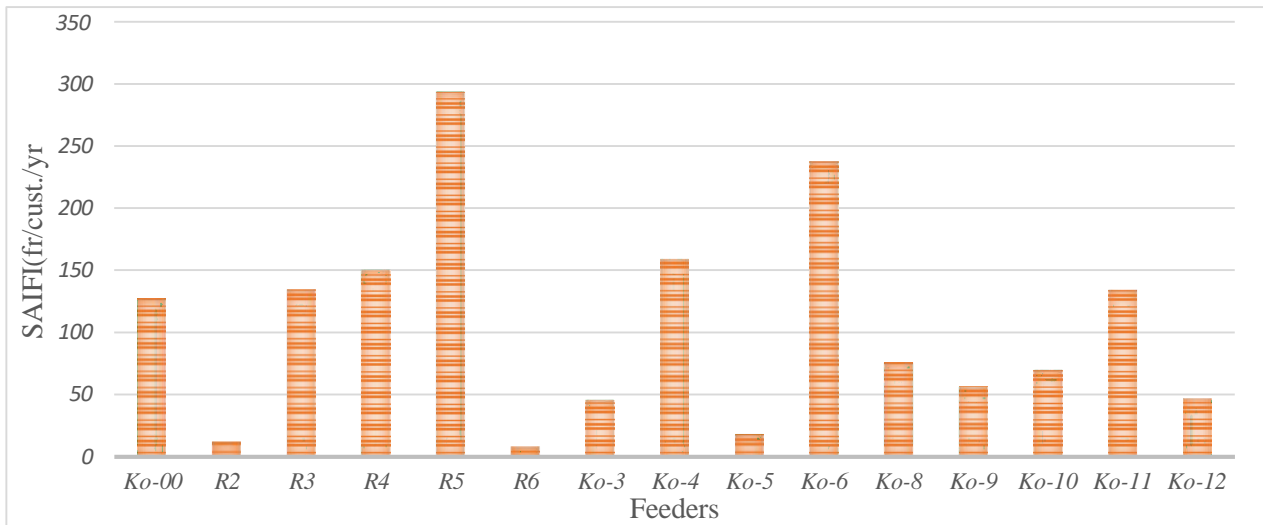
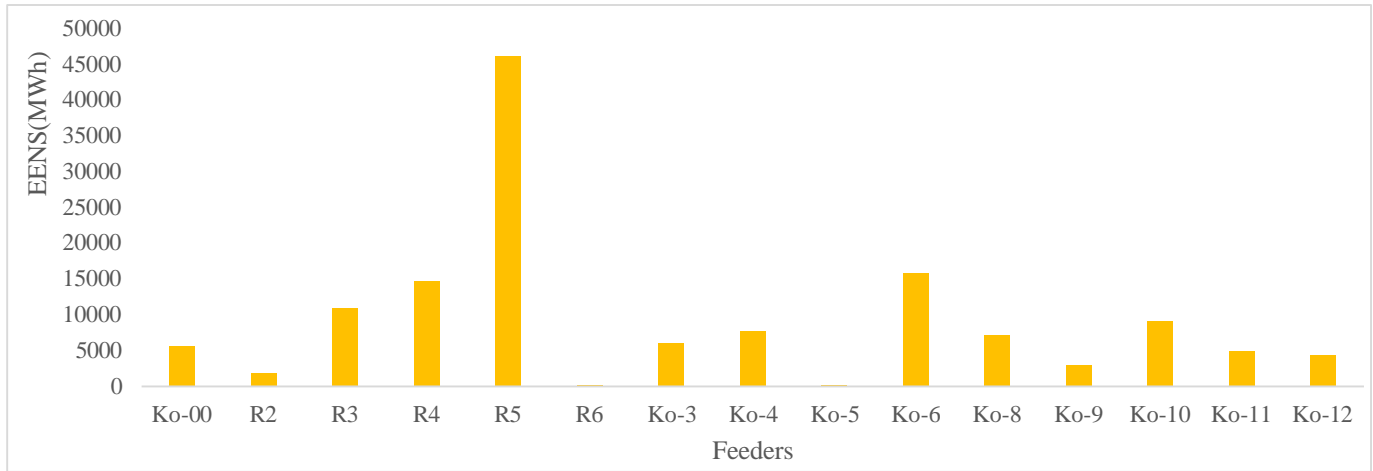


Figure 10 SAIFI value for the existing distribution network feeders

As shown in Fig. 4.2, R5 (with 293 f/customer/yr) has the highest SAIFI value while feeder R6 (with 8 f/customer/yr) has the lowest SAIFI value. The yearly SAIFI in these feeders ranges from 8 to 293 f/customer/yr, which is very large as compared to the benchmark of developed countries and Ethiopian Electric Agency. These figures indicate that the SAIFI value is 16 – 586 times as compared to the benchmark stated by Germany and 0.4 – 14.65 times as compared to the benchmark stated by the Ethiopian Electric Agency. Besides, the SAIFI value tells the status of the distribution network reliability. The higher value of SAIFI directs to the worst reliability and lower value of SAIFI points toward better reliability. Thus, the SAIFI value given in *Figure 10* reveals the distribution network reliability is very bad and needs to be modified.

Another important indices is the expected energy not supplied (EENS). For the distribution network under study, the annual EENS in all feeders is presented as in Figure 11.

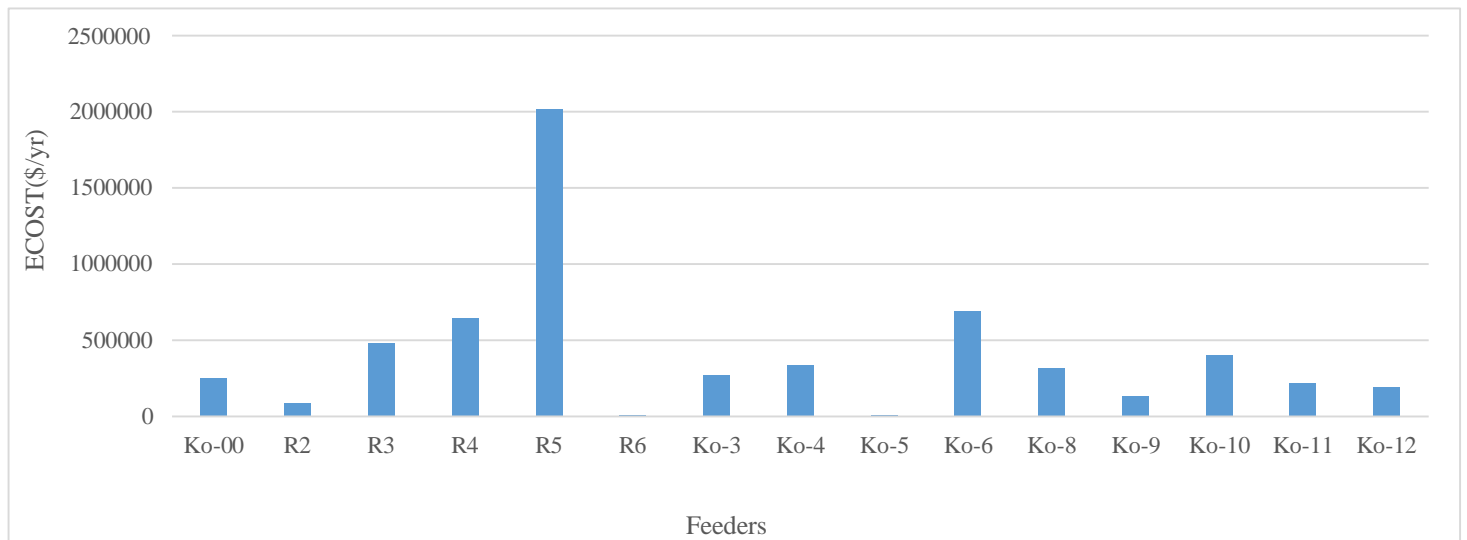
It can be observed from Figure 11 that the highest amount of energy not supplied is observed in R5. Besides, a significant amount of energy is wasted from all feeders due to the existing configuration.



*Figure 11 EENS value for the existing distribution network feeders*

The aforementioned wastage of energy 46,107.5 MWh/yr in feeder R1-03 is too much. The total amount of energy loss on the six feeders is 138,329.49 MWh/yr. Thus, the conventional distribution network faces this problem due to its lack of preventive maintenance and reliability centered maintenance.

In the same context of the expected energy not supplied, the expected interruption cost (ECOST) for the existing distribution network feeders is presented in Figure 12. As observed from Figure 12, the utility company wastes a lot of money due to the conventional distribution network. It is because the existing distribution network configuration and fault management system is very poor.



*Figure 12 ECOST values for the existing distribution network feeders*

Generally, as depicted in the above figures R5 is the most unreliable feeder from the reliability indices result. Thus, it is selected as a case study in this thesis. Furthermore, as shown in Table 3. R5 is one of the longest length

and large number of transformers installed over it from the other feeders. As discussed in Data Analysis the feeder length and load are the main causes for interruption in Mekelle city distribution network. Hence, the feeder R5 is highly affected by the reliability problem.

### 4.3 Reliability assessment with DG application

Reliability indices are crucial for assessing the performance and reliability of power systems, including electrical grids and PV systems. These indices can be broadly classified into two categories: load point and system indices.

#### 4.3.1 Load Point Indices:

These indices measure the reliability at specific points in the power system, typically at the customer or load points. The mainly used load point indices are SAIDI and SAIFI. The comparison of these indices with and without DG are presented in *Figure 14* shown below. By installing 3.6MW solar PV system in the Switching station the value of SAIDI and SAIFI are decreased by 49.77% and 31.7% respectively. This implies the reliability is improved. The solar PV system in ETAP software is presented as shown in *Figure 13*.

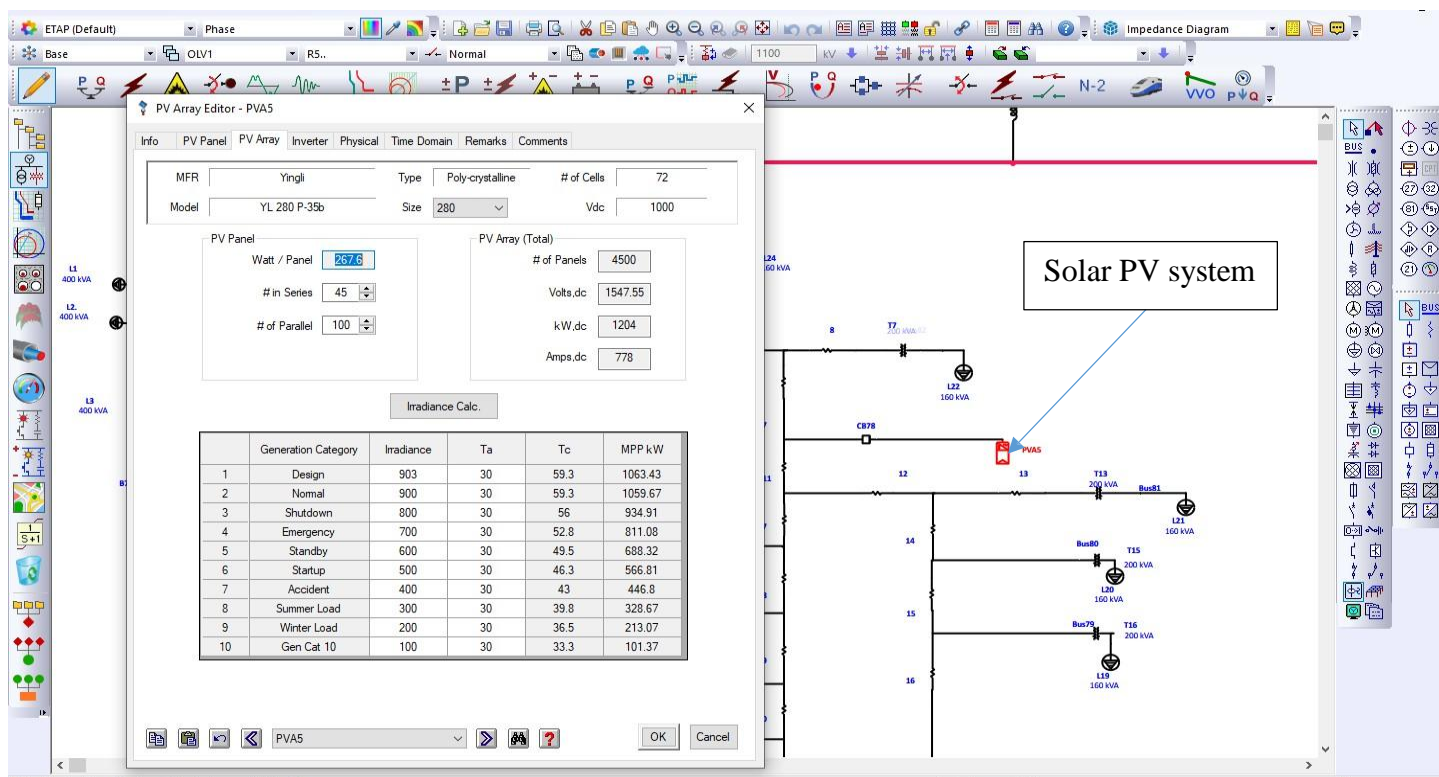


Figure 13 the solar PV system in ETAP software

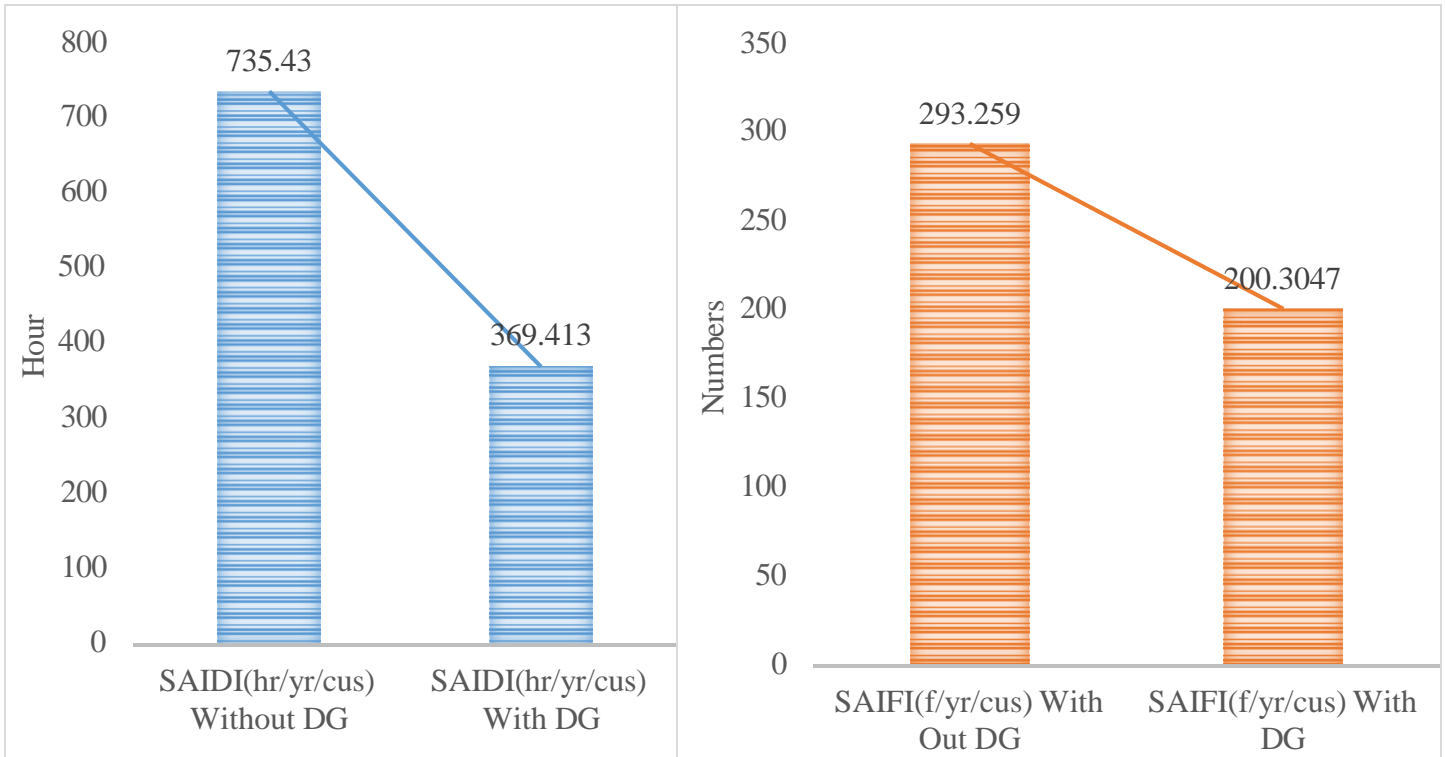
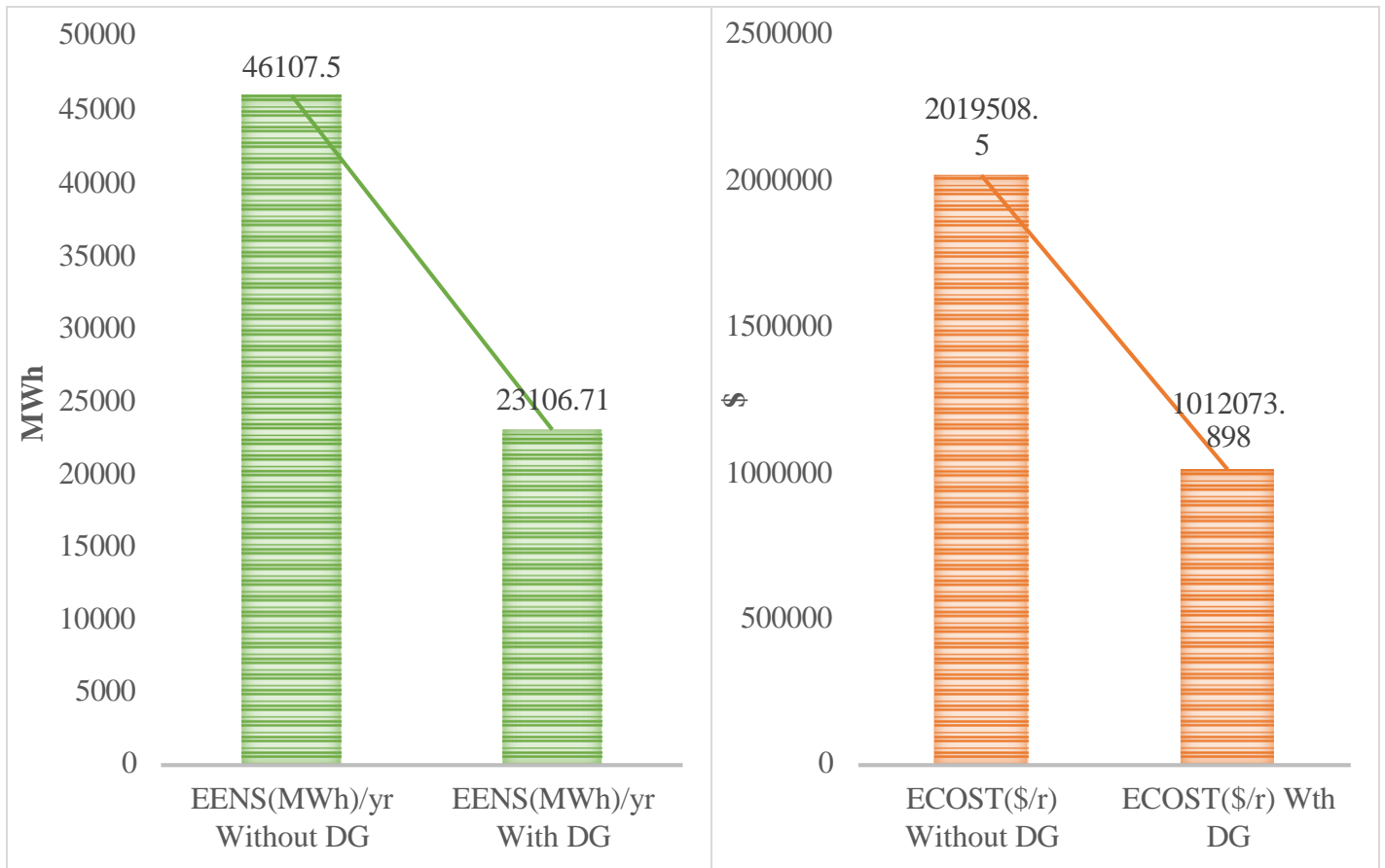


Figure 14. SAIDI and SAIFI Comparison of Feeder R5 With and Without DG Application

#### 4.3.2 System Indices:

These indices evaluate the reliability of the entire power system or network. Expected energy not supplied is the most measurable system indices and expected cost of interruption is the most measurable cost-worth reliability indices. The mainly used system indices are EENS and ECOST. The comparison of these indices with and without DG are presented in Figure 15 shown below. The value of EENS and ECOST are decreased by 49.88% after a DG application. This implies the Utility revenue is improved.



*Figure 15 EENS and ECOST Comparison of Feeder R5 With and Without DG Application*

The diagram shown in *Figure 16* is the network configuration of switching station five, which is the case study of this work. This network is drawn in Microsoft Visio for illustration of the network layout. It starts from substation the power conveys by 200mm<sup>2</sup> express line and entering to the switching station by the incoming circuit breaker (ICB) and it has three outgoing distributors, which has their own separate circuit breakers. The solar PV system is inserting on the load points after the sectionalizer switches. This is only for visualization but the detail; tasks are executed in ETAP software.

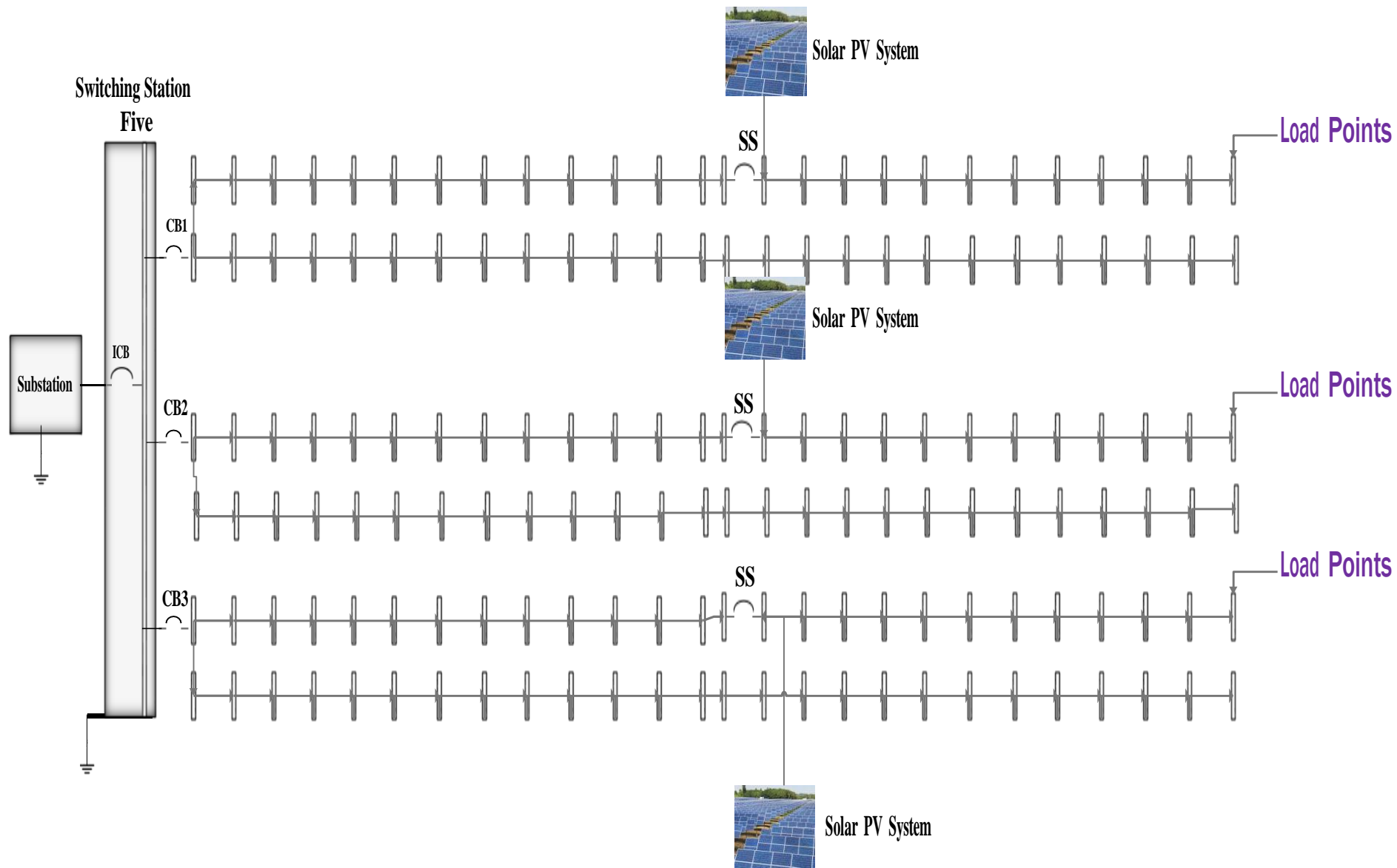


Figure 16 Solar DG application in Distribution Networks from Microsoft Visio

#### **4.4 Prioritization of feeders for reliability-centered maintenance**

One of the key issues related to the efficiency of distribution systems is the decline in reliability of distribution system components, such as distribution feeders. Distribution systems are crucial in power systems because they connect the system to the customer. While the severity of failures is greater in generation and transmission systems, the number of failures is higher in distribution systems. Throughout their lifespan, the failure rate of distribution system components increases significantly due to aging and daily operations. Consequently, a maintenance strategy is needed to lower the failure rate and enhance the reliability of the distribution system. Maintenance should be carried out with an appropriate economic strategy, highlighting the importance of prioritizing maintenance for distribution system components. Maintenance strategies include both preventive and corrective maintenance. Prioritizing and scheduling maintenance is essential for economic management, given limited capital and the need for investments to align with economic efficiency. In other words, prioritizing preventive maintenance of distribution system components aims to reduce costs associated with outages and maintenance activities. As distribution systems evolve, suitable reliability-centered maintenance (RCM) strategies are being explored. Several studies, including [19] [20], have examined the impact of component aging on reliability evaluation of distribution systems. Aging components directly lead to higher costs and decreased power availability.

In order to prioritize the feeders of distribution system for maintenance action, the commonly used reliability indices and the distribution system interruptions is analyzed. Then the feeders are prioritized for preventive maintenance in order of their reliability indices result.

Based on the system average interruption frequency index and system average interruption duration index result shown below the feeders with high values are required to give a priority for preventive maintenance to improve the reliability of the overall distribution network.

As shown in *Figure 17* and *Figure 18* the SAIFI and SAIDI value of R5 and R6 large and low respectively. Large in SAIDI and SAIFI value means worst in reliability and vice versa. Then the reliability centered maintenance using feeder prioritization have been conducted according to the reliability indices result. To keep the reliability of distribution network in normal state it needs to perform a preventive maintenance based on the prioritization order of the feeder.

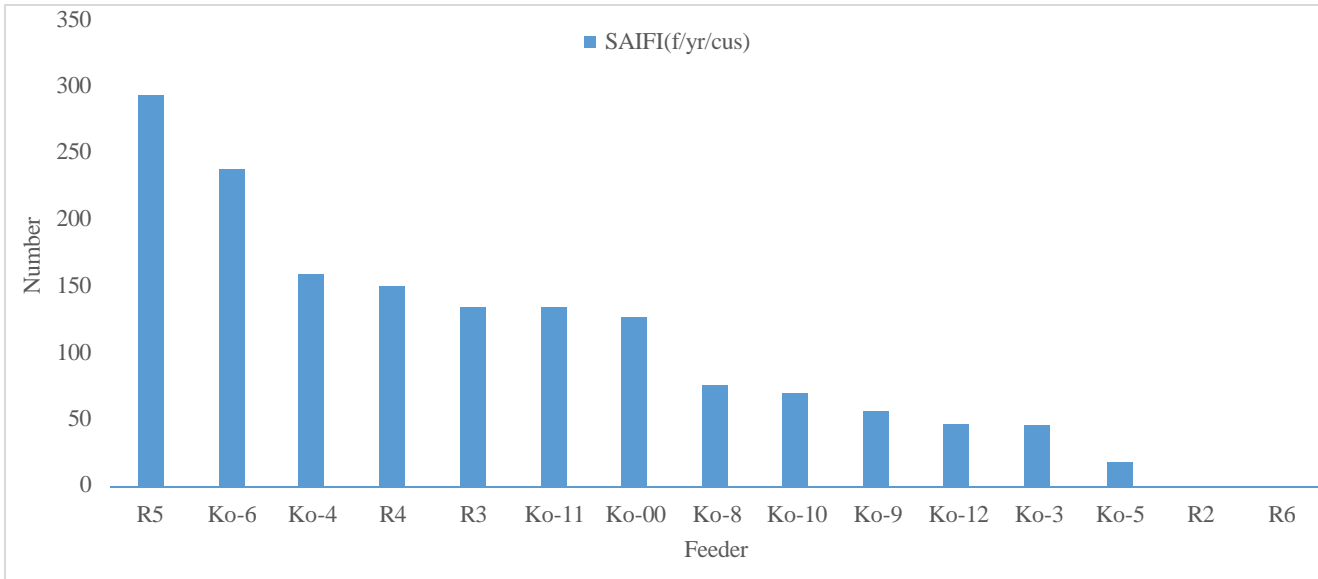


Figure 17 The SAIFI value of Mekelle distribution network feeders for preventive maintenance prioritization

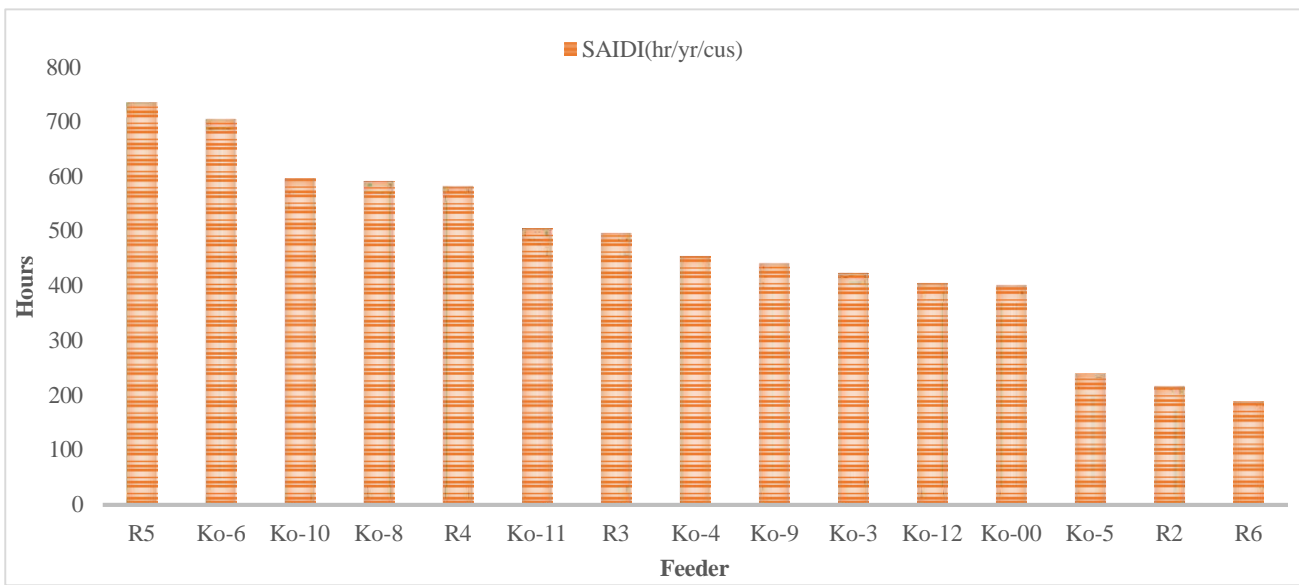


Figure 18 The SAIDI value of Mekelle distribution network feeders for preventive maintenance prioritization

## 4.5 Cost benefit analysis

A cost-benefit analysis (CBA) of a solar photovoltaic (PV) system involves assessing the costs associated with installing and maintaining the system against the benefits derived from it over its lifetime. It is important and critical section to examine the feasibility of the thesis work. The total investment cost for this work would be explain in the following sections.

### 4.5.1 Cost Factors

## Initial Costs

### Solar PV System Installation:

- Solar Panels: \$0.30 to \$0.50 per watt
- Inverters: \$0.10 to \$0.20 per watt
- Mounting Structures and Electrical Components: \$0.10 to \$0.20 per watt
- Labor and Installation: \$0.50 to \$0.80 per watt
- Permitting and Inspection Fees: \$5,000 to \$10,000
- Grid Connection Fees: \$5,000 to \$10,000
- Miscellaneous Costs: \$5,000 to \$10,000

### Ongoing Costs

- Operation and Maintenance (O&M): \$10 per kW per year
- Inverter Replacement: \$200,000 every 10 years
- Insurance: \$10,000 annually

### Benefits

- Energy Savings and Revenue
- Annual Electricity Generation:  $3.6 \text{ MW} * 1,600 \text{ hours/year} = 5,760 \text{ MWh/year}$
- Electricity Price: Varies; local utility rates or avoided diesel cost should be used
- Annual Revenue from Electricity: Assuming \$80/MWh,  $5,760 \text{ MWh} * \$80/\text{MWh} = \$460,800$

## 4.5.2 Calculate Payback Period

The payback period is the time it takes for the savings and benefits to cover the initial investment.

### Initial Costs

Total Initial Cost:

- Solar Panels:  $3,600,000 \text{ watts} * \$0.40 = \$1,440,000$
- Inverters:  $3,600,000 \text{ watts} * \$0.15 = \$540,000$
- Mounting Structures and Electrical Components:  $3,600,000 \text{ watts} * \$0.15 = \$540,000$
- Labor and Installation:  $3,600,000 \text{ watts} * \$0.65 = \$2,340,000$
- Permitting and Other Costs: \$25,000
- Total Initial Cost: \$4,885,000

Local Financial Incentives: Assuming no significant tax credits or rebates, but verify with local authorities.

Net Initial Cost: \$4,885,000 (assuming no local incentives for simplicity).

#### Annual Revenue and Savings

- Annual Revenue from Electricity: \$460,800

#### Annual Ongoing Costs:

- O&M:  $3,600 \text{ kW} * \$10/\text{kW} = \$36,000$
- Insurance: \$10,000
- Total Annual Costs: \$46,000

Annual Net Savings:  $\$460,800 - \$46,000 = \$414,800$

#### Payback Period

Payback Period =  $\text{Net Initial Cost} / \text{Annual Net Savings} = 4,885,000 / 414,800 \approx 11.77 \text{ years.}$

## Conclusion

For a 3.6 MW solar PV system in this thesis work:

Net Initial Cost: \$4,885,000

Annual Net Savings: \$460,800

Payback Period: Approximately 11.77 years

These estimates suggest a substantial financial benefit from integrating a solar PV system (which has a life span of 25 years), with a reasonable payback period.

## **Chapter 5 – Conclusion and Recommendation**

### **5.1 Conclusion**

This study investigates performance improvements for the Mekelle medium voltage distribution network, focusing on reliability indices such as SAIDI, SAIFI, EENS, and ECOST. The current network's reliability and configuration were analyzed, revealing feeder R5 as the least reliable. By integrating a distribution generation using ETAP software, the feeder reliability and availability of power improves.

The study found that increasing the capacity of the DG enhances system reliability, though it also raises investment costs. A significant improvement of reliability indices have been achieved with a valuable profit. The value of SAIDI is reduced from 735.43 hours/customer to 369.77 hours/customer (an 49.77% decrease) and SAIFI from 293.259 occurrences/customer to 200.30 occurrences/customer (an 31.7% decrease). These changes also substantially improved cost-worth reliability indices, with EENS decreasing from 46,107.5 MWh/year to 23,106.71 MWh/year and ECOST dropping from \$2,019,508.5/year to \$1,012,073.898/year (an 49.88% reduction). These improvements indicate enhanced revenue for the distribution network.

### **5.2 Recommendation**

This study recommends that Ethiopian Electric Utility support similar research to address reliability issues in its distribution network. Providing funding and field advisors for such research is crucial, and applying these findings can lead to ongoing improvements. Additionally, Ethiopian Electric Utility should implement a data management system to track the causes of frequent interruptions, which currently is a significant issue due to the lack of organized data. Accurate and continuous data recording, as per IEC standards, is essential for identifying and solving reliability problems.

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## Appendix

## Ko-4 Reliability Indices Result

### Ko-00 Reliability Indices Result

#### SUMMARY

#### SUMMARY

#### System Indexes

#### System Indexes

ACCI	35843.22 kVA / customer
AENS	102.0358 MW hr / customer.yr
ALII	126.80 pu (kVA)
ASAI	0.9541 pu
ASUI	0.04588 pu
CAIDI	3.170 hr / customer interruption
CTAIDI	401.910 hr / customer.yr
ECOST	10,952,850.00 \$ / yr
EENS	5714.003 MW hr / yr
IEAR	1.917 \$ / kW hr
SAIDI	401.9100 hr / customer.yr
SAIFI	126.7921 f / customer.yr

ACCI	45334.17 kVA / customer
AENS	116.9570 MW hr / customer.yr
ALII	158.69 pu (kVA)
ASAI	0.9481 pu
ASUI	0.05192 pu
CAIDI	2.866 hr / customer interruption
CTAIDI	454.848 hr / customer.yr
ECOST	10,848,700.00 \$ / yr
EENS	7719.163 MW hr / yr
IEAR	1.405 \$ / kW hr
SAIDI	454.8483 hr / customer.yr
SAIFI	158.6836 f / customer.yr

## Ko-5 Reliability Indices Result

### Ko-03 Reliability Indices Result

#### SUMMARY

#### SUMMARY

#### System Indexes

#### System Indexes

ACCI	16329.33 kVA / customer
AENS	129.5615 MW hr / customer.yr
ALII	45.40 pu (kVA)
ASAI	0.9516 pu
ASUI	0.04840 pu
CAIDI	9.331 hr / customer interruption
CTAIDI	423.969 hr / customer.yr
ECOST	26,889,570.00 \$ / yr
EENS	6089.390 MW hr / yr
IEAR	4.416 \$ / kW hr
SAIDI	423.9687 hr / customer.yr
SAIFI	45.4384 f / customer.yr

ACCI	2434.51 kVA / customer
AENS	28.1071 MW hr / customer.yr
ALII	17.60 pu (kVA)
ASAI	0.9727 pu
ASUI	0.02731 pu
CAIDI	13.564 hr / customer interruption
CTAIDI	239.234 hr / customer.yr
ECOST	1,332,929.00 \$ / yr
EENS	168.643 MW hr / yr
IEAR	7.904 \$ / kW hr
SAIDI	239.2341 hr / customer.yr
SAIFI	17.6380 f / customer.yr

## Ko-6 Reliability Indices Result

### SUMMARY

#### System Indexes

ACCI	59021.96 kVA / customer
AENS	157.9207 MW hr / customer.yr
ALII	237.13 pu (kVA)
ASAI	0.9195 pu
ASUI	0.08048 pu
CAIDI	2.973 hr / customer interruption
CTAIDI	705.045 hr / customer.yr
ECOST	22,784,870.00 \$ / yr
EENS	15792.070 MW hr / yr
IEAR	1.443 \$ / kW hr
SAIDI	705.0446 hr / customer.yr
SAIFI	237.1309 f / customer.yr

## Ko-8 Reliability Indices Result

### SUMMARY

#### System Indexes

ACCI	16773.73 kVA / customer
AENS	111.9794 MW hr / customer.yr
ALII	75.31 pu (kVA)
ASAI	0.9324 pu
ASUI	0.06755 pu
CAIDI	7.852 hr / customer interruption
CTAIDI	591.755 hr / customer.yr
ECOST	22,141,530.00 \$ / yr
EENS	7166.679 MW hr / yr
IEAR	3.090 \$ / kW hr
SAIDI	591.7554 hr / customer.yr
SAIFI	75.3646 f / customer.yr

## Ko-9 Reliability Indices Result

### SUMMARY

#### System Indexes

ACCI	32178.60 kVA / customer
AENS	215.0609 MW hr / customer.yr
ALII	56.17 pu (kVA)
ASAI	0.9496 pu
ASUI	0.05039 pu
CAIDI	7.865 hr / customer interruption
CTAIDI	441.412 hr / customer.yr
ECOST	9,539,208.00 \$ / yr
EENS	3010.852 MW hr / yr
IEAR	3.168 \$ / kW hr
SAIDI	441.4116 hr / customer.yr
SAIFI	56.1208 f / customer.yr

## Ko-10 Reliability Indices Result

### SUMMARY

#### System Indexes

ACCI	18006.85 kVA / customer
AENS	131.4286 MW hr / customer.yr
ALII	69.38 pu (kVA)
ASAI	0.9320 pu
ASUI	0.06801 pu
CAIDI	8.587 hr / customer interruption
CTAIDI	595.734 hr / customer.yr
ECOST	50,908,410.00 \$ / yr
EENS	9200.003 MW hr / yr
IEAR	5.534 \$ / kW hr
SAIDI	595.7338 hr / customer.yr
SAIFI	69.3777 f / customer.yr

## Ko-11 Reliability Indices Result

## SUMMARY

### System Indexes

ACCI	30382.93 kVA / customer
AENS	102.6885 MW hr / customer.yr
ALII	133.94 pu (kVA)
ASAI	0.9423 pu
ASUI	0.05768 pu
CAIDI	3.772 hr / customer interruption
CTAIDI	505.274 hr / customer.yr
ECOST	10,265,740.00 \$ / yr
EENS	5031.734 MW hr / yr
IEAR	2.040 \$ / kW hr
SAIDI	505.2737 hr / customer.yr
SAIFI	133.9586 f / customer.yr

## Ko-12 Reliability Indices Result

## SUMMARY

### System Indexes

ACCI	25169.58 kVA / customer
AENS	185.4533 MW hr / customer.yr
ALII	46.75 pu (kVA)
ASAI	0.9537 pu
ASUI	0.04628 pu
CAIDI	8.667 hr / customer interruption
CTAIDI	405.377 hr / customer.yr
ECOST	28,007,720.00 \$ / yr
EENS	4450.880 MW hr / yr
IEAR	6.293 \$ / kW hr
SAIDI	405.3773 hr / customer.yr
SAIFI	46.7744 f / customer.yr

## R2 Reliability Indices Result

## SUMMARY

### System Indexes

ACCI	18140.33 kVA / customer
AENS	277.8261 MW hr / customer.yr
ALII	12.04 pu (kVA)
ASAI	0.9752 pu
ASUI	0.02475 pu
CAIDI	18.021 hr / customer interruption
CTAIDI	216.849 hr / customer.yr
ECOST	14,280,280.00 \$ / yr
EENS	1944.783 MW hr / yr
IEAR	7.343 \$ / kW hr
SAIDI	216.8485 hr / customer.yr
SAIFI	12.0334 f / customer.yr

## R3 Reliability Indices Result

## SUMMARY

### System Indexes

ACCI	33623.84 kVA / customer
AENS	110.3320 MW hr / customer.yr
ALII	135.09 pu (kVA)
ASAI	0.9433 pu
ASUI	0.05674 pu
CAIDI	3.709 hr / customer interruption
CTAIDI	497.015 hr / customer.yr
ECOST	17,612,310.00 \$ / yr
EENS	11033.200 MW hr / yr
IEAR	1.596 \$ / kW hr
SAIDI	497.0146 hr / customer.yr
SAIFI	134.0013 f / customer.yr

## R4 Reliability Indices Result

### SUMMARY

#### System Indexes

ACCI	38217.16 kVA / customer
AENS	132.4626 MW hr / customer.yr
ALII	152.70 pu (kVA)
ASAI	0.9335 pu
ASUI	0.06648 pu
CAIDI	3.883 hr / customer interruption
CTAIDI	582.363 hr / customer.yr
ECOST	24,331,230.00 \$ / yr
EENS	14703.350 MW hr / yr
IEAR	1.655 \$ / kW hr
SAIDI	582.3632 hr / customer.yr
SAIFI	149.9818 f / customer.yr

## R5 Reliability Indices Result

### SUMMARY

#### System Indexes

ACCI	108028.10 kVA / customer
AENS	240.1433 MW hr / customer.yr
ALII	310.03 pu (kVA)
ASAI	0.9160 pu
ASUI	0.08395 pu
CAIDI	2.508 hr / customer interruption
CTAIDI	735.429 hr / customer.yr
ECOST	110,656,100.00 \$ / yr
EENS	46107.510 MW hr / yr
IEAR	2.400 \$ / kW hr
SAIDI	735.4294 hr / customer.yr
SAIFI	293.2591 f / customer.yr

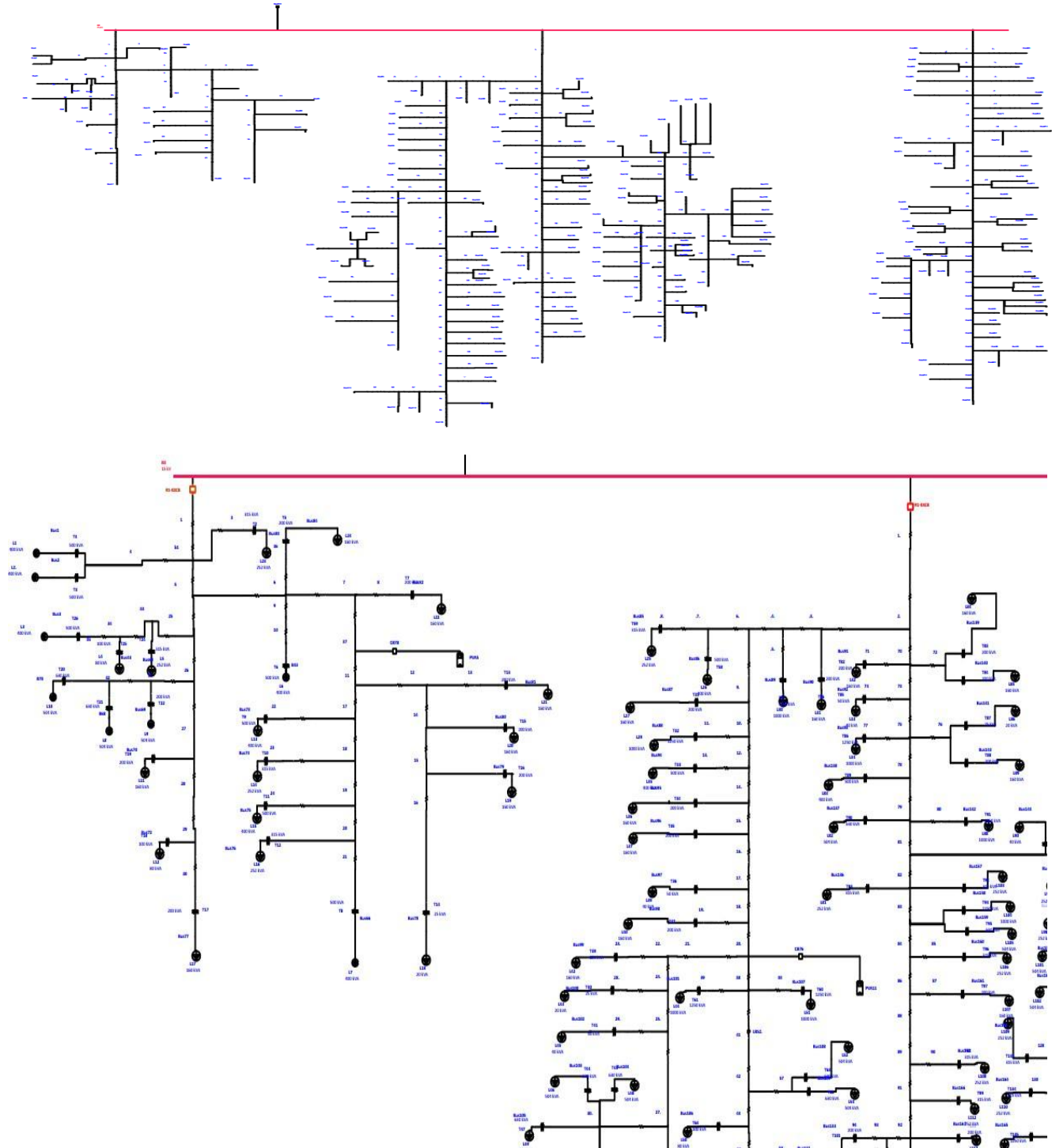
## R6 Reliability Indices Result

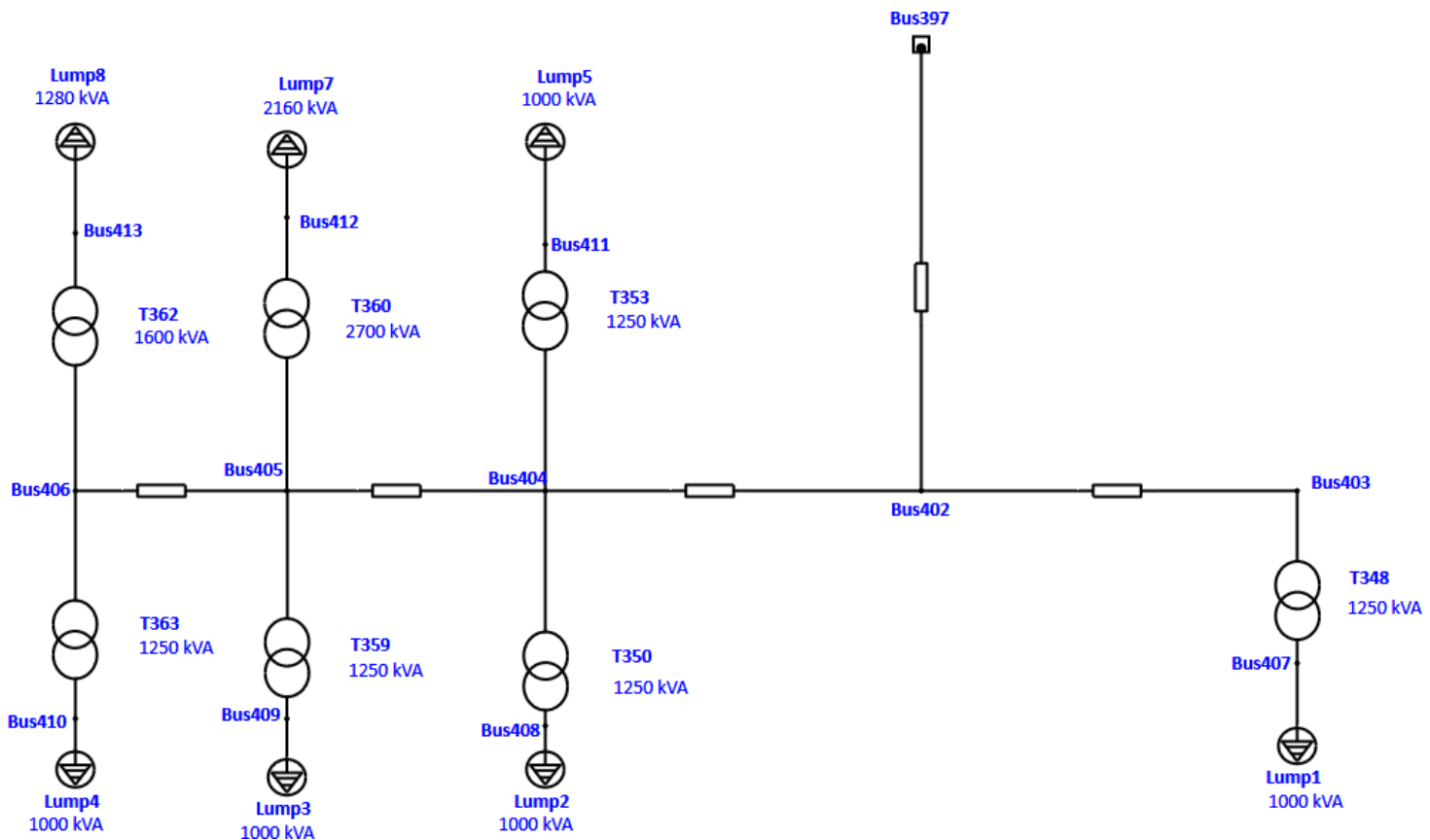
### SUMMARY

#### System Indexes

ACCI	10264.37 kVA / customer
AENS	200.0549 MW hr / customer.yr
ALII	8.21 pu (kVA)
ASAI	0.9785 pu
ASUI	0.02149 pu
CAIDI	22.930 hr / customer interruption
CTAIDI	188.287 hr / customer.yr
ECOST	1,482,652.00 \$ / yr
EENS	200.055 MW hr / yr
IEAR	7.411 \$ / kW hr
SAIDI	188.2870 hr / customer.yr
SAIFI	8.2115 f / customer.yr

The networks daigram from ETAP software





Mekelle city distributed network interruption frequency and duration data for the year 2014 E.C

Yearly Interruption Report from Hamle-2013 up to Sene-2014																
MEKELE(33KV)																
Feeder Name	Interruption Type	F & D	Hamle	Nehase	Meskerem	Tkmt	Hidar	Tahas	Tir	Yekaitit	Megabit	Mayziya	Gunbet	Sen	Total	
DLF1	Interruption	F	4	9	2	4	1	1	7	3	9	4	2	6	52	
		D	36:48:00	8:28:00	3:40	1:16	0:32	22:30	10:15	3:37	19:09	21:52	17:40	6:59	152:46:00	
	Voluntary	F	6	3	2	4	0	3	2	6	4	10	4	3	47	
		D	1:52	0:55	3:40	1:16	0:00	1:23	1:27	7:28	7:51	30:47	4:38	5:57	67:14:00	
	Load shading	F			2	3	1		6	6	3	7	5		33	
		D			3:40	1:02	0:56		9:59	8:10	24:43	6:33	6:50		61:53:00	
DLF2	Interruption	F	7	3	18	23	25	14	16	22	33	37	28	27	253	
		D	13:53	4:34	15:39	57:32	28:21	32:53	59:32	39:13	79:28	123:20	59:28	91:07	677:00:00	
	Voluntary	F	8	--	3	3	3	3	3	4	6	3	2	1	39	
		D	4:45	--	2:07	2:42	3:43	5:37	3:33	4:42	12:52	4:13	3:38	2:08	50:00:00	

	Load shading	F			2	2	4		10	8	3		5		34	
		D			4:40	0:47	2:23		13:38	16:56	5:44		6:34		50:42:00	
<b>DLF3</b>	Interruption	F	36	31	20	32	25	14	18	21	28	31	16	25	297	
		D	96:47:00	82:27:00	187:30	187:39	167:00	73:38	146:01	149:44	157:03	212:55	75:36	168:39	1704:59:00	
	Voluntary	F	6	7	0	1	4		1	3	4	2	1	2	31	
		D	3:32	5:07	0:00	10:47	3:20		0:36	1:06	5:30	1:32	3:16	3:47	38:33:00	
	Load shading	F			1		1		1	3			2		8	
		D			2:24		0:33		1:53	5:13			3:31		13:34:00	
<b>DLF4</b>	Interruption	F	0	0	0:00	1	0	1		1		1			4	
		D	0	0	0:00	10:47	0:00	2:45		3:28		0:10			17:10:00	
	Voluntary	F	0	0	0:00	0:00	0	1		1	4	1	1		8	
		D	0	0	0:00	0:00	0:00	0:14		1:36	23:58	2:34	3:36		31:58:00	
	Load shading	F			19	1									20	
		D			28:19	27:03									55:22:00	

Feeder Name	Interruption Type	F & D	Hamle	Nehase	Meskerem	Tkmt	Hidar	Tahas	Tiri	Yekait	Megabit	Maziya	Gunbet	Sen	Total	
<b>KO-00</b>	Interruption	F	3	9	7	12	3	5	3	7	7	8		7	71	
		D	2:33	4:10	9:32	15:14	4:20	3:28	1:29	3:51	9:03	18:12		7:46	79:38:00	
	Voluntary	F	5	4	10	9	20	1	1	1		5	3	1	60	
		D	5:05	3:28	13:45	13:04	15:26	13:01		1:16	0:26		11:41	9:46	4:55	91:53:00
	Load shading	F	3	6		17	18	25	23	17	18	5	13	12	157	
		D	2:43	10:54		19:37	7:27	9:18	49:00	48:24	19:25	7:24	20:41	27:46	294:39:00	
<b>KO-2</b>	Interruption	F	8	17	10	13	21	1		8	22	14	2	8	124	
		D	4:52	13:15	15:12	13:04	25:32:00	0:49		44:16	46:36	43:52	7:39	34:29	249:36:00	
	Voluntary	F	19	27	6	4	7		1	1		3			68	
		D	8:54	7:39	5:51	8:21	8:47		1:15	1:03		28:05			69:55:00	
	Load shading	F	2	1	14	6	6	6	17	9	11	7	10	7	96	
		D	2:01	0:20	13:12	11:28	6:54	8:17	36:12	25:32	15:38	4:05	16:35	13:46	154:00:00	
<b>KO-3</b>		F	23	32	10	5	3	11		2	2	14	3	6	111	

	Interruption	<b>D</b>	55:30:00	17:35	9:48	7:12	2:16	44:51		6:52	2:42	16:05	1:05	25:16	237:12:00	
	Voluntary	<b>F</b>	3	2	2	2	0	2				5	2	1	19	
		<b>D</b>	0:34	5:20	1:07	0:47	0	1:34				3:09	1:32	1:10	15:13:00	
	Load shading	<b>F</b>								1	1				2	
		<b>D</b>									3:43	0:04				3:47:00
<b>KO-4</b>	Interruption	<b>F</b>	4	1	3	5	3	6	4	8	4	16	2	1	57	
		<b>D</b>	4:24	1:07	5:12	7:38	5:53	41:05	12:10	20:55	8:35	41:33	3:15	0:03	150:43:00	
	Voluntary	<b>F</b>	13	11	7	6	31	7	4	12	10	8	5	8	122	
		<b>D</b>	5:28	4:15	4:14	15:58	9:40	6:26	2:29	11:26	15:46	4:45	10:13	13:43	104:23:00	
	Load shading	<b>F</b>	2	8	6	6	22	11	28	21	8	5	8	7	132	
		<b>D</b>	2:38	14:00	6:04	6:23	15:27	20:25	38:23	34:45	11:16	3:42	11:04	16:25	180:32:00	
<b>KO-5</b>	Interruption	<b>F</b>	3	4	2	3	2	3	2	3	1	5		3	31	
		<b>D</b>	4:12	8:12	4:47	3:27	3:37	5:00	5:51	10:05	1:24	8:54		4:15	59:44:00	
	Voluntary	<b>F</b>	8	10	8	9	20	5	3	5	2	13	4	3	90	
		<b>D</b>	2:56	3:58	8:06	8:23	4:14	5:57	1:45	2:18	1:10	24:57	1:35	1:40	66:59:00	

	Load shading	F	4	8	12	12	14	17	27	17	14	10	12	10	157	
		D	7:40	16:11	11:04	13:51	22:33	7:44	44:53	33:22	17:51	11:15	14:28	20:08	245:00	
<b>KO-6</b>	Interruption	F	7	10	2	0	8	7	6	11	7	11	2	9	80	
		D	20:53	17:47	3:24	0:00	11:03	48:51	6:33	17:33	19:35	15:28	6:29	21:19	188:55	
	Voluntary	F	5	19	0	2	1	2	3		11	10	6	1	60	
		D	4:55	10:03	0:00	0:46	0:36	0:56	2:05		9:13	5:31	4:51	3:31	42:27:00	
	Load shading	F	1						10	3				5	19	
		D	2:20						9:22	4:54				9:35	26:11:00	
<b>KO-8</b>	Interruption	F	1	1	13	8	3	8	7	3	3	7	1	12	67	
		D	0:01	1:13:00	20:39	12:38	3:16	42:56	41:53	5:10	9:52	20:35	4:03	47:37	209:53	
	Voluntary	F	_	3	10	12	20	2	2	2	5	7	2	1	66	
		D	_	3:20	12:28	14:19	3:40	2:27	2:06	1:35	4:09	5:08	5:24	0:43	55:19:00	
	Load shading	F	2	4	16	13	17	17	23	24	15	8	12	7	158	
		D	2:50	1:09	19:49	13:34	0:50	0:16	48:16	45:39	18:30	7:20	12:02	8:21	226:36	
<b>KO-9</b>		F	13	7	3	0	2	3	2	5	10	19		1	65	

	Interruption	<b>D</b>	2:45	21:00	12:39	0	2:22	7:34	4:28	30:55	37:16	47:22		0:17	190:38:00	
	Voluntary	<b>F</b>	5	2	0	4	2	5	1	6	7	11	1	9	53	
		<b>D</b>	10:57	1:45	0:00	3:48	3:33	11:18	3:20	6:48	6:25	11:30	0:30	16:16	76:10:00	
	Load shading	<b>F</b>		2		1			9	2					14	
		<b>D</b>		1:31		1:56			15:02	0:51					19:20:00	
<b>KO-10</b>	Interruption	<b>F</b>	5	5	9	6	0	3	1	4	1	4	3	3	44	
		<b>D</b>	2:55	12:08	12:35	9:34	0:00	54:49	0:56	6:28	0:09	5:24	9:16	1:40	115:54:00	
	Voluntary	<b>F</b>	18	23	9	13	27	5	6	9	9	11	9	6	145	
		<b>D</b>	19:50	4:37	11:05	14:44	9:31	2:17	3:12	6:37	3:55	9:43	11:34	3:08	100:13:00	
	Load shading	<b>F</b>	1	6	19	15	21	23	24	24	17	10	10	10	180	
		<b>D</b>	4:43	9:31	27:31	19:12	4:29	16:39	51:27	52:26	23:41	13:32	22:16	34:34	328:01:00	
<b>KO-11</b>	Interruption	<b>F</b>	8	3	4	1	0:00	3	2		14	5		5	45	
		<b>D</b>	30:00:00	5:00	5:34	6:43	0:00	22:39	7:32		31:37	16:43		16:57	142:45:00	
	Voluntary	<b>F</b>	3	–	0	0	2	3	4	1	11	3			27	
		<b>D</b>	1:08	–	0:00	0:00	0:51	3:57	4:23	0:42	7:52	8:35			27:28:00	

	Load shading	F							10	2					12		
		D							14:17	6:42					20:59:00		
<b>KO-12</b>	Interruption	F	2	1	0	0	0:00	1				5	1	3	13		
		D	4:09	1:07	0:00	0:00	0:00	7:33				11:54	0:34	10:04	35:21:00		
	Voluntary	F	2	1	0	0	0	6			2		2	3	16		
		D	0:26	0:21	0	0:00	0:00	7:59			2:15		2:16	2:39	15:56:00		
	Load shading	F														0	
		D														0:00:00	
<b>R1</b>	Interruption	F													0		
		D													0:00:00		
	Voluntary	F												3	3		
		D												7:09	7:09:00		
	Load shading	F														0	
		D														0:00:00	
<b>R2</b>		F			0	0	0					2		2			

	Interruption	<b>D</b>			0	0:00	0:00:00						14:17		14:17:00	
	Voluntary	<b>F</b>			2	0	0		1				1	4	8	
		<b>D</b>			3:57	0:00	0:00		1:02				0:08	7:43	12:50:00	
	Load shading	<b>F</b>				1				1					2	
		<b>D</b>				1:40					0:17				1:57:00	
<b>R3</b>	Interruption	<b>F</b>	5	13	3	3	0	1	3		11	5	3	11	58	
		<b>D</b>	4:52	8:57	4:12	2:54	0:00	0:10	2:49		8:11	7:58	0:24	7:49	48:16:00	
	Voluntary	<b>F</b>	_	4	6	12	21			1	1			7	52	
		<b>D</b>	_	14:31	9:08	2:31	7:41			0:30	0:20			18:27	53:08:00	
	Load shading	<b>F</b>	1	3	12	14	17		22	22	13	7	12	8	131	
		<b>D</b>	0:29	7:55	17:09	25:29	27:32		48:55	51:02	23:04	8:37	20:58	27:44	258:54:00	
<b>R4</b>	Interruption	<b>F</b>	6	5	5	3	1	3	3	1	5	4		6	42	
		<b>D</b>	4:52	2:57	6:49	2:27	0:13	2:36	17:13	0:18	2:21	2:13		1:54	43:53:00	
	Voluntary	<b>F</b>	1	1	5	8	23		3	4	2	2	1	7	57	
		<b>D</b>	0:30	0:03	6:20	9:53	20:14		1:09	1:58	0:19	3:55	0:03	18:39	63:03:00	

	Load shading	F	3	5	14	16	16	13	10	12	8	12	16	7	132	
		D	4:19	6:38	18:21	15:51	32:36	31:46	11:53	15:29	8:53	17:06	21:20	20:38	204:50:00	
<b>R6</b>	Interruption	F	0	0	0	0	0	2		5	7	22	9	4	49	
		D	0	0	0:00:00	0:00	0:00	0:44		7:16	11:41	30:39	8:20	9:53	68:33:00	
	Voluntary	F	0	0	0	1	0	2					1	4	8	
		D	0	0	0:00	1:40	0:00	0:25					0:15	7:49	10:09:00	
	Load shading	F				1		2	24	18	16	5	15	8	89	
		D				1:40		0:52	51:29	47:10	25:34	9:38	18:19	23:12	177:54:00	
<b>R5</b>	Interruption	F	0	0	5	3	2	5							15	
		D	0	0	4:53:00	2:38:00	1:07:00	2:11							10:49:00	
	Voluntary	F	0	0	7	7	5						1	4	24	
		D	0	0	7:17	7:46	4:05						0:08	7:49	27:05:00	
	Load shading	F		1	9	12	19	15		1	1				58	
		D		2:02	20:43	13:36	21:47	17:12		0:17	0:34				100:11:00	

**Mekelle city distributed network interruption frequency and duration data for the year 2015 E.C**

<b>YEARLY REPORT OF INTERRUPTION</b>																
<b>Mekelle Substation (33KV)</b>																
Feeder Name	Interruption Type	F&D	Hamle	Nehase	Meskerem	Tikimti	Hidar	Tahsas	Tiri	Yekaitit	Mgabita	Maziya	Gunbet	Sen	Total	
<b>DLF1</b>	Interruption(Fault)	F	14	7	2	4	4	7			10	20	5	5	78	
		D	60:53	51:54	3:14	6:17	17:24	63:51			23:30	84:44	5:20	5:18	182:43:00	
	Voluntary	F	9	7	1	4	2	4	3	1	12	10	7	4	64	
		D	12:24	6:05	5:34	7:20	1:15	11:50	4:58	0:55	8:59	12:59	9:37	1:21	83:17:00	
	Load shading	F	6	2	1	11	12	2	7	3	1		2	2	49	
		D	6:11	8:03	0:59	39:43	72:22	1:46	7:51	7:19	0:51		3:43	9:40	158:28:00	
<b>DLF2</b>	Interruption	F	25	33	5	7	10	7		1	40	38	32	22	220	
		D	122:55	113:27	9:46	59:50	166:44	29:50		0:51	70:24	87:10	102:06	89:39	852:42:00	
	Voluntary	F	4	6	3		1	2	8	17	15	5	8	1	70	
		D	19:24	18:07	4:32		0:10	3:02	21:28	18:20	11:00	10:48		0:31	107:22:00	
	Load shading	F		1		6	5		13	8				1	34	

			D		9:26		17:2 7	18:3 8		14: 38	7:05				0:4 4	67:58:0 0
	<b>DLF3</b>	Interruption	F	55	29	11	13	10	19			22	17	17	21	214
			D	303: 20	170: 47	58:14	88:4 9	42:4 2	125:3 2			76:5 6	72:1 7	64:0 3	76: 02	1078:42 :00
		Voluntary	F	8	6	4	1	3	1	8	16	15	14	4	5	85
			D	14:2 5	5:49	8:37	1:25	3:19	0:51	70: 35	46:2 8	5:43	5:48	4:31	1:0 4	192:35: 00
		Load shading	F			2	3	6		5	11					27
			D			2:08	2:10	32:1 2		4:2 8	3:56					44:54:0 0
	<b>DLF4</b>	Interruption	F	1	1	8						1	2	1		14
			D	1:31	1:17	27:41						3:20	25:0 5	1:37		60:31:0 0
		Voluntary	F	1	4					1	1	5	1	2		15
			D	0:44	6:35					15: 50	0:45	3:38	0:22	3:49		31:43:0 0
		Load shading	F				21		1	1	1					24
			D				44:4 6		0:53	2:1 2	1:19					1:19:00
	<b>Mekelle Substation (15KV)</b>															

	Feeder Name	Interruption Type	F&D	Hamle	Nehase	Meskerem	Tiki mti	Hida r	Tahsa s	Tiri	Yekait	Mga bit	Mazi ya	Gun bet	Sen e	Total	
	<b>Ko00</b>	Interruption	F	11	16	9	7	6	6			11	15	25	13	119	
			D	13:02	17:31	6:16	33:53	9:31	12:43			8:10	28:46	19:36	5:24	154:52:00	
		Voluntary	F	3	3			1			19	4	2	5	1	38	
			D	2:01	5:07			0:40			11:15	6:26	1:10	10:21	0:09	37:09:00	
		Load shading	F	13	21	26	21	20			3	1	5	2	2	4	118
			D	25:59	47:17	44:06	44:46	129:38			1:43	0:21	4:06	1:19	3:40	4:38	307:33:00
	<b>Ko2</b>	Interruption	F	15	17	41	9	3	6		5	1	8	3		91	
			D	22:04	55:18	52:55	27:57	15:20	25:54			4:07	1:28	24:37	24:49		254:29:00
		Voluntary	F		2						5	4	1	3		15	
			D		2:20						2:15	4:25	0:33				9:33:00
		Load shading	F	9	22	17	28	22			6	2	3			2	111
			D	11:13	45:29	29:45	79:22	100:11			2:06	0:11	4:10			3:59	276:26:00
	<b>Ko3</b>	Interruption	F	7	3	3	2	6	3		3	8	8	9	2	54	
			D	41:04	8:01	5:59	9:40	29:39	13:10			4:10	31:15	24:37	11:58	8:49	188:22:00

		Voluntary	F	4	2	2	4	5		2		12	4	6	1	42	
			D	2:55	1:14	1:46	3:32	11:0		1:3		13:5	2:28	8:06	4:3	51:05:0	
		Load shading	F				1			6	5					12	
			D				0:20			2:0	2:57						5:23:00
	<b>Ko4</b>	Interruption	F	11	5	5	8	3				10	10	6	4	62	
			D	45:2	23:1	5:51	19:1	22:2					17:2	22:0	8:22	8:2	172:22:
				8	0		6	8				6	1		0	00	
			Voluntary	F	13	7	10	5	4	8	2	12	22	14	23	8	128
				D	14:3	6:03	9:00	5:16	4:53	18:25	19:	55:5	12:3	3:17	15:2	3:4	168:14:
				0						15	3	3		4	5	00	
		Load shading	F	12	24	21	16	26	1	8	12	3	1	2	3	129	
			D	15:1	47:4	31:26	33:2	130:	0:28	4:1	8:03	6:04	1:01	1:36	3:0	282:39:	
			5	9		8	14		1					4	00		
	<b>Ko5</b>	Interruption	F	7	6	9	2	3	1		3	7	17	7	2	64	
			D	19:0	16:2	35:55	10:5	23:0	24:00			8:05	35:5	84:3	34:5	3:2	296:15:
				3	6		6	0				7	1	5	7	00	
			Voluntary	F	7	8	9	1	3	1	3	8	1	17	17	10	85
				D	4:22	9:18	14:26	0:34	2:20	0:12	9:1	17:2	1:43	13:5	22:3	4:0	100:06:
										0	1		9	4	7	00	
		Load shading	F	16	21	21	24	18	1	5	8	16		3	2	135	

			D	17:4 7	54:0 2	38:57	59:1 9	106: 53	0:28	5:1 0	15:1 9	27:2 8		3:30	7:2 3	336:16: 00
	<b>Ko6</b>	Interruption	F	19	13	5	3	2	3		1	3	3	2	4	58
			D	64:0 7	27:3 5	12:18	10:3 4	12:5 8	11:54		2:44	3:34	4:40	22:3 7	5:2 6	178:27: 00
		Voluntary	F	14	7	3	3	5		1	2	10	7	9	8	69
			D	12:1 8	9:44	2:41	2:25	2:34		0:4 7	2:28	9:44	5:31	9:01	1:5 8	59:11:0 0
		Load shading	F		1		1	4	1	8	3			2	1	6
			D		7:43		1:58	9:54	0:28	2:5 6	7:48			2:55	0:4 3	11:26:0 0
	<b>Ko8</b>	Interruption	F	19	13	8	5	3	9			5	10	8	4	84
			D	87:4 6	45:2 6	10:15	15:3 1	10:3 3	33:32			3:06	29:1 1	10:4 6	25: 11	271:17: 00
		Voluntary	F	7	4	4	6	1	1		6	13	14	10	5	71
			D	9:15	3:47	9:55	9:51	0:10	0:44		3:50	4:39	5:06	2:49	1:3 9	51:45:0 0
		Load shading	F	11	25	25	26	25		4	3	4	1	4	3	131
			D	16:4 7	52:0 6	37:25	83:4 8	105: 58		1:2 8	0:46	8:09	1:00	5:14	3:0 6	315:47: 00
	<b>Ko9</b>	Interruption	F	7	13	3	3	2	4		3	4	3	5	3	50
			D	46:4 4	59:1 4	6:08	28:1 5	7:31	12:34		6:06	4:54	21:1 4	51:2 1	3:4 2	247:43: 00

		Voluntary	F	8	3	5	4	1	1	2	2	2	3	6	4	41
			D	12:0 1	6:10	2:14	9:17	0:57	0:44	10: 23	1:36	2:59	5:14	10:5 1	2:4 4	65:10:0 0
		Load shading	F		1			1	1	2	5				1	11
			D		3:47			1:34	3:16	0:4 5	5:41				1:1 0	6:51:00
	<b>Ko10</b>	Interruption	F	12	15	3	1	7	2			6	19	8	5	78
			D	14:3 0	29:4 9	1:30	7:16	54:3 7	9:31			13:5 0	38:0 2	26:0 6	9:2 6	131:03: 00
		Voluntary	F	18	10	8	5	1	3	1	7	12	13	13	11	102
			D	12:4 1	6:00	8:45	2:54	1:19	2:36	0:3 0	19:4 6	3:18	5:28	5:56	4:0 4	73:17:0 0
		Load shading	F	12	22	25	18	17	2	7	5		1	4	3	116
			D	24:5 3	45:1 9	55:09	69:4 5	106: 47	2:20	7:0 3	3:03		0:27	5:14	13: 19	22:03:0 0
	<b>Ko11</b>	Interruption	F	4	7	6	11	3	7		4	4	192: 00	4	3	58
			D	8:05	45:5 9	12:23	22:5 8	32:0 8	31:45		2:54	2:01	10:4 7	12:3 6	4:0 7	185:43: 00
		Voluntary	F	3	4	3	2	3		9		3	7	3	3	40
			D	1:17	3:09	3:08	2:14	6:53		12: 04		1:13	3:05	7:23	9:1 0	20:51:0 0
		Load shading	F		1		5	2		7	1					16

			D		5:00		16:35	3:22		2:09	0:15					27:21:00
	<b>Ko12</b>	Interruption	F		3	4		1	1			4	6	7	6	32
			D		15:39	8:19		1:30	3:12			10:07	9:43	23:12	20:13	87:15:00
		Voluntary	F	3	6	4	1	2	1		3	5	9	6	4	20
			D	4:33	6:16	6:12	2:44	7:25	0:22		3:49	8:51	6:39	16:40	1:13	64:44:00
		Load shading	F						1	4	2					7
			D						0:28	2:58	3:31					6:57:00
	<b>R2</b>	Interruption	F		1			1	3							5
			D		0:13			3:10	0:07							3:30:00
		Voluntary	F	1				2			2	1		1	1	8
			D	3:20				4:26			24:55	2:36		3:39	1:30	32:40:00
		Load shading	F					2	1							3
			D					2:56	3:16							6:12:00
	<b>R3</b>	Interruption	F	8	8	4	7	7	10			16	17	14	12	103
			D	18:50	16:57	8:32	15:39	13:14	17:21			12:06	23:15	12:27	10:23	148:44:00
		Voluntary	F	2	1	1	2	4	1	3	7	3	5	6	8	43

			D	20:3 2	0:39	1:35	2:54	5:10	1:01	6:1 0	8:39	3:25	7:34	6:30	13: 21	77:30:0 0
		Load shading	F	16	21	23	18	23	1	2	8	3	3	4	2	23
			D	30:1 0	49:3 1	44:44	52:4 7	93:5 1	3:16	1:3 4	7:56	6:55	2:10	6:30	3:4 9	27:20:0 0
	<b>R4</b>	Interruption	F	2	6	5	4	1	7		3	5	7	9	4	53
			D	1:15	6:41	6:41	9:10	0:08	24:23: 00		6:55	12:4 1	6:14	6:05	0:5 4	55:13:0 0
		Voluntary	F	5	1	8	4	3		2	2	3	9	2	2	41
			D	1:32	0:19	9:11	8:05	2:19		0:5 5	2:47	3:35	4:56	3:55	1:0 3	38:37:0 0
		Load shading	F	8	17	28	18	26	2	3	2	3	1	6	3	117
			D	16:3 2	63:0 6	56:07	58:0 9	95:1 2	3:56	1:3 7	4:31	8:04	1:00	6:43	6:3 1	26:49:0 0
	<b>R5</b>	Interruption	F	14	13	9	3		2		2	10	17	6	5	81
			D	31:5 0	23:5 0	10:59	8:06		16:59		4:59	16:2 8	34:3 4	18:4 7	6:5 4	173:26: 00
		Voluntary	F	1	3	1					1	8	15	9	5	43
			D	0:29	2:16	0:32					0:30	5:21	4:12	6:34	1:2 9	18:06:0 0
		Load shading	F	6	24	26	27	27	3	2	<b>9</b>	3		2	3	132
			D	11:2 2	51:1 3	48:41	58:2 6	152: 27	7:01	0:4 6	3:34	7:41		2:07	18: 56	32:18:0 0

<b>R6</b>	Interruption	F					3		3		1		4	
		D					0:07		7:41		1:34		9:15:00	
	Voluntary	F	<b>1</b>				1			1		1		4
		D	<b>3:20</b>				0:10			2:36		3:39		9:45:00
	Load shading	F					1		1					2
		D					3:16		1:02					1:02:00

**Mekelle city distributed network interruption frequency and duration data for the year 2016 E.C**

<b>MDDO MONTHLY INTERRUPTION REPORT OF 2016 E.C</b>									
<b>Mekelle Substation (33KV)</b>									
Feeder Name	Interruption type	F&D	Hamle	Nehase	Meskerem	Tikmti	Hidar	Tahsas	Total
<b>DLF1</b>	Interruption(Fault)	F	28	44	3	20	2	4	101
		D	75:14	63:31	24:37	31:15	2:19	5:52	196:56
	Voluntary	F	22	49	10	10	4	5	100
		D	21:06	42:21	9:10	2:47	2:08	16:59	94:31
	Load shading	F	1		3		1	3	8
		D	3:44		5:28		1:10	2:15	12:37:00
<b>DLF2</b>	Interruption	F	31						31
		D	75:49						75:49:00

	Voluntary	F	1					2	3
		D	1:11					0:41	1:52:00
	Load shading	F							
		D							
<b>DLF3</b>	Interruption	F		71	14	22	10	15	132
		D		302:43	21:16	67:05	21:19	35:41	448:04:0 0
	Voluntary	F	6	19	1	1	2		29
		D	2:57	20:42	0:15	0:04	0:22		24:20:00
	Load shading	F					1		1
		D							
<b>DLF4</b>	Interruption	F		8	1	4			13
		D		39:58	4:51	3:35			48:24
	Voluntary	F	2	6					8
		D	3:36	17:34					21:10:00
	Load shading	F							
		D							
<b>Mekelle Substation (15kv)</b>									

<b>Feeder Name</b>	<b>Interruptiontype</b>	<b>F&amp;D</b>	<b>Hamle</b>	<b>Nehase</b>	<b>Meskerem</b>	<b>Tikmti</b>	<b>Hidar</b>	<b>Tahsas</b>	<b>Total</b>
<b>Ko00</b>	Interruption	F	9	13	2	6	2	2	34
		D	7:58	10:16	3:10	4:25	3:08	6:41	35:38:00
	Voluntary	F	5	28	10	4	1	1	49
		D	1:29	7:40	4:14	1:07	0:16	1:04	15:50:00
	Load shading	F	4	7	6	1	3	1	22
		D	9:18	4:25	13:35	0:51	3:34	0:12	31:55:00
<b>Ko2</b>	Interruption	F	5	35	24	13	17	8	102
		D	2:53	13:23	26:14	17:51	28:23	17:26	88:44:00
	Voluntary	F	1	2	9	11	7	10	40
		D	0:32	0:20	3:14	6:44	2:51	3:50	17:31:00
	Load shading	F	3	2	3	1	2	2	13
		D	3:19	3:02	5:00	1:23	3:06	1:38	17:28:00
<b>Ko3</b>	Interruption	F	1	15	5	4	1		26
		D	18:22	19:40	14:15	9:19	0:33		62:09:00
	Voluntary	F	4	9	2	3	3	3	24
		D	1:50	3:19	0:31	1:00	1:20	1:01	9:01:00
	Load shading	F					1		
		D					1:53		
<b>Ko4</b>	Interruption	F	9	10	11	7	1	2	40
		D	13:59	17:48	14:40	10:18	1:20	5:31	63:36:00

	Voluntary	F	14	44	7	5	4	5	79
		D	4:28	1:01	12:31	1:21	7:37	1:20	52:18:00
	Load shading	F	2	3	3	1	2	1	12
		D	8:41	1:30	7:57	0:07	1:32	0:48	20:35:00
<b>Ko5</b>	Interruption	F	9	11	8	3		1	32
		D	59:21	41:28	16:44	2:51		0:52	121:16:00
	Voluntary	F	13	35	7	7	2	9	73
		D	3:29	10:12	3:01	20:31	0:39	2:51	40:43:00
	Load shading	F	2	4	5	2		2	15
		D	10:06	2:56	12:32	0:52		1:16	27:42:00
<b>Ko6</b>	Interruption	F	24	24	5	11	2	4	70
		D	24:24	21:55	5:33	10:22	2:07	4:11	68:32:00
	Voluntary	F	13	19	8	12	6	7	65
		D	8:10	5:08	6:00	1:50	2:21	1:05	24:34:00
	Load shading	F							
		D							
<b>Ko8</b>	Interruption	F	8	28	12	4	1	3	56
		D	22:59	81:31	27:54	6:29	0:09	0:55	139:57:00
	Voluntary	F	10	23	8	4	5	6	56
		D	3:09	4:09	5:09	6:09	7:09	1:15	27:00
	Load shading	F	1	2	5				8

		D	1:00	3:14	9:30				13:44:00
<b>Ko9</b>	Interruption	F	8	14	2			4	24
		D	18:56	27:55	14:57			5:49	61:48:00
	Voluntary	F	6	15	5		2	1	29
		D	10:42	15:47	1:15		0:55	0:05	28:44:00
	Load shading	F							
		D							
<b>Ko10</b>	Interruption	F	7	16	3	6	9	4	45
		D	16:12	34:36	5:24	11:01	9:59	4:35	81:47:00
	Voluntary	F	13	28	8	11	4	11	75
		D	4:32	6:05	2:37	4:52	2:25	7:20	27:51:00
	Load shading	F	3	8	3	2	2		18
		D	1:55	9:25	3:14	0:24	3:36		18:34:00
<b>Ko11</b>	Interruption	F	14	11	8	2	2	1	38
		D	38:09	9:11	35:07	4:13	15:32	0:34	102:46:00
	Voluntary	F	7	12	4	2	4		29
		D	10:03	3:49	1:33	6:06	1:57		23:28:00
	Load shading	F							
		D							
<b>Ko12</b>	Interruption	F	7	11	8	3	1		30
		D	8:11	12:47	4:37	25:12	2:05		52:52:00

	Voluntary	F	4	6	3	3	3		19
		D	1:24	1:26	0:44	2:44	2:34		8:52:00
	Load shading	F							
		D							
<b>R2</b>	Interruption	F					1		
		D					1:18		
	Voluntary	F		5	1		1	1	8
		D		2:28	2:55		0:48	0:17	6:28:00
	Load shading	F							
		D							
<b>R3</b>	Interruption	F	33	60	6	7		3	109
		D	29:04:00	57:54:00	3:28:00	5:39:00		1:55:00	98:00:00
	Voluntary	F		1	1		1	1	4
		D		0:51	2:18		1:15	2:08	6:32:00
	Load shading	F	4	6	5		3	2	20
		D	10:38	3:00	13:58		3:14	12:10	43:00:00
<b>R4</b>	Interruption	F	3	16	2	2		3	26
		D	1:59	8:48	1:43	0:43		0:37	13:50:00
	Voluntary	F	2	7					9
		D	1:44	19:28					21:12:00
	Load shading	F	3	8	5	2	1	2	21
		D	4:33	6:38	7:29	2:04	0:22	1:07	22:13

<b>R5</b>	Interruption	F	21	10	5	4		2	42
		D	18:41	6:15	2:20	11:49		1:16	40:21:00
	Voluntary	F	1		1		1		3
		D	0:15		0:33		1:08		1:56:00
	Load shading	F	3	5	4		2	3	17
		D	10:16	5:43	9:41		1:13	1:42	26:53:00
<b>R6</b>	Interruption	F							
		D							
	Voluntary	F							
		D	<b>1</b>			<b>1</b>			2
	Load shading	F	<b>0:15</b>			<b>1:04</b>			1:19
		D							