ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

AFRICAN RAILWAY CENTER OF EXCELLENCE

Power Reliability Analysis of DC Traction Power Supply System: A Case Study of Addis Ababa Light Rail Transit

A Thesis in MSc. Railway Engineering (Traction and Train Control)

By Brian Watuwa

June, 2019

Addis Ababa

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

APPROVAL

The undersigned have examined the thesis entitled **'Power Reliability Analysis of DC Traction Power Supply System: A Case Study of Addis Ababa Light Rail Transit'** presented by **BRIAN WATUWA**, a candidate for the degree of **Master of Science in Railway Engineering (Traction and Train Control)** and hereby certify that it is worthy of acceptance.

Dr. ING. Getachew Biru	____________________	______________
Advisor	Signature	Date
Dr. Celestin Nkundineza	____________________	______________
Internal Examiner	Signature	Date
Mr. Fetene Mulugeta	____________________	______________
External Examiner	Signature	Date
Mr. Zewdie Moges	____________________	______________
Chair person	Signature	Date

UNDERTAKING

I certify that research work titled “Power Reliability Analysis of DC Traction Power Supply System: A Case Study of Addis Ababa Light Rail Transit” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Brian Watuwa

ABSTRACT

DC Railway Traction Power Supply System (TPPS) has been and is still widely used world over for train propulsion especially in the urban areas and inter- urban regions. With the evolution of electronic traction control technology giving compact size and reduced weight of chopper and inverter drives, DC railway traction has become advantageous especially where we have minimal provision for electrical clearances. Currently, the standard DC traction voltages are 750V, 1500V and 3000V which require less electrical clearance compared to AC Railway Traction Power Supply System catenary.

The basic function of an electrical power system is to meet its customer's expectations while maintaining the acceptable levels of quality and continuity of supplies. The reliability level of DC Railway Traction Power Supply System is a major contributor to the quality of service provided by a railway authority, thus there is a link between reliability and quality of service. While most of the contingency situations may be predicted and counteracted on the design stage, only the real-life experience is the ultimate test for reliability. Reliability is regarded by many researchers as the science of failures and the work of a reliability engineer is to assess the trend of failure data and determine the rate of occurrence of failures as accurately as possible.

This research, therefore, addresses the reliability question at AALRT through collection and analysis of power interruption data. This data is used to compute performance indicators or indices such as; Basic Reliability Indices (failure rate, MTBF, MTTR and availability), Customer Orientation Indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) and Energy and Cost Indices (EENS, AENS, ECOST and IEAR). From the period of study (2016, 2017 and 2018), this research finds out that the System Average Interruption Index SAIFI) is 7.47 interruptions per customer and System Average Interruption Duration Index (SAIDI) of 58.17 hours per customer. These indices are benchmarked with the those of other countries. A model of the AALRT TPSS is developed and three cases of potential reliability improvement alternatives are simulated using an ETAP software. These improvements gave an overall reduction in EENS of 80.869 MWhr/yr. A cost-benefit analysis of the reliability improvement alternatives is also done to justify the investment.

Key words: *DC Railway Traction Power Supply System, Reliability, Power interruption data, Performance Indicators, reliability improvement alternatives.*

ACKNOWLEDGMENTS

I would first like to thank my thesis advisor Dr. ING. Getachew of the School Computer and Electrical Engineering at Addis Ababa Institute of Technology- Addis Ababa University. The door to Dr. Ing. Getachew office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work but steered me in the right direction whenever he thought I needed it.

I would also like to thank the experts at Addis Ababa Light Rail Transit: Mr. Bisrat Zewdie- Manager Operation Control Center, Mr. Nahome Girmaye- Manager Power Department and Mr. Ashenafi Kifleyohans- Technician Power Department. Without their passionate participation as far as sharing with me the research data, this research could not have been successfully conducted.

I would also like to acknowledge the Germany government through the DAAD scholarship which has enabled me to peruse this master of science degree and brace myself with knowledge in railway engineering at Addis Ababa University. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

Term	Definition
AALRT	Addis Ababa Light Rail Transit
AENS	Average Energy Not Supplied
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Consumer Average Interruption Duration Index
CEER	Council of European Energy Regulators
DPS	Distributed Power System
ECOST	Expected Energy Not Supplied Cost
EENS	Expected Energy Not Supplied
EEU	Ethiopia Electricity Utility
ETB	Ethiopian Birr
IEAR	Interrupted Energy Assessment Rate
MDT	Mean Down Time
MTBF	Mean Operating Time Before Failure
MTTR	Mean Time to Restore
OCC	Operation and Control Centre
OCS	Overhead Contact System
PDF	Probability Density Function
RAMS	Reliability, Availability, Maintainability and Safety
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
TPS	Traction Power Substation
TPSS	Traction Power Supply System

Chapter 1 INTRODUCTION

Power transmission to electric locomotives and railway vehicles can be done using DC or single-phase AC networks. To choose whether to use DC or single-phase AC network, a number of technical considerations such as operational requirements (for urban metro, high-speed passenger or heavy haul freight), physical route characteristics (such as gradients, and bridge and tunnel clearances), proximity of generating plant and utility or railway-owned power networks, available traction technology (converters, traction motors and regenerative capability), are carefully looked at. DC supply is still advantageous and widely used because power electronic traction control technology has evolved, thus compact size and weight of chopper and inverter drives [1], [2].

DC networks with trackside rectifiers and transmission voltages between 600 V and 1.5 kV are standard for urban and regional lines up to about 100 km long, although there are extensive 3 kV DC mainline systems dating from the 1920s and 1930s. Currently, DC traction voltages have been standardized and are 750 V (for urban metros), 1500 V (for interurban and regional systems) and 3000 V. Three-phase voltage from the local utility company is stepped down and rectified in the traction substation to provide the required DC voltage. The rating of DC substations varies between 1.5 and 10 MW, and substation spacing can be up to 3 km for 600 V, 10 km for 1.5 kV and 20 km for 3 kV supply [1], [2].

A lot of projects of subway, tram systems and MRT (Mass Rail Transit) systems are proposed and under construction all over the world and 750V DC or 1.5 kV DC power supply systems have been adopted during the last decade, especially in Asian countries. In China, for example, the total length of urban transportation will be 4200 km in 2020, about 8 times as large as that in 2007 [3]. Below is a breakdown of the traction power supply voltage in the world as of 2017.

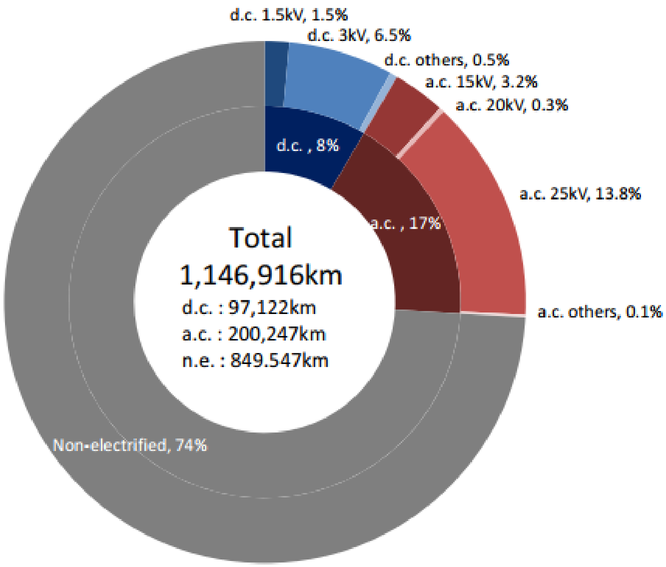


Figure 1-1: Breakdown traction power supply voltage in the world as of 2017

Source: [3]

TPPS faults such as grounding fault caused by malfunction of auxiliary relay circuit of DC circuit breaker, air arc expansion and its replication of DC circuit, melting of braided wire in auxiliary contact of DC circuit breaker, have reduced the quality of service of the railway system especially where there is minimal redundancy [4], [5]. The reliability of the system is a very important aspect and therefore reliability analysis must be carried out to ascertain the availability of the system. There is also a direct relationship between the reliability of TPS and the level of redundancy therein for different TPS configurations, i.e. the more the level of redundancy, the higher the reliability.

Reliability is regarded by many researchers as the science of failures and the work of a reliability engineer is to assess the trend of failure data and determine the rate of occurrence of failures as accurately as possible [6]. The reliability analysis as captured in RAMS standards is qualitative rather than quantitative, thus there is need for a sounding approach that will give a quantitative reliability analysis while at the same time referencing international reliability standards [7].

While for utility power systems the performance criteria are well established and standardized, traction power systems are different and unique, and therefore there is a need for development of such criteria, standards and guidelines in order to reach the optimal performance by means of improved design, construction and operation practices. Unlike the Utility Power Systems' Reliability whose evaluation is expressed in outage minutes per year (ratio of customers' electrical energy deprivation to system's total power capacity), Traction Power System reliability evaluation is based on minutes of train delays caused by power interruption or relative values such as delays minutes per-passenger-mile [8].

The basic function of an electrical power system is to meet its customer's expectations while maintaining the acceptable levels of quality and continuity of supplies. In designing and planning in a distributed power system or any other kind of power system such as TPSS, reliability assessment is considered as of primary importance to operate in an economical manner with minimal interruption of customer loads. This evaluation also provides qualitative analysis and indices in power supply performance for the operation and planning of a power system (TPSS). Furthermore, this evaluation will ensure adequacy (related to total energy demand) and system security (includes reliability and availability) which is related to the dynamic response of the system, such as fault and failure [9], [10].

The main function of an electric system is to supply customers with electric energy that has an acceptable degree of reliability and quality. The power system continuity of supply is controlled through indices. The most widely used indices are SAIFI, SAIDI and CAIDI (IEEE standard 1366- 2000). Historical electrical indices, reliability indices, threshold and satisfaction index are used as a guide for electric network performance, which measures the adequacy and security of power supply. The main objective of a power distribution company is ensuring a high level of quality, availability and continuity of supply to distribution customers. Continuity of power supply is generally characterized as the frequency and duration of interruption in supply [11].

1.1 Statement of the Problem

A typical DC Traction Power Supply System has many Traction Power Substations which convert the high voltage electricity of the public grid to the suitable voltage which is then supplied to the locomotives through a catenary system. The Traction Power Supply System reliability evaluation is critical and should occasionally be done to predict its health of Traction Power Supply System in both the short and long run [7]. For the case of the AALRT where power interruptions are often, it is this evaluation that will help quantify the impact of power interruptions on the operational schedule and the monetary losses incurred as a result of the power outage.

Faults in any power system are inevitable and these largely affect the Traction Power Substation devices as well as Traction Power Supply System in terms of their reliability. Faults such as grounding fault trouble caused by malfunction of auxiliary relay circuit of DC circuit breaker for traction power supply significantly reduce the lifetime of DC traction power equipment [5], [12]. Generally, power system faults are the main contributors to power outages.

1.2 Objectives

1.2.1 Main Objective

The main objective of this research is to perform reliability analysis of DC Traction Power Supply System of the Addis Ababa Light Rail Transit and evaluate potential power reliability mitigation methods.

1.2.2 Specific Objectives

1. To study the different configurations of DC TPSS.
2. To assess the causes of power interruptions/ outages at AALRT.
3. To perform reliability analysis of the DC TPSS of Addis Ababa Light Rail Transit basing on power interruptions/ outage data.
4. Develop the model of the substation and simulate potential reliability improvement methods.
5. To propose viable mitigation measures to counter power system interruptions for the specific case of AALRT.

1.3 Scope

The aim of this research is to carry out a reliability analysis of the DC Traction Power Supply System of the Addis Ababa Light Rail Transit. It will consider failure data in terms of power interruptions and outages as recorded in the maintenance intervention database during a determined period of time. This research will focus on power system interruption right from the utility substation to the TPSS.

1.4 Methodology

The methodology used in this research is listed in the activities below;

- Literature Review: A number of journal articles, journal papers, conference papers, master's and PhD thesis reports in the field of power system reliability especially those related to traction power supply are reviewed in this research.
- Theoretical Background: To support this research, a scientific background is given on the field of reliability especially power system reliability. Power supply system reliability indices, as well as power interruption and outage standards, are presented.
- Data Collection and Analysis: Data used in this research paper is from daily reports prepared by the Operations Control Center of AALRT and is for a period of three years (2016, 2017 and 2018). This data is processed, analyzed and sorted giving important reliability aspects such as failure cause, failure mode, outage/ downtime.
- System Reliability Assessment: Reliability assessment is done through calculation of basic reliability indices, customer orientation indices, energy and cost indices. In this assessment, the causes of traction power interruptions are discussed.
- System modelling and simulation: Reliability improvement alternatives are simulated by integrating them into the existing traction power supply system. Improvement alternatives come as solutions to alleviate the causes of power supply interruptions.

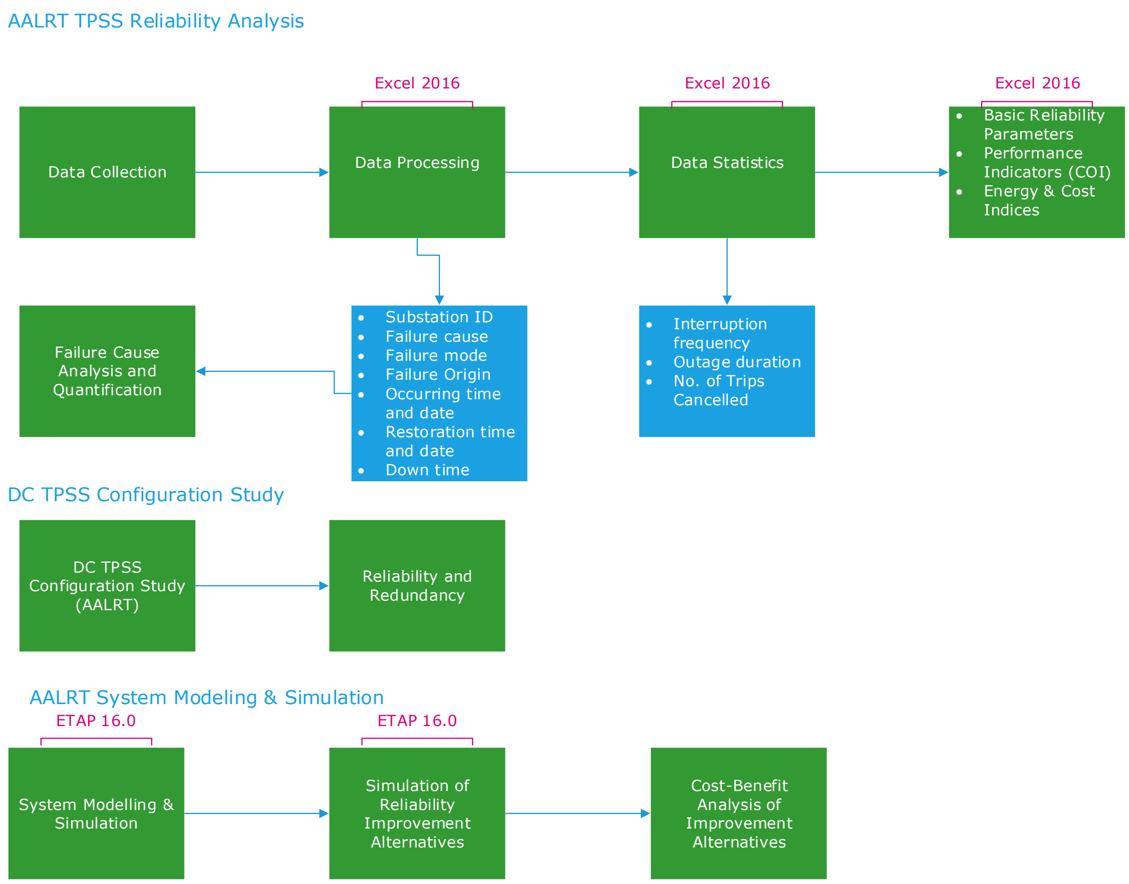


Figure 1-2: Research Methodology

1.5 Thesis Layout

This is research laid out in chapters and a brief overview is given below;

- Chapter one: Presents introduction, problem statement, main objective, specific objectives, thesis methodology and scope.
- Chapter two: Presents the review of past literature concerning the reliability of power supply systems and the reliability of the traction power supply system.
- Chapter three: Presents the reliability standards and concepts.
- Chapter four: Presents the AALRT reliability study and analysis. DC traction power supply system configurations are presented here.
- Chapter five: Presents the results and discussions of the AALRT power supply reliability.
- Chapter six: Presents AALRT system modelling and simulation of reliability improvement alternatives.
- Chapter seven: Presents the conclusion and discussion of the thesis.

Chapter 2 LITERATURE REVIEW

In this section, brief literature about the DC traction system configuration is discussed as well as the various research that has been done on the reliability of traction power supply systems.

The DC traction system consists of wayside traction power substations (TPSSs), overhead contact system (OCS), positive and negative feeder cables, tracks consisting of running rails, and the vehicle. Transformer- rectifier (TR) units convert three-phase utility voltage to the required DC voltage which may vary from 750 V to 3000 V depending upon the choice of vehicle and other system considerations. Having been rectified, this voltage is then applied to the OCS system via a positive polarity DC switchgear and negative polarity bus to power the electric vehicles. AC switchgear, TR units, DC switchgear, and the negative bus are installed inside the TPSS building. The pantograph mounted on top of the vehicle makes a sliding contact with the OCS wire to pick up DC power and deliver it to onboard propulsion equipment. The negative return current from the propulsion system is injected to the running rails, from where it comes back to the negative bus via negative feeder cables. DC TPS rating varies between 1.5 and 10 MW, and substation spacing can be up to 3 km for 750 V, 10 km for 1.5 kV and 20 km for 3 kV supply [12].

The use of inverting substations has been made feasible by the development of high power thyristor and rectifiers. Here, regenerated energy can be returned to the AC supply when there are no suitable nearby loads. In order to have such a system, a careful operating strategy including blending of regenerative and dynamic braking systems and close monitoring of the line voltage is critical [1].

Different researches have been done on power system reliability especially on the reliability of TPSS which have shown that it is impossible to separate reliability from availability or vice versa [3], [5], [13], [14]. Mean time to restore (MTTR) and mean operating time between failures (MTBF) of the various components of the TPSS must be known in order to determine the system availability or unavailability.

Different researchers acknowledge the fact that the behavior of an electric power system in terms of failure is stochastic in nature [15], [16], [17], [6], and therefore it is only logical to assess such a system using probabilistic techniques. Probabilistic techniques are becoming critical in the power systems especially the TPSS because a failure of the TPSS may lead to a delay or outage train service and this will not only have a direct impact on the entire operation schedule but will also cause tremendous losses [17] . Therefore, the reliability assessment of the traction power supply system is extremely important to ensure transportation quality and improve the economy [17].

Ghiasi et al [9] investigate an analytical methodology for reliability assessment and failure analysis techniques in a distributed power system. Through the use of outage data, reliability analysis is used in this paper to evaluate system design which was modelled and simulated in ETAP. The results of theoretical and practical reliability and failure analysis such as mean operating time between failure (MTBF), mean time to restore (MTTR), availability, system average interruption frequency index, system average interruption duration index, consumer average interruption duration index, average service availability index, average service unavailability index, expected energy not supplied, expected interruption costs, and interrupted energy assessment rate are compared with the summary of reliability assessment simulation.

Mahmood *et al* [15] analyze the reliability of frequency converters based on failures and outages reports. Two-state (in service or forced outage) and four-state (in service, reverse shutdown, forced- out needed and forced- out not needed) reliability models that recognize the operating characteristics of baseload units and peaking units are presented and compared in the study. Four-state model is modified to a three-state (in service, reverse shutdown, forced outage) model by combining the ‘needed’ and ‘not needed’ forced-out states. Transitions in the three-state model for power frequency converter were designed according to real operational data. An outage-reporting database modelled considering IEEE STD 762 is presented and compared with the existing failure-reporting database of the case considered here. Furthermore, a method to extract information missing in the failure reporting database by electrical readings is proposed to meet the requirements of the outage-reporting database. The study found that the results of indexes based on the IEEE four-state model are not reasonable for the frequency converter. The four-state reliability model for power converters was then into a three-state model by combining the ‘needed forced-out’ and the ‘not-needed forced-out’ states into a single ‘forced-outage’ state.

Liang *et al* [16] investigate the external power supply reliability in high-speed railway. The major goal of this reliability evaluation was to have traction substation power supply without interruption. The study involved use of Bayesian network to establish Bayesian networks model, write the reliability calculation program, quantitative evaluation of external power failure probability of traction power substation. It also involved bidirectional reasoning technology based on Bayesian network, identification of the weak links of high speed railway external power supply to optimize the design of high- speed railway external power supply scheme. They also used IEEE RBTS system as an example to estimate the reliability of high- speed railway external power supply scheme and quantitatively calculated the high-speed railway traction power substation of probability. In their findings, the IEEE RBTS system proved the correctness and feasibility thus can be applied to high-speed railway external power supply reliability evaluation. Furthermore, based on bidirectional reasoning technology of Bayesian network, the future probability of each element in the external power supply system can be calculated, thus identifying the weakness about the external power supply, and therefore provide the basis for carrying out external power supply reliability analysis in the future.

Feng *et al* [17] present a reliability evaluation method for the traction power supply system based on Quantification of Margins and Uncertainties (QMU). The authors argue that the traditional assessment methods such as fault tree model, numerical simulation and expert system have the following problems: they characterize system reliability simple true or false, based on performance status of each device, there is few or even no experiment for TPSS on the system level, the reliability test of traction power supply equipment (TPSE) is usually conducted once a year or several years. As a result of these problems, the authors suggest that cognitive uncertainties in the reliability assessment should be considered. In this method, the characteristics of the TPSE and system are combined to establish the observation list and then the performance channel for the equipment and system is determined. Finally, the confidence factor is calculated and the reliability of the equipment and system quantified by the quantification of the performance margin and uncertainty. To validate the effectiveness of the QMU method, simulations were conducted using practical operation data from a Chinese traction power supply system. The simulation results demonstrate that the proposed reliability assessment method can account for the uncertainty and quantify the system reliability index. Thus the authors showed that the

QMU method has good applicability and can be used to effectively evaluate the reliability of the traction power supply system.

Conradie *et al* [6] put their focus on quantifying the reliability of railway rolling stock and the application of reliability techniques to define a forward-looking and leading reliability measure. Furthermore, they used the leading reliability measure in deciding on maintenance intervals. The method was applied on data from a South African rail operator that operates an ageing rolling stock fleet and predominantly makes use of time-based maintenance. Reliability Block Diagrams (RBD) were used to model the system to show the inter-relationship of the components and the redundancy. Individual reliabilities for each component and the reliability of the traction motor sub-system were calculated. Failure distributions and the interdependency of different systems were used to determine the impact of component failures on overall system reliability, and to determine the reliability of individual train sets. It was shown that instead of using time-based maintenance, maintenance schedules can now be created based on the reliability of individual train sets. Train sets that meet the reliability target can be scheduled for maintenance less frequently than train sets that do not meet the target. Not only will the availability of train sets be higher, but the effort of the maintenance department will be focused on the less reliable train sets. This provides a different approach to maintenance management for ageing rolling stock fleets, and with the abundance of failure statistics, this method can contribute to RAMS in rolling stock.

Sagareli *et al* [8] defines traction power system reliability as "its ability to continuously supply electrical power of adequate quality during sudden disturbances such as a short circuit or loss of system elements, while operating with a normal scheme configuration, or during scheduled maintenance and repairs, without causing safety hazards, train delays or public nuisance." The authors assert that, while most of the contingency situations may be predicted and counteracted on the design stage, only the real-life experience is the ultimate test for reliability. They agree with Matsumoto [14] on the need to keep outage records during traction power system operation. These records are useful during reliability analysis.

Up until 1950s traction power systems had independent power systems i.e. they had their own power plants, transmission lines and substations[1]. Sagareli *et al* [8] agrees with Hill [1] that in recent times there have been changes such as incorporation with utility power systems at the substation level, change from rotary motor-generator type rectifier substations to mercury diodes, to solid state rectifiers, and they still continue to develop, thus their reliability, cost-effectiveness, and environmentally clean performance directly affects the overall performance of the railroads they serve.

For utility power systems, the performance criteria are well established and standardized, while on the other hand, traction power systems, being quite different, still need development of such criteria, standards and guidelines in order to reach the optimal performance by means of improved design, construction and operation practices [8]. This is in disagreement with Yuan [7] *et al* who acknowledges that TPSS standards are present but are only qualitative and thus proposes that a quantitative approach should be sought.

Reliability concerns are of utmost importance because issues like mass transit service interruptions always have strong negative effects on business and economy in the regions. In some cases, power failures may cause life-threatening situations with catastrophic consequences. Therefore, reliability standards should also be developed for TPSS [8]. In order to do so, there should be an equipment failure investigation and reporting system based on the participation of manufacturers, consultants and users of equipment, in order to assure non-partisan decisions in determining the cause of failure [8]. However, having equipment failure data alone is not enough to ensure system reliability, other issues concerning system reliability such as design schemes, operations, definitions of reliability events, contingencies, violations of reliability and so forth all this would make a good reliability standard for TPPS.

Sagareli *et al* [8] conclude that system serviceability is “absence of power supply interruptions in repair or maintenance mode,” i.e. a system that is not easily serviceable is not reliable. The question is, in which part of the system should we consider redundancy with minimal cost implication?

Hayashiya *et al* [3] investigate the reliability of DC TPSS basing on the statistical data of the DC traction power supply system in the Tokyo area of East Japan Railway Company. The aim of their study was to propose redundant DC circuit configuration through quantitative analysis and therefore come up with a relationship between the redundant configuration of traction substation circuit and the reliability of the power supply system. In his study, MTTR (mean time to restore) and MTBF (mean operating time before failure) are calculated based on the statistical data for the past 10 years. According to IEC 62278 [18], availability of the system considering a single substation was calculated. This was a product of the various availabilities in each part of the circuit i.e. the receiving circuit (99.99915%), the transformer circuit (99.99887%) and the DC feeding circuit (99.99976%). Having these values of availability at hand, the effect of redundant DC feeder circuit and the effect of redundant transformer and rectifier was evaluated. The authors found out that the difference of availabilities of total traction substation between the systems with and without redundant DC circuit breaker circuit is 0.00096% and the difference of availabilities is 0.0011% redundant transformer and rectifier. In this regard, redundancy is justified especially for the case of a redundant DC feeder circuit. An evaluation of economic impact was carried out to justify whether to deploy redundant equipment in TPSS or not. For the specific case of the traction power supply system in Tokyo metropolitan area, deployment of such redundant equipment was economically viable. In conclusion, redundancy especially on DC feeder increases system availability and thus reliability. However, an economic evaluation must be done before investing in redundancy [3].

Yuan *et al* [7] assert that reliability evaluation standard IEC 62278 is qualitative and therefore a quantitative evaluation approach must be developed because this gives the “availability” of the system in terms of actual figures. Since the availability of a system or a component is a probability, the availability (quantitative evaluation approach) of a system or component gives a true picture of how reliable that system/ component is. In their study, they argue that reliability models and indices to evaluate the static adequacy and the dynamic security of power system cannot be used on TPSS despite the fact that they can be used on a traditional power system. This is because the power system loads are independent, whereas TPSS traction substations (traction loads) are all designed to have the section-crossing power supplying ability. Thus, the Traction Power Substations (TPS) are taken as the composite loads of the bulk power system. In their study, four reliability indices for TPS and five indices for the entire high- speed railway, including the successful section-crossing supply between adjacent substations, were proposed and their analytical expressions and sensitivity to the system component reliability parameters were deduced. A heuristic load shedding approach was also discussed, where the behavior of the grid operator under emergencies is simulated. In conclusion, Yuan *et al* [7] observed that reliabilities of TPS and the entire railway are more sensitive to the generators than the transmission lines. If the reliability of the generators is improved, the reliability of the entire railway will be improved to a great extent.

Chapter 3 RELIABILITY STANDARDS AND CONCEPTS

EN 50126 [19] is the earliest international railway reliability standard and now it has been upgraded to IEC 62278 [18]. IEC 62278 is the standard for management related to RAMS and economic efficiency when developing and operating railway systems related to safety. IEC 62278 applies to a wide range of items and there is no defined specific limit, i.e. whether wayside or onboard or power system as long as the system making up a part of the railway is connected to safety in the slightest way, the standard will apply. This standard, however, has no defined way regarding the positioning or scope of systems to which it applies i.e. what is considered a “system” is decided on a case-by-case basis thus can be applied to a broad-ranging, large-scale system in its entirety or to a single device [13].

Definitions according to the IEC 62278 [18] RAMS Standard

- Reliability: Probability that an item can perform a required function under given conditions for a given time interval ($t1$, $t2$)
- Availability: Ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided.
- Maintainability: Probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources.
- Safety: Freedom from unacceptable risk of harm
- RAMS: Reliability, Availability, Maintainability and Safety.
- Reliability and maintainability program: Documented set of time scheduled activities, resources and events serving to implement the organization structure, responsibilities, procedures, activities, capabilities and resources that together ensure that an item will satisfy given reliability performance and maintainability performance requirements relevant to a given contract or project.
- Failure cause: Circumstances during design, manufacture or use which have led to a failure.
- Failure mode: Predicted or observed results of a failure cause on a stated item in relation to the operating conditions at the time of the failure.

- Failure rate: Limit, if this exists, of the ratio of the conditional probability that the instant of time, T, of a failure of a product falls within a given time interval (t, t+Δt) and the length of this interval, Δt, when Δt tends towards zero, given that the item is in an upstate at the start of the time interval.
- Dependent failure: Failure of a set of events, the probability of which cannot be expressed as the simple product of the unconditional probabilities of the individual events.
- Downtime: A time interval during which a product is in a down state.
- Repair: That part of corrective maintenance in which manual actions are performed on the item.
- Restoration: That event when the item regains the ability to perform a required function after a fault.
- Risk: Probable rate of occurrence of a hazard causing harm and the degree of severity of the harm.

Railway RAMS is a major contributor to the quality of service provided by a railway authority, thus there is a link between RAMS and Quality of Service. Details on the concept of RAMS shown in figure 4 according to the standard[18] and quality of service is seen as being most important, and that quality of service is made up of RAMS for railways and other attributes.

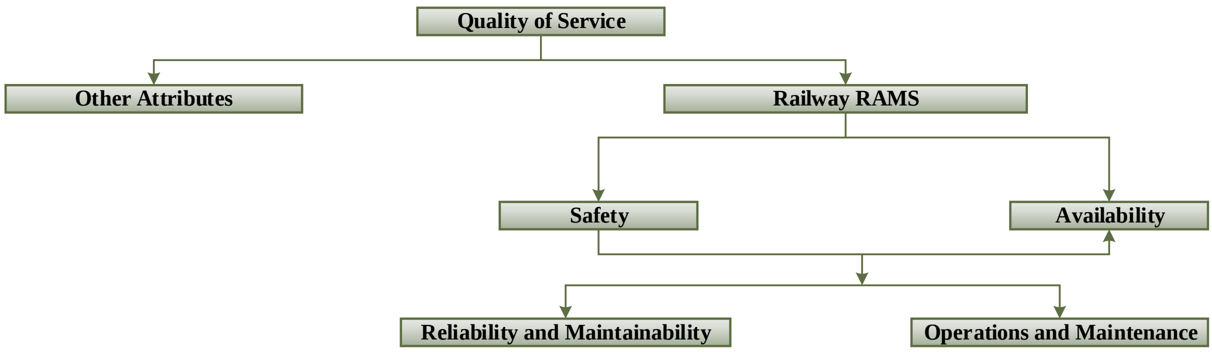


Figure 3-1: The Concept of RAMS

There are three possible ways the RAMS of a railway system is influenced, i.e. by sources of failure introduced internally within the system at any phase of the system life cycle (system conditions), by sources of failure imposed on the system during operation (operating conditions) and by sources of failure imposed on the system during maintenance activities (maintenance conditions). These sources of failure can interact [18]. This relationship is briefly shown in Fig. 3.2 below:

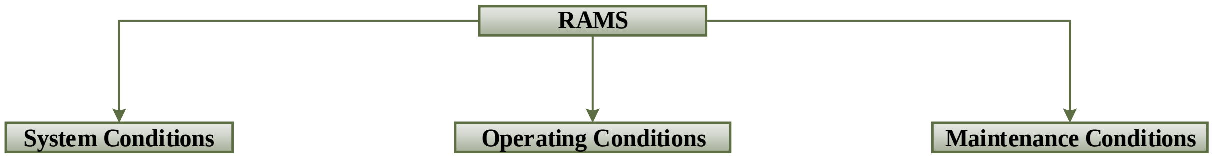


Figure 3-2: Influence on RAMS

The derivation of detailed railway specific influencing factors should include, a consideration of each of the following railway specific factors such as; system operation, environment, application conditions, operating conditions, and failure categories and should be adapted to the scope and purpose of the application. Human should also be included [18].

3.1 Power Interruption and Outage Standards

Different researchers and committees (such as IEEE) have proposed definitions on the subject of a power system outage and interruption analysis [20], [21]. This analysis cannot be done in isolation but in regards to measures of reliability as well. To discuss power outage and power interruptions, we need to define the following two general terms and regards to this subject matter;

I. Component: A component is a piece of equipment, a line, a section of the line, or a group of items which is viewed as an entity for purposes of reporting, analyzing, and predicting outages.

II. System: A system is a group of components connected together in some fashion to provide for the flow of power from one point or points to another point or points.

A. Outage Terms

I. Outage: An outage describes the state of a component when it is not available to perform its intended function due to some event directly associated with that component. An outage may or may not cause an interruption of service to consumers depending on system configuration. An outage is classified as either *a forced outage* or *a scheduled outage*. *A forced outage* results from emergency conditions directly associated with a component requiring that component be taken out of service immediately, either automatically or as soon as switching operations can be performed WHILE *A scheduled outage* is an outage that results when a component is deliberately taken out of service at a selected time, usually for purposes of construction, preventive maintenance, or repair.

II. Outage Rate: Depending on the classification of outage and type of component, the *outage rate* is defined as the mean number of outages per unit time per component.

III. Outage Duration: Outage duration is the period from the initiation of a component outage until the affected component once again becomes available to perform its intended function.

IV. Switching Time: Is the period from the time a switching operation is required due to a forced outage until that switching operation is performed. Switching operations include reclosing a circuit breaker after a trip-out, opening or closing a sectionalizing switch or circuit breaker, or replacing a fuse link.

B. Interruption Terms

I. Interruption: An interruption is the loss of service to one or more consumers or other facilities and is the result of one or more component outages, depending on system configuration. An interruption is classified by type of outage which causes the interruption. *Forced Interruption* is caused by a forced outage WHILE *Scheduled Interruption* is an interruption caused by a scheduled outage.

II. Interruption Duration: Is the period from the initiation of an interruption to consumers or other facilities until service has been restored to that consumer or facility.

C. Measures of Reliability

Measures of reliability usually relate to the frequency or duration of interruptions or both. Properties of measures of reliability include; be calculable from the operating history of a system and be calculable from component data using system reliability calculation techniques. Two indices used to describe the average service reliability provided to consumers served by a system are as follows:

I. Interruption Frequency Index: Average number of interruptions per consumer served per time unit. It is estimated from operating history by dividing the number of consumer interruptions observed in a time unit by the number of consumers served. A consumer interruption is considered to be one interruption of one consumer.

II. Interruption Duration Index: Average interruption duration for consumers interrupted during a specified time period. It is estimated from operating history by dividing the sum of all consumer interruption durations during the specified period by the number of consumer interruptions during that period.

3.2 Reliability Evaluation

Reliability concepts and analysis can be applied to virtually any engineered system. It is a measure of system performance. This measure can be used to help systems meet performance criteria, to help quantify comparisons between various options, and to help make economic decisions. The ultimate goal of reliability analysis is to help answer questions like "is the system reliable enough?" "which scheme will fail less?" and "where can the next dollar be best spent to improve the system? [22]"

Reliability evaluation is, therefore, the analysis of failures, their causes and consequences. It is the most important characteristic of product quality as things have to be working satisfactorily before considering other quality attributes [23].

Reliability Definition: Is the probability that the system will perform its intended function under specified working condition for a specified period of time [23]. Quantitatively, reliability is expressed as a mathematical function of time: $R(t)$ = Probability that the system still works correctly at time *t*. Reliability is a real number between 0 and 1; that is, at any time $0 \le R(t) \le 1$.

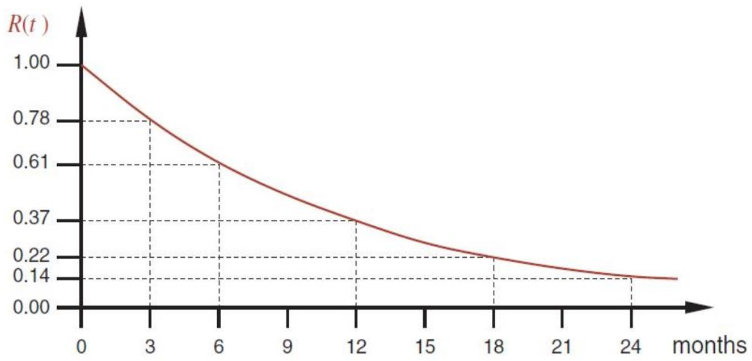


Figure 3-3: Typical Reliability function

3.2.1 Power System Reliability

Reliability in power system can be divided into two basic aspects; System adequacy and System security. Adequacy relates to the capacity of the system in relation to energy demand and security relates to the dynamic response of the system to disturbances (such as faults). Since distribution systems are seldom loaded near their limits, system adequacy is of relatively small concern and reliability emphasis in on system security [24], [25].

Reliability evaluation of power distribution systems is majorly analyzed using the following approaches;

- Simulation methods based on drawings from statistical distributions (Monte Carlo).
- Analytical methods based on the solution of mathematical models.

The Monte Carlo techniques are normally very "time" consuming due to a large number of drawings necessary in order to obtain accurate results. The fault contribution from each component is given by a statistical distribution of failure rates and outage times. The analytical approach is based on assumptions concerning the statistical distributions of failure rate and repair times. The most common evaluation techniques using a set of approximate equations are failure mode analysis or minimum cut set analysis. This method is less time consuming than the simulation methods but suffers from problems of representing repair times adequately [24], [26].

3.2.2 Indices of distribution system reliability

To ably evaluate the reliability and failure rate in power systems, there is need for sufficient data in terms of outage duration and the frequency of interruption that leads to an outage i.e. the random variable is frequency time and so the standard function that best fit is the exponential function because it has only time as the independent variables[27] [28]. According to [29] and[27], it is only a descriptive function as it has only time as the independent variable. Inevitably, one of the critical factors for this function, which can be used, is known as the failure rate(λ) [28]. According to [28] and [30], the density function is defined as follows;

$$\mathbf{f(t) = \lambda}\,. \tag{3-1}$$

The Hazard rate is then given by

$$\boldsymbol{\lambda}(\mathbf{t}) = \frac{\mathbf{f}(\mathbf{t})}{\mathbf{1} - \mathbf{f}(\mathbf{t})} = \boldsymbol{\lambda}\,. \tag{3-2}$$

Failure rate (λ) is given by

$$\boldsymbol{\lambda} = \frac{\textbf{Number of times that the failure ocured}}{\textbf{Number of unit} - \textbf{hours of operation}}\,. \tag{3-3}$$

The reliability function is then given by

$$\mathbf{R}(\mathbf{t}) = \mathbf{1} - \mathbf{f}(\mathbf{t}) = \mathbf{e}^{-\boldsymbol{\lambda}\mathbf{t}}\,. \tag{3-4}$$

Other reliability parameters are described in [27][31] and include;

Mean Time Between Failure (MTBF)

$$\textbf{MTBF} = \frac{\textbf{Total system operating hours}}{\textbf{Number of failures}}\,, \tag{3-5}$$

Mean Time to Repair (MTTR) or Mean Down Time (MDT)

$$\textbf{MTTR} = \frac{\textbf{Total duration of outages}}{\textbf{Frequency od outages}}\,,\textbf{and} \tag{3-6}$$

Availability (A)

$$\textbf{Availability} = \frac{\textbf{MTBF} - \textbf{MTTR}}{\textbf{MTBF}}\,. \tag{3-7}$$

In addition, the reliability of the DPSs is usually measured in terms of several indices as defined below [27], [31], [9], [23], [32], [33]:

a) System Average Interruption Duration Index (SAIDI): It is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information as to the average time the customers are interrupted.

$$\textbf{SAIDI} = \frac{\textbf{Sum of customer interruption}}{\textbf{Total number of customers served}} = \frac{\sum_{\mathbf{i}} \mathbf{r_i N_i}}{\mathbf{N_T}}\,, \tag{3-8}$$

where r_i is the outage time for each interruption event.

b) System Average Interruption Frequency Index (SAIF): It is the average frequency of sustained interruptions per customer over a predefined area. It is the total number of customer interruptions divided by the total number of customers served.

$$\textbf{SAIFI} = \frac{\textbf{Sum of customer interruption durations}}{\textbf{Total number of customers served}} = \frac{\sum_{\mathbf{i}} \boldsymbol{\lambda}_{\mathbf{i}} \mathbf{N_i}}{\mathbf{N_T}}\,, \tag{3-9}$$

where λi is the failure rate at load point i and Ni is the number of interrupted customers for each interruption event during the reporting period at load point i. N_T is the total number of customers served for the area.

c) Consumer Average Interruption Duration Index (CAIDI): It is the average time needed to restore service to the average customer per sustained interruption. It is the sum of customer interruption duration divided by the total number of customer interruptions.

$$\mathbf{CAIDI} = \frac{\textbf{Sum of customer interruption durations}}{\textbf{Total number of customer interruptions}} = \frac{\sum_i \mathbf{r_i N_i}}{\sum_i \boldsymbol{\lambda}_i \mathbf{N_i}} = \frac{\mathbf{SAIDI}}{\mathbf{SAIFI}}\,. \quad (3\text{-}10)$$

d) Average Service Availability Index (ASAI): This index represents the fraction of time (often in percentage) that a customer has power provided during one year or defined reporting period.

$$\mathbf{ASAI} = \frac{\textbf{Customer hours of available service}}{\textbf{Customer hours demanded}} = \frac{\sum_i \mathbf{N_i}\ \mathbf{X\ 8760} - \sum_i \mathbf{r_i N_i}}{\sum_i \mathbf{N_i}\ \ \mathbf{X\ 8760}}\,. \quad (3\text{-}11)$$

e) Average Service Unavailability Index (ASUI): This index is the complementary value to the average service availability index.

$$\mathbf{ASUI} = \frac{\textbf{Customer hours of unavailable service}}{\textbf{Total customer hours demanded}} = \frac{\sum_i \mathbf{r_i N_i}}{\sum_i \mathbf{N_i}\ \ \mathbf{X\ 8760}}. \quad (3\text{-}12)$$

Where 8760 defined in Eq.3-11 and Eq.3-12 is the number of hours in the calendar year.

f) Energy Not Supplied Index (ENS): This index represents the total energy not supplied by the system. This index is sometimes referred to as Expected Energy Not Supplied (EENS)

$$\mathbf{ENS} = \sum_{\mathbf{i}} \mathbf{L_{a\,(i)} r_i}\ , \quad (3\text{-}13)$$

where: $L_{a(i)}$ is the average load given by:

$$L_{a(i)} = L_{P(i)} L_{F(i)} = \frac{E_{d(i)}}{t}\,,$$

where L_P is the peak load demand, L_F is the load factor and E_d is the total energy demanded in the period of interest t.

g) Average Energy Not Supplied (AENS): This index represents the average energy not supplied by the system.

$$\mathbf{AENS} = \frac{\mathbf{Total\ energy\ not\ supplied}}{\mathbf{Total\ number\ of\ customers\ served}} = \frac{\sum_{\mathbf{i}} \mathbf{L_{a(i)} r_i}}{\mathbf{N_T}} . \quad (3\text{-}14)$$

h) Average Customer Curtailment Index (ACCI): This index represents the total energy not supplied per affected customer by the system.

$$\mathbf{ACCI} = \frac{\mathbf{Total\ energy\ not\ supplied}}{\mathbf{Total\ number\ of\ customers\ affected}} = \frac{\sum_{\mathbf{i}} \mathbf{L_{a(i)} r_i}}{\sum_{\mathbf{i}} \mathbf{N_o}} , \quad (3\text{-}15)$$

where $L_{a(i)}$ is the average load and N_o is the number of customers affected.

i) Average Load Interruption Frequency Index (ALIFI): This factor is analogous to the System Average Interruption Frequency Index (SAIFI) and describes the interruptions on the of connected load (kVA) served during the year by the distribution system.

$$\mathbf{ALIFI} = \frac{\mathbf{Total\ load\ interruption}}{\mathbf{Total\ connected\ load}} = \sum_{\mathbf{i=1}}^{\mathbf{m}} \frac{\mathbf{L_i}}{\mathbf{L}} , \quad (3\text{-}16)$$

where m is the number of interruptions in a subdivision of the network (feeder, substation, operating district, etc.) for a given time period, L is the total connected load (kVA) in a subdivision and L_i is the total connected load (kVA) the interrupted by i^{th} interruption.

3.2.3 Economics of Reliability for Power Distribution System

Outage costs are generally divided into two i.e. utility outage costs and customer outage costs [23].

- Utility outage costs: These include; loss of revenue for energy not supplied, and increased maintenance and repair costs to restore power to the customers affected. The maintenance and repair costs can be quantified as;

$$C_{m\,\&\,r} = \sum_{i}^{n} C_i + C_{comp} ,$$

where C_i is the labour cost for each repair and maintenance action, and C_{comp} is the component replacement cost.

The total utility cost for an outage is

$$C_{out} = (ENS)X\left(\frac{cost}{kWh}\right) + C_{m\,\&\,r} ,$$

where ENS is the Energy Not Supplied.

- Customer outage costs: While the outage costs to the utility can be significant, often the costs to the customer are far greater. These costs vary greatly by customer type. In general, customer outage costs are more difficult to quantify, can be quantified by sector:

$$\mathbf{COST_i} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{IC_i \; x \; L_i} \; , \qquad (3\text{-}17)$$

where: L_i is the energy demand for load point i. IC is the interruption cost for the sector.

The index of interrupted energy assessment rate at load point i, ($IEAR_i$) in (ETB/kWh) is defined as:

$$\mathrm{IEAR_i} = \frac{\mathrm{ECOST_i}}{\mathrm{EENS_i}} \; . \qquad (3\text{-}18)$$

Chapter 4 AALRT RELIABITY STUDY AND ANAYLSIS

4.1 General Information About AALRT

Addis Ababa Light Rail Transit (AALRT) has two lines i.e. from Ayat to Torhailoch (EW line) and from Kality to Menelik II square (NS line). The total length is 31.05 km. It has a common section from Stadium to St. Kidest Lideta stations which stretches 2.662 km and covers five passenger stations. There are two depots for maintenance purposes at Kality (10 hectares) and Ayat (7.2 hectares). There are 39 passenger stations out of which nine are elevated, two are semi-underground and one underground. Escalators and lifts were constructed at some of the stations for the persons in need. Currently, there are forty-one trains available for the operation and they are marked with different colors so that passengers can identify them easily. Trains with green and white color provide service from East- West and trains with blue and white color run from North to South direction. The trains get electricity generated from hydropower and it makes service environmentally friendly. There are thirty-nine ticket offices available near to the passenger stations. This kind of service is the first of its kind in the Sub- Sharan countries.

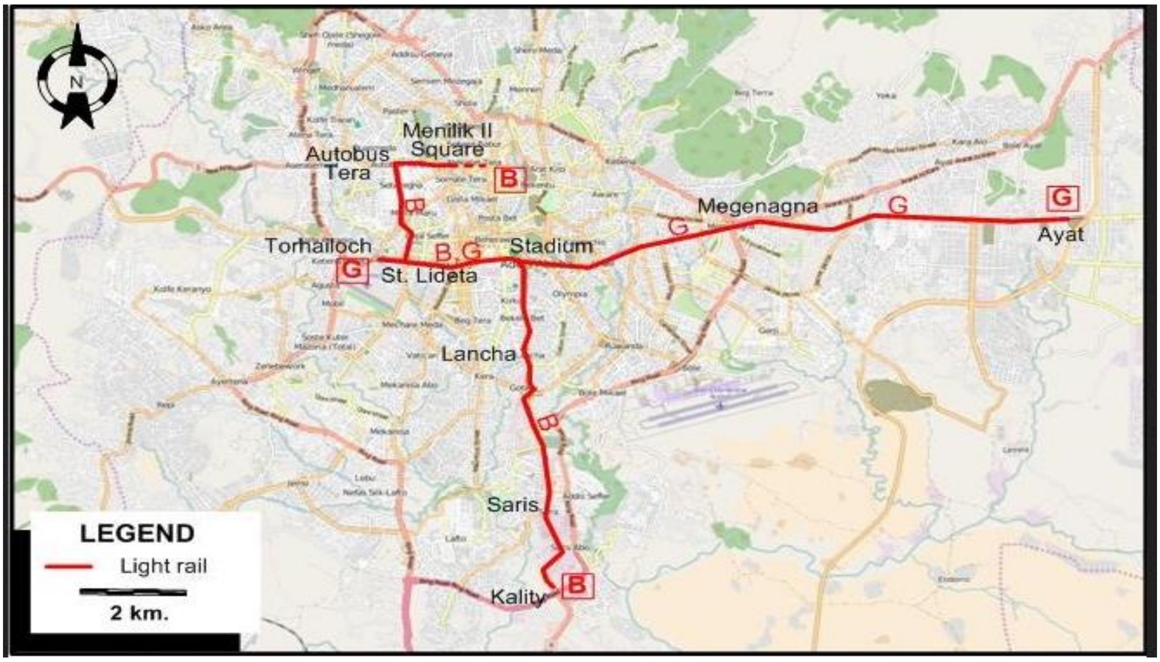


Figure 4-1: Map Addis Ababa Light Transit.

Source: [34]

The AALRT power system is supplied by Ethiopia Electricity Utility Company from four gas insulated substations with two step down transformers (132/15 kV 500 MVA) each. The East-West line is supplied from EW22 and AYAT electric power substations and these two support each other i.e. one substation can support the entire load in case one is out. Similarly, the North and South is supplied from Line NS27 and Kality electric power substations and these two support each other. These four electric power substations supply nineteen traction power step down hybrid substations and one step down substation (EW 18) for purposes of supplying communication and signaling equipment. There is a traction step-down substation at an interval of 3 to 4 passenger stations on the light rail. Traction step-down hybrid substation features a mixed step-down function i.e. voltage level step-down for traction, signaling and communication, and auxiliary use. Each traction step-down hybrid substation is fitted with a rectifier transformer (three-winding dry-type, 15 kV / 590 V) and another transformer (15 kV / 400 V) fed by the same section of the bus. The 590 VAC at the secondary of the rectifier transformer is converted to 750V DC by means of a 12- pulse diode rectifier and this is what energizes the catenary. The other step down transformer energizes the communication and signaling equipment as well as the lighting system in and around the substation. It also supports depot offices at Kality and Ayat.

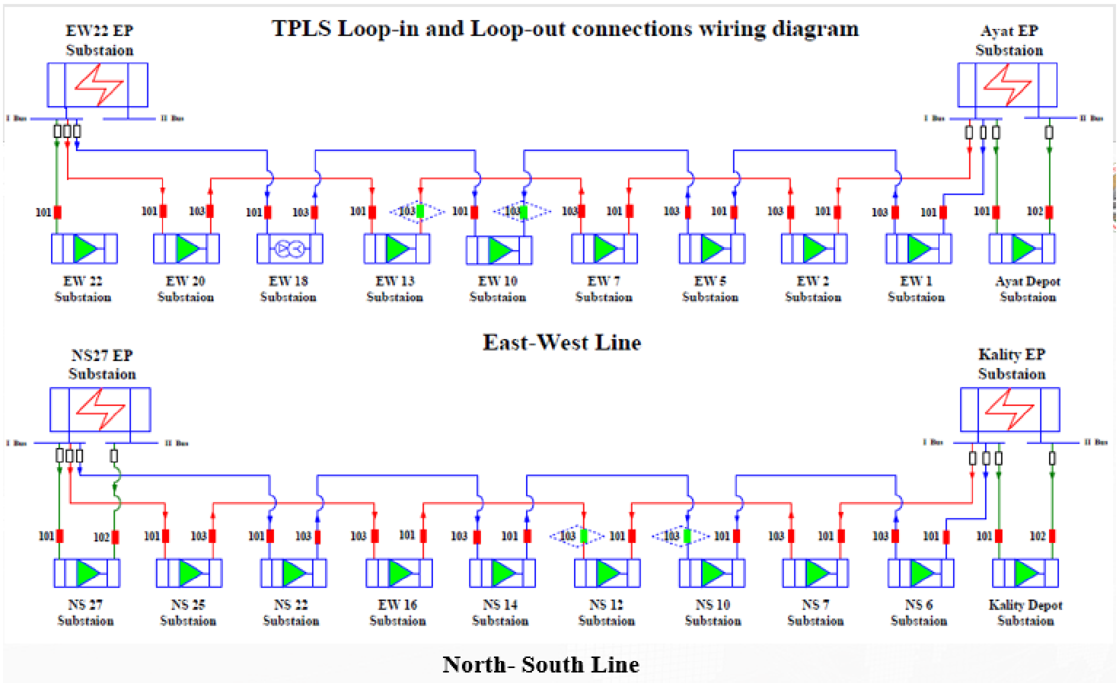


Figure 4-2: AALRT Traction Power Substations Layout

Traction substations are no different from other distribution power substations only that during the design, the priority is to have increased reliability (such that faults to individual elements do not affect others) and increased operational flexibility (i.e. no scheduled/ forced outage is required on associated element for maintenance of switchgear) [35]. In this section, DC TPSS configuration is presented with a background on substation design i.e. types of electric substations, electric substations configurations, substation equipment categories, as well as substation auxiliaries.

Types of Electric Substations

There are four major types of electric substations and these include [36];

- Switchyard at a generating station: These facilities connect the generators to the utility grid and also provide off-site power to the plant.
- Switching Substation: Facilitates the transfer of bulk power within the network. Their feeders typically originate from generating switchyards. They enable the transmission of large amounts of energy from the generators to the load centers.
- Distribution Substation: Provides the distribution circuits that directly supply most electric power customers.
- Customer Substation: Functions as the main source of electric power supply for one (or more) business customers. The technical requirements and the business case for this type of facility highly depend on the customer’s requirements.

It is important to point out that substation projects trigger load growth, improve system stability, system reliability and system capacity. However, substation design poses the following challenges to the designer; optimal technical performance at least cost, design considerations, low life-cycle cost, safety standardization (equipment and station configurations) [36].

There are four standard substation configurations and therefore most substations are designed/ built according to one of the four *bus configurations.* The aluminum cable or pipe typically used to make power connections among individual substation equipment is, therefore, simply a *conductor.* The collection of equipment used to connect one or two transmission lines (depending on the bus configuration) into a substation is called a *position.* The main conductors that serve to connect positions together are called a *bus.* It is the configuration of the bus that gives a configuration its name [37].

4.1.1 **Power Substation Configurations**

Substation configuration is largely determined by a number of factors and these revolve around the priority of the circuit i.e. in terms of reliability and availability. Substation configurations **(**typical single line diagram**)** are discussed below [36];

1. Single Bus Configuration

All elements (transformers and transmission lines) are directly connected to one bus.

Advantages

- Relatively low construction.

Disadvantages

- Reliability is low.
- Low operational flexibility (e.g. outage required on the associated element for the maintenance of switchgear).

Single bus configuration is suitable where load and availability requirements are low.

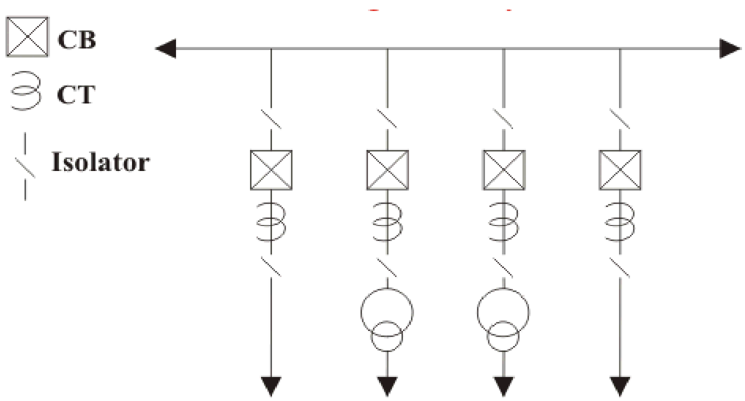


Figure 4-3: Layout of Single Bus Substation Configuration

Source: [38]

2. Main and Transfer Bus Configuration

In this configuration, one more bus is added. The elements (transformers and transmission lines) are arranged and circuits are connected between main and transfer bus. In this arrangement, one more circuit breaker may be used, known as tie circuit breaker (bus coupler) and no circuit is associated with this tie breaker.

Advantages

- Cost of construction is relatively low.

- Operational flexibility is higher than the single bus scheme due to transfer bus and tie breaker (Outage is not required on the associated element for the maintenance of switchgear).

Disadvantages

- Reliability is low

The main and transfer bus is suitable where load & availability requirements are low.

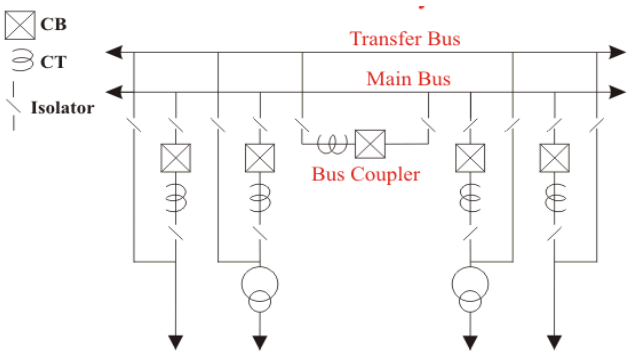


Figure 4-4: Main and Transfer Bus Substation Configuration

Source: [38]

3. Double Bus Single Breaker Configuration

This configuration has two buses. Each circuit has one breaker and connected to both buses by isolators. There is one tie breaker between two buses. The tie breaker is normally closed. For the tie breaker in a closed position, the circuit can be connected to either of the buses by closing the corresponding switch. It is clear that fault on one bus requires isolation of the bus and the circuits are fed from the other bus.

Advantages

- Cost of construction is relatively low.
- Reliability higher than Main & Transfer bus scheme (Bus fault limited to the affected bus due to availability of tie breaker)

Disadvantages

- Low operational flexibility (e.g. Outage required on the associated element for the maintenance of switchgear).

The double bus single breaker is suitable where: load transfer & improved operating reliability are important.

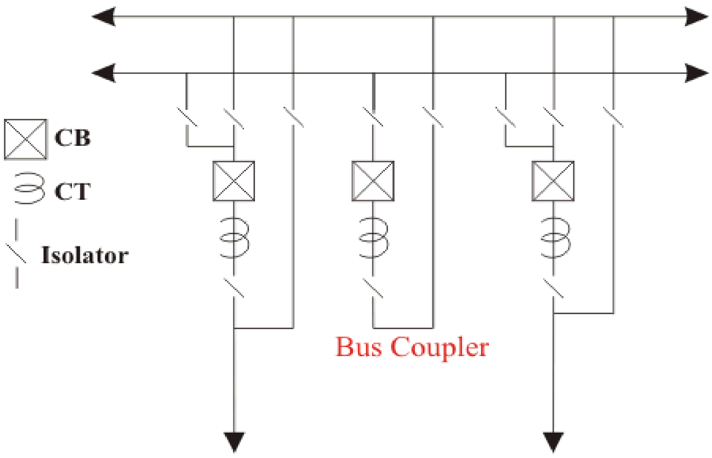


Figure 4-5: Double Bus Single Breaker Substation configuration

Source: [38]

4. Double Bus Double Breaker Configuration

In this configuration, two buses and two circuit breakers per circuit are used. In normal state both the buses are energized. Any circuit breaker can be removed for maintenance without interruption of the corresponding circuit. Also, the failure of one of the two buses does not interrupt any circuit as all the circuits can be fed from the remaining bus while isolating the failed bus. By shifting circuit from one bus to other the loading on the buses can be balanced.

Advantages

- Increased reliability (Bus fault does not affect any element)
- Increased Operational Flexibility (e.g. no outage required for maintenance of circuit breakers)

Disadvantages

- Cost of construction is relatively high
- The double bus, double breaker configuration is suitable where reliability and availability of the circuit is a high priority.

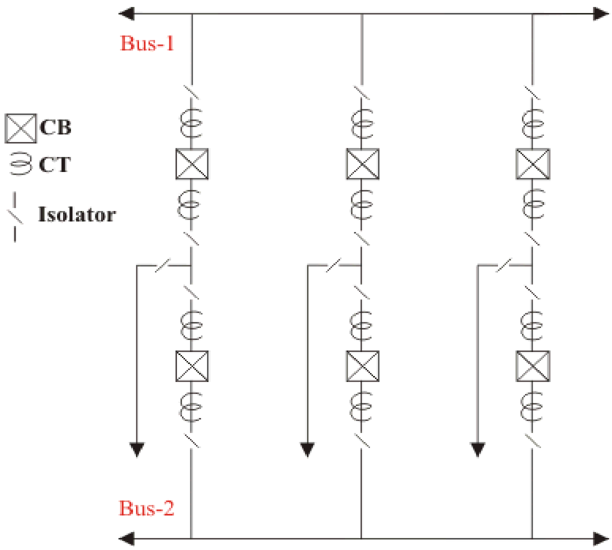


Figure 4-6: Double Bus Double Breaker Substation configuration

Source: [38]

5. Ring Bus Configuration

The breakers are connected to form a ring. There are isolators on both sides of each breaker. Circuits terminate between the breakers. The number of breakers is the same as the numbers of circuits. Each of the circuits in the ring bus system is fed from both sides. Any of the breakers can be opened and isolated for maintenance without interrupting any of the circuits. A fault on any of the circuit is isolated by tripping of two breakers on both sides of the circuit. By tripping the two breakers only the faulted circuit is isolated and all other circuits continue to operate in open ring state. This scheme has good operational flexibility and high reliability.

Advantages

- Increased reliability (Bus fault limited to affected section & faults to individual elements do not affect others)
- Increased Operational Flexibility (e.g. no outage required on the associated element for the maintenance of switchgear)

Disadvantages

- Cost of construction is relatively high

The ring bus configuration is suitable where reliability and availability of the circuit is a high priority.

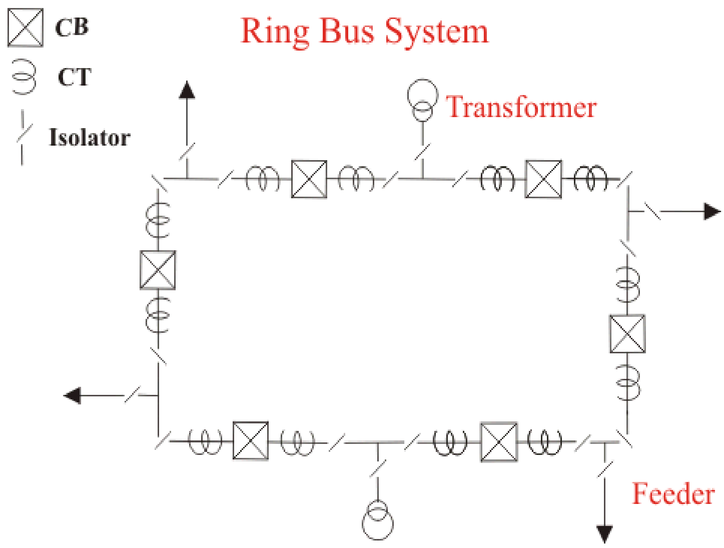


Figure 4-7: Ring Bus Substation Configuration

Source: [38]

6. Breaker and a Half Bus Configuration

The Breaker and Half scheme has two main buses. Both the buses are normally energised. Three breakers are connected between the buses. The circuits are terminated between the breakers. In this bus configuration for two circuits three breakers are required, hence the name "one- and- half scheme." To control one circuit one full and a half breaker is required. The middle breaker is shared by both the circuits. Like the ring bus scheme, each circuit is fed from both buses.

Advantages

- Increased reliability (Bus fault does not affect any element)
- Increased Operational Flexibility (e.g. no outage required for maintenance of circuit breakers)

Disadvantages

- Cost of construction is relatively high.

The breaker and a half bus configuration is suitable where: reliability and availability of the circuit is a high priority.

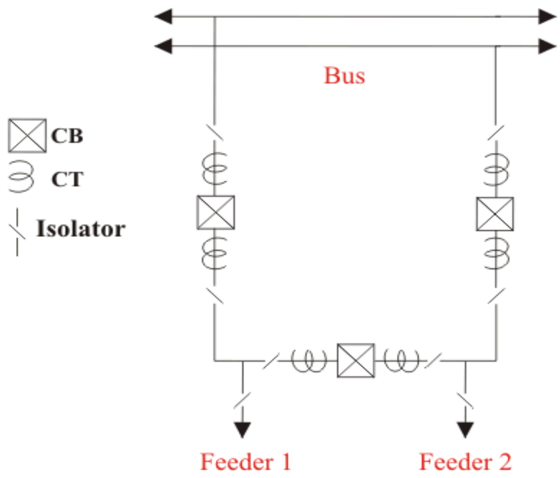


Figure 4-8: Breaker and Half Substation Configuration

Source: [38]

While there are many minor variations, the four bus configurations are; breaker-and-a-half, double-bus double-breaker, double-bus-single-breaker, and ring bus.

The bus in each of these configurations serves to connect the transmission lines together from a node in the system. It is also important to note that, in all configurations, there is a disconnect switch (isolator) on each side of each circuit breaker. In this way, the circuit breaker can be isolated for performing maintenance. In the ring bus, any circuit breaker can be damaged and taken out of service without affecting the operation of the system. If two adjacent circuit breakers are taken out of service, the line between them will be isolated from the substation. If nonadjacent circuit breakers of the bus are taken out of service, the original node formed by the ring bus will be divided into two nodes and change the configuration of the network [37]. The bus and breaker configuration has a direct impact on the reliability of the system.

Substation Equipment

Substation equipment can be categorised as Switchgear, Power Transformers, Capacitor Banks & Static Var Compensators (SVC), Instrument Transformers, Protection & Control Equipment, Auxiliaries, and SCADA & Communication [36].

4.1.2 Configuration of DC Traction Power Substations

DC Traction substations connect the AC high voltage network and the DC traction network. A DC traction substation is composed of a transformer and a rectifier.

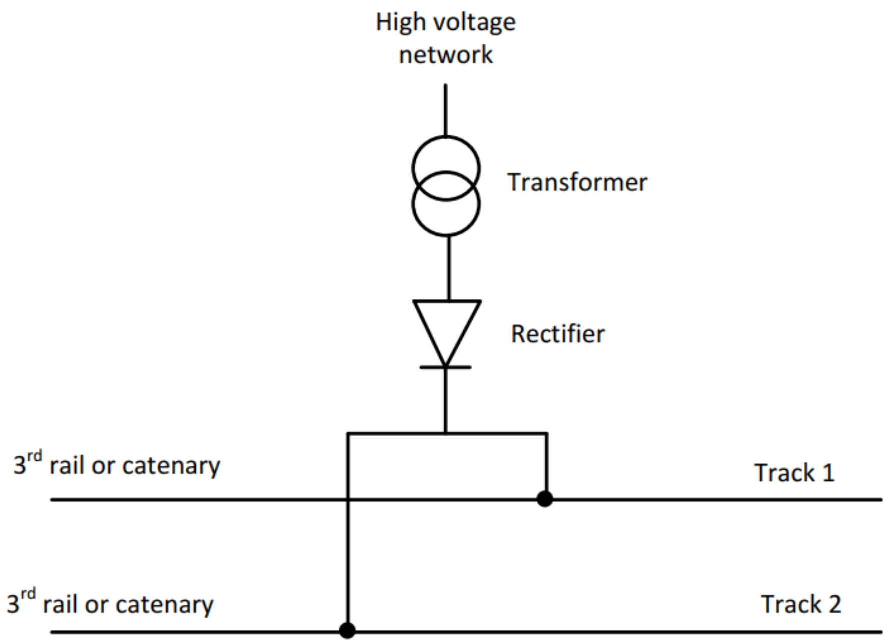


Figure 4-9:Traction substation: Diode rectifier substation

Source: [39]

In DC electrified railways, traction substation powers are usually in the range of 1.5 MW to 5.5 MW [39].

4.1.2.1 Diode Rectification Traction Substation Over View

Under this section, the composition and equipment of a diode rectification substation are discussed.

1) Outside a Diode Rectification Substation

The input part of the diode traction substation is a *high voltage switchgear unit* that can be of a classic vault or up-to-date box version. The spatial separation of the input part and supplies of the power utility company from the substation is the common place. The high voltage switchgear unit supplies *traction transformers* modified for traction operation and with usable outputs ranging from 400 kVA, 630 kVA, 800kVA, 1100kVA, 1650 kVA, 2000 kVA and 2500 kVA. The transformer technology can be dry, vacuum impregnated or with resin-filled winding. The input voltage can be up to 35 kV, the output voltage corresponds with DC rating of the substation (660 V and 825 V) [40].

Figure 4-10: Traction transformer 1100 kVA, 22/0.65 kV in the vault of trolley bus substation

2) Substation Unit

The substation unit consists of three basic switchgears on the DC side. The first of them is positive DC switchgear including boxes of *traction converters, outlet feeders, or longitudinal coupling.* The longitudinal coupling box can be used advantageously when a new substation shall be built and put into operation in two phases or when an old substation shall be restored during the operation. The second basic switchgear is a negative DC switchgear including boxes of *negative cables* and supplemented by a *longitudinal coupling* if required. If required, this switchgear can be also supplemented by *supply boxes* for purposes of cable connection of the negative switchgear with traction converters. Through an installed disconnector, these boxes enable to disconnect traction converter outputs from the negative cable boxes. Recently, with telescopic converter technology, converters are groundless. To ensure functions of the above two DC switchgears, the substation is equipped with its own consumption switchgear including one or two boxes with its own consumption transformers, its own consumption AC distribution box and its own consumption DC distribution box with accumulators and chargers [40].

3) Traction Converters (660 and 825 VDC)

Traction converters (diode rectification) are either in six pulse or twelve pulse connection. The converter output voltage (substation voltage) is usually 10% higher than the traction network value (600 or 750VDC). There are two versions of converters and these include; *The non-telescopic converter version and Telescopic converter version* [40].

The non-telescopic converters can be in box or frame with cables connected from above or from below. These converters are three-phase bridge connected. Depending on rectifier current, the converter has one-to-three parallel elements equipped with a quick safety. The diodes are cooled by coolers designed especially for non-telescopic traction converters. The standard equipment includes overvoltage protection that compensates magnetizing current of the traction transformer, two-stage diode temperature signaling and overvoltage protection [40].

Figure 4-11: Non telescopic converter

Telescopic converter version consists of six (6-pulse converter) or twelve (12-pulse converter) of high-parameter elements, cooled by heat pipes with natural cooling. The diode Monobloc is equipped with sensors for two-stage contact temperature signaling. The cooling air is sucked from the front of the trolley. The box height is used for necessary air thermos circulation. The converter can also be equipped also with a continuous temperature measurement system with an isolation converter. The easily accessible trolley also includes a reactive energy compensation circuit of a traction transformer and limitation of commutation and turning off over-voltages. Auxiliary circuits of the converter are placed in the instrument panel behind the upper box door. There is a control automatic panel placed on the door that is connected to the commutation line of the converter technology [40].

Figure 4-12: Telescopic converter 12p 1500A / 825 V

Table 4.1: Converter current carrying capacity

Version of Converter	**Telescopic Converter**				**Non-telescopic Converter**	
Current Carrying Capacity	800A	1500A	2250A	3000A	1500A	2250A

4) Outlet Feeders

Cable outputs pass through the box bottom. The main component of the charger box (which enables easy access to the individual parts of the unit and overview of the running operations) is a rapid circuit breaker with the nominal current 2600 A or 3600 A. The rapid circuit breaker is placed on the telescopic part – trolley that is mechanically and electronically interchangeable with trolleys of other chargers of the substation. The auxiliary circuits of the rapid circuit breaker, including the control automatic unit, are placed on the frame of the trolley under the rapid circuit breaker. The power distribution is placed in the box rear. There is a motor controlled (can also be manual) disconnector in the middle part to connect to the auxiliary bus bar and there are four manual controlled cable disconnectors with current measurement in the bottom part that can be controlled either from the box front after taking out the trolley without any access to the box rear, or from the box rear after opening the lower door. The auxiliary circuits of the chargers offer voltage-free control of the motor disconnector of the auxiliary bus bar or of the charger in case of a failure of the control automatic unit. To detect the status of the supplied section (if there is a short circuit or not) before turning on the rapid circuit breaker, the line resistance measurement current is used [40].

4.1.3 Circuit Configuration of AALRT Traction Power Substations

A typical DC circuit configuration for railway substation has two receiving circuit breakers. The major components of DC substation are; ac circuit breaker (CB), disconnector (DS), traction transformer (SRTr), diode rectifier (SR) and dc circuit breaker (HSCB) as shown in figure 11. In this section, the discussion is limited to how DC Traction Power Substations can be configured in terms of redundancy. The effect of redundancy (i.e. the effect of redundancy in the DC circuit and effect of redundancy in rectifier and transformer circuit) on reliability will be discussed.

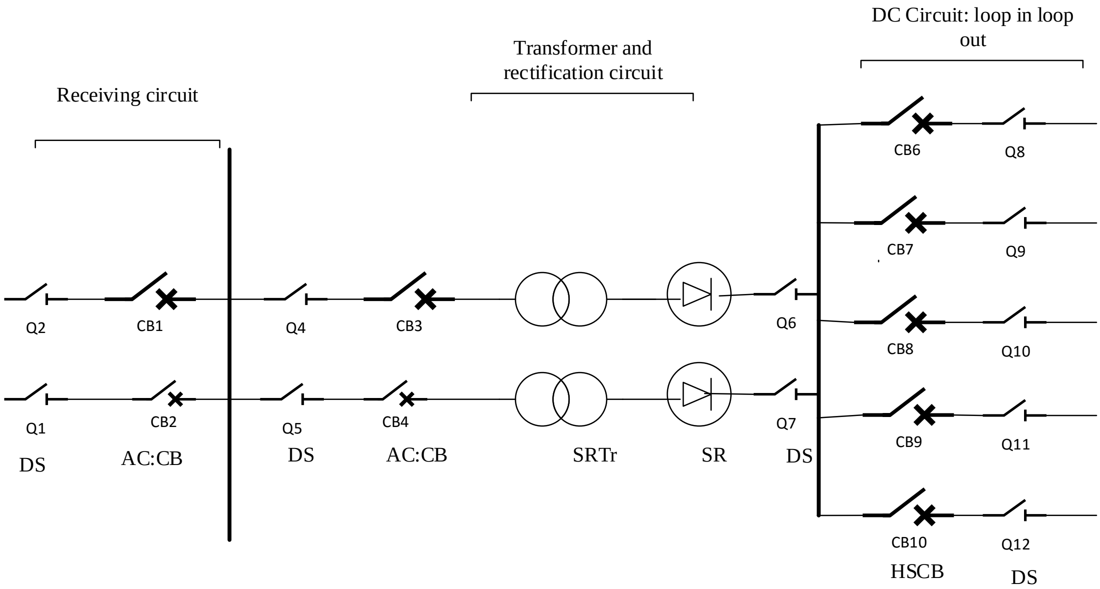


Figure 4-13: Typical circuit configuration of DC railway substation

The AALRT has two receiving circuit breakers, with two traction transformers (SRTr) and a single diode rectifier as shown below

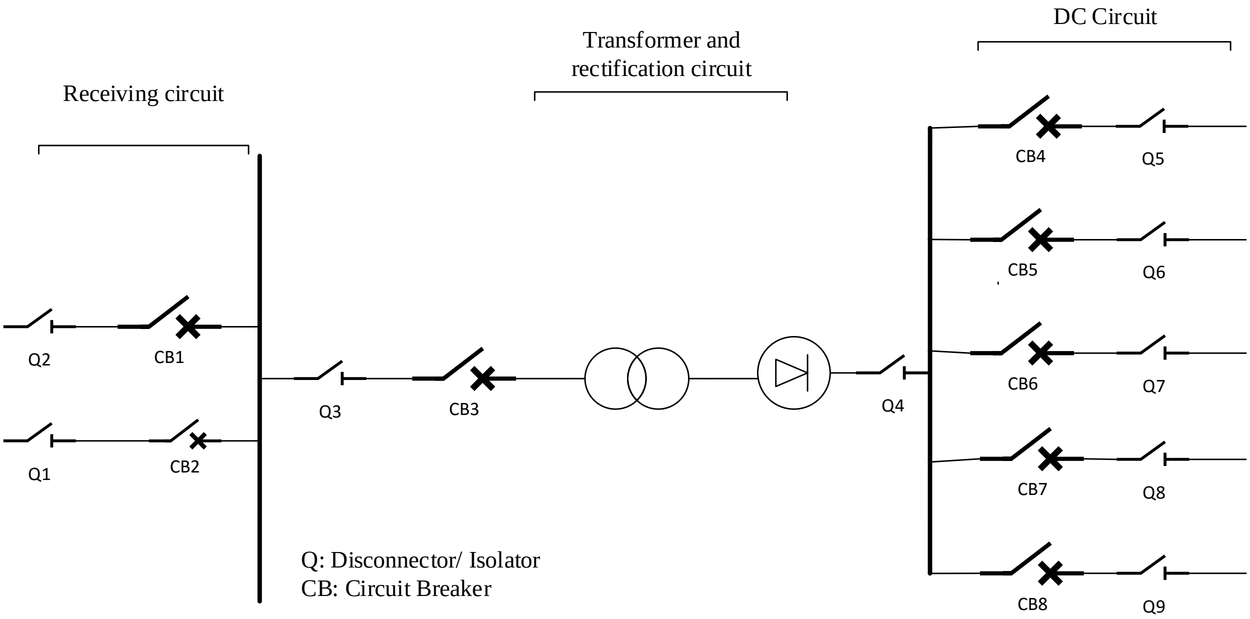


Figure 4-14: Typical Circuit Configuration of the AALRT

4.1.3.1 Redundant Circuit Configurations/ Schemes

The effect of a redundant DC circuit configuration and effect of a redundant in rectifier and transformer circuit on reliability are discussed below:

1. Redundant DC circuit Configuration

The redundant DC circuit configuration can be visualized as in figure 13 below;

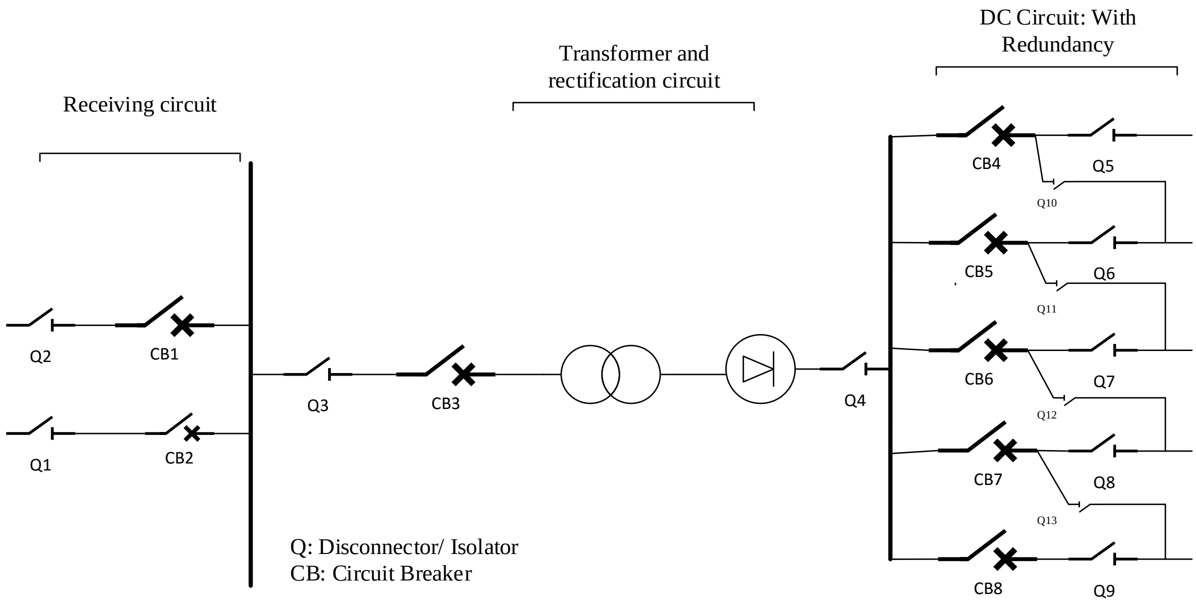


Figure 4-15: Redundant dc circuit

Hayashirya et al [3] studied the reliability analysis DC traction power supply system for electric railway in Tokyo, Japan. The study was based on the major components that make up the DC traction power supply system. These components include; ac circuit breaker (CB), disconnector (DS), traction transformer (SRTr), diode rectifier (SR) and dc circuit breaker (HSCB). The reliabilities of these components were calculated and using Reliability Block Diagrams(RBD's) the reliability of the receiving circuit, transformer circuit and DC supply circuit were calculated. The difference of availabilities of total traction substation between the systems with and without redundant dc circuit breaker circuit was 0.00096% and it corresponds to 2.5-hour operation stop during 30 years[3].

2. Redundant Rectifier and Transformer

The redundant DC circuit configuration can be visualized as in figure 11 below;

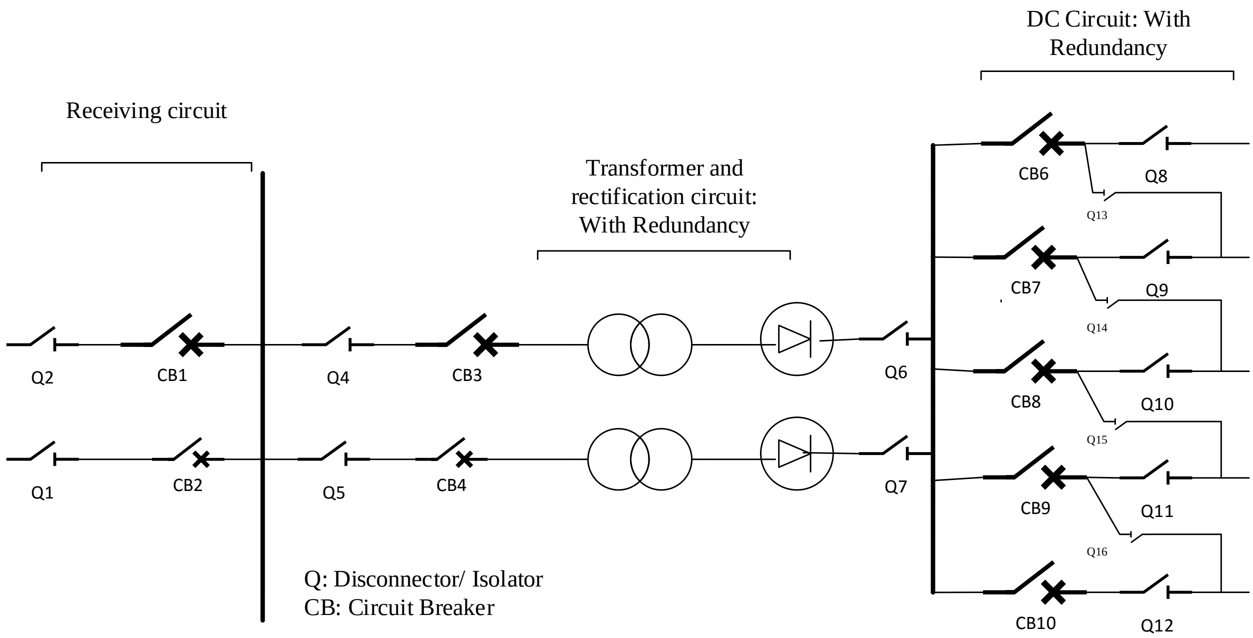


Figure 4-16: Redundant Rectifier and Transformer

Similarly, as seen above using Reliability Block Diagrams(RBD’s) the reliability of the receiving circuit, transformer circuit and DC supply circuit were calculated. The difference of availabilities of total traction substation between the systems with (99.99999997%) and without (99.99886596%) redundant transformer and rectifier was 0.0011% and it corresponds to 3.0 hour stop during 30 years [3].

4.2 Causes of Power Interruptions at AALRT

From the collected data, the major causes of power interruption on the AALRT are; cable failures on certain sections of the line on both East-West and North-South line, internal system faults, and interruption from the Ethiopia Electricity Utility Company (utility side power interruption). The pie charts below give the contribution of each of these causes;

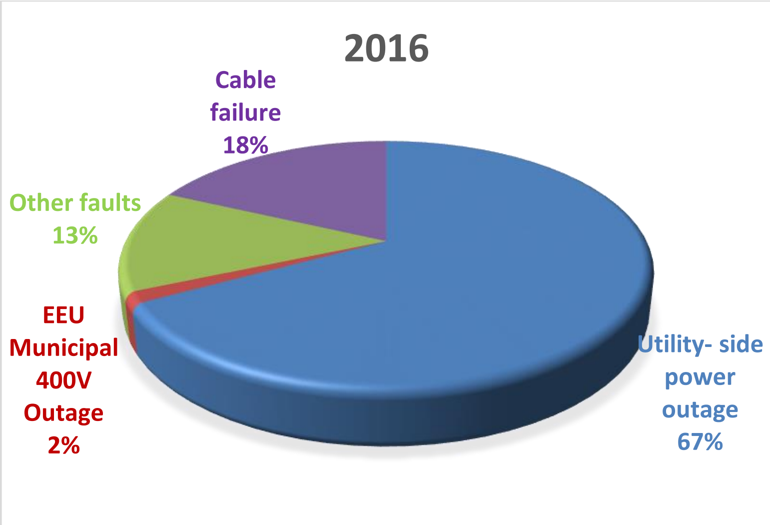


Figure 4-17: Pie chart showing the contribution of each cause of power interruption in the year 2016

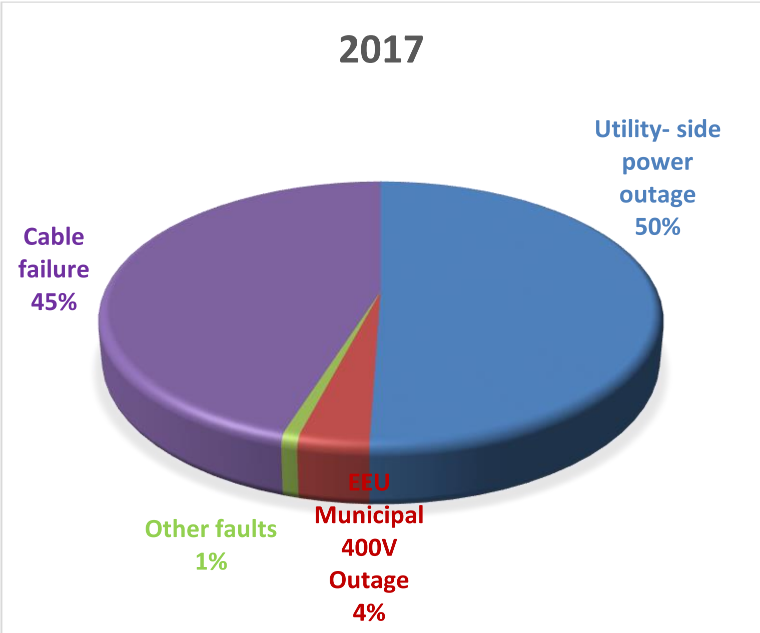


Figure 4-18: Pie chart showing the contribution of each cause of power interruption in the year 2017

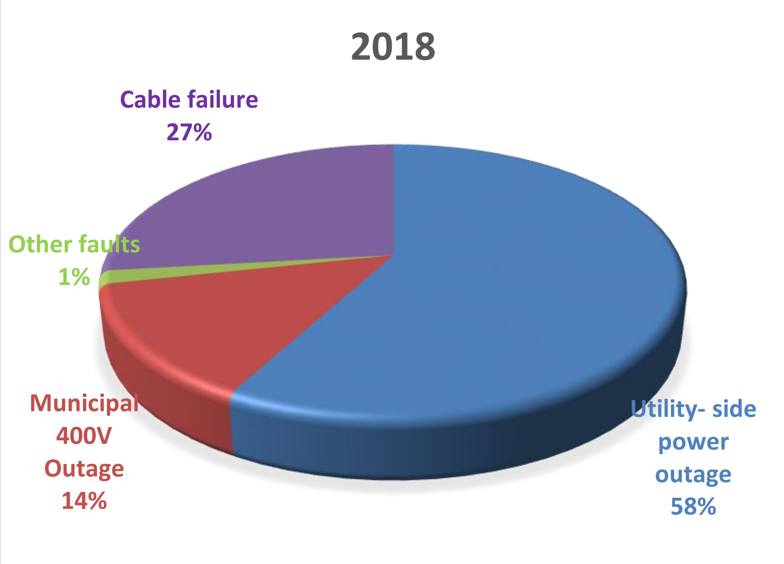


Figure 4-19: Pie chart showing the contribution of each cause of power interruption in the year 2018

From Fig. 4.17, 4.18 and 4.19, it is visible that interruption from the Ethiopia Electricity Utility Company is the main contributors of power outages at the AALRT averagely contributing 58.3% in this period of study (2016, 2017 and 2018). Cable failure comes second with about with an average of 30% for this period of study. Municipal power outage comes third with an average of 6.67% for this period of study. Other faults (internal to AALRT) come fourth with an average of 5% for this period of study. The power interruption cause at the AALRT are further discussed below;

I. Cable Failure

It was observed on the SCADA that cable failure is major because of overload and overvoltage, however, there is need for further investigation as there is no scientific proof for this problem. The failure of underground cables due to overload conditions is easily prevented by proper cable sizing. When cable sizing is combined with SCADA system, we can easily track the amount of time a cable is exposed to overload or overvoltage, however, the case of cable failure at AALRT is majorly poor cable quality at certain sections. This was revealed by the engineers in charge of the power section at AALRT thus making it hard to estimate the remaining life of the cables. Almost all substation power cables have experienced cable failure as per the data recorded in the daily reports. Currently, the section from EW2 to EW7 is the most affected section due to cable failure.

II. Utility-Side Power Interruption

As discussed above, this is the major contributor to power interruptions at the AALRT averagely contributing 58.3% for this three- year study period. The AALRT is supplied from four 15-kV Gas Insulated Substations (GISs) which directly receive power from the national grid. These substations, owned by the Ethiopian Electric Power Company, are located at Kality in the South, Ayat in the East, Menelik Square in the North, Torhailoch in the West and Egziabher-Ab Church. Kality area also serves as the main depot of the railway network. The substations supply a total power of 160 MW to the electrified AALRT. The substations supply power to the rail network through air insulated Switching Substations owned by the Ethiopian Railways Corporation. This research, however, does not quantify how much of the 58.3% of the interruption from the utility company is scheduled and that unscheduled. Since this is an establishment that has been in operation for about six years, the interruptions from the utility company side could be majorly from system faults and relay coordination as this is still a problem on either side of the power system network.

III. EEU Municipal- Side Power Interruption

To enhance system operation especially when there is a 15-kV outage, the AALRT through its traction substations EW7, EW 20, EW 16 and NS10 receives 'civic' or municipal power at 400V. This is used for communication equipment, signaling equipment and auxiliary supply during an outage. The scope of this research does not investigate the causes of municipal power interruptions. In fact, the Ethiopian Electric Power Company (EEU) is responsible for this supply as well.

IV. Other Faults

The AALRT has encountered other internal system faults such as circuit breaker failure, relay coordination problems, OCS faults, often malfunctioning of switches such as isolators, voltage spikes, and lighting. Some internal system faults are as a result of recklessness from the side of the public, for example, a truck moving with its trunk up cut the catenary on January 5, 2017.

4.3 Reliability Analysis of AALRT TPSS

Reliability analysis with regard to distribution systems involves gathering outage data as a result of power interruption and evaluating system designs. A customer or substation connected to any load point of such a system requires all components between himself and the supply point to be operating. The outage data collected from AALRT, OCC department comprise of information on each failure event within the period of three years (January to December 2016 to 2018). The information recorded in daily reports was translated into a statistical database as shown in the appendix A. The outage causes were classified as external and internal. The total hours of outages and the number of interruptions (frequency) per month were computed from the statistical database. Hence, using this data on interruption rates and repair/ restoration times of the TPSS (distribution system), reliability parameters were calculated. Reliability parameters (MTBF, MDT, and Availability), Customer Orientation Indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) and Energy and Cost Indices (EENS, AENS, ECOST and IEAR) using equations 3-1 to 3-18.

A low value of MDT (MTTR) indicates good maintainability. SAIFI indicates how often an average customer is subjected to sustained interruption over a predefined time interval whereas SAIDI indicates the total duration of interruption an average customer is subjected for a predefined time interval. CAIDI indicates the average time required to restore the service. ASAI specifies the fraction of the time that a customer has received power during the predefined interval of time and vice versa for ASUI.

Chapter 5 RESULTS AND DISCUSSION

In this chapter, the results of the calculated Basic Reliability Parameters (MTBF, MDT, and Availability), Customer Orientation Indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) and Energy and Cost Indices (EENS, AENS, ECOST and IEAR) are discussed. The results of the modelled and simulated system are also discussed.

5.1.1 Results and Discussion of the AALRT TPSS Reliability Analysis

The results are shown in Tables 5.1 to 5.9 and analyzed graphically in Figure 5.1 to Figure 5.45

Table 5.1: Computed Basic Reliability parameters January to December 2016

Year	Month	Frequency	Outage Duration [hr]	Hours of Operation [hr]	Failure rate [event/hr]	MTBF [hr]	MTTR [hr]	Availability [p.u]
2016	January	7	81.3667	744	0.0094	106.2857	11.6238	0.8906
	February	3	31.7000	696	0.0043	232.0000	10.5667	0.9545
	March	7	33.8667	744	0.0094	106.2857	4.8381	0.9545
	April	5	13.0500	720	0.0069	144.0000	2.6100	0.9819
	May	8	139.7500	744	0.0108	93.0000	17.4688	0.8122
	June	4	21.8500	720	0.0056	180.0000	5.4625	0.9697
	July	5	56.0333	744	0.0067	148.8000	11.2067	0.9247
	August	10	51.0167	744	0.0134	74.4000	5.1017	0.9314
	September	10	147.2833	720	0.0139	72.0000	14.7283	0.7954
	October	10	40.8167	744	0.0134	74.4000	4.0817	0.9451
	November	4	102.3000	720	0.0056	180.0000	25.5750	0.8579
	December	14	228.4167	744	0.0188	53.1429	16.3155	0.6930
	Total	**87**	**947.4500**	**8784**	**0.0099**	**100.9655**	**10.8902**	**0.8921**

Table 5.1 above shows the computed reliability parameters in the year 2016 and also shows the number of interruptions as well as the monthly outage hours in the year 2016. As shown in the in Table 5.1, there is a relationship between; failure rate, hours of operation and frequency of interruptions; MTBF hours of operation and frequency of interruptions; MTTR, frequency of interruptions and outage duration; availability, MTTR and MTBF. From this information, the monthly trend of these reliability parameters based on their relationship is discussed and interpreted in the graphs below;

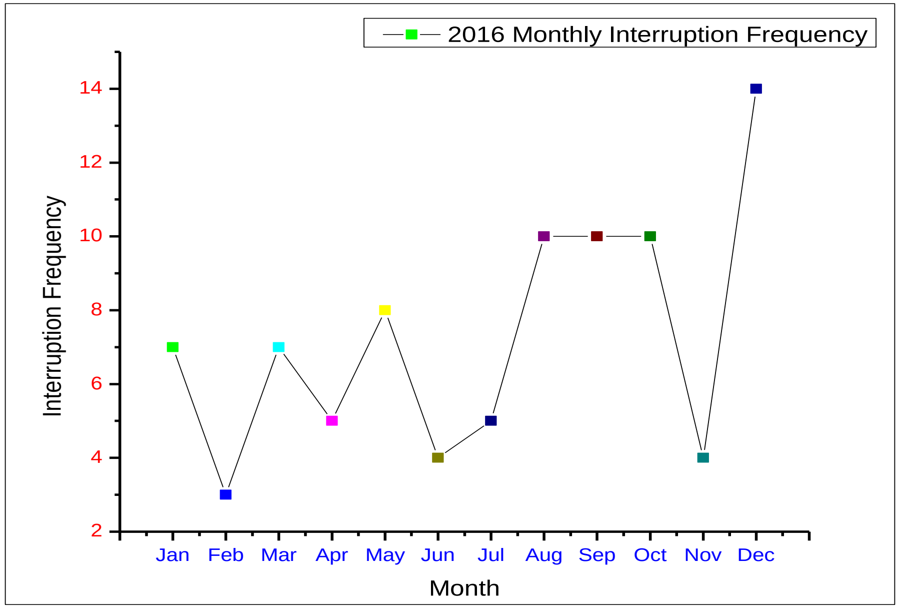


Figure 5-1: Line graph of monthly interruption frequency experienced on AALRT in the year 2016

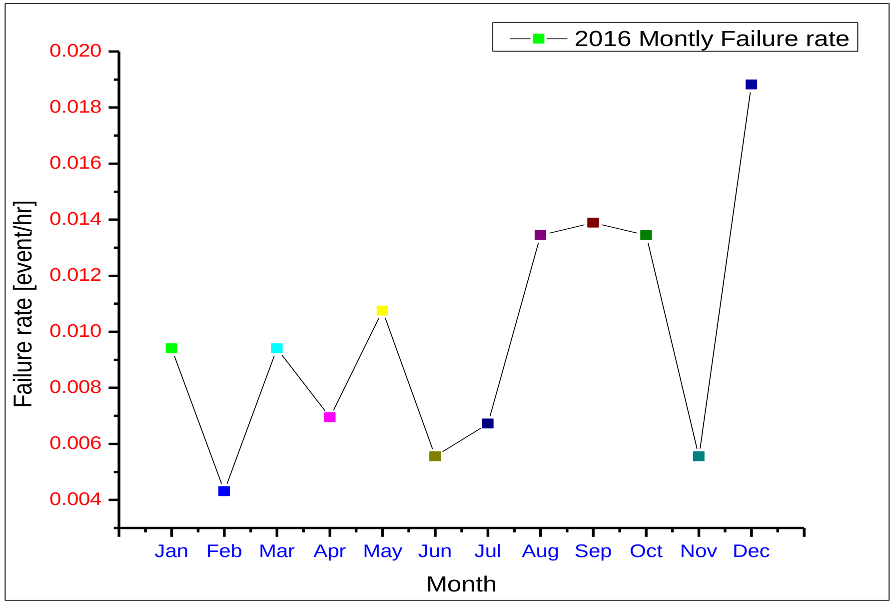


Figure 5-2: Line graph of monthly failure rate in the year 2016

From Fig. 5.1 and Fig. 5.2 above, it is visible that there is a direct relationship between the interruption frequency and the failure rate, given the fact that hours of operation are constant in a month. The month of December registered the highest number of interruption and thus had the highest failure rate. The months of August, September and October show a constant failure rate because these months registered these same number of interruptions in the year 2016.

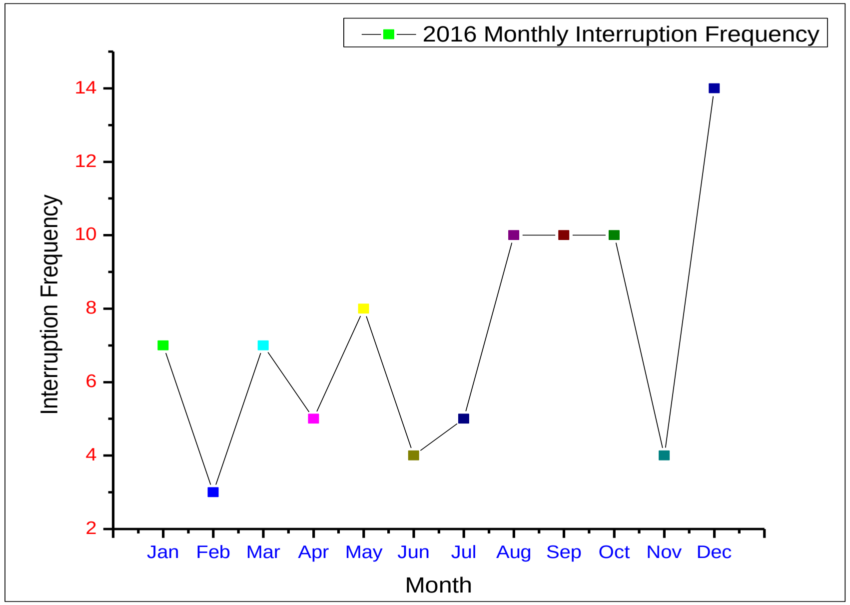


Figure 5.1: Line graph of monthly interruption frequency experienced on AALRT in the year 2016

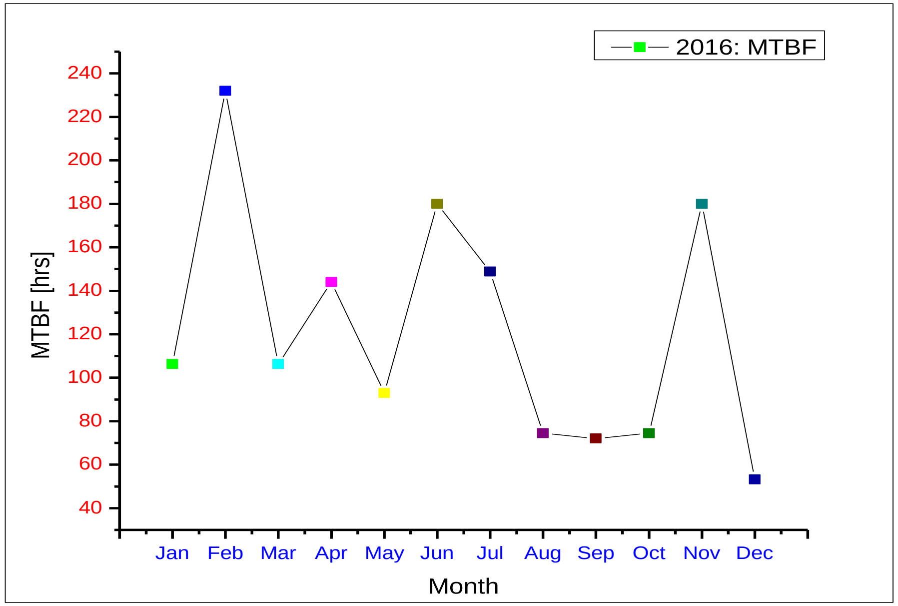


Figure 5-3: Line graph of monthly MTBF on AALRT in the year 2016

From Fig. 5.1 and Fig. 5.3, it is visible that the MTBF is inversely proportional to the interruption frequency. This means that the lower the interruption frequency the higher the MTBF (this is desirable) as shown in the month February and the higher the interruption frequency the lower the MTBF (this is undesirable) as shown in the month of December.

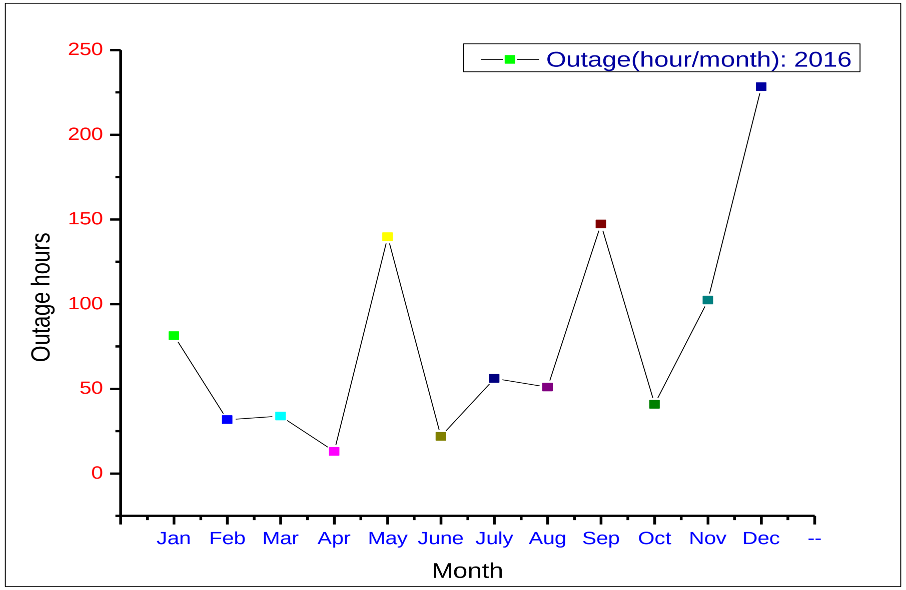


Figure 5-4: Line graph of monthly outage duration experienced on AALRT in the year 2016

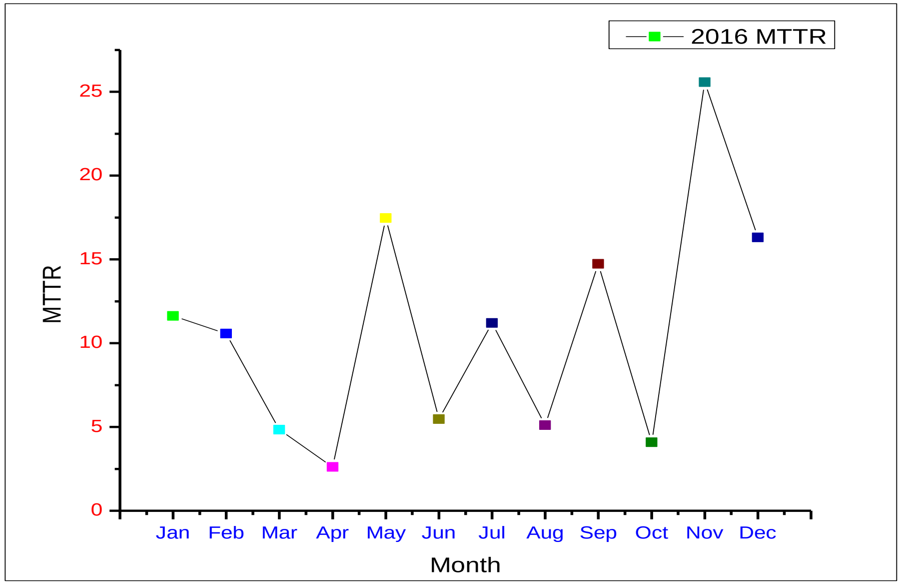


Figure 5-5: Line graph of monthly MTTR in the year 2016

From Fig. 5.4 and Fig. 5.5, outage duration is somewhat proportional to MTTR/ MDT but not exactly proportional because the interruption frequency is different for each month and is indirectly proportional to MTTR. Low MDT means good maintainability and this takes two inputs i.e. outage duration in hours and frequency of interruptions.

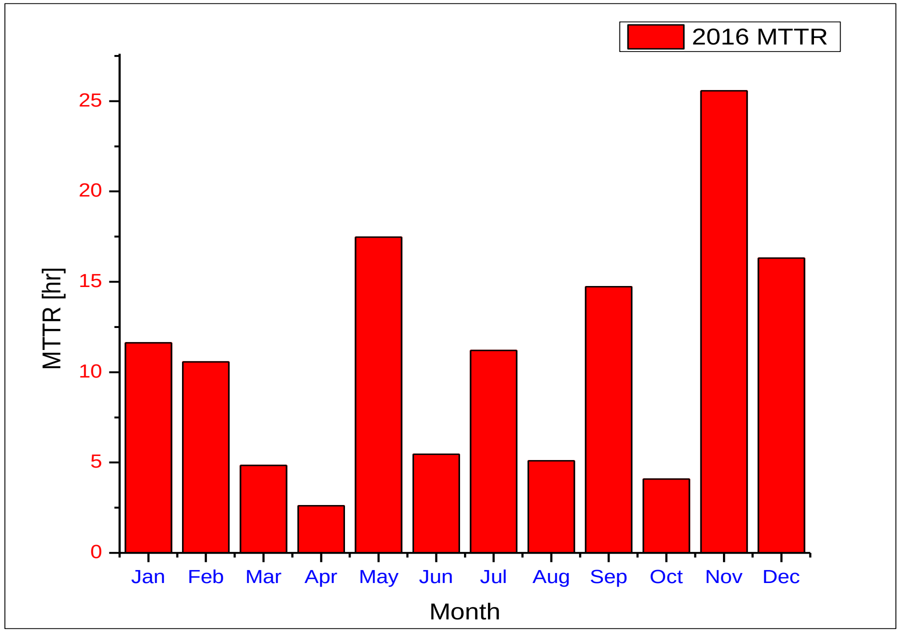


Figure 5-6: Bar graph of monthly MTTR (hours) exhibited on AALRT in the year 2016

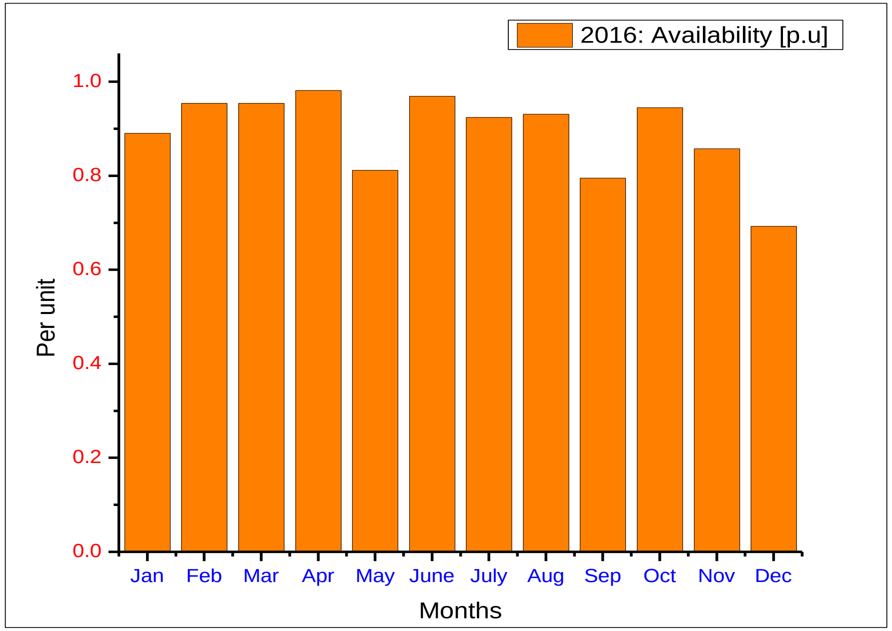


Figure 5-7: Bar graph of monthly availability in the year 2016

From Fig. 5.6 and Fig. 5.7, it is evident that low values of MTTR not only mean good maintainability but also indicate a high probability of availability as shown in the month of April and October, and higher values of MTTR indicate low availability as shown in the month of November.

Table 5.2: Computed Basic Reliability indices January to December 2017

Year	Month	Frequency	Outage Duration [hr]	Hours of Operation [hr]	Failure rate [event/hr]	MTBF [hr]	MTTR [hr]	Availability [p.u]
2017	January	8	17.9833	744	0.0108	93.0000	2.2479	0.9758
	February	7	75.9667	672	0.0104	96.0000	10.8524	0.8870
	March	10	94.6333	744	0.0134	74.4000	9.4633	0.8728
	April	12	39.7333	720	0.0167	60.0000	3.3111	0.9448
	May	9	72.8167	744	0.0121	82.6667	8.0907	0.9021
	June	13	95.4500	720	0.0181	55.3846	7.3423	0.8674
	July	12	65.5833	744	0.0161	62.0000	5.4653	0.9119
	August	16	122.7167	744	0.0215	46.5000	7.6698	0.8351
	September	13	318.3833	720	0.0181	55.3846	24.4910	0.5578
	October	21	116.7000	744	0.0282	35.4286	5.5571	0.8431
	November	7	79.4000	720	0.0097	102.8571	11.3429	0.8897
	December	9	40.0833	744	0.0121	82.6667	4.4537	0.9461
	Total	**137**	**1139.4500**	**8760**	**0.0156**	**63.9416**	**8.3172**	**0.8699**

Table 5.2 shows the computed reliability parameters in the year 2017 and also shows the number of interruptions as well as the monthly outage hours in the year 2017. As shown in the in Table 5.2, there is a relationship between; failure rate, hours of operation and frequency of interruptions; MTBF hours of operation and frequency of interruptions; MTTR, frequency of interruptions and outage duration; availability, MTTR and MTBF. From this information, the monthly trend of these reliability parameters based on their relationship is discussed and interpreted in the graphs below;

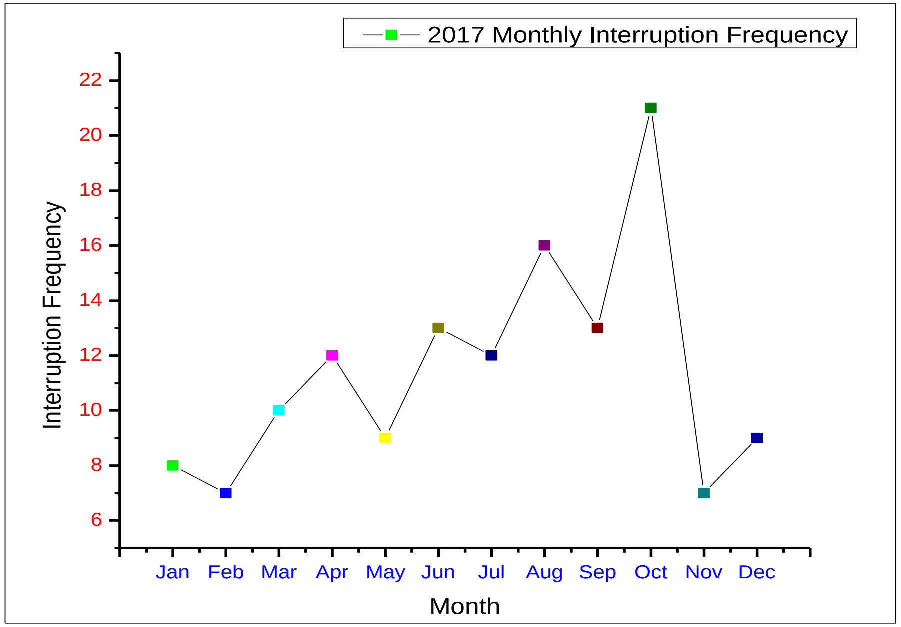


Figure 5-8: Line graph of monthly interruption frequency experienced on AALRT in the year 2017

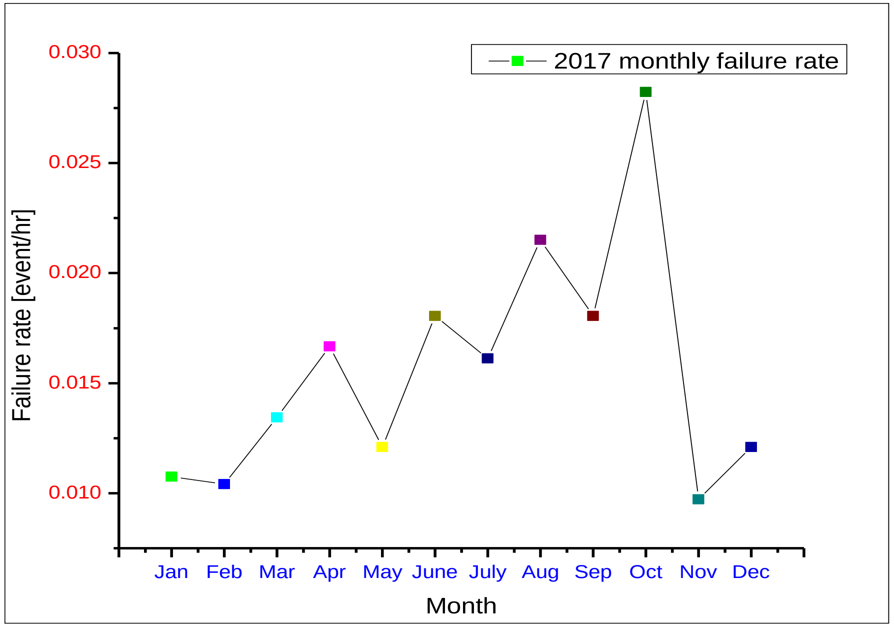


Figure 5-9: Line graph of monthly failure rate in the Year 2017

From Fig. 5.8 And Fig. 5.9, it is visible that a direct relationship between the interruption frequency and the failure rate, given the fact that hours of operation are constant in a month. The month of October registered the highest number of interruption and thus had the highest failure rate

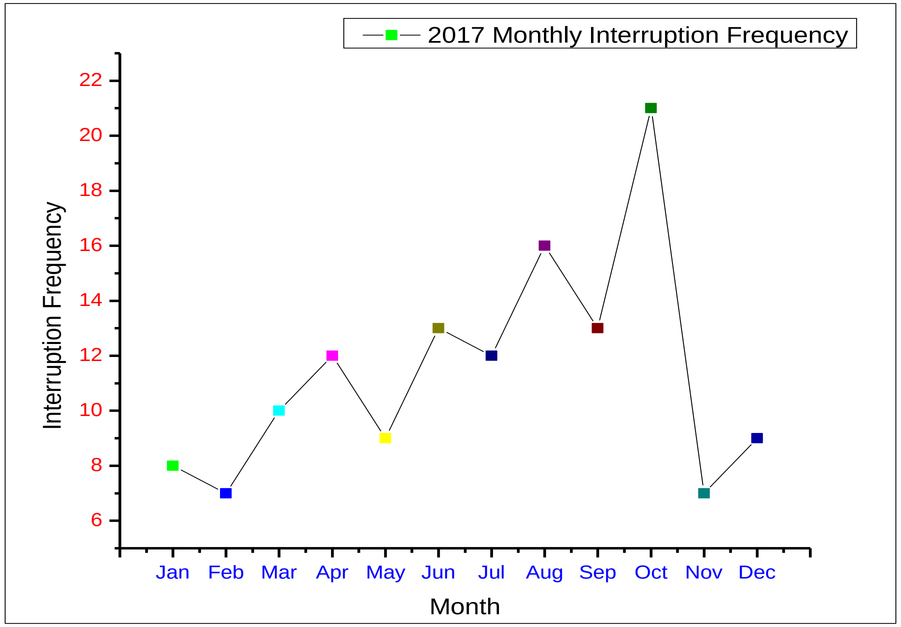


Figure 5.8: Line graph of monthly interruption frequency experienced on AALRT in the year 2017

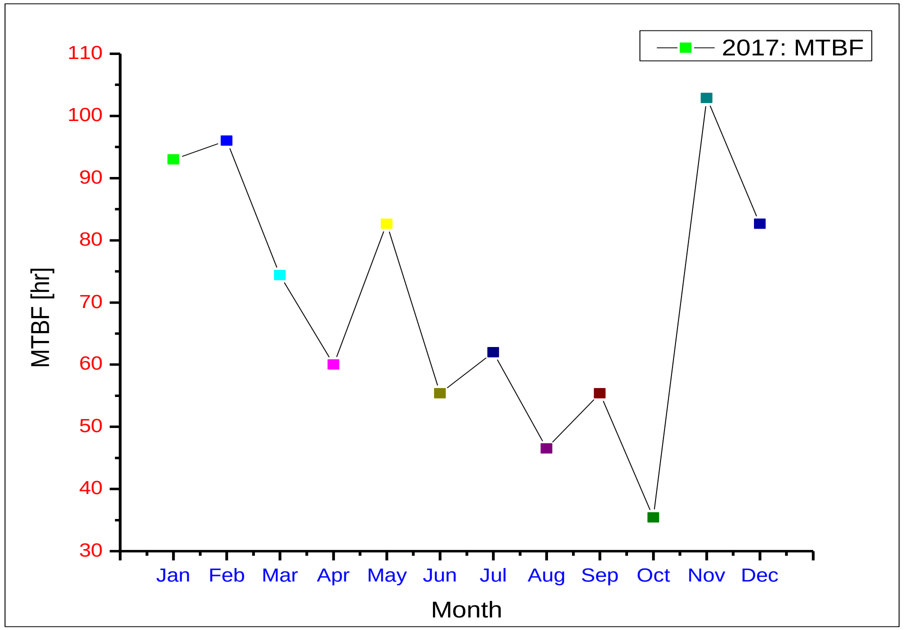


Figure 5-10: Line graph of monthly MTBF on AALRT in the year 2018

From Fig. 5.8 And Fig. 5.10, it is visible that the MTBF is inversely proportional to the interruption frequency. This means that the lower the interruption frequency the higher the MTBF (this is desirable) as shown in the month January and the higher the interruption frequency the lower the MTBF (this is un desirable) as shown in the month of October.

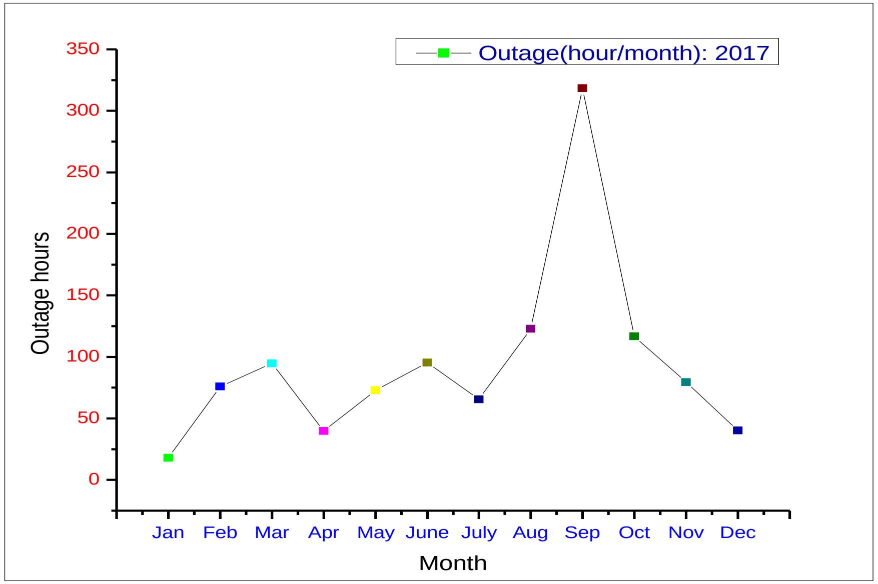


Figure 5-11: Line graph of monthly outage duration experienced on AALRT in the year 2017

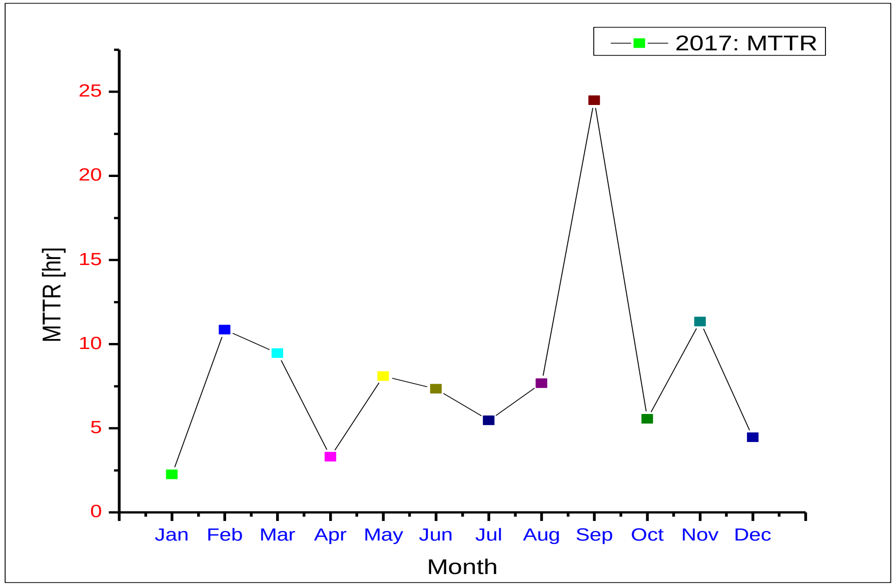


Figure 5-12: Line graph of monthly MTTR (hours) exhibited on AALRT in the year 2017

From Fig. 5.11 And Fig. 5.12, outage duration is somewhat proportional to MTTR/ MDT but not exactly proportional because the interruption frequency is different for each month and is indirectly proportional to MTTR. Low MDT means good maintainability and this takes two inputs i.e. outage duration in hours and frequency of interruptions.

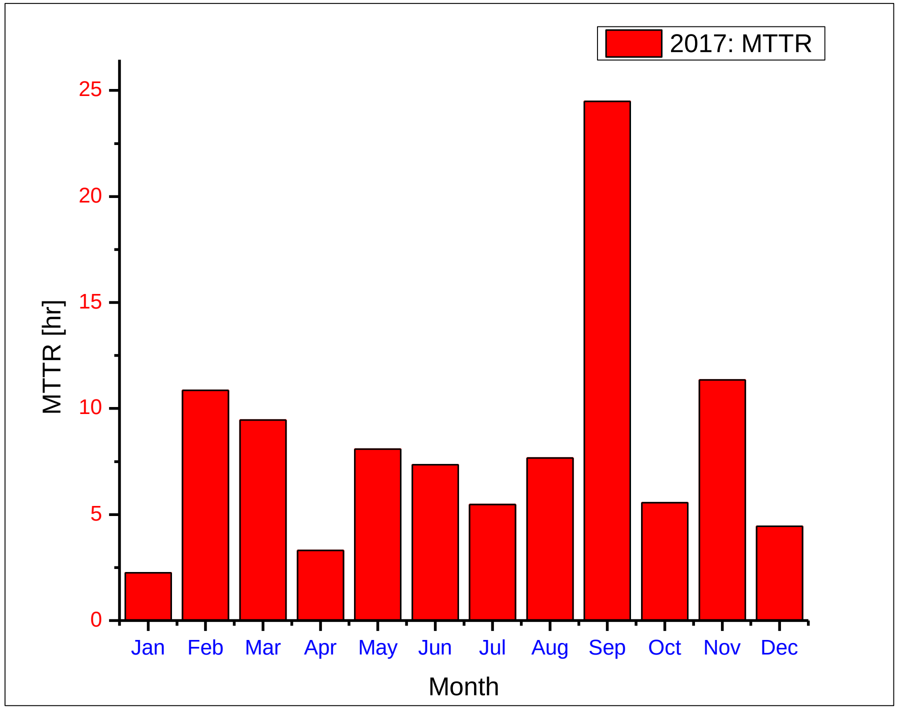


Figure 5-13: Bar graph of monthly MTTR (hours) exhibited on AALRT in the year 2017

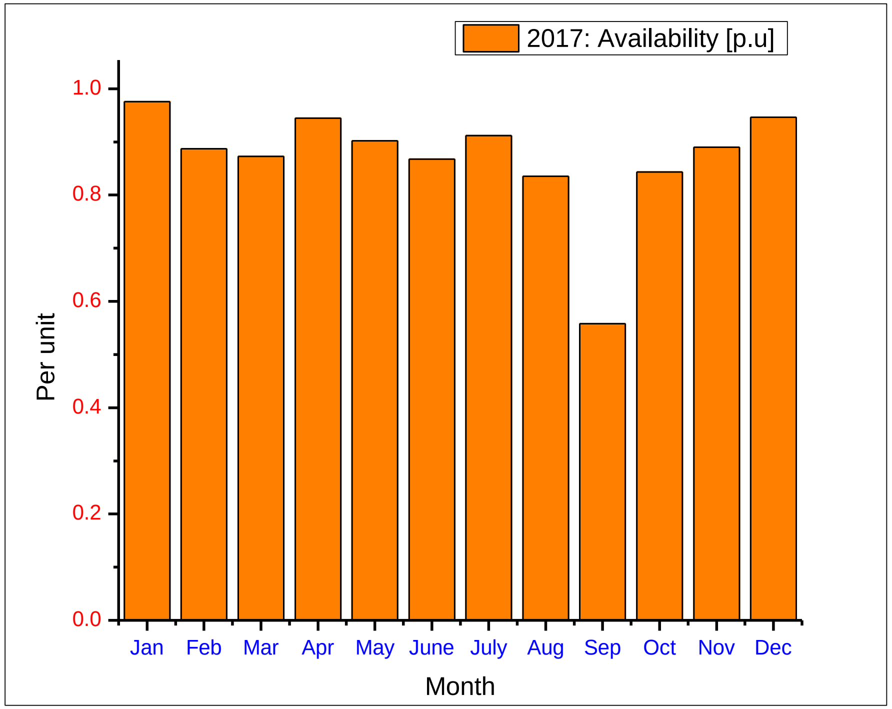


Figure 5-14: Figure 8: Bar graph of monthly availability in the Year 2017

From Fig. 5.13 And Fig. 5.114 above, it is evident that low values of MTTR not only mean good maintainability but also indicate a high probability of availability as shown in the month of January and higher values of MTTR indicate low availability as shown in the month of September.

Table 5.3: Computed Basic Reliability indices January to December 2018

Year	Month	Frequency	Outage Duration [hr]	Hours of Operation [hr]	Failure rate [event/hr]	MTBF [hr]	MTTR [hr]	Availability [p.u]
2018	January	11	37.2333	744	0.0148	67.6364	3.3848	0.9500
	February	16	35.6667	672	0.0238	42.0000	2.2292	0.9469
	March	14	78.9833	744	0.0188	53.1429	5.6417	0.8938
	April	30	157.1833	720	0.0417	24.0000	5.2394	0.7817
	May	13	155.5500	744	0.0175	57.2308	11.9654	0.7909
	June	30	227.3500	720	0.0417	24.0000	7.5783	0.6842
	July	20	86.7000	744	0.0269	37.2000	4.3350	0.8835
	August	12	42.9333	744	0.0161	62.0000	3.5778	0.9423
	September	24	152.2333	720	0.0333	30.0000	6.3431	0.7886
	October	23	151.4000	744	0.0309	32.3478	6.5826	0.7965
	November	12	45.4000	720	0.0167	60.0000	3.7833	0.9369
	December	19	232.9000	744	0.0255	39.1579	12.2579	0.6870
	Total	**224**	**1403.5333**	**8760**	**0.0256**	**39.1071**	**6.2658**	**0.8398**

Table 5.3 shows the computed reliability parameters in the year 2018 and also shows the number of interruptions as well as the monthly outage hours in the year 2018. As shown in the in Table 5.3, there is a relationship between; failure rate, hours of operation and frequency of interruptions; MTBF, hours of operation and frequency of interruptions; MTTR, frequency of interruptions and outage duration; availability, MTTR and MTBF. From this information, the monthly trend of these reliability parameters based on their relationship is discussed and interpreted in the graphs below;

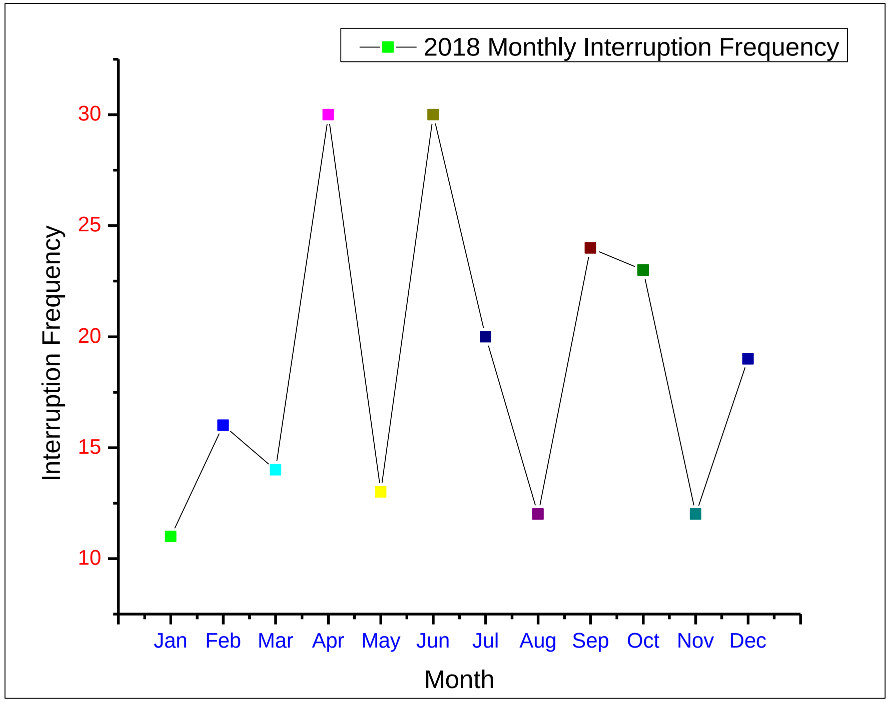


Figure 5-15: Line graph of monthly interruption frequency experienced on AALRT in the year 2018

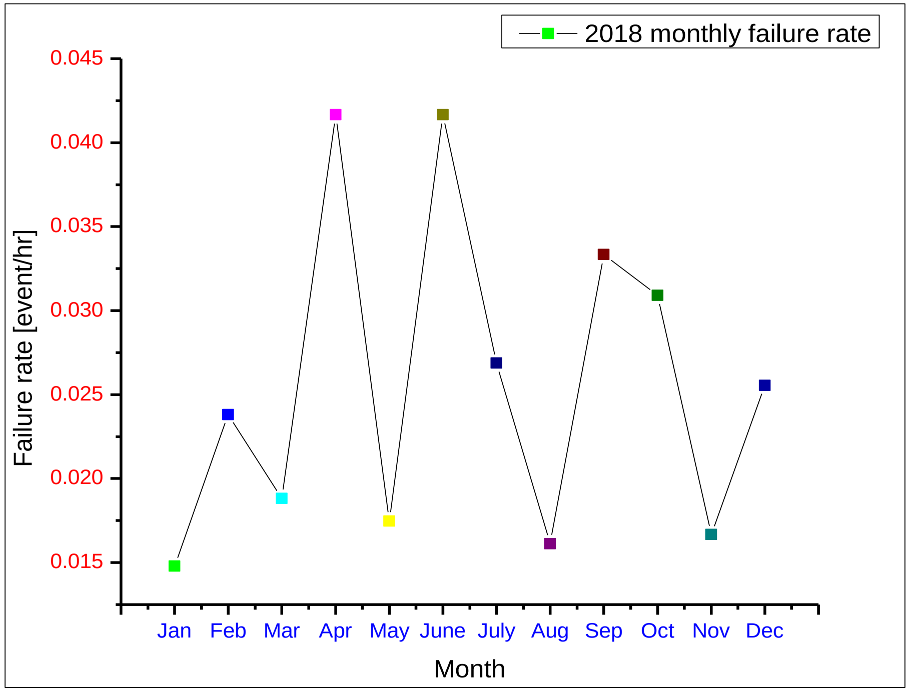


Figure 5-16: Line graph of monthly failure rate in the Year 2018

From Fig. 5.15 And Fig. 5.16 it is visible that there is a direct relationship between the interruption frequency and the failure rate, given the fact that the hours of operation are constant in a month. The month of April and June registered the highest number of interruption and thus had the highest failure rates with January registering the lowest failure rate.

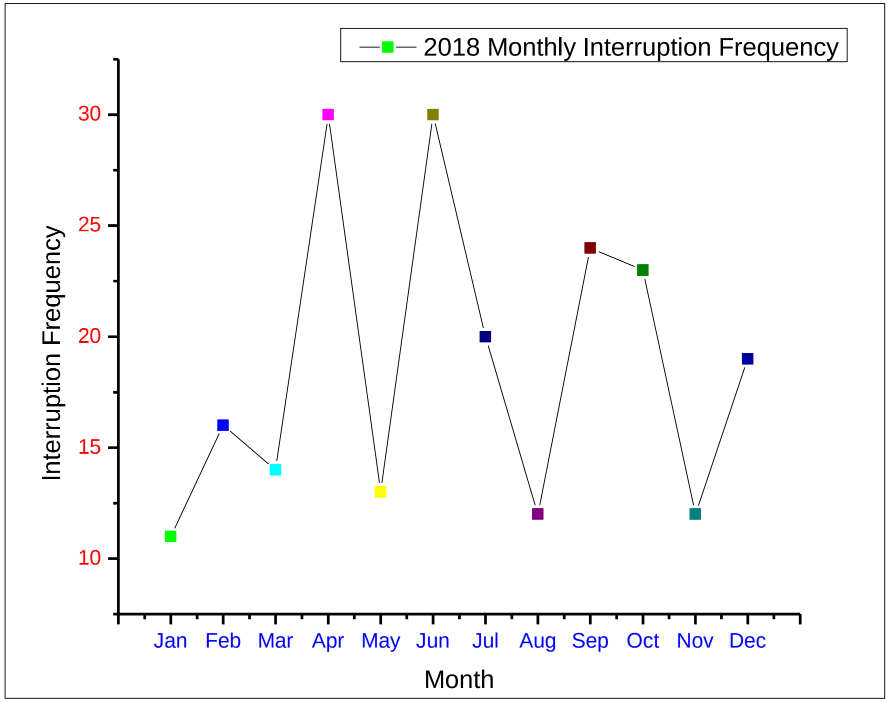


Figure 5-17: Line graph of monthly interruption frequency on AALRT in the year 2018

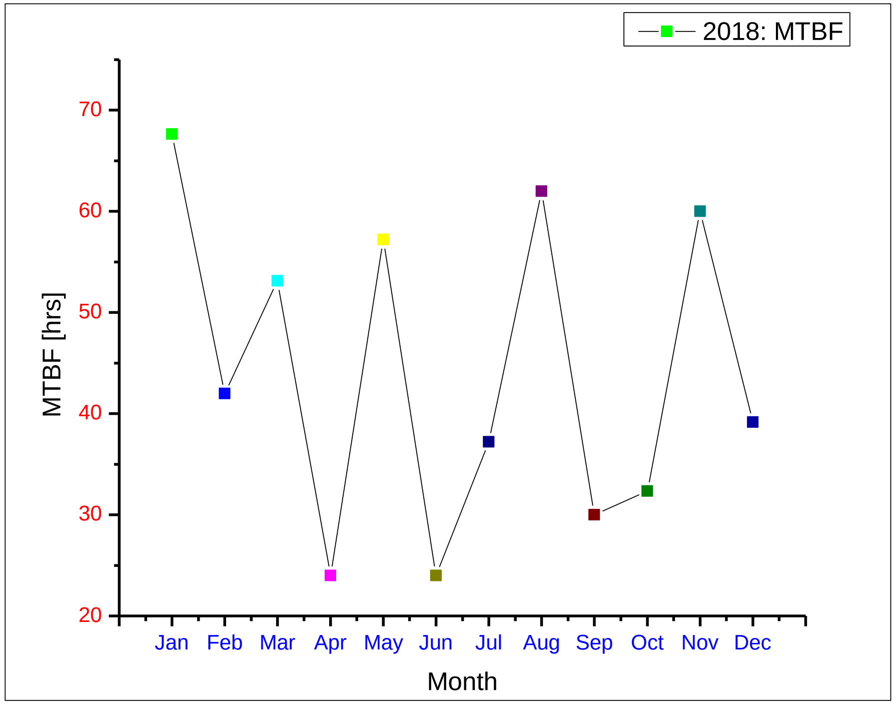


Figure 5-18: Line graph of monthly MTBF on AALRT in the year 2018

From Fig. 5.17 And Fig. 5.18 it is visible that the MTBF is inversely proportional to the interruption frequency. This means that the lower the interruption frequency the higher the MTBF (this is desirable) as shown in the month January and the higher the interruption frequency the lower the MTBF (this is undesirable) as shown in the months of April and June.

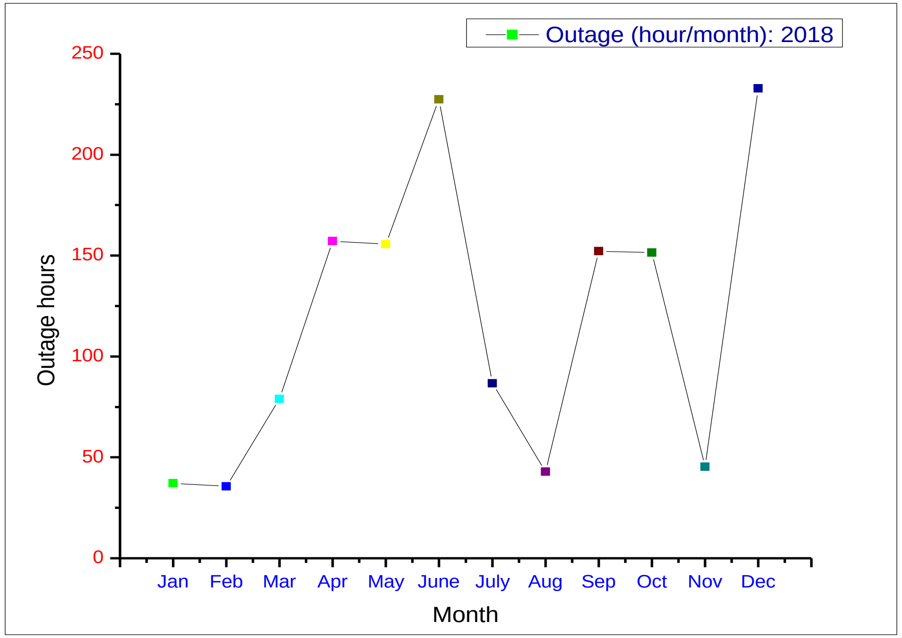


Figure 5-19: Line graph of monthly outage duration experienced on AALRT in the year 2018

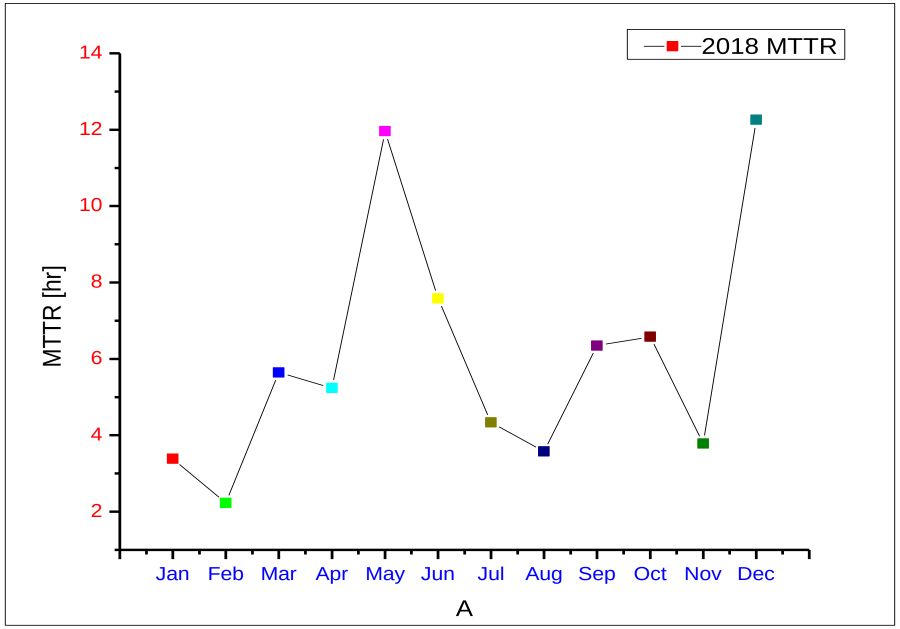


Figure 5-20: Line graph of monthly MTTR (hours) exhibited on AALRT in the year 2018

From Fig. 5.19 and Fig.5.20, outage duration is somewhat proportional to MTTR/ MDT but not exactly proportional because the interruption frequency is different for each month and is indirectly proportional to MTTR. Low MDT means good maintainability and this takes two inputs i.e. outage duration in hours and frequency of interruptions.

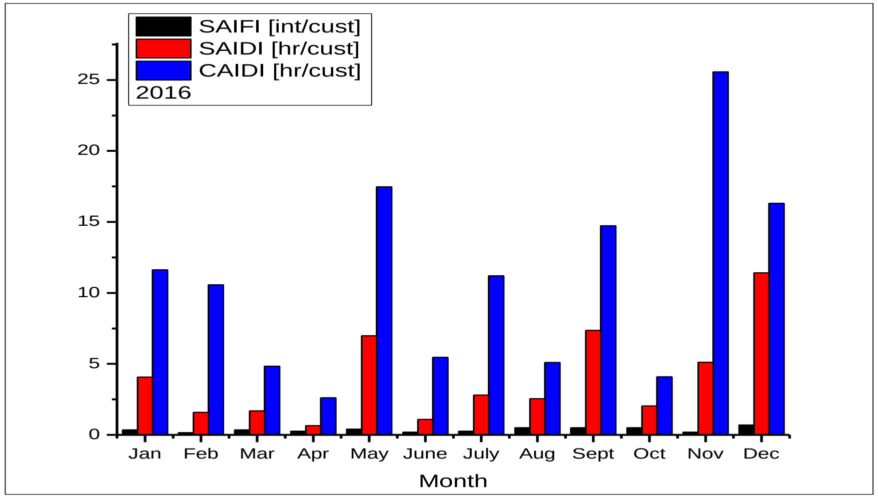


Figure 5-21: Bar graph of monthly SAIFA, SAIDI & CAIDI indices for the year 2016

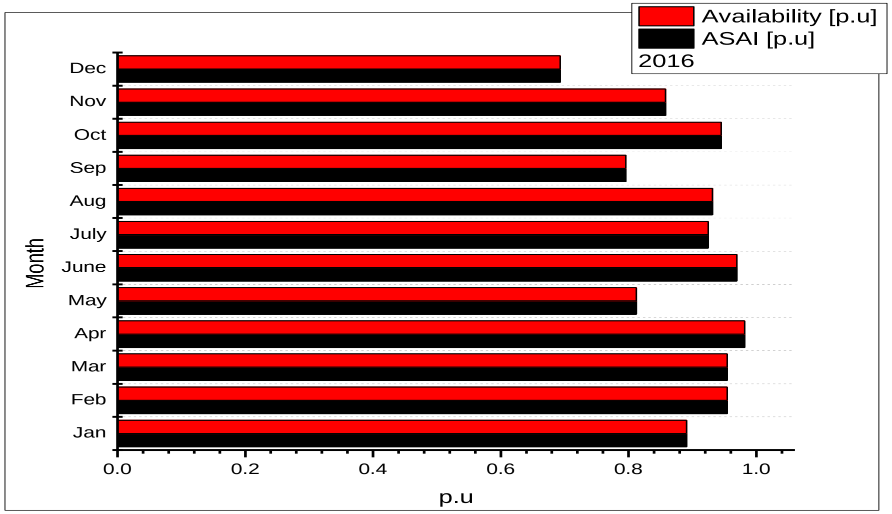


Figure 5-22: Monthly Availability in the Year 2016

From Fig. 5.21 above, it is seen that in the year 2016, the month of February registered the lowest SAIFI value but the month of April registered the lowest SAIDI value. This means that the system can be subjected to a few interruptions but with long duration of an outage. The CAIDI index is, therefore, a good measure because it looks at how fast the service is restored, thus the month of April as of 2016 is most outstanding in terms of good maintainability.

From Fig. 5.22 above, it is visible that ASAI and Availability indices coincide. ASAI is that time the system was free from an outage over the total hours of operation in a month and is not influenced by the frequency of interruption. On the other hand, Availability parameter is greatly influenced by the frequency of interruption but mathematically these two parameters are the same and therefore, all quantify the probability that a customer has received power over a defined period.

Table 5.4: Computed Customer Orientation Indices, January to December 2017

Year	Month	Freq.	Outage [hr]	Total Hours	Customer	SAIFI [int/cust]	SAIDI [hr/cust]	CAIDI [hr/cust]	ASAI [p.u]	ASUI [p.u]
2017	January	8	17.9833	744	20	0.4	0.8992	2.24792	0.9758	0.0242
	February	7	75.9667	672	20	0.35	3.7983	10.85238	0.8870	0.1130
	March	10	94.6333	744	20	0.5	4.7317	9.46333	0.8728	0.1272
	April	12	39.7333	720	20	0.6	1.9867	3.31111	0.9448	0.0552
	May	9	72.8167	744	20	0.45	3.6408	8.09074	0.9021	0.0979
	June	13	95.4500	720	20	0.65	4.7725	7.34231	0.8674	0.1326
	July	12	65.5833	744	20	0.6	3.2792	5.46528	0.9119	0.0881
	August	16	122.7167	744	20	0.8	6.1358	7.66979	0.8351	0.1649
	September	13	318.3833	720	20	0.65	15.9192	24.49103	0.5578	0.4422
	October	21	116.7000	744	20	1.05	5.8350	5.55714	0.8431	0.1569
	November	7	79.4000	720	20	0.35	3.9700	11.34286	0.8897	0.1103
	December	9	40.0833	744	20	0.45	2.0042	4.45370	0.9461	0.0539
	Total	**137**	**1139.4500**	**8760**	**20**	**6.85**	**56.9725**	**8.31715**	**0.8699**	**0.1301**

Table 5.4 shows the computed customer orientation indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) in the year of 2017. As shown in the in Table 5.4, there is a relationship between; SAIFI, frequency of interruptions and number of customers; SAIDI, outage duration and number of customers; CAIDI, SAIDI and SAIFI; ASAI, total hours of operation and outage duration (this similar to availability and in fact is the same for this research). From this information, the monthly trend of these customer orientation indices based on their relationship is discussed and interpreted in the graphs below;

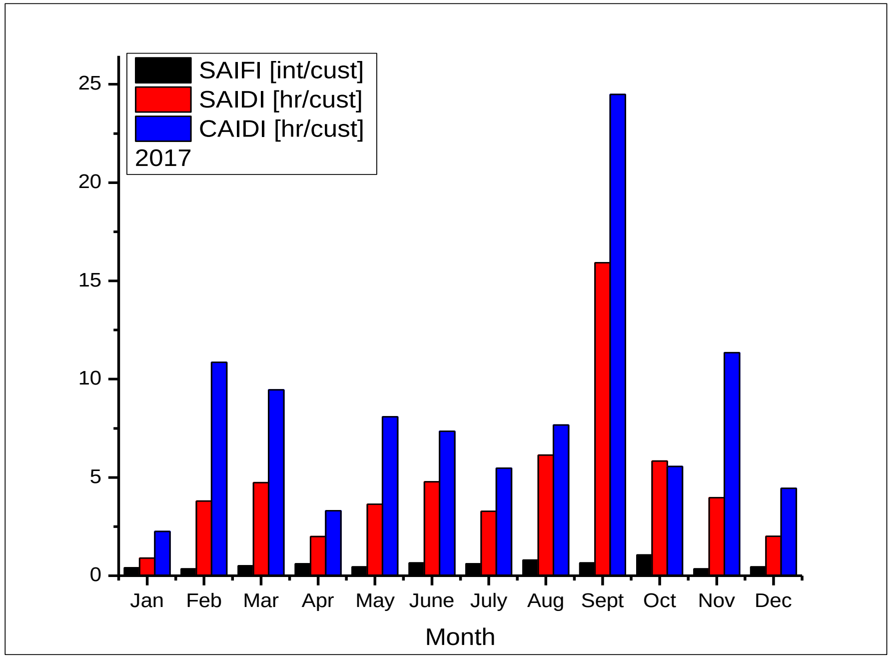


Figure 5-23: Bar graph of monthly SAIFA, SAIDI & CAIDI indices for the year 2017

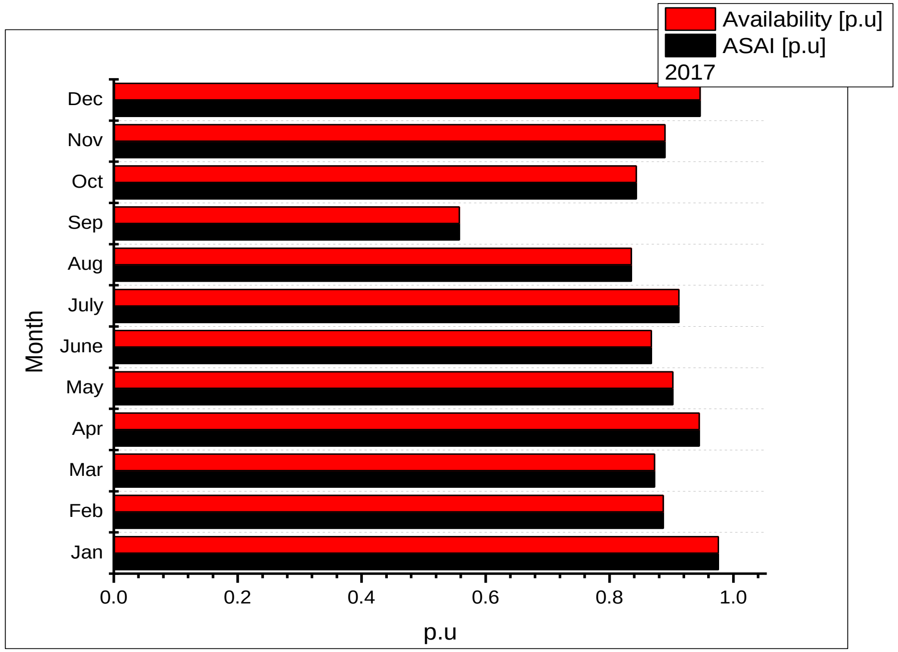


Figure 5-24: Monthly Availability in the Year 2017

Similarly, (as explained in Fig. 5.21), from Fig. 5.23 above, the month of January has the best CAIDI value while the month of September has the worst CAIDI value largely because it has the highest SAIDI value.

Similarly, (as explained in Fig. 5.22), from Fig. 5.23 above, ASAI which is a mathematical proof for Availability shows that the month of January has the best value of ASAI while September has the worst.

Table 5.5: Computed Customer Orientation Indices, January to December 2018

Year	Month	Freq.	Outage [hr]	Total Hours	Customer	SAIFI [int/cust]	SAIDI [hr/cust]	CAIDI [hr/cust]	ASAI [p.u]	ASUI [p.u]
2018	January	11	37.2333	744	20	0.55	1.8617	3.38485	0.9500	0.0500
	February	16	35.6667	672	20	0.8	1.7833	2.22917	0.9469	0.0531
	March	14	78.9833	744	20	0.7	3.9492	5.64167	0.8938	0.1062
	April	30	157.1833	720	20	1.5	7.8592	5.23944	0.7817	0.2183
	May	13	155.5500	744	20	0.65	7.7775	11.96538	0.7909	0.2091
	June	30	227.3500	720	20	1.5	11.3675	7.57833	0.6842	0.3158
	July	20	86.7000	744	20	1	4.3350	4.33500	0.8835	0.1165
	August	12	42.9333	744	20	0.6	2.1467	3.57778	0.9423	0.0577
	September	24	152.2333	720	20	1.2	7.6117	6.34306	0.7886	0.2114
	October	23	151.4000	744	20	1.15	7.5700	6.58261	0.7965	0.2035
	November	12	45.4000	720	20	0.6	2.2700	3.78333	0.9369	0.0631
	December	19	232.9000	744	20	0.95	11.6450	12.25789	0.6870	0.3130
	Total	**224**	**1403.5333**	**8760**	**20**	**11.2**	**70.1767**	**6.26577**	**0.8398**	**0.1602**

Table 5.5 shows the computed customer orientation indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) in the year of 2018. As shown in the in Table 5.5, there is a relationship between; SAIFI, frequency of interruptions and number of customers; SAIDI, outage duration and number of customers; CAIDI, SAIDI and SAIFI; ASAI, total hours of operation and outage duration (this similar to availability and in fact is the same for this research). From this information, the monthly trend of these customer orientation indices based on their relationship is discussed and interpreted in the graphs below;

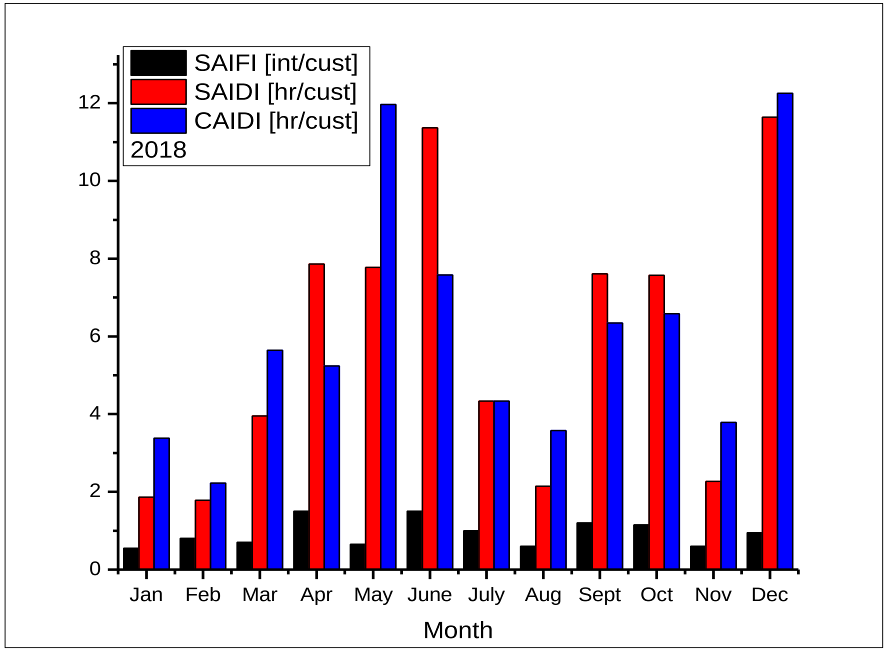


Figure 5-25: Bar graph of monthly SAIFA, SAIDI & CAIDI indices for the year 2018

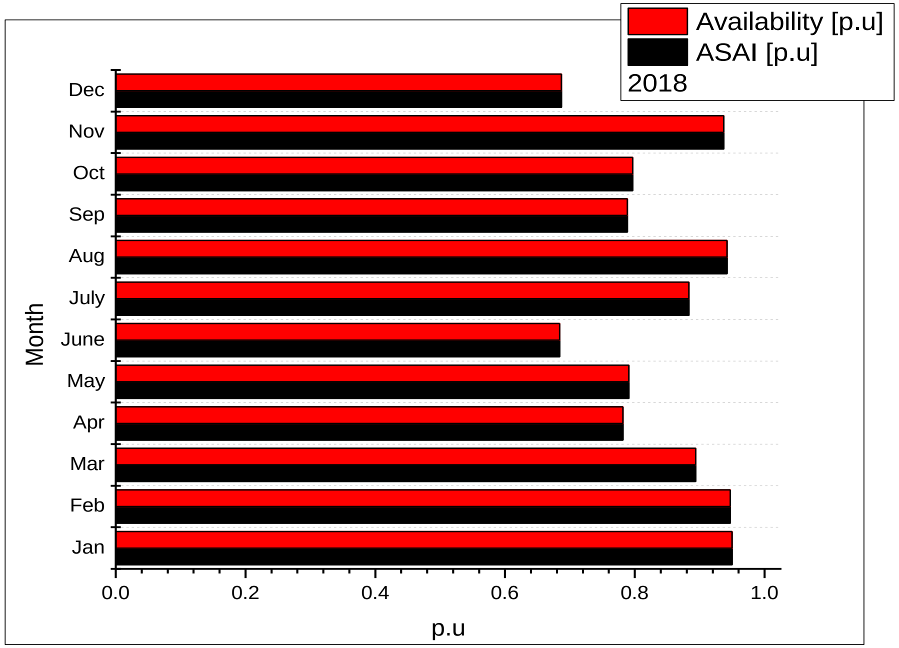


Figure 5-26: Monthly Availability in the Year 2018

Similarly, (as explained in Fig. 5.21), from Fig. 5.21 above, the month of February has the best CAIDI value while the month of December has the worst CAIDI value largely because it has the highest SAIDI value.

Similarly, (as explained in Fig. 5.22), from Fig. 5.26 above, ASAI which is a mathematical proof for Availability shows that the month of January has the best value of ASAI while June has the worst.

Table 5.6: Computed Energy and Cost indices between January and December, 2016

Year	Month	Average Outage duration [hr]	P [kW]	EENS [MWhr]	AENS [MWhr/ycust]	Monthly Cost of Cancelled Trips [ETB]	ECOST [ETB]	IEAR [ETB/kWh]
2016	January	81.37	127.5	10.3743	0.5187	200807.1	2083223.06	200.8071
	February	31.70	127.5	4.0418	0.2021	24702.36	99840.76	24.7024
	March	33.87	127.5	4.3180	0.2159	5689.52	24567.35	5.6895
	April	13.05	127.5	1.6639	0.0832	0	0.00	0.0000
	May	139.75	127.5	17.8181	0.8909	39888.63	710740.60	39.8886
	June	21.85	127.5	2.7859	0.1393	5351.36	14908.22	5.3514
	July	56.03	127.5	7.1443	0.3572	42743.36	305369.25	42.7434
	August	51.02	127.5	6.5046	0.3252	0	0.00	0.0000
	September	147.28	127.5	18.7786	0.9389	26231.4	492589.62	26.2314
	October	40.82	127.5	5.2041	0.2602	15483.36	80577.34	15.4834
	November	102.30	127.5	13.0433	0.6522	15301.08	199575.81	15.3011
	December	228.42	127.5	29.1231	1.4562	163557.1	4763293.87	163.5571
	Total	**947.45**	**127.5**	**120.7999**	**6.0400**	**539755.27**	**65202369.15**	**539.7553**

Table 5.6 shows the computed energy and cost indices (EENS, AENS, ECOST and IEAR) in the year of 2016. As shown in the in Table 5.6, there is a relationship between; EENS, average outage duration and power (i.e. average load at point i); AENS, EENS and the number of customers; ECOST, EENS and monthly cost of cancelled trips; IEAR, ECOST and EENS. The EENS is an energy index that computes the energy not supplied as a result of an outage. This energy not supplied is quantified in monetary terms by the ECOST index. The IEAR index quantifies the money (ETB) lost per kilo watt hour as a result of computed outages in a month or year. From this information, the monthly trend of these energy and cost indices based (with emphasis on EENS and ECOST) on their relationship is discussed and interpreted in the graphs below;

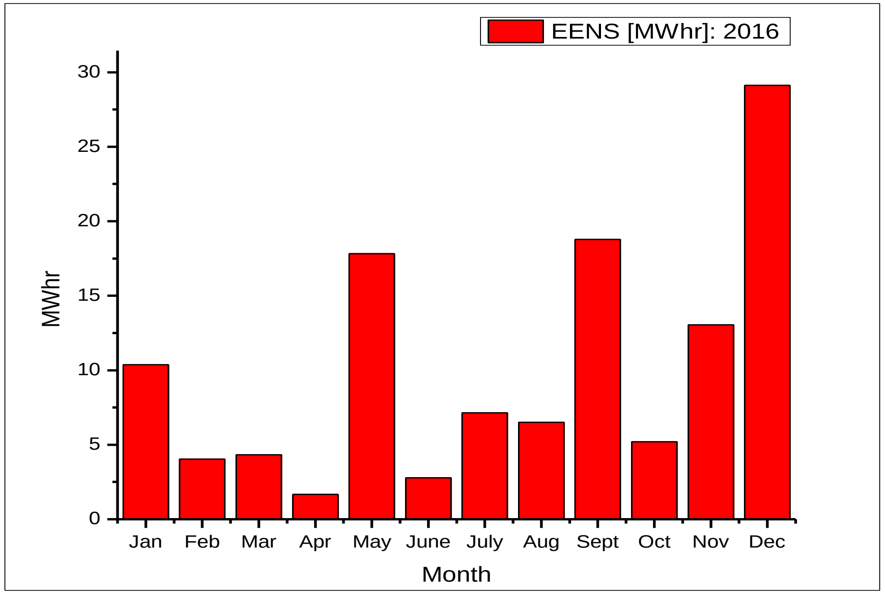


Figure 5-27: Bar graph showing monthly EENS in the year 2016

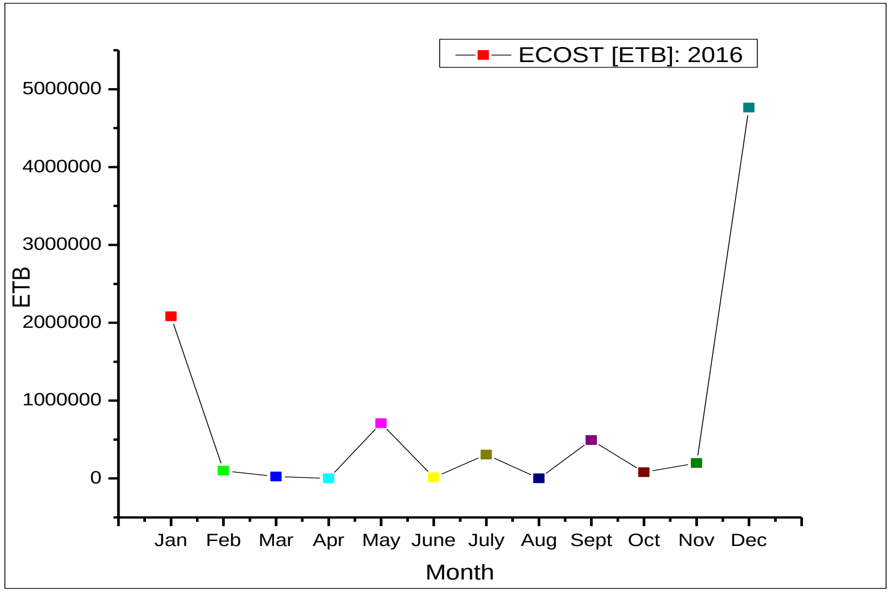


Figure 5-28: Bar graph showing monthly ECOST in the year 2016

From Fig. 5.27, it is visible that since the month of December has the highest outage hours the Expected Energy Not Supplied (EENS) is highest in this month and the month of April which recorded the lowest outage hours has the least value of EENS and therefore had a good performance in terms of reliability of power supply.

From Fig. 5.27, Fig. 5.28, shows a direct relationship between EENS and ECOST but not entirely. This is because the cost in terms of trips cancelled as a result of an outage per month varies. Nonetheless, higher values of EENS imply a high ECOST.

Table 5.7: Computed Energy and Cost indices between January and December, 2017

Year	Month	Average Outage duration [hr]	P [kW]	EENS [MWhr]	AENS [MWhr/ycust]	Monthly Cost of Cancelled Trips [ETB]	ECOST [ETB]	IEAR [ETB/kWh]
2017	January	17.98	127.5	2.2929	0.1146	0	0	0.0000
	February	75.97	127.5	9.6858	0.4843	82545.12	799511.396	82.5451
	March	94.63	127.5	12.0658	0.6033	44928.21	542092.55	44.9282
	April	39.73	127.5	5.0660	0.2533	26903.58	136293.536	26.9036
	May	72.82	127.5	9.2841	0.4642	72435.1	672496.523	72.4351
	June	95.45	127.5	12.1699	0.6085	201322.68	2450071.85	201.3227
	July	65.58	127.5	8.3619	0.4181	144292.82	1206558.52	144.2928
	August	122.72	127.5	15.6464	0.7823	200511.6	3137279.69	200.5116
	September	318.38	127.5	40.5939	2.0297	453638.64	18414950.2	453.6386
	October	116.70	127.5	14.8793	0.7440	1345482	20019763	1345.4820
	November	79.40	127.5	10.1235	0.5062	143109.37	1448767.71	143.1094
	December	40.08	127.5	5.1106	0.2555	62517	319500.943	62.5170
	Total	**1139.45**	**127.5**	**145.2799**	**7.2640**	**2777686.12**	**403541892**	**2777.6861**

Table 5.7 shows the computed energy and cost indices (EENS, AENS, ECOST and IEAR) in the year of 2017. As shown in the in Table 5.7, there is a relationship between; EENS, average outage duration and power (i.e. average load at point i); AENS, EENS and the number of customers; ECOST, EENS and monthly cost of cancelled trips; IEAR, ECOST and EENS. From this information, the monthly trend of these energy and cost indices based (with emphasis on EENS and ECOST) on their relationship is discussed and interpreted in the graphs below;

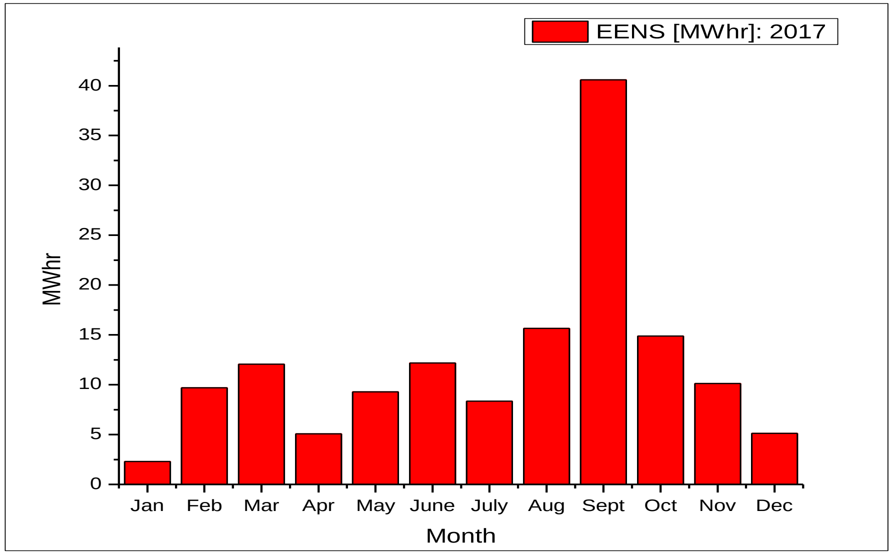


Figure 5-29: Bar graph showing monthly EENS in the year 2017

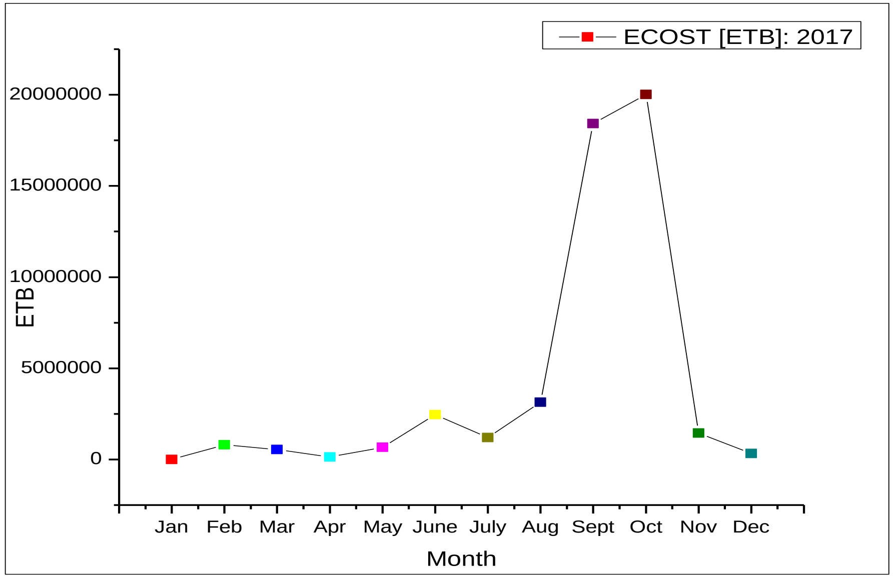


Figure 5-30: Bar graph showing monthly ECOST in the year 2017

Similarly, from Fig. 5.27 above, Fig. 5.29 shows the month of September has the highest outage hours the Expected Energy Not Supplied (EENS) is highest in this month and the month of January recorded the lowest outage hours has the least value of EENS and therefore had a good performance in terms of reliability of power supply.

Similarly, from Fig. 5.28, Fig. 5.30 above, shows a direct relationship between EENS and ECOST but not entirely. It is observed that the month of October has the highest ECOST value despite the fact the month of September had the highest EENS. This can be attributed to the time of outage i.e. the impact of outage at peak and off peak hours is different in terms of trips cancelled.

Table 5.8: Computed Energy and Cost indices between January and December, 2018

Year	Month	Average Outage duration [hr]	P [kW]	EENS [MWhr]	AENS [MWhr/ycust]	Monthly Cost of Cancelled Trips [ETB]	ECOST [ETB]	IEAR [ETB/kWh]
2018	January	37.23	127.5	4.7473	0.2374	42466	201596.719	42.4660
	February	35.67	127.5	4.5475	0.2274	11247.66	51148.7339	11.2477
	March	78.98	127.5	10.0704	0.5035	77385.6	779302.012	77.3856
	April	157.18	127.5	20.0409	1.0020	196432.88	3936686.79	196.4329
	May	155.55	127.5	19.8326	0.9916	148477.89	2944706.31	148.4779
	June	227.35	127.5	28.9871	1.4494	333654.38	9671681.22	333.6544
	July	86.70	127.5	11.0543	0.5527	352567.6	3897370.39	352.5676
	August	42.93	127.5	5.4740	0.2737	82101.76	449425.034	82.1018
	September	152.23	127.5	19.4098	0.9705	292270	5672887.63	292.2700
	October	151.40	127.5	19.3035	0.9652	85804.43	1656325.81	85.8044
	November	45.40	127.5	5.7885	0.2894	126221.92	730635.584	126.2219
	December	232.90	127.5	29.6948	1.4847	443509.29	13169897.5	443.5093
	Total	**1403.53**	**127.5**	**178.9505**	**8.9475**	**2192139.41**	**392284443**	**2192.1394**

Table 5.8 above shows the computed energy and cost indices (EENS, AENS, ECOST and IEAR) in the year of 2018. As shown in the in Table 5.8, there is a relationship between; EENS, average outage duration and power (i.e. average load at point i); AENS, EENS and the number of customers; ECOST, EENS and monthly cost of cancelled trips; IEAR, ECOST and EENS. From this information, the monthly trend of these energy and cost indices based (with emphasis on EENS and ECOST) on their relationship is discussed and interpreted in the graphs below;

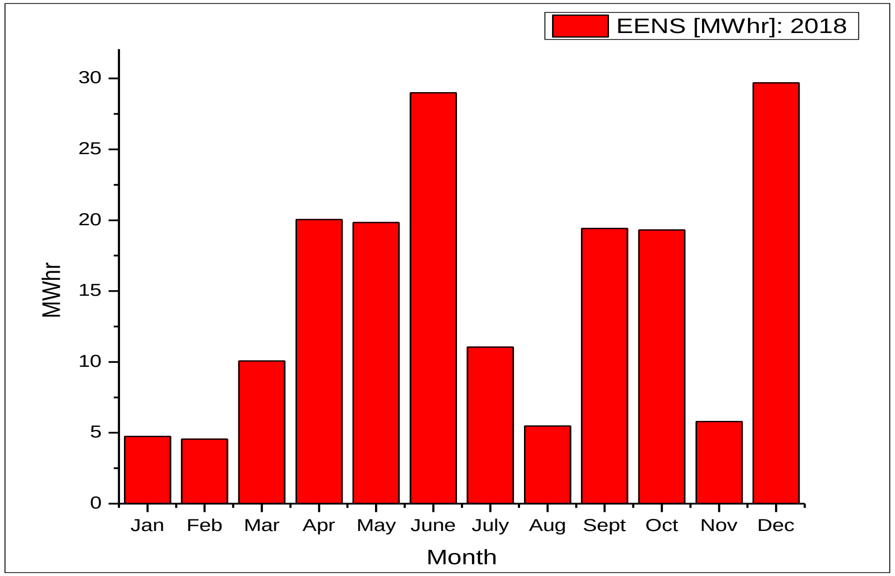


Figure 5-31: Bar graph showing monthly EENS in the year 2018

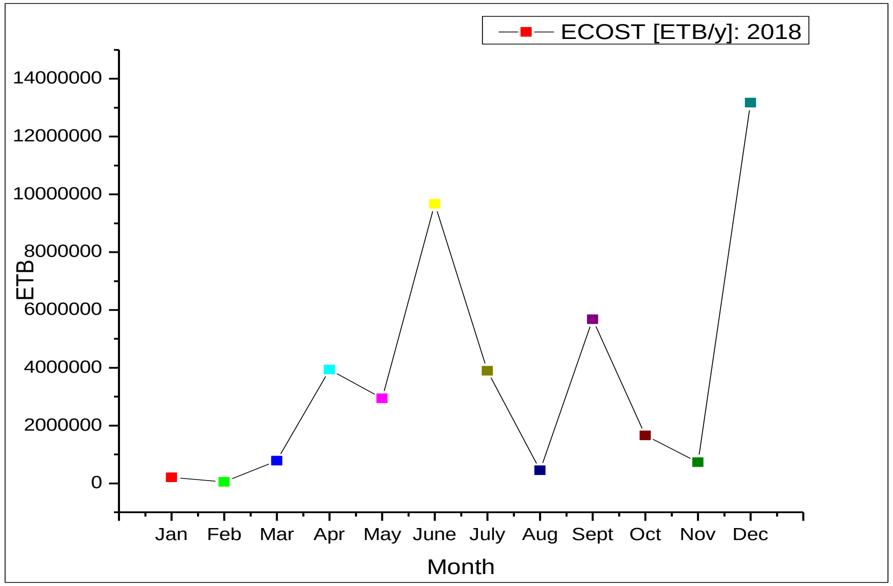


Figure 5-32: Line graph showing monthly ECOST in the year 2018

Similarly, from Fig. 5.27, Fig. 5.33 shows the month of December has the highest outage hours the Expected Energy Not Supplied (EENS) is highest in this month and the month of August recorded the lowest outage hours has the least value of EENS and therefore had a good performance in terms of reliability of power supply.

Similarly, from Fig. 5.28, Fig. 5.34, shows a direct relationship between EENS and ECOST but not entirely. It is observed that the month of December has the highest ECOST value while August has the lowest ECOST.

5.1.2 Summary of Results and Discussion of the AALRT TPSS Reliability Analysis

Table 5.9 below gives a summary of the reliability study and computations in the period of study.

Table 5.9: Basic Reliability, Customer Orientation, Energy and Cost Indices for 2016, 2017 & 2018

Year	2016	2017	2018
Outage Duration [hr]	947.4500	1139.4500	1403.5333
Frequency	87.0000	137.0000	224.0000
Failure Rate [event/hr]	0.0099	0.0156	0.0256
MTBF [hr]	100.9655	63.9416	39.1071
MTTR [hr]	10.8902	8.3172	6.2658
Availability [p.u.]	0.8921	0.8699	0.8398
SAIFI [int/cust]	4.3500	6.8500	11.2000
SAIDI [hr/cust]	47.3725	56.9725	70.1767
CAIDI [hr/cust]	10.8902	8.3172	6.2658
ASAI [p.u]	0.8921	0.8699	0.8398
ASUI [p.u]	0.1079	0.1301	0.1602
EENS [MWhr]	120.7999	145.2799	178.9505
AENS [MWhr/cust]	6.0400	7.2640	8.9475
ECOST [ETB/y]	65202369.15	403541892	392284443
IEAR [ETB/kWh]	539.7553	2777.6861	2192.1394

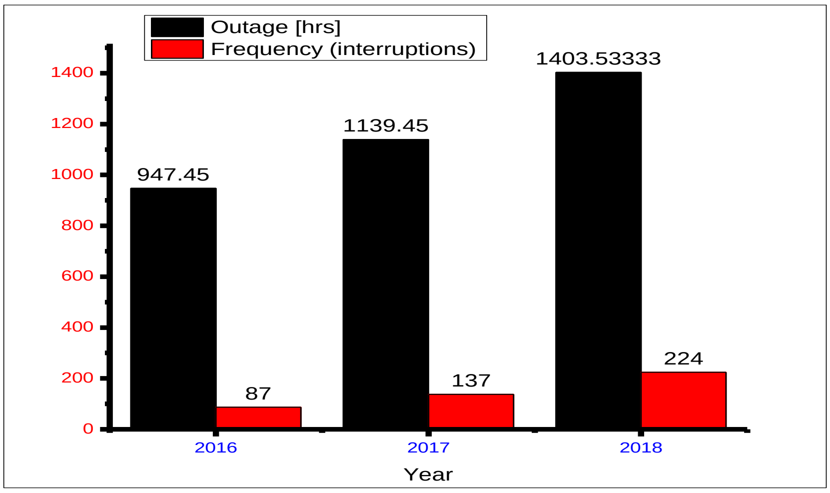


Figure 5-33: Bar graph of annual power interruptions and corresponding outage duration (hours) on for the years 2016, 2017& 2018

Fig. 5.33, shows the yearly power interruptions and corresponding outage duration (hours) for the years 2016, 2017& 2018. It is from this information that we can quantify Basic Reliability Parameters, Customer Orientation, Energy and Cost Indices. It is clearly visible that there is a progressive increase in both the frequency of interruptions and the outage duration of power supply at the AALRT. The impact of this increase is shown and interpreted in the graphs below:

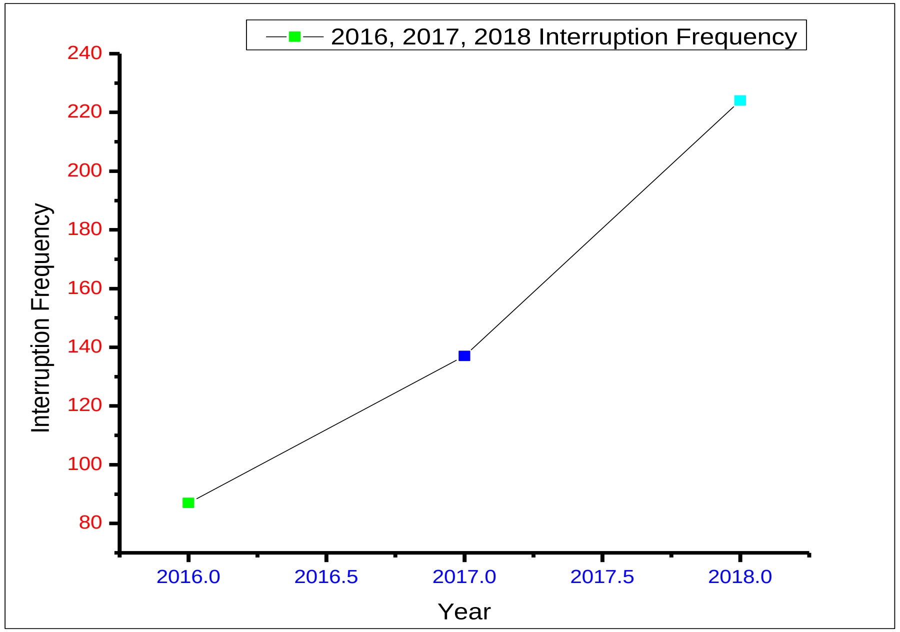


Figure 5-34: Line graph of annual interruption frequency experienced on AALRT in the Years 2016, 2017 & 2018

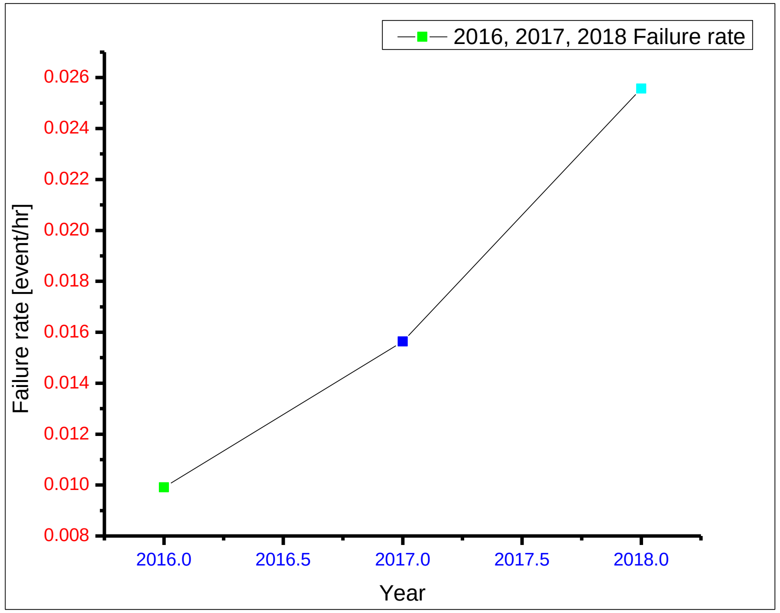


Figure 5-35: Line graph of annual failure rate in the Years 2016, 2017 & 2018

From Fig. 5.34 and Fig. 5.35, it is visible that there is a direct relationship between the interruption frequency and the failure rate, given the fact that hours of operation are constant in a year. The trend shows that there is a progressive increase in power interruptions over these three years of study which in turn gives a progressive failure rate.

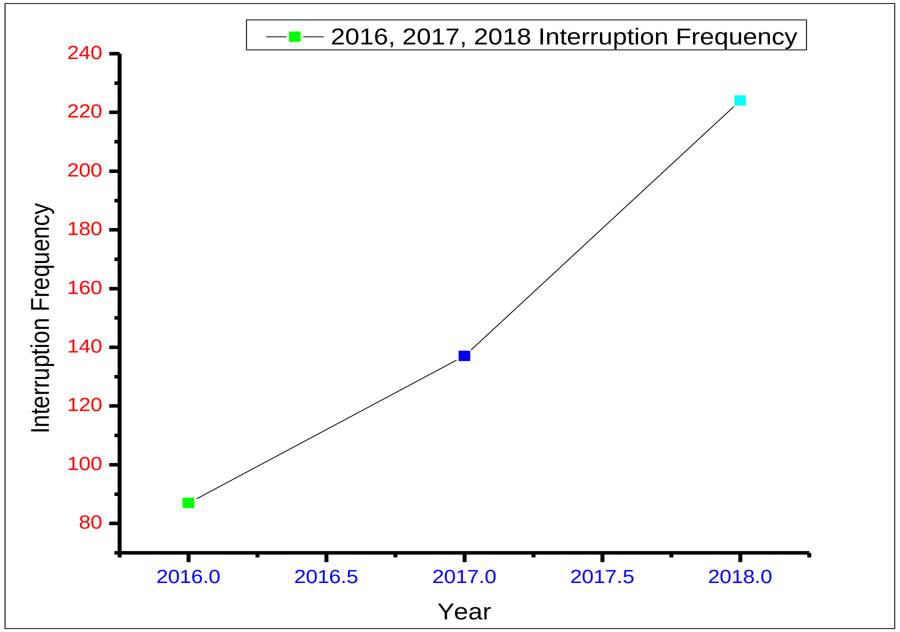


Figure 5- 34: Line graph of annual interruption frequency experienced on AALRT in the Years 2016, 2017 & 2018

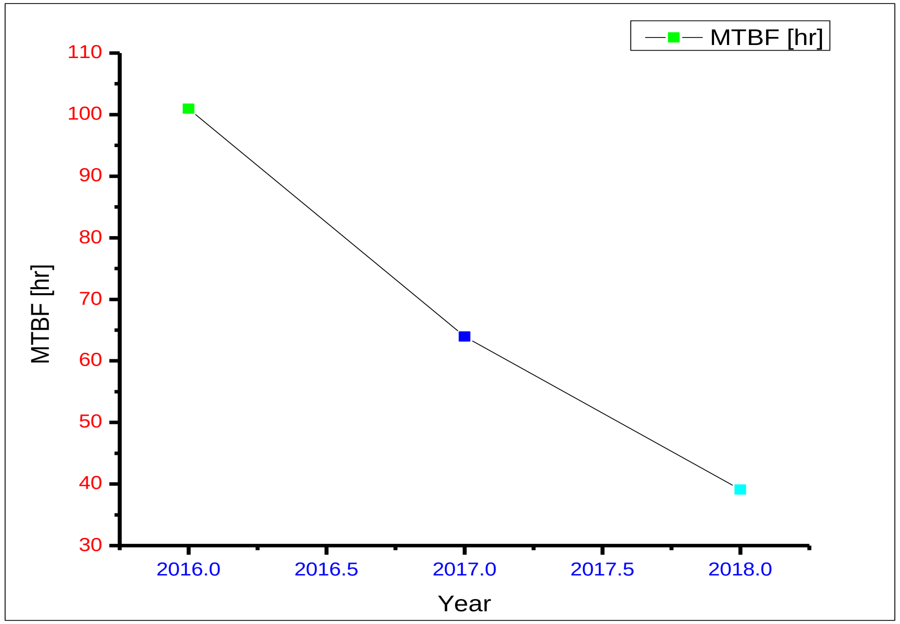


Figure 5-36: Line graph of annual MTBF (hours) in the Years 2016, 2017 & 2018

From Fig. 5.34 and Fig. 5.36 above, it is visible that the MTBF is inversely proportional to the interruption frequency. This means that the lower the interruption frequency the higher the MTBF (this is desirable). Over these three years of study, it's indicative that MTBF is reducing due to increase in the number of power interruptions. This poses a serious threat (financial loss) to the railway industry because AALRT entirely runs its operations on electric power.

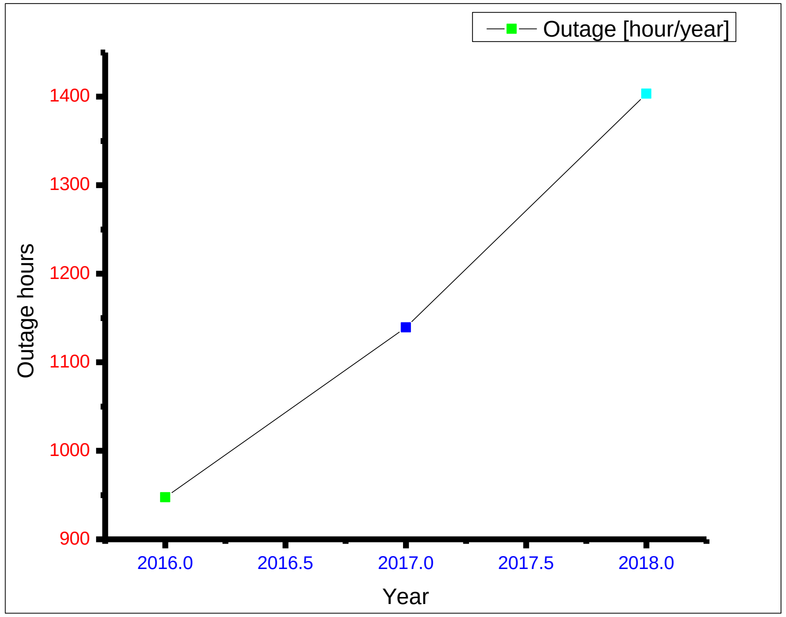


Figure 5-37: Line graph of annual outage duration (hours) experienced on AALRT in the years 2016, 2017 & 2018

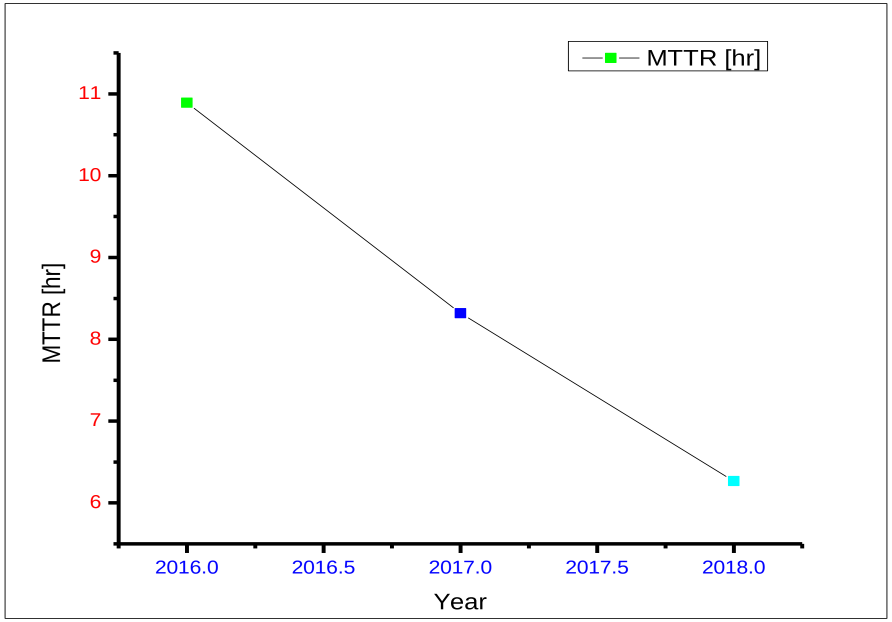


Figure 5-38: Line graph of annual MTTR (hours) for AALRT in the years 2016, 2017 & 2018

From Fig. 5.37 and Fig. 5.38, despite the fact that the outage duration curve has a positive slope, the MTTR curve has a negative slope. This means that there is good maintainability which is clearly visible through a low MDT/ MTTR.

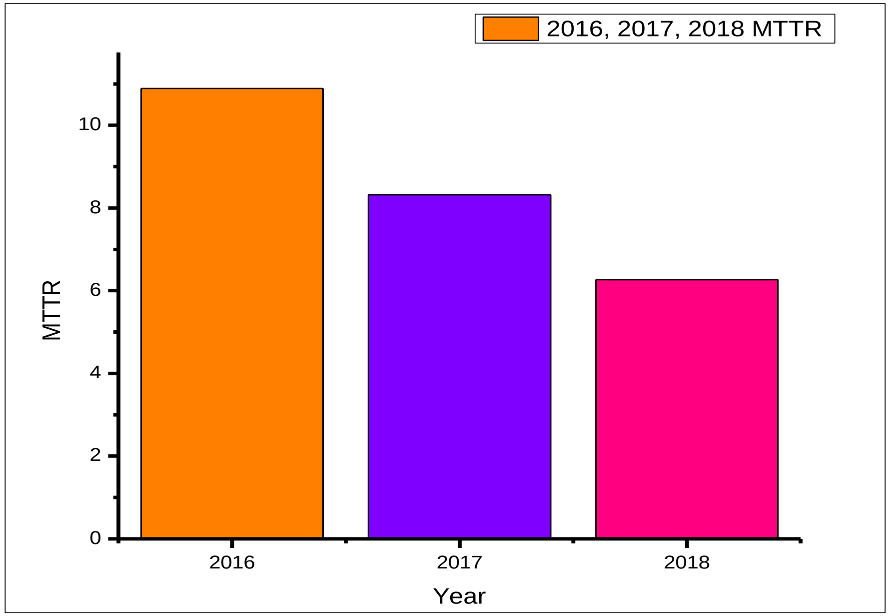


Figure 5-39: Bar graph of annual MTTR in the Years 2016, 2017 & 2018

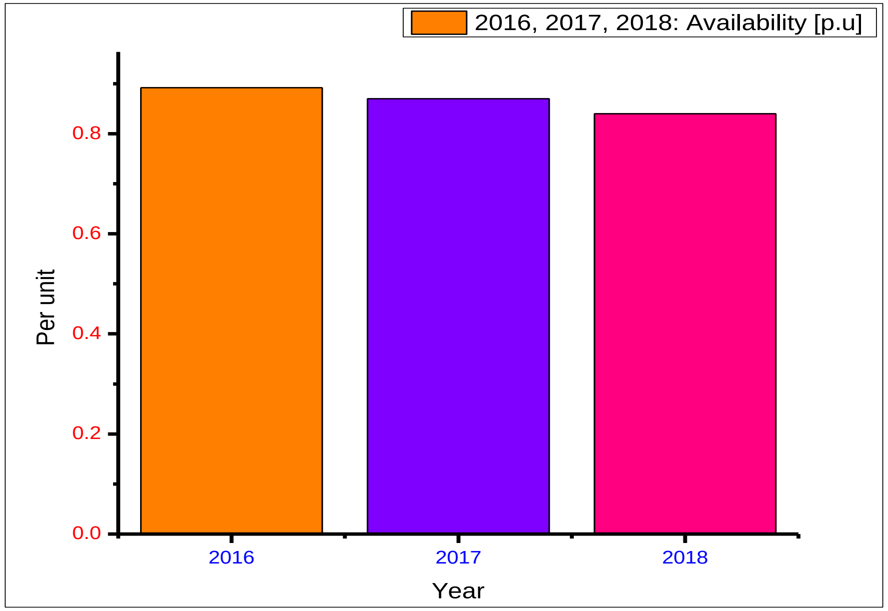


Figure 5-40: Bar graph of annual availability in the Years 2016, 2017 & 2018

From Fig. 5.39 and Fig. 5.40, even though the MTTR/MDT is reducing (implying mean good maintainability) over the years of study, the service availability is reducing.

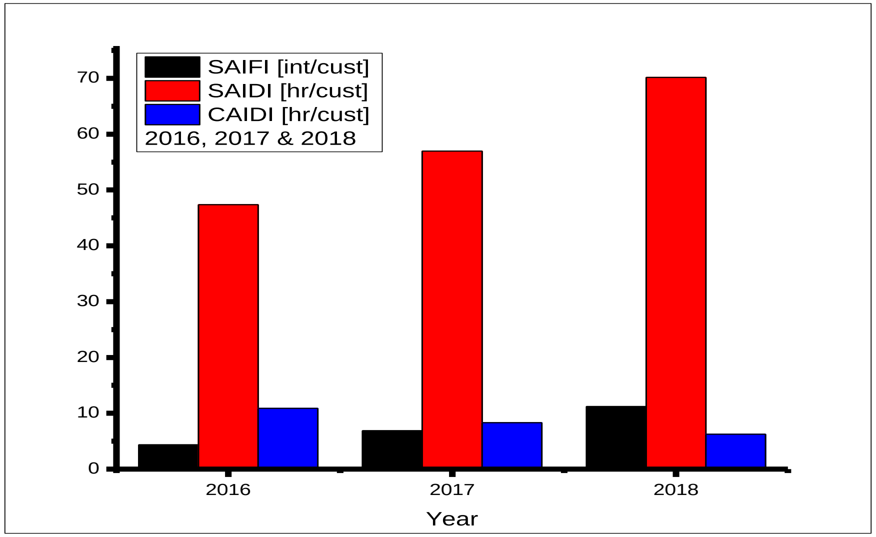


Figure 5-41: Bar graph of annual SAIFI, SAIDI and CAIDI in the Years 2016, 2017 & 2018

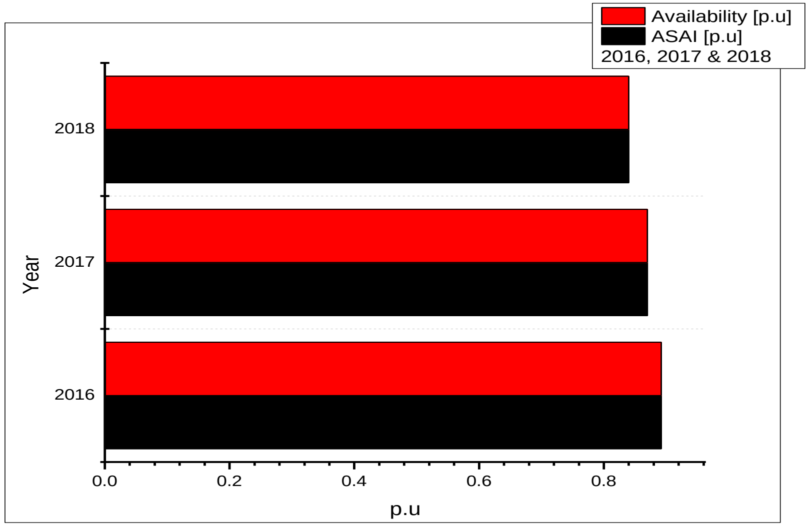


Figure 5-42: Annual Availability for 2016, 2017 & 2018

From Fig. 5.41 above, it is seen that over the three years of study the SAIFI and SAIDI values are increasing. However, the CAIDI value is decreasing. This means that, despite the increase in power interruptions as well as duration in outage, service restoration has improved over the years.

From Fig 5.42 above, it is visible that ASAI (time the system was free from an outage over the total hours of operation in a year) and Availability indices coincide in this period of study. ASAI is that and is not influenced by frequency of interruption. On the other hand, Availability parameter is greatly influenced by frequency of interruption but quantifies the probability that a customer has received power over a defined period.

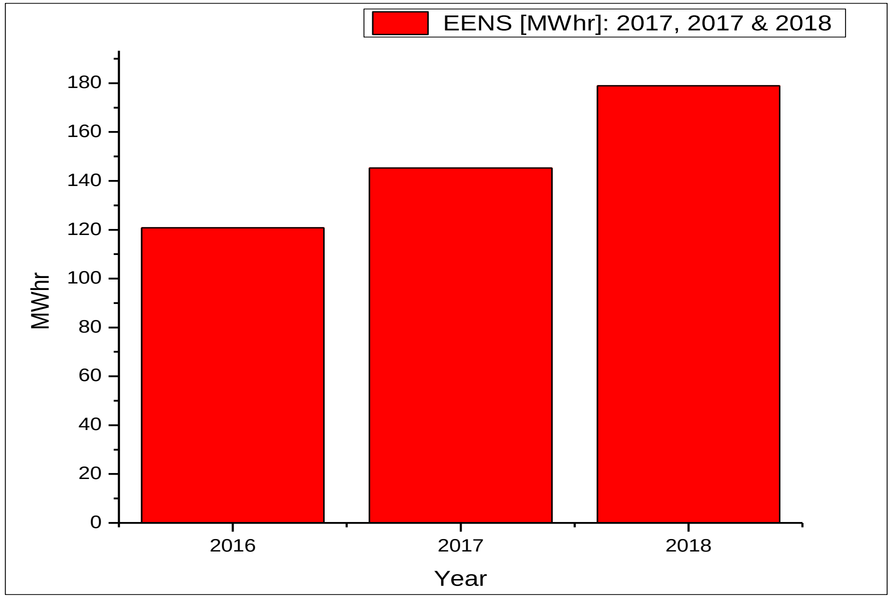


Figure 5-43: Bar graph showing annual EENS in the years 2016, 2017 & 2018

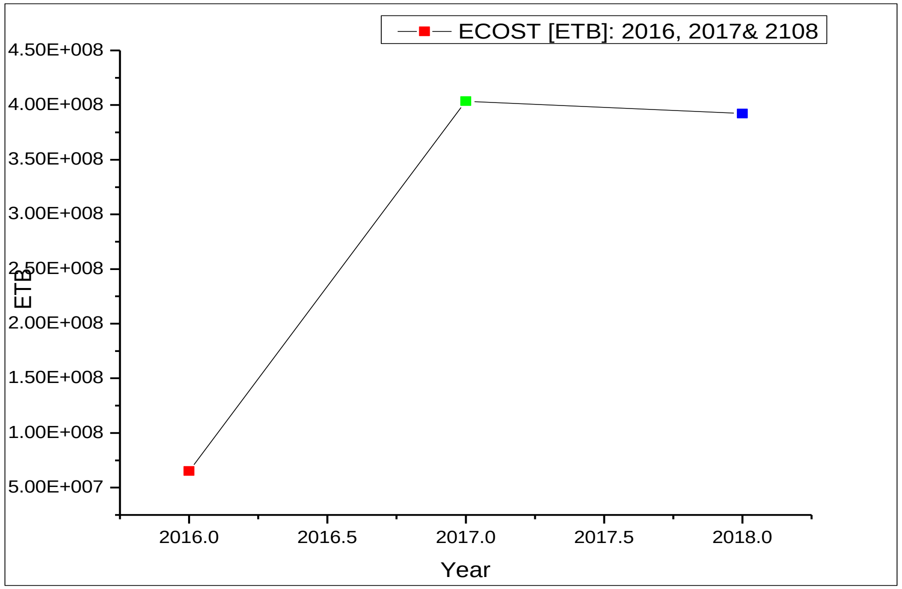


Figure 5-44: Bar graph showing annual ECOST in the years 2016, 2017 & 2018

From Fig. 5.43 above, it is visible that over the years under study, the Expected Energy Not Supplied (EENS) increases progressively. Fig. 5.44 shows a direct relationship between EENS and ECOST but not entirely. This is because the cost in terms of trips cancelled as a result of an outage per year varies. Nonetheless, higher values of EENS imply a high ECOST. It is also seen that ECOST dropped in 2018 as compared 2017 and this can be attributed to MTTR/ MDT.

5.1.3 Interpretation and Comparison of Results

Based on the results discussed above, this section compares and further interprets the most important power reliability indices with selected countries.

In order to make sense of reliability problem at the AALRT (which this research is quantifying through a statistical approach), it is necessary to bench mark the international "System Average Interruption Duration Index" which measures the total duration of electricity blackouts longer than three minutes for the average customer. A country comparison conducted by the Council of European Energy Regulators (CEER) revealed the following findings for 2016 (shown in the figure below).

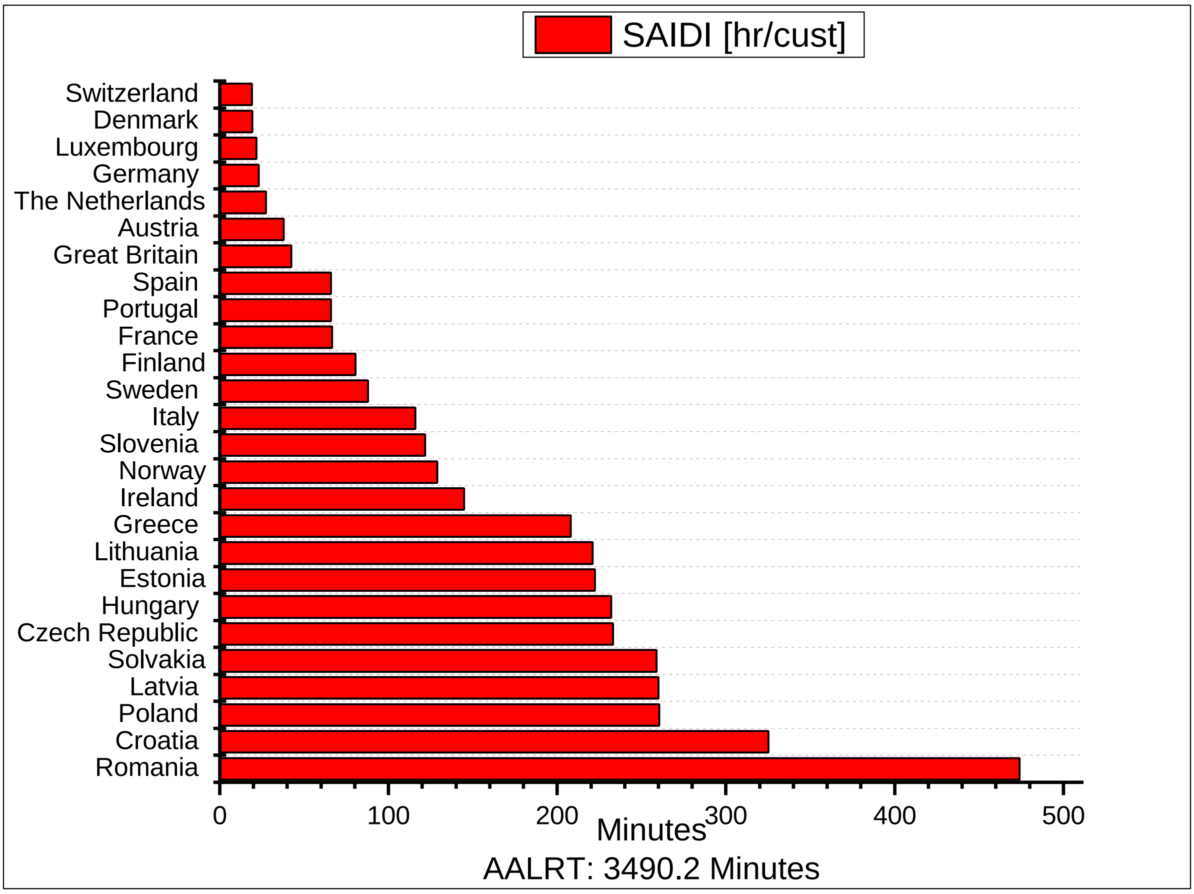


Figure 5-45: Average annual power supply interruption in minutes for European countries in 2016.

Source: CEER Benchmarking Report 6.1, 2018 [41] [42].

Table 5.10: Comparison of AALRT case study with European reliability performance, with major events.

Country		SAIFI [int/cust]	SAIDI [min/cust]
Austria		0.9	72
Denmark		0.5	24
France		1	62
Germany		0.5	23
Italy		2.2	58
The Netherlands		0.3	33
Spain		2.2	104
UK		0.8	90
		SAIFI [int/cust]	**SAIDI [min/cust]**
Case Study: AALRT	**2016**	**4.35**	**2842.350**
	2017	**6.85**	**3418.350**
	2018	**11.2**	**4210.602**
	Average	**7.47**	**3490.200**

Source: [34] and Council of European Energy Regulator ASBL (2008) 4th benchmarking report on the quality of electricity supply. Brussel CEER [43].

As shown Table 5.10 above, from 2016 to 2018, the SAIFI and SAIDI indices have shown a significant increment over these three years of study which implies that the frequency of electric power interruptions has increased over the years and this suggests a direct relation with the increase in electric power outage time in hours. This is graphically visible in Fig. 5.33 but also indicative from the failure rate shown in Fig. 5.35 which has also has increased over these years of study (2016 to 2018). This therefore, has a direct impact on the Expected Energy Not Supplied (EENS) with recorded figures of 120.7999MWhr for 2016, 145.2799MWhr and 178.9505MWhr for 2018. The EENS is directly affected by electric power outage hours i.e. EENS is the product of total outage hours and average load in kilo watts.

The System Average Interruption Duration Index (SAIDI) calculates annual power interruption. It is compiled using the time, duration, extent, and cause of a supply disruption, providing the average duration in minutes (in hours for this research) of a supply disruption per connected end consumer. A power outage can be caused by many different reasons. For example, natural disasters, the general influence of the weather can lead to interruptions in supply and power equipment quality problems such cable failures

(A typical case at the AALRT). Technical failure and human error are further potential causes of a power outage. These would include interruptions that can be traced back to the operator, the influence of third-parties, or other grid problems.

US citizens on average "went without power for four hours during the year" in 2016, according to the US Energy Information Agency (EIA). In Western Australia's three grids, the SAIDI score was 233, 1077 and 343 minutes in 2016-17 [42] [44].

Generally, security of supply strongly correlates with the share of underground electricity cables. In Germany, 80 percent of its 1.8 million kilometers of cables are buried, whereas in the US – with around 40 percent – and Australia and many Southern European countries, this share tends to be lower. This makes the grid more vulnerable to being disrupted, for example by fallen tree branches [42]. One of the main causes of power outages at the AALRT is cable failure yet in other countries that have recorded very good values of SAIDI, security of supply strongly correlates with the share of underground electricity cables.

In Indonesia, SAIDI is given as average hours of outage duration per customer per year, SAIFI is given as outage events per customer per year. In the period between 2010 and 2015 Indonesia recorded on average SAIDI of 7.175 hours and SAIFI of 6.925 [45].

The Manufacturers' Association of Nigeria (MAN) reported Nigeria SAIDI of 60,000 min but another independent research reported a figure of 87,639 minutes This is in spite of the fact that only about 40% of the 140 million Nigerians have access to electricity [46].

The AALRT alone which has dedicated supply from Ethiopian Utility Company has a SAIFI value of 7.47 and SAIDI value of 3490.2 min on average over the years of 2016, 2017 and 2018 with 20 traction substations which represent the number of customers as used in this research. The major factors responsible for the interruption of electric power at AALRT are to be pointed out in the above section. Results of the possible remedies are discussed in the section below.

Chapter 6 SYSTEM MODELLING AND SIMULATION OF RELIABILITY IMPROVEMENT ALTERNATIVES

Modelling and simulation of the assumed system is implemented in Electrical Transient Analyzer Program (ETAP) software. The capability and effectiveness of reliability evaluation are demonstrated according to the simulation results through ETAP which are obtained by applying it to the AALRT power system. To predict the reliability indices of a distribution system, values of failure rates each component are necessary. Table 6.1 shows the number and failure rates of selected elements used for reliability assessment in this research. In Table 6.1, 423 is the total number of elements and 0.017 is the average system failure rate (event per hour).

Table 6.1: Number of elements and failure rate

Element	Number	Failure rate [event/year]
Bus	255	0.001
Power grid	1	0.643
Power cable	105	0.02
Lumped Load	40	0.016
Rectifier	19	0.021
Total	**423**	**0.017**

Source: IEEE Standard 493- 1997

6.1 AALRT System Modelling and Reliability Simulation

According to the system layout shown in Fig. 4.2 (TPLS Loop-in and Loop- out connection wiring diagram) , Fig. B.0.1 and Fig. B.0.2 (as shown in the appendix), the distribution power system (DPS) network of AALRT is supplied from four High Voltage Substations (HVS). All HVSs in this system comprise 132/15 kV and are of Gas Insulated Substation (GIS) type. Each station has two lighting and power substations (LPS). The LPSs supply electric power for equipment and loads. The LPS is located at each substation platform. Through the air insulated switching substations, Rectifier Substation (RS) converts AC to DC power to supply electric energy for traction motors of trains. The RS are nineteen in number; ten on the North- South (NS) line and nine on the East- West (EW) line. The EW line has another substation (EW18- 15 kV/400 V) in Loop-in and Loop- out connection purposely to enhance supply to the signaling and communication equipment as well as auxiliary supply. All the nineteen stations have one RS. Each RS is capable to convert 15 kV (AC) to 750 V (DC) using a twelve- pulse diode rectifier. The 750 V (DC) is the nominal voltage and can vary up to 800 V (DC). The single line diagrams of the distribution power system network drawn in ETAP and are displayed in Fig. 6.1 below;

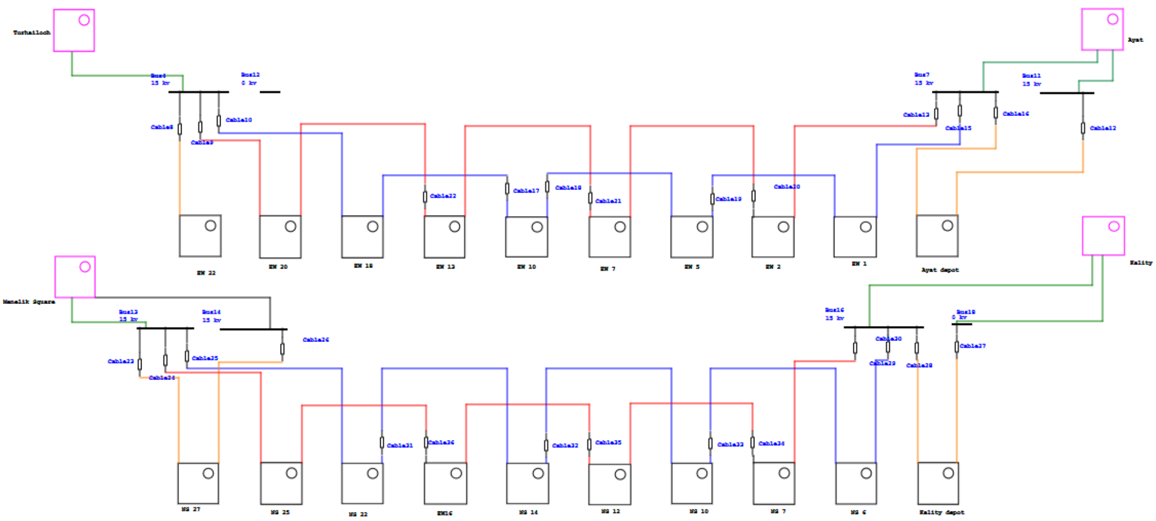


Figure 6-1: Single- line diagram of the AALRT distributed power system

Fig. 6.1 shows the AALRT distributed power system as modelled in ETAP software according to Fig. 4.2. The upper power system is the EW line while the lower system is the NS line. To reduce the complexity of the system, ETAP software allows the user to create composite networks and these can be joined together electrically. As shown in the single line diagram above, the twenty-four boxes represent the composite networks and these were electrically joined together in a loop-in and loop- out connection. There are ten composite networks in cascade on either side i.e. the upper (EW line) and lower (NS line) power system network. These twenty composite networks represent the traction power substations accept EW18 which is a normal step- down 15 kV/400 V substation. Each of this twenty substation receives an incoming line at 15 kV on their bus- bar and there are two receiving step-down transformers i.e. traction transformer (15 kV (AC) to 590 V (AC) to 750 V (DC)) and 15 kV (AC) to 400 V step- down transformer for purposes of signaling and communication as well as auxiliary supply. The connection of this arrangement as drawn in ETAP software is shown in Fig. 6.3 and is representative of the nineteen traction power substations. Fig. 6.4 shows the composite network EW18 as modelled in ETAP software. The two adjacent substations on either side of the EW and NS line (traction substation) are the gas insulated substations and are similar to each other. These four 132/15 kV substations supply the 20 substations in cascade (ten for each two GIS) are also represented as composite power networks. The gas insulated substations receive power from two transformers i.e. redundancy in supply is ensured. The connection of one of the GIS as modelled in the ETAP software is shown in Fig. 6.2 below.

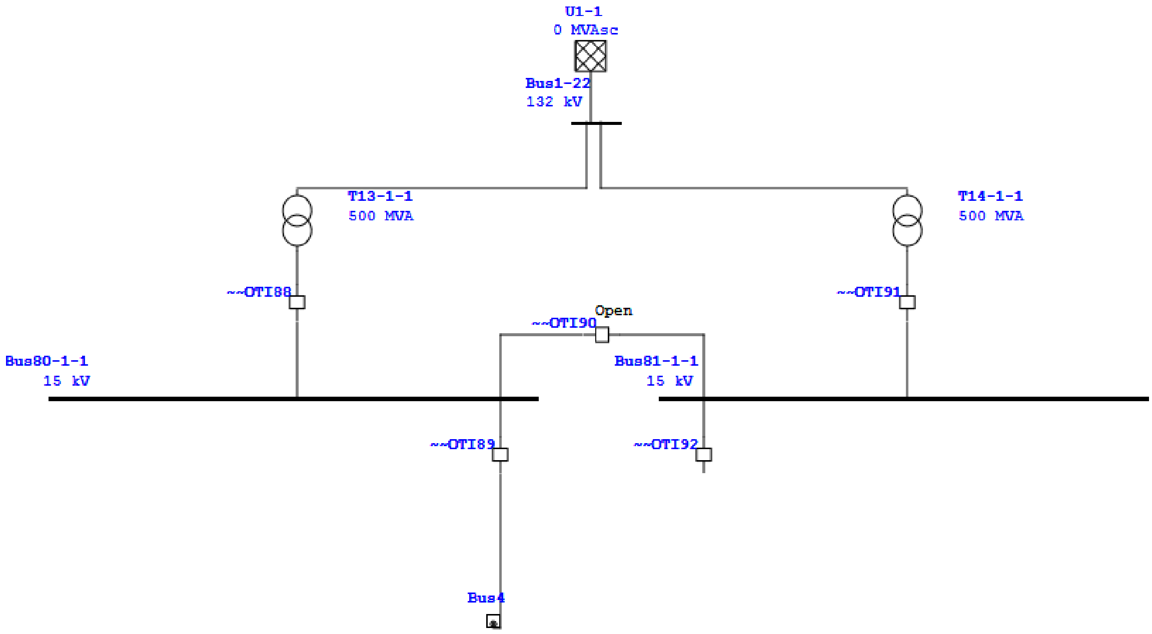


Figure 6-2: GIS substation single- line as drawn in ETAP software

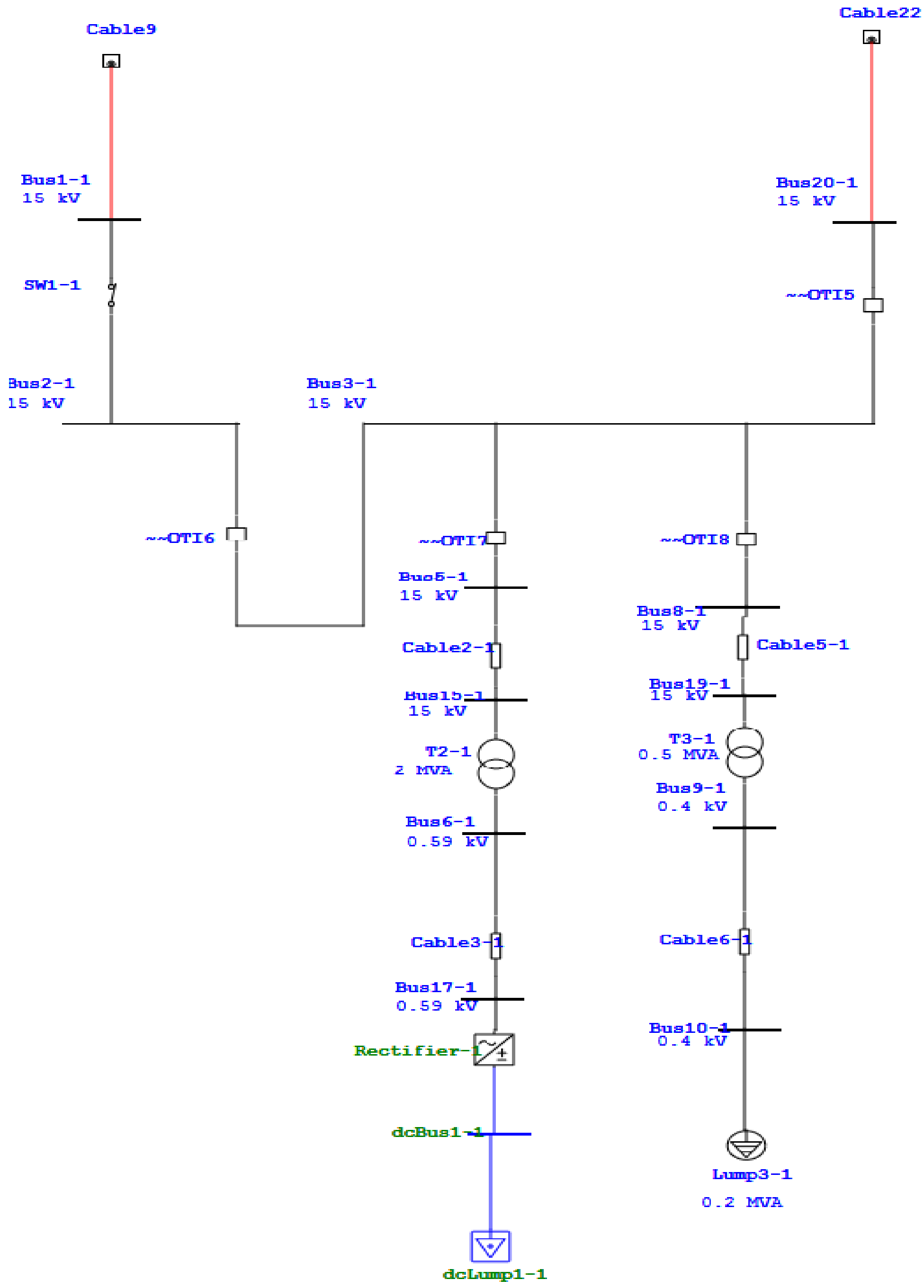


Figure 6-3: Traction substation single- line as drawn in ETAP software

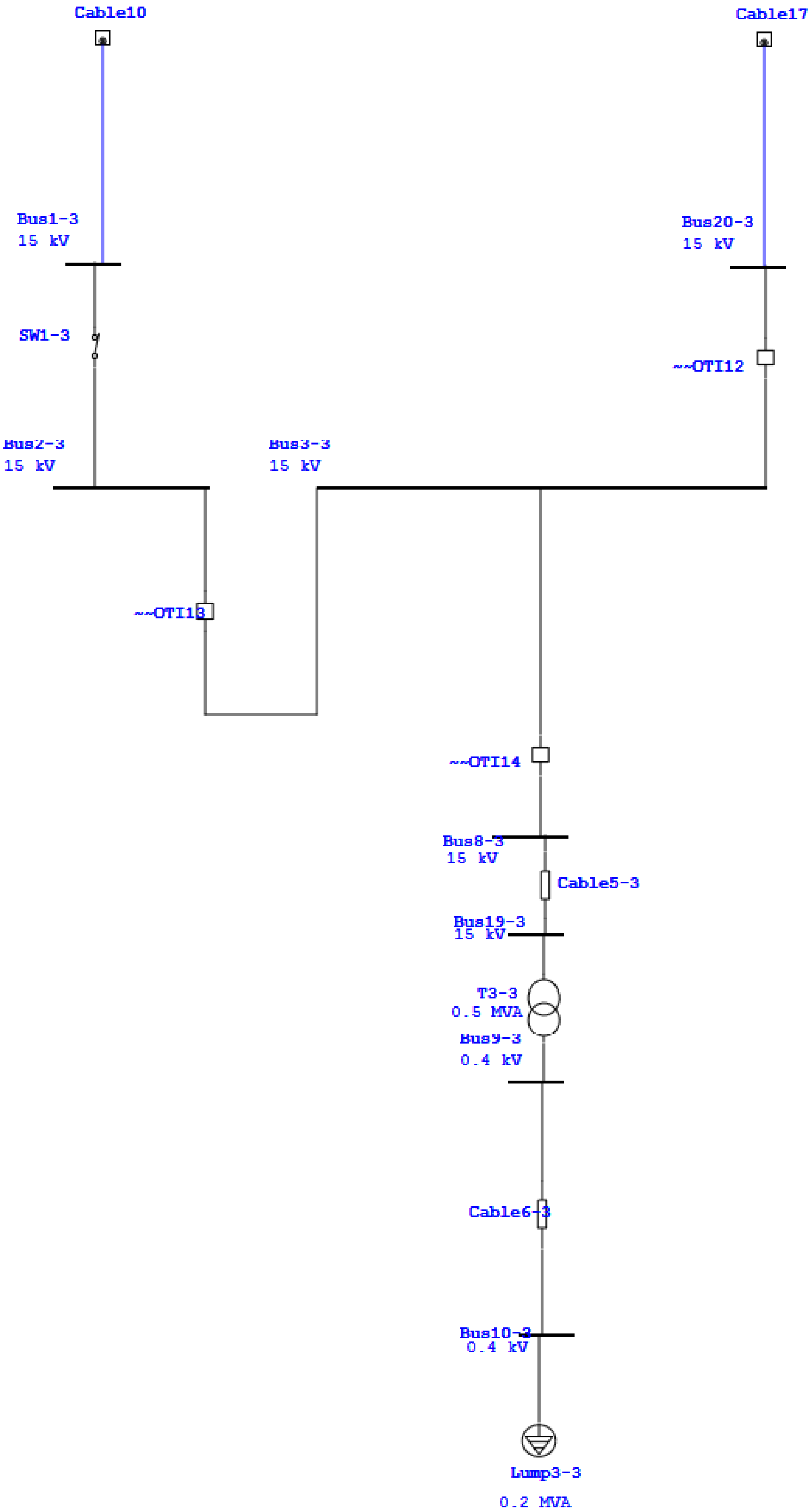


Figure 6-4: EW18 substation single- line as drawn in ETAP software

6.1.1 Reliability Simulation and Results of the Existing System

Based on the failure rates shown in Table 6.1, the model system is simulated in ETAP software by running the 'reliability assessment.' The simulation results are shown and discussed below:

Project: Power Reliability Analysis of DC Traction Power Supply System

Location: AAiT- AAU

Student: Brian Watuwa

Filename: AALRT Case Study Modelling: Existing System Simulation

ETAP: 16.0.0C

Date: 31-05-2019

SN: 4359168

Config.: Normal

SUMMARY

System Indexes

SAIFI: 0.1189 f / customer.yr

SAIDI: 6.5126 hr / customer.yr

CAIDI: 54.783 hr / customer interruption

ASAI: 0.9993 pu

ASUI: 0.00074 pu

EENS: 282.197 MW hr / yr

AENS: 7.2358 MW hr / customer.yr

Where;
AENS: Average Energy Not Supplied
ASAI: Average service Availability Index
ASUI: Average Service Unavailability Index
CAIDI: Customer Average Interruption Duration Index
EENS: Expected Energy Not Supplied
SAIDI: System Average Interruption Duration Index
SAIFI: System Average Interruption Frequency Index

The AENS index results of the collected data (7.4172 MWhr/yr) and those of modelled and simulated (7.2358 MWhr/yr) are matching despite marginal differences in SAIFI and SAIDI indices.

ETAP is Verified and Validated against field results, real system measurements, published cases, other programs, and hand calculations in order to ensure its technical accuracy [47]. For this research therefore, validation of results is not done.

6.2 Simulation of Reliability Improvement Alternatives

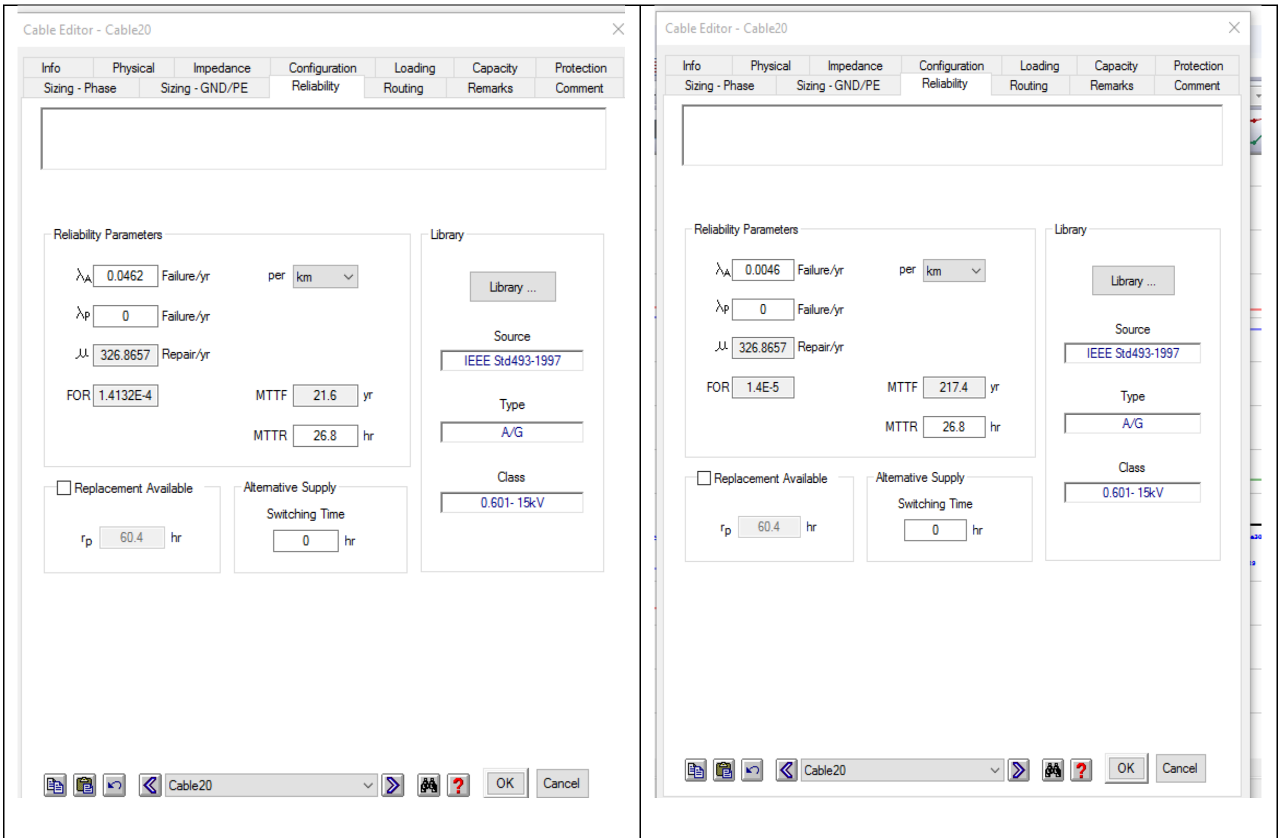
Improvement alternatives as per this research will focus on the ‘how’ causes of power interruptions happening at the AALRT (as discussed in *section 4.3*) can be alleviated. The following improvement alternative cases (based on the above existing modelled and simulated system) are simulated and results are discussed below;

I. Network Cable Replacement

Ring network cable failure has contributed 30% of the overall power interruption causes on the AALRT over this period of reliability study (2016, 2017 & 2018). There are certain sections i.e. EW2 to EW7 and NS6 to NS14 notorious for cable failure and simulation improvement focuses on these sections of the power supply system. Under ring network cable failure replacement analysis, two cases were looked at and these are described below;

a) Case One: Cable replacement in section EW3 to EW7

A cable with a different but better value of failure rate is used in the section EW3 to EW7.



Original case: Cable failure rate, λ = 0.0462	Case one Cable failure rate, λ = 0.0046

Figure 6-5: Example of cable replacement depicting a change in failure rate

The results of case one are shown in Fig 6.6;

Project: Power Reliability Analysis of DC Traction Power Supply System

ETAP: 16.0.0C

Location: AAiT- AAU

Student: Brian Watuwa

Filename: AALRT Case Study Modelling: Existing System Simulation

Date: 31-05-2019

SN: 4359169

Config.: Normal

SUMMARY

System Indexes

SAIFI: 0.1061 f / customer.yr

SAIDI: 6.1611 hr / customer.yr

CAIDI: 58.080 hr / customer interruption

ASAI: 0.9993 pu

ASUI: 0.00074 pu

EENS: 266.545 MW hr / yr

AENS: 6.8345 MW hr / customer.yr

Figure 6-6: ETAP result window capture of reliability improve alternatives, case one

The above results show an overall system reliability improvement as a result of cable replacement in section EW2 to EW7. Cable replacement in section NS6 to NS14 gives similar overall system reliability improvement when simulated independently while keeping section EW2 to EW7 as the original case. Case two below gives the overall effect on system reliability improvement as a result of cable replacement in both EW2 to EW7 and NS6 to NS14 sections.

b) Case Two: Cable replacement in both EW2 to EW7 and NS6 to NS14 sections

After simulating section EW2 to EW7 and NS6 to NS14 independently, cable replacement is done on both sections and simulated. Cables of $\lambda = 0.0046$ are used as in the case one (shown in Fig. 6.5) for both sections. The results are shown in Fig. 6.7 below and these show an overall system reliability improvement.

Project: Power Reliability Analysis of DC Traction Power Supply System	ETAP: 16.0.0C
Location: AAiT- AAU	Date: 31-05-2019
Student: Brian Watuwa	SN: 4359170
Filename: AALRT Case Study Modelling: Existing System Simulation	Config.: Normal

SUMMARY

System Indexes

SAIFI: 0.0677 f / customer.yr

SAIDI: 5.1065 hr / customer.yr

CAIDI: 75.451 hr / customer interruption

ASAI: 0.9994 pu

ASUI: 0.00058 pu

EENS: 222.331 MW hr / yr

AENS: 5.7008 MW hr / customer.yr

Figure 6-7: ETAP result window capture of reliability improve alternatives, case two

II. Ethiopia Electricity Utility Company Power Outage

Power interruptions from the side of utility supply company have contributed an average of 58.3% of the overall power interruption causes on the AALRT over this period of reliability study (2016, 2017 & 2018). This is the biggest cause of power interruptions, however, this research does not investigate the outages on the side of utility company (i.e. whether the interruptions are a result of planned/operational shutdown, system faults, load shedding, etc.).

c) Case Three: Ring network connection of GIS substations

In this case, the four gas insulated substations (which supply the AALRT load) are connected in a ring network. This is done considering the fact that cable failure has been alleviated by replacing cables in both EW2 to EW7 and NS6 to NS14 sections. Therefore, case three is a continuation of case two. The connection as drawn in ETAP software is shown below;

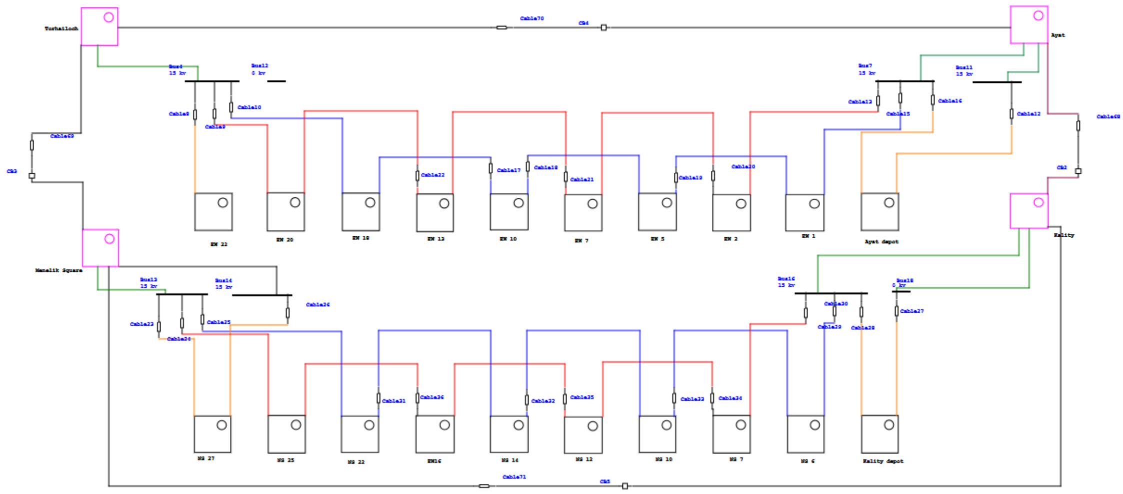


Figure 6-8: Ring network connection of GIS substations in ETAP

The simulation results are shown in Fig. 6.8 below and the results show an overall system reliability improvement.

Project: Power Reliability Analysis of DC Traction Power Supply System

Location: AAiT- AAU

Student: Brian Watuwa

Filename: AALRT Case Study Modelling: Existing System Simulation

ETAP: 16.0.0C

Date: 31-05-2019

SN: 4359171

Config.: Normal

SUMMARY

System Indexes

SAIFI: 0.0493 f / customer.yr

SAIDI: 4.8045 hr / customer.yr

CAIDI: 97.454 hr / customer interruption

ASAI: 0.9997 pu

ASUI: 0.00038 pu

EENS: 201.328 MW hr / yr

AENS: 5.1622 MW hr / customer.yr

Figure 6-9: ETAP result window capture of reliability improve alternatives, case three

Table 6.2: Summary of reliability indices for the simulated existing model and the reliability improvement alternatives.

					Reduction in;			
CASE	**SAIFI**	**SAIDI**	**EENS**	**AENS**	**SAIFI**	**SAIDI**	**EENS**	**AENS**
Existing Case	0.1189	6.5126	282.197	7.2358	0	0	0	0
Case One	0.10611	6.1611	266.545	6.8345	0.0128	0.3515	15.652	0.4013
Case Two	0.0677	5.1065	222.331	5.7008	0.0512	1.4061	59.866	1.5350
Case Three	0.0493	4.8045	201.328	5.1622	0.0696	1.7081	80.869	2.0736

SAIFI: int/cust, SAIDI: hr/cust, EENS: MWhr, AENS [MWhr/cust]

6.2.1 Cost Benefit Analysis of the Reliability Improvement Alternatives

From the Computed Energy and Cost indices for the years 2016, 2017 and 2018 shown in Tables 5.6, 5.7 and 5.8, the cost of the energy not supplied (ECOST) is computed as below;

$$ECOST = EENS \ x \ \ Cost\ of\ trips\ Cancelled\ \ in\ a\ year,$$

where; cost of trips cancelled are the trips that were cancelled due to a power interruption.

Considering the above reliability improvement alternatives shown in Tables 6.2, ECOST is quantified as shown in the table below;

Assumption: The cost of trips cancelled is the average cost of trips cancelled in 2016, 2017 and 2018. This is given by;

$$Average\ Cost\ of\ Trips\ Cancelled = \frac{539755.3 + 2777686 + 2192139}{3}$$

$$= 1{,}836{,}527\ ETB$$

Table 6.3: Summary of EENS and ECOST showing a reduction in ECOST as a result of application of the reliability improvement alternatives.

			Reduction in	
CASE	**EENS [MWhr/yr]**	**ECOST [ETB]**	**EENS [MWhr/yr]**	**ECOST [ETB]**
Existing Case	282.197	518,262,391	0	0
Case One	266.545	489,517,071	15.652	28,745,319.56
Case Two	222.331	408,316,870	59.866	109,945,521.4
Case Three	201.328	369,744,294	80.869	148,518,096.6

From Table 6.3 above, it is evident that when the cables in section EW2 to EW7 and NS6 to NS14 are replaced, there is a significant reduction in ECOST. Furthermore, creating a ring network for four gas insulated further reduces the ECOST.

Chapter 7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

In this research, power reliability analysis of DC traction power supply system for Addis Ababa Light Rail Transit was conducted. The period of study for reliability analysis was three years; 2016, 2017 and 2018. The reliability analysis of traction power supply system for Addis Ababa Light Rail Transit was analyzed in form of power interruptions experienced on the system during operation. Failure data was extracted from daily reports provided by the Operations and Control Centre department of the AALRT. From this failure data, information such as the causes of power interruptions, outage time/ down, failure mode, and affected substation was extracted.

Reliability analysis involved failure analysis and calculation of Basic reliability parameters (which include; failure rate, MTBF, MTTR and Availability), Customer Orientation Indices (SAIFI, SAIDI, CAIDAI, ASAI and ASUI) and Energy and Cost indices (EENS, AENS, ECOST and IEAR). The trend from these indices shows that power interruptions have progressively increased over these three years of study. For the power system availability was 0.8921 in 2016, 0.8699 in 2017 and 0.8398 in 2018. Internationally, SAIFI and SAIDI customer orientation indices are used to quantify how reliable a power supply system is and this research benchmarked the results of SAIFI and SAIDI of AALRT power supply system with the Council of European Energy Regulator Benchmarking Report of 2016. The results showed that there is a lot still to be done at the AALRT. AALRT power supply system recorded on average a SAIFI value7.47 interruptions/customer and a SAIDI value 3490.2 minutes/ customer for the period of study. This is not desirable because of the nature of service provided by the AALRT. Other countries compared were: USA (SAIDI 240 minutes in the year 2016, according to the US Energy Information Agency), Western Australia's three grids, the SAIDI score was 233, 1077 and 343 minutes in 2016-17, In the period between 2010 and 2015 Indonesia recorded on average SAIDI of 215.25 minutes and SAIFI of 6.925, The Manufacturers’ Association of Nigeria (MAN) reported Nigeria SAIDI of 60,000 min. The energy and cost indices especially EENS (which quantifies energy not supplied) and ECOST (which quantifies the cost of energy not supplied) have progressively increased for this period of study.

From the extracted data, this research also identified four main causes of power interruptions and they include; interruption from the Ethiopia Electricity Utility Company contributing 58.3%, ring network cable failure contributing 30%, interruptions from Municipal power system contributing 6.67% and internal power system faults of 5%.

To mitigate the causes of power interruptions at the AALRT, this research developed and simulated a model using an Electrical Transient Analyzer Program (ETAP) software. The existing power supply system was modelled through the ETAP software and simulated. Reliability improvement techniques to tackle the causes of power interruption were simulated by integrating them in the 'existing' system. Three different power interruption mitigation cases were simulated and these showed significant improvement in the reliability indices (ASAI, ASUI, SAIFI, SAIDI, EENS and ECOST). These improvements gave an overall reduction in EENS of 80.869 MWhr/yr. A cost benefit analysis was of these three cases of reliability improvement alternatives was conducted to justify the investment.

In a nutshell, this research has quantified how reliable the AALRT traction power supply system was for this three- year period of study. The trend shows the interruptions are increasing yearly, in some incidences, sometimes, interruption of electricity occurred several times in a day which greatly affected operations in terms of trip cancellation. However, the MTTR has reduced implying a good maintenance strategy. Nonetheless, the reliability of traction power supply system has to be improved to keep valued customers satisfied.

7.2 Recommendations

The reliability question in traction power supply system of the AALRT is a critical issue because of the nature of service it offers to the end user. The AALRT power system reliability compared to other international power system reliability indices is still in deer need of improvement and further research work could be carried out in the areas;

- Cable failure investigation: Cable failure one of the leading causes of traction power supply interruptions contributing about 30% yet the AALRT has been in operation for only five years. Power supply cables should be investigated on issues such as; heating caused by long term overload conditions, proper cable sizing, cable protection system, cable working temperatures, cable safe level and voltage 'spikes' analysis. If cable failure is caused by over voltage or overload, there is need to find out, how much over voltage causes cable failure, what brings about the over load, how does over voltage and over load affect the protection system?
- Ethiopia Electricity Utility supply side outage investigation: This contributes 58.3% of the power interruption causes on the AALRT. There is urgent need to find out what through scientific research the what goes wrong at the utility company side and what are the possible mitigation measures.
- More detailed research on the effect of a power outage on both trip cancellation, train punctuality, passenger clambering out of one of the affected trains between stations when the power tripped. This is because train service punctuality is a very important issue due to the fact it directly impacts on the productivity of the population especially where train service is used by the majority population.

REFERENCES

[1] R. J. Hill, "Electric railway traction, Part 3 Traction power supplies," *Power Eng. J.*, pp. 275–286, 1994.

[2] S. Frey, *Railway Electrification Systems & Engineering*, First. White Word Publications, 2012.

[3] H. Hayashiya, M. Masuda, Y. Noda, K. Suzuki, and T. Suzuki, "Reliability Analysis of DC Traction Power Supply System for Electric Railway," in *19th European Conference on Power Electronics and Applications*, 2017, pp. 1–6.

[4] H. Hayashiya, N. Koguchi, T. Ozaki, T. Sakurai, and R. Inoue, "Improvement of grounding system of DC traction substation in railway power supply system," 2012.

[5] M. R. Haghifam, A. Ghaderi, and M. Abapour, "Enhancement Circuit Breaker Reliability by Using Fault Current Limiter," pp. 1–5, 2009.

[6] T. P.D.F. Conradie, C.J. Fourie, P.J. Vlok, "Quantifying System Reliability in Rail Transportation in an Ageing Fleet Environment," *South African J. Ind. Eng.*, vol. 26, no. 2, pp. 128–142, 2015.

[7] Y. Yuan, W. J. Yong, and X. J. Jian, "Reliability Evaluation of a Bulk Power System for the Traction Power Supply System of a High-Speed Railway," in *Annual Reliability and Maintainability Symposium*, 2009.

[8] S. Sagareli, "Traction Power Systems Reliability Concepts," in *Proceedings of the 2004 ASME/IEEE Joint Rail Conference*, 2004, pp. 1–5.

[9] M. Ghiasi, N. Ghadimi, and E. Ahmadinia, "An analytical methodology for reliability assessment and failure analysis in distributed power system," *SN Appl. Sci.*, no. November 2018, 2018.

[10] E. Berhanu, "Assessment and Study of Power Distribution System Reliability the case of Jimma Town," 2017.

[11] E. Ahmed, S. Abdualla, K. Youssef, and H. Waheed, "Development of Reliability Indices for Electric Distribution Network in Egypt," *Renew. Energy Sustain. Dev.*, vol. 3, no. 1, pp. 19–23, 2017.

[12] S. Abe, S. Yang, M. Shoyama, T. Ninomiya, A. Matsumoto, and A. Fukui, "Operating Mechanism of SiC-SIT DC Circuit Breaker in 400V-DC Power Supply

System for Data Center -In Case of Grounding Fault,” *IEEE*, vol. 2, pp. 2189–2194, 2012.

[13] M. Matsumoto, “Changing RAMS for Railways: Proposals from Japan,” no. 25, pp. 5–8, 2014.

[14] INFRALERT, “Linear Infrastructure Efficiency Improvement by Automated Learning and Optimised Predictive Maintenance Techniques,” 2016.

[15] Y. A. Mahmood, A. H. S. Garmabaki, A. Ahmadi, and A. Kumar, “Electrical Power and Energy Systems Reliability model for frequency converter in electrified railway,” *Int. J. Electr. Power Energy Syst.*, vol. 94, pp. 385–392, 2018.

[16] Z. Liang, M. Chen, G. Shang, and B. Lv, “High-speed Railway External Power Supply Reliability Evaluation of Bayesian Network,” *Energy Power Eng.*, no. July, pp. 828–832, 2013.

[17] D. Feng, S. Lin, X. Sun, and Z. He, “Microelectronics Reliability Reliability assessment for traction power supply system based on Quanti fi cation of Margins and Uncertainties,” *Microelectron. Reliab.*, vol. 88–90, no. June, pp. 1195–1200, 2018.

[18] *International Electrotechnical Commission, IEC 62278 Railway applications – Specification and demonstration of reliability, availability, maintainability and safety (RAMS)*. 2002.

[19] “British Standards Institution, “BS EN 50126-1 The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)",” 2017.

[20] I. C. Report, “Proposed Definitions of Terms for Reporting and Analyzing Outages of Electrical Transmission and Distribution Facilities and Interruptions,” no. 5, pp. 1318–1323, 1968.

[21] I. S. Board, “IEEE Standard Terms for Reporting and Analyzing Outage Occurrences and Outage States of Electrical Transmission Facilities IEEE Standard Terms for Reporting and Analyzing Outage Occurences and Outage States of Electrical Transmission Facilities,” 1988.

[22] R. E. Brown, S. Gupta, R. D. Christie, S. S. Venkata, and R. Fletcher, “Distribution system reliability assessment using Hierarchical Markov Modeling,” *IEEE Trans.*

Power Deliv., vol. 11, no. 4, pp. 1929–1934, 1996.

[23] G. Biru, “Power Relaibaility.” .

[24] T. Dorji, “Reliability assessment of distribution systems,” 2009.

[25] E. Berhanu, “Assessment and Study of Power Distribution System Reliability the case of Jimma Town,” 2017.

[26] R. ANTHONY, “RELIABILITY ANALYSIS OF DISTRIBUTION NETWORK,” 2014.

[27] O. Franklin and A. G. A, “Reliability Analysis of Power Distribution System in Nigeria : A Case Study of Ekpoma Network , Edo State,” *Int. J. Electron. Electr. Eng.*, vol. 2, no. 3, pp. 175–182, 2014.

[28] M. Ghiasi, N. Ghadimi, and E. Ahmadinia, “An analytical methodology for reliability assessment and failure analysis in distributed power system,” *SN Appl. Sci.*, no. November 2018, 2019.

[29] G. Anders, S. Asgarpoor, R. Billinton, N. Chowdhury, and V. Regulation, “The Present Status of Maintenance Strategies and the Impact of Maintenance on Reliability,” *IEEE Trans. Power Syst.*, vol. 16, no. December, 2001.

[30] K. Kolowrocki, “Limit reliability functions of some non- homogeneous series-parallel and parallel- series systems,” *J. Appl. Math. Comput.*, vol. 62, pp. 129–151, 1994.

[31] T. Prakash and K. Thippeswamy, “Reliability Analysis of Power Distribution System : a Case Study,” *Int. J. Eng. Res. Technol.*, vol. 6, no. 07, pp. 557–562, 2017.

[32] *IEEE Trial-Use Guide for Electric Power Distribution Reliability Indices: IEEE Std 1366- 1998*. .

[33] E. Ahmed, S. Abdualla, K. Youssef, and H. Waheed, “Development of Reliability Indices for Electric Distribution Network in Egypt,” vol. 3, no. 1, pp. 1–3, 2017.

[34] “Addis-Ababa-2015.jpg (JPEG Image, 656 × 425 pixels).” [Online]. Available: Addis-Ababa-2015.jpg (JPEG Image, 656 × 425 pixels). [Accessed: 17-Apr-2019].

[35] “Electrical Systems: Substation Bus Schemes.” [Online]. Available: https://www.skm-eleksys.com/2011/09/substation-bus-schemes.html. [Accessed: 25-Mar-2019].

[36] FRANCIS ARTHUR, "PRESENTATION ON SUBSTATION DESIGN - ppt video online download." [Online]. Available: https://slideplayer.com/slide/5845091/. [Accessed: 20-Mar-2019].

[37] E. P. and C. Committee and T. C. on L. E. Engineering, "Guide to Improved Earthquake Performance of Electric Power Systems: Substation Bus Configurations Appendix C," in *American Society of Civil Engineers*, AnshelJ.Schiff, Ed. 1999, pp. 248–249.

[38] "Electrical Bus System and Electrical Substation Layout | Electrical4U," *https://www.electrical4u.com/*. [Online]. Available: https://www.electrical4u.com/. [Accessed: 25-Mar-2019].

[39] D. Seimbille, *Design of power supply system in DC electrified transit railways - Influence of the high voltage network*. 2014.

[40] Č. ELEKTROTECHNIKA, *Substations for DC and AC tractions*. ČKD ELEKTROTECHNIKA, JSC, 2013.

[41] Council of European Energy Regulators (CEER), "Energy Quality of Supply Work Stream (EQS WS) CEER Benchmarking Report 6 . 1 on the Continuity of Electricity and Gas Supply Data update 2015 / 2016," 2018.

[42] "Germany's electricity grid stable amid energy transition | Clean Energy Wire." [Online]. Available: https://www.cleanenergywire.org/factsheets/germanys-electricity-grid-stable-amid-energy-transition. [Accessed: 04-May-2019].

[43] Council of European Energy Regulators (CEER), "4th Benchmarking Report on Quality of Electricity Supply 2008," 2008.

[44] "Average frequency and duration of electric distribution outages vary by states - Today in Energy - U.S. Energy Information Administration (EIA)." [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=35652. [Accessed: 04-May-2019].

[45] A. Reinders and Kunaifi, "Perceived and Reported Reliability of the Electricity Supply at Three Urban Locations in Indonesia," pp. 1–27, 2018.

[46] S. Olayinka, "Towards achieving energy for sustainable development in Nigeria," vol. 34, pp. 255–272, 2017.

[47] ETAP, *Validation Cases and Comparison Results*. 2005.

APPENDIX A

TableA.1: 2016 AALRT Power- Interruption Data

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
January	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.1.3 7:24:00	2016.1.3 8:27:00	1.05
	EW18	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.1.3 7:24:00	2016.1.3 8:27:00	1.05
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.1.3 7:24:00	2016.1.3 8:27:00	1.05
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:17:00	2016.1.6 16:47:00	0.5
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:17:00	2016.1.6 16:47:00	0.5
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:17:00	2016.1.6 16:47:00	0.5
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:17:00	2016.1.6 16:47:00	0.5
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:17:00	2016.1.6 16:47:00	0.5
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 17:17:00	0.9
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 17:17:00	0.9
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 17:17:00	0.9
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 17:17:00	0.9
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 17:17:00	0.9

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.6 16:23:00	2016.1.6 16:53:00	0.5
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:02:00	2.05
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:02:00	2.05
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:02:00	2.05
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:02:00	2.05
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:02:00	2.05
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:02:00	2.05
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:02:00	2.05
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 11:07:00	3.133333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 11:07:00	3.133333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 11:07:00	3.133333333
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 12:13:00	4.233333333
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 12:13:00	4.233333333
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 12:13:00	4.233333333
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 12:13:00	4.233333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 12:13:00	4.233333333
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 12:13:00	4.233333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:35:00	2.6
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:35:00	2.6
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:35:00	2.6
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.17 7:59:00	2016.1.17 10:35:00	2.6
	EW22	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 17:08:00	2016.1.21 18:19:00	1.183333333
	EW20	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 17:08:00	2016.1.21 18:19:00	1.183333333
	EW18	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 17:08:00	2016.1.21 18:19:00	1.183333333
	EW13	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 17:08:00	2016.1.21 18:19:00	1.183333333
	EW22	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 19:18:00	2016.1.21 19:47:00	0.483333333
	EW20	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 19:18:00	2016.1.21 19:47:00	0.483333333
	EW18	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 19:18:00	2016.1.21 19:47:00	0.483333333
	EW13	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.1.21 19:18:00	2016.1.21 19:47:00	0.483333333
	TOTAL						**81.36666667**
February	Ayat depot	222,201 switch protect off	Substation Power Outage	Internal	2016.2.6 0:44:00	2016.2.6 1:51:00	1.116666667
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 9:09:00	2016.2.22 9:55:00	0.766666667
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 11:00:00	0.95
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 11:00:00	0.95

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 11:00:00	0.95
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 11:00:00	0.95
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 11:00:00	0.95
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.2.22 10:03:00	2016.2.22 10:45:00	0.7
	TOTAL						**31.7**

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
March	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 20:41:00	2016.3.2 22:22:00	1.683333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 20:41:00	2016.3.2 22:22:00	1.683333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 20:41:00	2016.3.2 22:22:00	1.683333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 20:41:00	2016.3.2 22:22:00	1.683333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 20:41:00	2016.3.2 22:22:00	1.683333333
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 21:36:00	2016.3.2 22:22:00	0.766666667
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 21:36:00	2016.3.2 22:22:00	0.766666667
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 21:36:00	2016.3.2 22:22:00	0.766666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 22:48:00	2016.3.2 23:30:00	0.7
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 22:48:00	2016.3.2 23:30:00	0.7
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 22:48:00	2016.3.2 23:30:00	0.7
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.2 22:48:00	2016.3.2 23:30:00	0.7
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.3.6 18:21:00	2016.3.6 18:57:00	0.6
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.3.6 18:21:00	2016.3.6 18:57:00	0.6
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.3.6 18:21:00	2016.3.6 18:57:00	0.6
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.3.6 18:21:00	2016.3.6 18:57:00	0.6
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.3.6 18:21:00	2016.3.6 18:57:00	0.6
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.3.6 18:21:00	2016.3.6 18:57:00	0.6
	NS12	211 Switch: Over current	Substation Power Outage	Internal	2016.3.9 18:06:00	2016.3.9 19:12:00	1.1

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.25 0:01:00	2016.3.25 2:29:00	2.466666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.25 0:01:00	2016.3.25 2:29:00	2.466666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.25 0:01:00	2016.3.25 2:29:00	2.466666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.25 0:01:00	2016.3.25 2:29:00	2.466666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.25 0:01:00	2016.3.25 2:29:00	2.466666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.3.25 0:01:00	2016.3.25 2:29:00	2.466666667
	EW20	400V Switch Trip	Substation Power Outage	Internal	2016.3.26 9:44:00	2016.3.26 10:35:00	0.85
	TOTAL						**33.86666667**
April	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.4.11 12:22:00	2016.4.11 22:45:00	10.38333333
	EW16	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2016.4.13 19:20:00	2016.4.13 19:28:00	0.133333333
	NS25	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2016.4.13 19:20:00	2016.4.13 20:09:00	0.816666667
	NS27	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2016.4.13 19:20:00	2016.4.13 20:09:00	0.816666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.4.14 11:32:00	2016.4.14 11:38:00	0.1
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.4.14 11:32:00	2016.4.14 11:38:00	0.1
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.4.14 11:32:00	2016.4.14 11:38:00	0.1
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.4.14 11:32:00	2016.4.14 11:38:00	0.1
	Ayat depot	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2016.4.21 19:20:00	2016.4.21 19:30:00	0.166666667
	EW1	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2016.4.21 19:20:00	2016.4.21 19:30:00	0.166666667
	EW2	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2016.4.21 19:20:00	2016.4.21 19:30:00	0.166666667
	TOTAL						**13.05**

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
May	NS25	111 Switch Over current	Substation Power Outage	Internal	2016.5.7 8:12:00	2016.5.7 11:15:00	3.05
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.11 9:12:00	2016.5.11 18:49:00	9.616666667
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 2:16:00	2016.5.16 3:47:00	1.516666667
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.16 4:39:00	2016.5.16 5:06:00	0.45
	NS10	15kV Power Outage	OCS Power Off	Internal	2016.5.22 6:25:00	2016.5.22 8:16:00	1.85
	NS12	15kV Power Outage	OCS Power Off	Internal	2016.5.22 6:25:00	2016.5.22 8:16:00	1.85
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.5.22 12:27:00	2016.5.22 14:10:00	1.716666667
	TOTAL						**139.75**
June	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.6.4 8:50:00	2016.6.4 9:16:00	0.433333333
	EW22	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2016.6.7 17:14:00	2016.6.7 19:21:00	2.116666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.17 3:42:00	2016.6.17 5:14:00	1.533333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.17 3:42:00	2016.6.17 5:14:00	1.533333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.17 3:42:00	2016.6.17 5:14:00	1.533333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.17 3:42:00	2016.6.17 5:14:00	1.533333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.17 3:42:00	2016.6.17 5:14:00	1.533333333
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.6.24 11:42:00	2016.6.24 11:45:00	0.05
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.6.24 11:42:00	2016.6.24 11:45:00	0.05
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.6.24 11:42:00	2016.6.24 11:54:00	0.2
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.6.26 9:45:00	2016.6.26 10:37:00	0.866666667
	EW22	101 Switch Trip	400V Substation Power Outage	Internal	2016.6.27 14:32:00	2016.6.27 15:55:00	1.383333333
	EW22	102 Switch Trip	400V Substation Power Outage	Internal	2016.6.27 14:32:00	2016.6.27 15:55:00	1.383333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW22	101 Switch Trip	400V Substation Power Outage	Internal	2016.6.27 16:42:00	2016.6.27 18:33:00	1.85
	EW22	102 Switch Trip	400V Substation Power Outage	Internal	2016.6.27 16:42:00	2016.6.27 18:33:00	1.85
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.6.30 9:50:00	2016.6.30 10:14:00	0.4
	TOTAL						**21.85**
July	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.7.10 12:26:00	2016.7.10 12:46:00	0.333333333
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.7.14 23:21:00	2016.7.15 0:12:00	0.85
	Ayat depot	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2016.7.18 15:40:00	2016.7.18 16:51:00	1.183333333
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.7.31 3:54:00	2016.7.31 6:35:00	2.683333333
	TOTAL						**56.03333333**
August	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.3 12:52:00	2016.8.3 13:06:00	0.233333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.6 20:42:00	2016.8.7 12:12:00	15.5
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.8 14:48:00	2016.8.8 15:09:00	0.35
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.8 23:48:00	2016.8.9 1:22:00	1.566666667
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.13 9:15:00	2016.8.13 9:32:00	0.283333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 9:24:00	5.383333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 7:49:00	3.8
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.8.14 4:01:00	2016.8.14 5:55:00	1.9
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.17 12:10:00	2016.8.17 12:16:00	0.1
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.18 14:50:00	2016.8.18 16:08:00	1.3
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.18 14:50:00	2016.8.18 16:08:00	1.3
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.18 14:50:00	2016.8.18 16:08:00	1.3
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.18 14:50:00	2016.8.18 16:08:00	1.3

Month	**Substation**	**Failure Cause**	**Failure Mode**	**Analysis**	**Occurring Date & Time**	**Restoration Date & Time**	**Outage Duration (hrs)**
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.18 14:50:00	2016.8.18 16:08:00	1.3
	EW13	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.18 14:50:00	2016.8.18 16:08:00	1.3
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.24 23:12:00	2016.8.24 23:24:00	0.2
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.24 23:12:00	2016.8.24 23:24:00	0.2
	EW13	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.24 23:12:00	2016.8.24 23:24:00	0.2
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.8.24 23:12:00	2016.8.24 23:24:00	0.2
	TOTAL						**51.01666667**
September	EW22	400V Power Outage	Communication Outage	Internal	2016.9.6 0:55:00	2016.9.6 14:11:00	13.26666667
	EW2	400V Power Outage	Communication Outage	Internal	2016.9.6 14:48:00	2016.9.6 15:25:00	0.616666667
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.9.11 18:26:00	2016.9.11 18:28:00	0.033333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.9.14 15:36:00	2016.9.14 16:28:00	0.866666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.9.14 15:36:00	2016.9.14 16:28:00	0.866666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.9.14 15:36:00	2016.9.14 16:28:00	0.866666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.9.14 15:36:00	2016.9.14 16:28:00	0.866666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.9.14 15:36:00	2016.9.14 16:28:00	0.866666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.9.14 15:36:00	2016.9.14 16:28:00	0.866666667
	EW1	400V Power Outage	Communication Outage	Internal	2016.9.15 7:46:00	2016.9.16 0:23:00	16.61666667
	EW2	400V Power Outage	Communication Outage	Internal	2016.9.15 7:46:00	2016.9.16 0:23:00	16.61666667
	EW5	400V Power Outage	Communication Outage	Internal	2016.9.15 7:46:00	2016.9.16 0:23:00	16.61666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW10	400V Power Outage	Communication Outage	Internal	2016.9.15 7:46:00	2016.9.16 0:23:00	16.61666667
	EW13	400V Power Outage	Communication Outage	Internal	2016.9.15 7:46:00	2016.9.16 0:23:00	16.61666667
	EW16	400V Power Outage	Communication Outage	Internal	2016.9.15 15:17:00	2016.9.16 0:23:00	16.61666667
	EW13	400V Power Outage	Communication Outage	Internal	2016.9.17 11:39:00	2016.9.17 13:37:00	1.966666667
	EW13	400V Power Outage	Communication Outage	Internal	2016.9.18 0:59:00	2016.9.18 12:38:00	11.65
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.9.19 12:09:00	2016.9.19 12:35:00	0.433333333
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.9.23 3:17:00	2016.9.23 6:10:00	2.883333333
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.9.23 3:17:00	2016.9.23 6:10:00	2.883333333
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.9.23 3:17:00	2016.9.23 6:10:00	2.883333333
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.9.23 3:17:00	2016.9.23 6:10:00	2.883333333
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.9.23 3:17:00	2016.9.23 6:10:00	2.883333333
	TOTAL						**147.2833333**
October	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.14 4:01:00	2016.10.14 23:45:00	19.73333333
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.14 4:01:00	2016.10.14 5:56:00	1.916666667
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.14 4:01:00	2016.10.14 5:56:00	1.916666667
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.14 4:01:00	2016.10.14 5:56:00	1.916666667
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.18 23:38:00	2016.10.19 5:35:00	5.95
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.19 1:10:00	2016.10.19 6:00:00	4.833333333
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.19 16:49:00	2016.10.19 17:11:00	0.366666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.19 16:49:00	2016.10.19 17:11:00	0.366666667
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.19 16:49:00	2016.10.19 17:11:00	0.366666667
	EW	Abnormal Isolator Switch	Substation Power Outage	Internal	2016.10.22 2:54:00	2016.10.22 4:00:00	1.1
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.10.25 18:31:00	2016.10.25 18:58:00	0.45
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.10.25 18:31:00	2016.10.25 18:58:00	0.45
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.10.25 18:31:00	2016.10.25 18:58:00	0.45
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.10.25 18:31:00	2016.10.25 18:58:00	0.45
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.30 19:04:00	2016.10.30 19:26:00	0.366666667
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.10.30 19:04:00	2016.10.30 19:15:00	0.183333333
	TOTAL						**40.81666667**
November	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.11.7 3:01:00	2016.11.7 5:50:00	2.816666667
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.11.7 3:01:00	2016.11.7 5:50:00	2.816666667
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.11.7 3:01:00	2016.11.7 5:50:00	2.816666667
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.11.7 3:01:00	2016.11.7 5:50:00	2.816666667
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.11.7 21:38:00	2016.11.7 21:54:00	0.266666667
	Ayat depot	400V Power Outage	Communication Outage	EEU Power Mains Outage	2016.11.9 3:55:00	2016.11.9 16:53:00	12.96666667
	EW1	400V Power Outage	Communication Outage	Internal	2016.11.9 3:55:00	2016.11.9 16:53:00	12.96666667
	EW2	400V Power Outage	Communication Outage	Internal	2016.11.9 3:55:00	2016.11.9 16:53:00	12.96666667
	EW5	400V Power Outage	Communication Outage	Internal	2016.11.9 3:55:00	2016.11.9 16:53:00	12.96666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW7	400V Power Outage	Communication Outage	Internal	2016.11.9 3:55:00	2016.11.9 16:53:00	12.96666667
	EW10	400V Power Outage	Communication Outage	Internal	2016.11.9 3:55:00	2016.11.9 16:53:00	12.96666667
	EW13	400V Power Outage	Communication Outage	Internal	2016.11.9 3:55:00	2016.11.9 16:53:00	12.96666667
	TOTAL						**102.3**
December	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.12.1 16:33:00	2016.12.1 16:51:00	0.3
	Ayat depot	400V Power Outage	Communication Outage	Internal	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	EW1	400V Power Outage	Communication Outage	Internal	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	EW2	400V Power Outage	Communication Outage	Internal	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	EW5	400V Power Outage	Communication Outage	Internal	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	EW7	400V Power Outage	Communication Outage	Internal	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	EW10	400V Power Outage	Communication Outage	Internal	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	EW13	400V Power Outage	Communication Outage	Internal	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.3 5:04:00	2016.12.3 7:30:00	2.433333333
	EW22	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2016.12.6 12:55:00	2016.12.6 13:38:00	0.716666667
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2016.12.6 12:50:00	2016.12.7 14:02:00	13.96666667
	Ayat depot	CB:201&223 Opened	Substation Power Outage	Internal	2016.12.13 10:20:00	2016.12.13 12:55:00	2.583333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	Ayat depot	400V Power Outage	Communic ation Outage	Internal	2016.12.17 9:11:00	2016.12.17 11:16:00	2.083333333
	EW1	400V Power Outage	Communic ation Outage	Internal	2016.12.17 9:11:00	2016.12.17 11:16:00	2.083333333
	EW2	400V Power Outage	Communic ation Outage	Internal	2016.12.17 9:11:00	2016.12.17 11:16:00	2.083333333
	EW5	400V Power Outage	Communic ation Outage	Internal	2016.12.17 9:11:00	2016.12.17 11:16:00	2.083333333
	EW7	400V Power Outage	Communic ation Outage	Internal	2016.12.17 9:11:00	2016.12.17 11:16:00	2.083333333
	EW10	400V Power Outage	Communic ation Outage	Internal	2016.12.17 9:11:00	2016.12.17 11:16:00	2.083333333
	EW13	400V Power Outage	Communic ation Outage	Internal	2016.12.17 9:11:00	2016.12.17 11:16:00	2.083333333
	EW2	400V Power Outage	Communic ation Outage	Internal	2016.12.23 18:21:00	2016.12.23 20:29:00	2.133333333
	EW2	400V Power Outage	Communic ation Outage	Internal	2016.12.24 8:03:00	2016.12.24 11:15:00	3.2
	Ayat depot	400V Power Outage	Communic ation Outage	Internal	2016.12.24 11:02:00	2016.12.24 13:23:00	2.35
	EW13	400V Power Outage	Communic ation Outage	Internal	2016.12.24 23:46:00	2016.12.25 11:15:00	11.48333333
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2016.12.30 8:42:00	2016.12.30 16:13:00	7.516666667
	TOTAL						**228.4166667**

TableA.2: 2016 Power Interruption frequency and effect on operation (Trips Cancelled)

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
January						
2016.1.3		1	0			
2016.1.6		1	16		1	15
2016.1.17		1	35		1	34
2016.1.21		2	17			18
Total	**0**	**5**	**68**	**0**	**2**	**67**
February						
2016.2.6	1		0			
2016.2.22		1	9		1	8
Total	**1**	**1**	**9**	**0**	**1**	**8**
March						
2016.3.2		2	2		1	0
2016.3.6					1	0
2016.3.9				1		2
2016.3.25					1	0
2016.3.26	1		0			
Total	**1**	**2**	**2**	**1**	**3**	**2**
April						
2016.4.11		1	0			
2016.4.13		1			1	0
2016.4.14		1	0			
2016.4.21		1				
Total	**0**	**4**	**0**	**0**	**1**	**0**
May						
2016.5.7				1		0
2016.5.11					1	15
2016.5.16		2	0		2	0
2016.5.22				1	1	16
Total	**0**	**2**	**0**	**2**	**4**	**31**
June						
2016.6.4					1	0
2016.6.7		1	2			
2016.6.17					1	0
2016.6.24					1	0

Date	**EW Line Power Interruption**			**NS Line Power Interruptions**		
	Internal	**External**	**Effect on Operation (Trips Cancelled)**	**Internal**	**External**	**Effect on Operation (Trips Cancelled)**
2016.6.26		1	0			
2016.6.27	2		0			
2016.6.30			2		1	0
Total	**2**	**2**	**4**	**0**	**4**	**0**
July						
2016.7.10					1	0
2016.7.14					1	0
2016.7.18		1	0			
2016.7.31		1	17		1	15
Total	**0**	**2**	**17**	**0**	**3**	**15**
August						
2016.8.3		1	0			
2016.8.6				1		0
2016.8.8					1	0
2016.8.12		1	0		1	0
2016.8.13		1	0			
2016.8.14					1	0
2016.8.17		1	0			
2016.8.18		1	0			
2016.8.24		1	0			
Total	**0**	**6**	**0**	**1**	**3**	**0**
September						
2016.9.6	2					
2016.9.11		1	0			
2016.9.14			2		1	8
2016.9.15	2					
2016.9.17	1					
2016.9.18	1					
2016.9.19					1	0
2016.9.23			5		1	5
Total	**6**	**1**	**7**	**0**	**3**	**13**
October						
2016.10.14					1	1
2016.10.18					1	0
2016.10.19		1	11		1	0
2016.10.20	1			1		

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
2016.10.22	1		0			
2016.10.25		1	0			
2016.10.30		1			1	
Total	**2**	**3**	**11**	**1**	**4**	**1**
November						
2016.11.7		2	6		1	6
2016.11.9	1					
Total	**1**	**2**	**6**	**0**	**1**	**6**
December						
2016.12.1		1	0			
2016.12.3		1	16		1	17
2016.12.6		2	0			
2016.12.7		1	0			
2016.12.13	1	0				
2016.12.17	1	0				
2016.12.23	1	0				
2016.12.24	3					
2016.12.30		1	56		1	56
Total	**6**	**6**	**72**	**0**	**2**	**73**
		2016 SUMMARY				
January	0	5	68	0	2	67
February	1	1	9	0	1	8
March	1	2	2	1	3	2
April	0	4	0	0	1	0
May	0	2	0	2	4	31
June	2	2	4	0	4	0
July	0	2	17	0	3	15
August	0	6	0	1	3	0
September	6	1	7	0	3	13
October	2	3	11	1	4	1
November	1	2	6	0	1	6
December	6	6	72	0	2	73
Total	**19**	**36**	**196**	**5**	**31**	**216**
	NS & WE COMBINED					

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	**External**	**Effect on Operation (Trips Cancelled)**	**Internal**	**External**	**Effect on Operation (Trips Cancelled)**
	Total power interruption: Internal	**Total power interruption: External**	**Total number of Trips Cancelled**			
	24	**67**	**412**			

TableA.3: 2017 Power- Interruption Data

Month	**Substation**	**Failure Cause**	**Failure Mode**	**Analysis**	**Occuring Date & Time**	**Restoration Date & Time**	**Outage Duration (hrs)**
January	OCS at NS23 platform	Over voltage	TCU icon turned red	Ring network Cable Failure	2017.01.1 23:22:00	2017.01.1 23:30:00	0.133333333
	EW7	Protection Settings	Substation Power Outage	Internal	2017.01.4 11:49:00	2017.01.4 12:16:00	0.45
	OCS:EW2-EW5	OCS Damaged at crossing	OCS Power Outage	Internal	2017.01.5 20:50:00	2017.01.6 2:00:00	5.166666667
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.01.11 9:09:00	2017.01.11 14:01:00	4.866666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.01.18 22:37:00	2017.01.19 1:55:00	3.3
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.01.18 22:37:00	2017.01.19 1:55:00	3.3
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.01.31 13:26:00	2017.01.31 14:12:00	0.766666667
	TOTAL						**17.98333333**
February	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.8 5:08:00	2017.02.8 10:37:00	5.483333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 5:48:00	2017.02.9 7:56:00	2.133333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 5:48:00	2017.02.9 7:56:00	2.133333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 5:48:00	2017.02.9 7:56:00	2.133333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 5:48:00	2017.02.9 7:56:00	2.133333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 5:48:00	2017.02.9 7:56:00	2.133333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 5:48:00	2017.02.9 7:56:00	2.133333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 5:48:00	2017.02.9 7:56:00	2.133333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 8:33:00	2017.02.9 8:51	0.3
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 8:33:00	2017.02.9 8:51	0.3

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 8:33:00	2017.02.9 8:51	0.3
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 8:33:00	2017.02.9 11:46:00	3.216666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 8:33:00	2017.02.9 8:51	0.3
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 8:33:00	2017.02.9 8:51	0.3
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.9 8:33:00	2017.02.9 8:51	0.3
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.12 5:31:00	2017.02.12 13:13:00	7.7
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.02.16 10:10:00	2017.02.16 14:27:00	4.283333333
	TOTAL						**75.96666667**
March	EW1	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.3 12:03:00	2017.03.3 14:08:00	2.083333333
	EW2	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.3 12:03:00	2017.03.3 14:08:00	2.083333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW5	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.3 12:03:00	2017.03.3 14:08:00	2.083333333
	EW7	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.3 12:03:00	2017.03.3 14:08:00	2.083333333
	NS6	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.3 12:03:00	2017.03.3 14:08:00	2.083333333
	NS7	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.3 12:03:00	2017.03.3 14:08:00	2.083333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.3 12:03:00	2017.03.3 14:08:00	2.083333333
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 10:02:00	3.55
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 8:08:00	1.65
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 8:08:00	1.65
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 8:08:00	1.65
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.7 6:29:00	2017.03.7 8:08:00	1.65

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.8 9:08:00	2017.03.8 13:07:00	3.983333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.9 13:38:00	2017.03.9 16:10:00	2.533333333
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.03.15 13:37:00	2017.03.15 14:40:00	1.05
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.03.20 18:01:00	2017.03.21 17:10:00	23.15
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.28 12:34:00	2017.03.28 16:32:00	3.966666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.28 12:34:00	2017.03.28 13:30:00	0.933333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.28 12:34:00	2017.03.28 13:30:00	0.933333333
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.28 17:16:00	2017.03.28 17:44:00	0.466666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.28 17:16:00	2017.03.28 17:44:00	0.466666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.03.28 17:16:00	2017.03.28 17:44:00	0.466666667
	TOTAL						**94.63333333**
April	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.04.7 16:05:00	2017.04.7 16:09:00	0.066666667
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.04.9 3:03:00	2017.04.9 6:43:00	3.666666667
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.04.9 6:50:00	2017.04.9 8:50:00	2
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.04.9 22:50:00	2017.04.10 0:55:00	2.083333333
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.10 22:53:00	2017.04.11 1:40:00	2.783333333
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.04.12 9:34:00	2017.04.12 10:43:00	1.15
	NS7	15kV Power Outage	Substation Power Outage	Ring network	2017.04.12 9:34:00	2017.04.12 10:43:00	1.15

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
				Cable Failure			
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.04.12 9:34:00	2017.04.12 10:43:00	1.15
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 8:26:00	2017.04.15 9:05:00	0.65
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 8:26:00	2017.04.15 9:05:00	0.65
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 8:26:00	2017.04.15 9:05:00	0.65
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 8:26:00	2017.04.15 9:05:00	0.65
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 9:40:00	2017.04.15 10:02:00	0.366666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 9:40:00	2017.04.15 10:02:00	0.366666667
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 9:40:00	2017.04.15 10:02:00	0.366666667
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 9:40:00	2017.04.15 10:02:00	0.366666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 11:47:00	2017.04.15 12:02:00	0.25
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 11:47:00	2017.04.15 12:02:00	0.25
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 11:47:00	2017.04.15 12:02:00	0.25
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.15 11:47:00	2017.04.15 12:02:00	0.25
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.22 9:18:00	2017.04.22 10:10:00	0.866666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.22 9:18:00	2017.04.22 10:10:00	0.866666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.22 9:18:00	2017.04.22 10:10:00	0.866666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.22 9:18:00	2017.04.22 10:10:00	0.866666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.22 9:18:00	2017.04.22 10:10:00	0.866666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.22 9:18:00	2017.04.22 10:10:00	0.866666667
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.23 21:25:00	2017.04.24 1:49:00	4.4
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.23 21:25:00	2017.04.24 1:49:00	4.4
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.04.23 21:25:00	2017.04.24 1:49:00	4.4
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.25 12:50:00	2017.04.25 13:10:00	0.333333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.25 12:50:00	2017.04.25 13:10:00	0.333333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.25 12:50:00	2017.04.25 13:10:00	0.333333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.25 12:50:00	2017.04.25 13:10:00	0.333333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.25 12:50:00	2017.04.25 13:10:00	0.333333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.25 12:50:00	2017.04.25 13:10:00	0.333333333
	EW22	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.04.30 5:45:00	2017.04.30 5:58:00	0.216666667
	TOTAL						**39.73333333**
May	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.2 7:48:00	2017.05.2 7:51:00	0.05
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.17 5:45:00	2017.05.17 8:25:00	2.666666667
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.17 5:45:00	2017.05.17 8:25:00	2.666666667
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.17 5:45:00	2017.05.17 8:25:00	2.666666667
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.17 5:45:00	2017.05.17 11:05:00	5.333333333
	EW5	15kV Power Outage	Substation Power Outage	Ring network	2017.05.17 5:45:00	2017.05.17 11:05:00	5.333333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
				Cable Failure			
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.17 5:45:00	2017.05.17 11:05:00	5.333333333
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.24 5:34:00	2017.05.24 7:04:00	1.5
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.24 5:34:00	2017.05.24 7:04:00	1.5
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.24 5:34:00	2017.05.24 7:04:00	1.5
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.24 5:34:00	2017.05.24 7:04:00	1.5
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.24 5:34:00	2017.05.24 11:46:00	6.2
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.24 5:34:00	2017.05.24 11:46:00	6.2
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.25 12:46:00	2017.05.25 15:15:00	2.483333333
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.05.28 14:54:00	2017.05.28 15:27:00	0.55
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.05.28 14:54:00	2017.05.28 15:27:00	0.55
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:38:00	0.566666667
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 21:00:00	3.933333333
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:38:00	0.566666667
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 20:10:00	3.1
	EW7	15kV Power Outage	Substation Power Outage	Ring network	2017.05.29 17:04:00	2017.05.29 17:38:00	0.566666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
				Cable Failure			
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 20:10:00	3.1
	EW13	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:52:00	0.8
	EW18	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 20:10:00	3.1
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:52:00	0.8
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:52:00	0.8
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:26:00	0.366666667
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:26:00	0.366666667
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:26:00	0.366666667
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 17:26:00	0.366666667
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 18:03:00	0.983333333
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 18:03:00	0.983333333
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 18:03:00	0.983333333
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 18:03:00	0.983333333
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 18:03:00	0.983333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.29 17:04:00	2017.05.29 18:03:00	0.983333333
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.31 15:19:00	2017.05.31 15:44:00	0.416666667
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.31 15:19:00	2017.05.31 15:44:00	0.416666667
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.31 15:19:00	2017.05.31 15:44:00	0.416666667
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.31 15:19:00	2017.05.31 15:44:00	0.416666667
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.05.31 15:19:00	2017.05.31 15:44:00	0.416666667
	TOTAL						**72.81666667**
June	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.06.1 4:00:00	2017.06.1 12:45:00	8.75
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.1 8:47:00	2017.06.1 8:56:00	0.15
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.1 8:47:00	2017.06.1 8:56:00	0.15
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.1 8:47:00	2017.06.1 8:56:00	0.15
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.1 8:47:00	2017.06.1 8:56:00	0.15
	NS25	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.2 11:00:00	2017.06.2 13:53:00	2.883333333
	NS22	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.2 11:00:00	2017.06.2 13:53:00	2.883333333
	NS25	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS22	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667
	NS14	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667
	EW16	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667
	NS25	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667
	NS12	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667
	NS7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.4 22:11:00	2017.06.4 23:09:00	0.966666667
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.7 10:25:00	2017.06.7 18:27:00	8.033333333
	EW7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.14 18:29:00	2017.06.14 23:05:00	4.6
	EW2	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.15 22:12:00	2017.06.16 2:29:00	4.283333333
	EW7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.15 22:12:00	2017.06.16 2:29:00	4.283333333
	NS25	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:13:00	2017.06.18 18:44:00	0.516666667
	NS22	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:13:00	2017.06.18 18:44:00	0.516666667
	NS14	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:13:00	2017.06.18 18:44:00	0.516666667
	EW16	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:13:00	2017.06.18 18:44:00	0.516666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:13:00	2017.06.18 18:44:00	0.516666667
	NS14	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:44:00	2017.06.18 23:09:00	4.416666667
	NS12	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:44:00	2017.06.18 23:09:00	4.416666667
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.18 18:44:00	2017.06.18 23:09:00	4.416666667
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.19 0:46:00	2017.06.19 10:16:00	9.5
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.20 6:41:00	2017.06.20 11:34:00	4.883333333
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.23 5:07:00	2017.06.23 23:46:00	18.65
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.24 14:05:00	2017.06.24 14:49:00	0.733333333
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.06.26 14:30:00	2017.06.26 16:18:00	1.8
	TOTAL						**95.45**
July	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.4 13:12:00	2017.07.4 21:56:00	8.733333333
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.4 13:12:00	2017.07.4 21:56:00	8.733333333
	NS25	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.10 17:20:00	2017.07.10 17:29:00	0.15
	NS22	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.10 17:20:00	2017.07.10 17:29:00	0.15
	NS14	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.10 17:20:00	2017.07.10 17:29:00	0.15

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW16	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.10 17:20:00	2017.07.10 17:29:00	0.15
	NS12	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.10 17:29:00	2017.07.10 23:40:00	6.183333333
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.13 4:00:00	2017.07.13 7:33:00	3.55
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.23 16:16:00	2017.07.23 16:50:00	0.566666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.23 16:16:00	2017.07.23 16:50:00	0.566666667
	NS27	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.25 14:13:00	2017.07.25 15:32:00	1.316666667
	NS25	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.25 14:13:00	2017.07.25 15:32:00	1.316666667
	NS22	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.25 14:13:00	2017.07.25 15:32:00	1.316666667
	NS14	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.25 14:13:00	2017.07.25 15:32:00	1.316666667
	EW16	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.25 14:13:00	2017.07.25 15:32:00	1.316666667
	NS12	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.25 14:13:00	2017.07.25 15:32:00	1.316666667
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.26 0:58:00	2017.07.26 11:02:00	10.06666667
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 4:41:00	2017.07.30 6:09:00	1.466666667
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 4:41:00	2017.07.30 6:09:00	1.466666667
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 4:41:00	2017.07.30 6:09:00	1.466666667
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 4:41:00	2017.07.30 12:58:00	8.283333333
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network	2017.07.30 17:05:00	2017.07.30 18:02:00	0.95

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
				Cable Failure			
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 17:05:00	2017.07.30 18:02:00	0.95
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 17:05:00	2017.07.30 18:02:00	0.95
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 17:05:00	2017.07.30 18:02:00	0.95
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.07.30 17:05:00	2017.07.30 18:02:00	0.95
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.31 6:21:00	2017.07.31 6:46:00	0.416666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.31 6:21:00	2017.07.31 6:46:00	0.416666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.07.31 6:21:00	2017.07.31 6:46:00	0.416666667
	TOTAL						**65.58333333**
August	EW16	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.3 22:20:00	2017.08.3 23:35:00	1.25
	NS6	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.3 22:20:00	2017.08.4 3:05:00	4.75
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.3 22:20:00	2017.08.4 3:05:00	4.75
	NS12	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.3 22:20:00	2017.08.4 3:05:00	4.75
	NS14	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.3 22:20:00	2017.08.4 3:05:00	4.75
	NS22	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.3 22:20:00	2017.08.4 3:05:00	4.75
	NS25	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.3 22:20:00	2017.08.4 3:05:00	4.75

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.4 12:07:00	2017.08.4 16:58:00	4.85
	NS6	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.5 1:21:00	2017.08.5 11:51:00	10.5
	NS7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.5 1:21:00	2017.08.5 11:51:00	10.5
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.5 1:21:00	2017.08.5 11:51:00	10.5
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.15 15:25:00	2017.08.15 16:13:00	0.8
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.15 15:25:00	2017.08.15 16:13:00	0.8
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.15 15:25:00	2017.08.15 16:13:00	0.8
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.15 15:25:00	2017.08.15 16:13:00	0.8
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.17 15:10:00	2017.08.17 15:25:00	0.25
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.17 15:10:00	2017.08.17 15:25:00	0.25
	Kality depot	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.17 19:00:00	2017.08.17 19:10:00	0.166666667
	NS6	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.17 19:00:00	2017.08.17 19:10:00	0.166666667
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.20 4:38:00	2017.08.20 5:36:00	0.966666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.20 4:38:00	2017.08.20 5:36:00	0.966666667
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.20 4:38:00	2017.08.20 5:36:00	0.966666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.20 4:38:00	2017.08.20 5:36:00	0.966666667
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.25 11:16:00	2017.08.25 12:23:00	1.116666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.26 0:02:00	2017.08.26 3:45:00	3.716666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.26 10:20:00	2017.08.26 11:06:00	0.766666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.26 10:20:00	2017.08.26 11:06:00	0.766666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.26 10:20:00	2017.08.27 11:37:00	1.283333333
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.27 14:57:00	2017.08.27 18:06:00	3.15
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.27 14:57:00	2017.08.27 15:21:00	0.4
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.27 14:57:00	2017.08.27 15:21:00	0.4
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.08.27 14:57:00	2017.08.27 20:26:00	5.483333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 11:55:00	0.566666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 11:55:00	0.566666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 13:10:00	1.816666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 13:10:00	1.816666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 11:55:00	0.566666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 11:55:00	0.566666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 11:55:00	0.566666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 11:55:00	0.566666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.29 11:21:00	2017.08.29 11:55:00	0.566666667
	NS10	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.08.31 9:50:00	2017.08.31 12:39:00	2.816666667
	TOTAL						**122.7166667**

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
September	EW18	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.1 18:43:00	2017.09.1 18:49:00	0.1
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.1 18:43:00	2017.09.1 18:49:00	0.1
	EW22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.1 18:43:00	2017.09.1 18:49:00	0.1
	EW18	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.1 18:49:00	2017.09.1 18:54:00	0.083333333
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:17:00	2017.09.5 16:45:00	0.466666667
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:17:00	2017.09.5 16:45:00	0.466666667
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:17:00	2017.09.5 16:45:00	0.466666667
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:17:00	2017.09.5 16:45:00	0.466666667
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:17:00	2017.09.5 16:45:00	0.466666667
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:17:00	2017.09.5 16:45:00	0.466666667
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:54:00	2017.09.5 16:58:00	0.066666667
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:54:00	2017.09.5 16:58:00	0.066666667
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:54:00	2017.09.5 16:58:00	0.066666667
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:54:00	2017.09.5 16:58:00	0.066666667
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:54:00	2017.09.5 16:58:00	0.066666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.5 16:54:00	2017.09.5 16:58:00	0.066666667
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.7 3:00:00	2017.09.7 4:27:00	1.45
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.7 3:00:00	2017.09.7 4:27:00	1.45
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.7 3:00:00	2017.09.7 4:27:00	1.45
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.7 3:00:00	2017.09.7 4:27:00	1.45
	NS11 & NS12 up-section	Lightning strike	Power Outage	Internal	2017.09.9 14:00:00	2017.09.9 18:36:00	4.6
	NS6	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.21 22:03:00	2017.09.24 23:38:00	73.75
	NS7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.21 22:03:00	2017.09.24 23:38:00	73.75
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.09.21 22:03:00	2017.09.24 23:38:00	73.75
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.25 21:36:00	2017.09.25 23:21:00	1.75
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.25 21:36:00	2017.09.25 23:21:00	1.75
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.25 21:36:00	2017.09.25 23:21:00	1.75
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.29 15:10:00	2017.09.29 19:01:00	3.85
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.29 22:38:00	2017.09.29 23:20:00	0.7
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.29 15:10:00	2017.09.30 23:53:00	32.16666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.29 15:10:00	2017.09.30 23:53:00	32.16666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.09.29 15:10:00	2017.09.30 0:11:00	9.016666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	TOTAL						**318.3833333**
October	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.10.1 21:20:00	2017.10.1 22:30:00	1.166666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.10.1 21:20:00	2017.10.1 22:30:00	1.166666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.10.1 21:20:00	2017.10.1 22:30:00	1.166666667
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.10.1 21:20:00	2017.10.1 23:46:00	2.433333333
	NS6	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.2 8:23:00	2017.10.5 16:30:00	10
	NS7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.2 8:23:00	2017.10.5 16:30:00	10
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.2 8:23:00	2017.10.5 16:30:00	10
	NS6	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.8 5:08:00	2017.10.21 12:33:00	20
	NS7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.8 5:08:00	2017.10.21 12:33:00	20
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.8 5:08:00	2017.10.21 12:33:00	20
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.25 17:25:00	2017.10.25 23:39:00	6.233333333
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.26 1:32:00	2017.10.26 12:01:00	10.48333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.10.26 1:32:00	2017.10.26 5:35:00	4.05
	TOTAL						**116.7**
November	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.11.4 6:17:00	2017.11.4 6:25:00	0.133333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.11.4 6:17:00	2017.11.4 6:25:00	0.133333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.11.4 6:17:00	2017.11.4 6:25:00	0.133333333
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:51:00	2017.11.4 9:26:00	2.583333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:17:00	2017.11.4 9:26:00	3.15
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.4 6:17:00	2017.11.4 6:25:00	0.133333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.11.8 19:03:00	2017.11.8 20:02:00	0.983333333
	NS10	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.13 2:04:00	2017.11.13 9:35:00	7.516666667
	NS14	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.13 2:04:00	2017.11.13 9:35:00	7.516666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.15 3:18:00	2017.11.15 4:40:00	1.366666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.15 3:18:00	2017.11.15 4:40:00	1.366666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.11.15 3:18:00	2017.11.15 4:40:00	1.366666667
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.11.27 9:46:00	2017.11.27 13:42:00	3.933333333
	TOTAL						**79.4**
December	NS14	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.5 12:22:00	2017.12.5 13:17:00	0.916666667
	NS12	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.5 12:22:00	2017.12.5 13:17:00	0.916666667
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.5 12:22:00	2017.12.5 13:17:00	0.916666667
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.8 6:56:00	2017.12.8 7:35:00	0.65
	NS6	15kV Power Outage	Substation Power Outage	Ring network	2017.12.8 6:56:00	2017.12.8 7:35:00	0.65

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
				Cable Failure			
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.8 6:56:00	2017.12.8 7:35:00	0.65
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.8 8:00:00	2017.12.8 8:35:00	0.583333333
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.8 8:00:00	2017.12.8 8:35:00	0.583333333
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.8 8:00:00	2017.12.8 10:42:00	2.7
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2017.12.12 14:29:00	2017.12.12 16:42:00	2.216666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.12.22 16:36:00	2017.12.22 17:08:00	0.533333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2017.12.25 11:19:00	2017.12.25 12:03:00	0.733333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.28 14:39:00	2017.12.28 15:23:00	0.733333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 7:45:00	1.5
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 7:45:00	1.5
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 10:24:00	4.15
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 10:36:00	4.35
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 11:36:00	5.35
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 11:36:00	5.35
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 7:06:00	0.85
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 7:06:00	0.85
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 7:06:00	0.85

Month	Substation	Failure Cause	Failure Mode	Analysis	Occuring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	201712..31 6:15:00	2017.12.31 7:06:00	0.85
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 7:06:00	0.85
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2017.12.31 6:15:00	2017.12.31 7:06:00	0.85
	TOTAL						**40.08333333**

TableA.4: 2017 Power Interruption frequency and effect on operation (Trips Cancelled)

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
January						
2017.01.1				1		0
2017.01.4	1		0	1		
2017.01.11					1	0
2017.01.18		1	0	1	1	0
2017.01.31					1	0
Total	**1**	**1**	**0**	**3**	**3**	**0**
February						
2017.02.8					1	12
2017.02.9		1	2		2	2
2017.02.12					1	36
2017.02.16		1	8		1	12
Total	**0**	**2**	**10**	**0**	**5**	**62**
March						
2017.03.3		1	0		1	0
2017.03.7		1	21		1	10
2017.03.8					1	0
2017.03.9					1	6
2017.03.15		1	0			
2017.03.20					1	2
2017.03.28		1	1		1	1
Total	**0**	**4**	**22**	**0**	**6**	**19**
April						
2017.04.7		1	0			
2017.04.9		1	1		1	13
2017.04.10		1	5			
2017.04.12					1	0
2017.04.15		2	0		1	0
2017.04.22					1	3
2017.04.23		1	0			
2017.04.25					1	0
2017.04.30		1				
Total	**0**	**7**	**6**	**0**	**5**	**16**
May						
2017.05.2		1	0			

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
2017.05.17		1	16			
2017.05.24		1	4		1	10
2017.05.25					1	11
2017.05.28		1	0			
2017.05.29		1	8		1	4
2017.05.31					1	0
Total	**0**	**5**	**28**	**0**	**4**	**25**
June						
2017.06.1					2	31
2017.06.2			4		1	7
2017.06.4					1	0
2017.06.7					1	37
2017.06.14		1	4			
2017.06.15		1	0			
2017.06.18					1	13
2017.06.19					1	20
2017.06.20					1	21
2017.06.23					1	0
2017.06.24					1	0
2017.06.26					1	1
Total	**0**	**2**	**8**	**0**	**11**	**130**
July						
2017.07.4		1	0			
2017.07.10		1			1	0
2017.07.13		1	5		1	
2017.07.23					1	0
2017.07.25		1			1	2
2017.07.26					1	47
2017.07.30		1	6		1	34
2017.07.31					1	0
Total	**0**	**5**	**11**	**0**	**7**	**83**
August						
2017.08.3		1			1	0
2017.08.4					1	14
2017.08.5					1	45
2017.08.15					1	0
2017.08.17					2	0
2017.08.20		1	4			

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
2017.08.25		1	6		1	8
2017.08.26		1	0		2	0
2017.08.27			23		1	24
2017.08.29					1	0
2017.08.31					1	12
Total	**0**	**4**	**33**	**0**	**12**	**103**
September						
2017.09.1		2	0			
2017.09.5		1	4		1	3
2017.09.7		1	0			
2017.09.9				1		16
2017.09.21					1	48
2017.09.22					1	48
2017.09.23					1	52
2017.09.24					1	46
2017.09.25					1	1
2017.09.29			46		2	48
Total	**0**	**4**	**50**	**1**	**8**	**262**
October						
2017.10.1			2		1	3
2017.10.2					1	51
2017.10.3					1	46
2017.10.4					1	53
2017.10.5					1	47
2017.10.8					1	57
2017.10.9					1	53
2017.10.10					1	52
2017.10.11					1	48
2017.10.12					1	51
2017.10.13					1	53
2017.10.14					1	50
2017.10.15					1	50
2017.10.16					1	53
2017.10.17					1	48
2017.10.18					1	52
2017.10.19					1	52
2017.10.20					1	47
2017.10.21					1	32

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
2017.10.25		1				
2017.10.26		1				
Total	**0**	**2**	**2**	**0**	**19**	**898**
November						
2017.11.4		1	24		2	28
2017.11.8		1	0			
2017.11.13					1	17
2017.11.15			3		1	2
2017.11.27			3		1	32
Total	**0**	**2**	**30**	**0**	**5**	**79**
December						
2017.12.5					1	0
2017.12.8			11		2	12
2017.12.12					1	9
2017.12.22					1	0
2017.12.25					1	2
2017.12.28					1	2
2017.12.31		1	10		1	4
Total	**0**	**1**	**21**	**0**	**8**	**29**
		2017 SUMMARY				
January	1	1	0	3	3	0
February	0	2	10	0	5	62
March	0	4	22	0	6	19
April	0	7	6	0	5	16
May	0	5	28	0	4	25
June	0	2	8	0	11	130
July	0	5	11	0	7	83
August	0	4	33	0	12	103
September	0	4	50	1	8	262
October	0	2	2	0	19	898
November	0	2	30	0	5	79
December	0	1	21	0	8	29
Total	**1**	**39**	**221**	**4**	**93**	**1706**
	NS & EW COMBINED					

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	**External**	**Effect on Operation (Trips Cancelled)**	**Internal**	**External**	**Effect on Operation (Trips Cancelled)**
	Total power interruption: Internal	**Total power interruption: External**	**Total number of Trips Cancelled**			
	5	**132**	**1927**			

TableA.5: 2018 AALRT Power- Interruption Data

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
January	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.01.09 15:05:00	2018.01.09 15:25:00	0.333333333
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.12 21:40:00	2018.01.12 22:37:00	0.95
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.12 21:40:00	2018.01.12 22:37:00	0.95
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.12 21:40:00	2018.01.12 22:37:00	0.95
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.12 21:40:00	2018.01.12 22:37:00	0.95
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.16 16:19:00	2018.01.16 18:15:00	1.933333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.01.17 7:08:00	2018.01.17 7:56:00	0.8
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.17 17:26:00	17.01.2018 20:39:00	3.216666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.17 17:26:00	2018.01.17 20:17:00	2.85
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.17 17:26:00	2018.01.17 20:17:00	2.85
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.17 17:26:00	2018.01.17 20:17:00	2.85
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.17 17:26:00	2018.01.17 21:14:00	3.8
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.01.23 9:25:00	2018.01.23 11:04:00	1.65
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.24 22:25:00	2018.01.24 22:53:00	0.466666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.24 22:25:00	2018.01.24 22:53:00	0.466666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.24 22:25:00	2018.01.24 22:53:00	0.466666667
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.24 23:20:00	2018.01.24 23:40:00	0.333333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.24 23:20:00	2018.01.24 23:40:00	0.333333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.24 23:20:00	2018.01.24 23:40:00	0.333333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.24 22:25:00	2018.01.24 23:40:00	1.25
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.24 22:25:00	2018.01.25 1:24:00	2.983333333
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.24 22:25:00	2018.01.25 1:24:00	2.983333333
	EW1	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.26 14:08:00	2018.01.26 14:14:00	0.1
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.01.26 14:08:00	2018.01.26 14:14:00	0.1
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.30 9:52:00	2018.01.30 10:42:00	0.833333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.30 9:52:00	2018.01.30 10:42:00	0.833333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.30 9:52:00	2018.01.30 10:42:00	0.833333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.01.30 9:52:00	2018.01.30 10:42:00	0.833333333
	TOTAL						**37.23333333**
February	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.02.4 17:50:00	2018.02.4 19:35:00	1.75
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.5 8:25:00	2018.02.5 9:01:00	0.6
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.02.8 11:52:00	2018.02.8 12:24:00	0.533333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.9 11:14:00	2018.02.9 11:39:00	0.416666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.9 11:14:00	2018.02.9 11:39:00	0.416666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.9 11:14:00	2018.02.9 11:39:00	0.416666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.9 11:14:00	2018.02.9 11:39:00	0.416666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.9 11:14:00	2018.02.9 11:50:00	0.6
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.9 11:14:00	2018.02.9 11:50:00	0.6
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.10 9:05:00	2018.02.10 9:19:00	0.233333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.10 9:05:00	2018.02.10 9:19:00	0.233333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.10 9:05:00	2018.02.10 9:19:00	0.233333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.10 9:05:00	2018.02.10 9:19:00	0.233333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.10 9:05:00	2018.02.10 9:19:00	0.233333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.10 9:05:00	2018.02.10 9:19:00	0.233333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.02.10 9:05:00	2018.02.10 9:25:00	0.333333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.02.11 16:32:00	2018.02.11 17:04:00	0.533333333
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.13 21:25:00	13.02.2018 21:32:00	0.116666667
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.14 1:18:00	2018.02.14 4:52:00	3.566666667
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.14 1:18:00	2018.02.14 5:36:00	4.3
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.14 1:18:00	2018.02.14 5:36:00	4.3
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.02.16 9:30:00	2018.02.16 9:53:00	0.383333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.02.16 15:06:00	2018.02.16 16:08:00	1.033333333
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.20 11:33:00	2018.02.20 12:39:00	1.1
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.02.24 23:12:00	2018.02.25 0:52:00	1.666666667
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.02.27 22:09:00	2018.02.27 22:46:00	0.616666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.02.28 21:12:00	2018.02.28 22:46:00	1.566666667
	TOTAL						**35.66666667**
March	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.03.2 16:20:00	2018.03.2 17:25:00	1.083333333
	NS7	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.2 16:20:00	2018.03.2 20:03:00	3.716666667
	NS12	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.2 16:20:00	2018.03.2 20:03:00	3.716666667
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.3 1:52:00	2018.03.3 7:58:00	6.1

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.3 1:52:00	2018.03.3 7:58:00	6.1
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.03.4 19:07:00	2018.03.4 19:34:00	0.45
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.6 6:04:00	2018.03.6 15:30:00	9.433333333
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.8 1:08:00	2018.03.8 5:23:00	4.25
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.10 1:42:00	2018.03.10 5:25:00	3.716666667
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.10 1:42:00	2018.03.10 5:25:00	3.716666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.10 12:52:00	2018.03.10 14:09:00	1.283333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.10 12:52:00	2018.03.10 14:09:00	1.283333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	10.03.2018 12:52:00	10.03.2018 14:09:00	1.283333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.03.11 1:01:00	2018.03.11 1:32:00	0.516666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.03.18 16:25:00	2018.03.18 17:15:00	0.833333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.24 12:02:00	2018.03.24 13:09:00	1.116666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.24 12:02:00	2018.03.24 13:09:00	1.116666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.24 12:02:00	2018.03.24 13:09:00	1.116666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.24 12:02:00	2018.03.24 13:09:00	1.116666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.24 12:02:00	2018.03.24 13:09:00	1.116666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.27 0:30:00	2018.03.27 2:29:00	1.983333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.27 0:30:00	2018.03.27 2:29:00	1.983333333
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.27 0:30:00	2018.03.27 11:12:00	10.7

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.03.27 0:30:00	2018.03.27 11:12:00	10.7
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	28.03.2018 12:11:00	28.03.2018 12:44:00	0.55
	TOTAL						**78.98333333**
April	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.3 12:28:00	2018.04.3 12:48:00	0.333333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.3 14:10:00	2018.04.3 16:10:00	2
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.3 16:42:00	2018.04.3 18:06:00	1.4
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.4 14:05:00	2018.04.4 14:37:00	0.533333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.5 8:58:00	2018.04.5 10:06:00	1.133333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.5 15:36:00	2018.04.5 15:58:00	0.366666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.5 17:51:00	2018.04.5 18:30:00	0.65
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.7 8:01:00	2018.04.7 8:19:00	0.3
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.9 6:17:00	2018.04.9 8:17:00	2
	Ayat depot	400VCB Failure	Substation Power Outage	Ring network Cable Failure	2018.04.10 21:32:00	2018.04.10 23:08:00	1.6
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.14 2:58:00	2018.04.14 6:32:00	3.566666667
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.14 2:58:00	2018.04.14 6:32:00	3.566666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.15 9:36:00	2018.04.15 10:02:00	0.433333333
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.18 5:56:00	2018.04.18 12:40:00	6.733333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.18 9:42:00	2018.04.18 11:30:00	1.8
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.20 12:26:00	2018.04.20 13:46:00	1.333333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS14	213 HSCB Failure	Substation Power Outage		2018.04.23 0:05:00	2018.04.23 6:16:00	6.183333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.04.26 17:15:00	2018.04.26 18:43:00	1.466666667
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.28 13:24:00	2018.04.28 14:14:00	0.833333333
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.28 13:24:00	2018.04.28 14:14:00	0.833333333
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.28 13:24:00	2018.04.28 14:14:00	0.833333333
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.28 13:24:00	2018.04.28 14:14:00	0.833333333
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.04.29 1:52:00	2018.04.29 5:03:00	3.183333333
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 12:26:00	2018.04.30 13:42:00	1.266666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 18:36:00	2018.04.30 20:57:00	2.35
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:11:00	2018.04.30 21:26:00	0.25
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.04.30 21:43:00	2018.05.01 0:49:00	3.1
	TOTAL						**157.1833333**
May	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.1 8:30:00	2018.05.1 14:48:00	6.3
	NS7	15KV Circuit breaker trip	Substation Power Outage	EEU Power Mains Outage	2018.05.1 6:31:00	2018.05.1 17:00:00	10.48333333
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.05.4 12:21:00	2018.05.4 15:51:00	3.5
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.8 15:00:00	2018.05.8 15:56:00	0.933333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.8 15:00:00	2018.05.8 15:56:00	0.933333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.8 15:00:00	2018.05.8 15:56:00	0.933333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.8 15:00:00	2018.05.8 15:56:00	0.933333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.8 15:00:00	2018.05.8 15:56:00	0.933333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.05.11 12:54:00	2018.05.11 13:50:00	0.933333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.05.12 4:02:00	2018.05.12 6:01:00	1.983333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.05.19 15:11:00	2018.05.19 15:38:00	0.45
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.05.21 20:02:00	2018.05.21 20:48:00	0.766666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.23 22:25:00	2018.05.23 23:12:00	0.783333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.23 22:25:00	2018.05.23 23:12:00	0.783333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.23 22:25:00	2018.05.24 0:03:00	1.633333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.23 22:25:00	2018.05.23 23:12:00	0.783333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.23 22:25:00	2018.05.24 0:03:00	1.633333333
	EW20	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.05.24 6:30:00	2018.05.24 7:00:00	0.5
	EW10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.05.24 6:30:00	2018.05.24 7:00:00	0.5
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.05.31 15:54:00	2018.05.31 16:03:00	0.15
	TOTAL						**155.55**
June	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.05.1 2:43:00	2018.05.1 9:55:00	7.2
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.06.3 8:56:00	2018.06.3 10:20:00	1.4
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:17:00	5.633333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:17:00	5.633333333
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 3:08:00	3.483333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 3:08:00	3.483333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 9:06:00	9.45
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 9:06:00	9.45
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 5:25:00	5.933333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 3:07:00	3.466666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 3:07:00	3.466666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.4 23:39:00	2018.06.5 3:07:00	3.466666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.06.6 9:38:00	2018.06.6 10:13:00	0.583333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.6 17:13:00	2018.06.6 20:05:00	2.866666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.6 17:13:00	2018.06.6 20:05:00	2.866666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.8 12:19:00	2018.06.8 12:40:00	0.35
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.8 12:19:00	2018.06.8 12:40:00	0.35
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.8 12:19:00	2018.06.8 12:40:00	0.35
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.8 12:19:00	2018.06.8 12:40:00	0.35
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.8 12:19:00	2018.06.8 12:40:00	0.35
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.10 0:23:00	2018.06.10 2:43:00	2.333333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.10 0:23:00	2018.06.10 2:43:00	2.333333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.10 0:23:00	2018.06.10 2:43:00	2.333333333
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.06.13 13:53:00	2018.06.13 14:45:00	0.866666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.16 5:05:00	2018.06.16 6:47:00	1.7
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.16 5:05:00	2018.06.16 6:47:00	1.7
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.16 5:05:00	2018.06.16 6:47:00	1.7
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.16 5:05:00	2018.06.16 6:47:00	1.7
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.18 19:53:00	2018.06.18 20:27:00	0.566666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.18 19:53:00	2018.06.18 20:27:00	0.566666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.18 19:53:00	2018.06.18 20:27:00	0.566666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.18 20:32:00	2018.06.18 20:37:00	0.083333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.18 20:32:00	2018.06.18 20:37:00	0.083333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.18 20:32:00	2018.06.18 20:37:00	0.083333333
	NS10	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.18 22:02:00	2018.06.18 22:23:00	0.35
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 3:16:00	2018.06.20 3:50:00	0.566666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 3:16:00	2018.06.20 3:50:00	0.566666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 3:16:00	2018.06.20 19:39:00	16.38333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 3:16:00	2018.06.20 19:39:00	16.38333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 3:16:00	2018.06.20 19:39:00	16.38333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 3:16:00	2018.06.20 3:58:00	0.7
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 18:19:00	2018.06.20 18:43:00	0.4
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 18:19:00	2018.06.20 18:43:00	0.4
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 18:19:00	2018.06.20 18:43:00	0.4
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 18:19:00	2018.06.20 18:43:00	0.4
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 18:19:00	2018.06.20 18:31:00	0.2
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.20 18:19:00	2018.06.20 18:43:00	0.4
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 2:40:00	2018.06.23 3:28:00	0.8
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 2:40:00	2018.06.23 3:28:00	0.8
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 2:40:00	2018.06.23 3:28:00	0.8
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 3:49:00	2018.06.23 4:25:00	0.6
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 3:49:00	2018.06.23 4:25:00	0.6

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 3:49:00	2018.06.23 4:25:00	0.6
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 14:28:00	2018.06.23 14:55:00	0.45
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 14:28:00	2018.06.23 14:55:00	0.45
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 14:28:00	2018.06.23 14:55:00	0.45
	EW14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 14:28:00	2018.06.23 14:55:00	0.45
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.23 14:28:00	2018.06.23 14:55:00	0.45
	NS10	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.06.24 12:30:00	2018.06.24 13:09:00	0.65
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.06.25 12:55:00	2018.06.28 8:00:00	19.08333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.06.26 12:32:00	2018.06.26 13:05:00	0.55
	EW13	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.06.27 12:38:00	2018.06.27 13:08:00	0.5
	EW20	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.06.27 12:38:00	13:08:00	0.5
	TOTAL						**227.35**
July	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 3:28:00	2018.07.4 5:48:00	2.333333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 3:28:00	2018.07.4 5:48:00	2.333333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 3:28:00	2018.07.4 7:32:00	4.066666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 3:28:00	2018.07.4 7:32:00	4.066666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 7:14:00	2018.07.4 7:32:00	0.3
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 7:14:00	2018.07.4 7:32:00	0.3
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 10:37:00	2018.07.4 11:16:00	0.65

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 10:37:00	2018.07.4 11:27:00	0.833333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.2 10:37:00	2018.07.4 15:04:00	4.45
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.3 20:44:00	2018.07.3 21:33:00	0.816666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.3 20:44:00	2018.07.3 21:33:00	0.816666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.3 20:44:00	2018.07.4 0:47:00	4.05
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.4 9:49:00	2018.07.4 10:10:00	0.35
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.4 17:53:00	2018.07.4 18:05:00	0.2
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.4 17:53:00	2018.07.4 18:05:00	0.2
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.4 17:53:00	2018.07.4 18:05:00	0.2
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.4 17:53:00	2018.07.4 18:05:00	0.2
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.4 17:53:00	2018.07.4 18:05:00	0.2
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.5 16:12:00	2018.07.5 16:33:00	0.35
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.5 16:12:00	2018.07.5 16:33:00	0.35
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.5 16:12:00	2018.07.5 16:33:00	0.35
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.5 16:12:00	2018.07.5 16:33:00	0.35
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.5 16:12:00	2018.07.5 16:33:00	0.35
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.11 2:11:00	2018.07.11 6:28:00	4.283333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.11 2:11:00	2018.07.11 6:28:00	4.283333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.11 2:11:00	2018.07.11 6:28:00	4.283333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.11 6:49:00	2018.07.11 8:24:00	1.583333333
	NS10	15kV Power Outage	Substation Power Outage	Municipal 400V Outage	2018.07.16 15:54:00	2018.07.16 16:20:00	0.433333333
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.17 5:53:00	2018.07.17 8:35:00	2.7
	EW13	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.17 5:53:00	2018.07.17 8:35:00	2.7
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.17 5:53:00	2018.07.17 8:35:00	2.7
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.20 0:21:00	2018.07.20 1:41:00	1.333333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.20 0:21:00	2018.07.20 1:41:00	1.333333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.20 0:21:00	2018.07.20 1:41:00	1.333333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.20 0:21:00	2018.07.20 1:41:00	1.333333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.20 0:21:00	2018.07.20 1:41:00	1.333333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.07.22 6:50:00	2018.07.22 16:54:00	10.06666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.07.25 23:26:00	2018.07.26 9:32:00	10.1
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.31 14:40:00	2018.07.31 15:10:00	0.5
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.07.31 14:40:00	2018.07.31 15:10:00	0.5
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.31 14:47:00	2018.07.31 21:15:00	6.466666667
	Ayat	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.07.31 23:49:00	2018.08.1 1:08:00	1.316666667
	TOTAL						**86.7**
August	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.08.2 11:52:00	2018.08.2 12:24:00	0.533333333
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.08.4 16:13:00	2018.08.4 16:55:00	0.7

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.08.4 16:13:00	2018.08.4 16:55:00	0.7
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.08.4 16:13:00	2018.08.4 16:55:00	0.7
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 16:53:00	0.283333333
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 16:53:00	0.283333333
	EW16	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 16:53:00	0.283333333
	EW18	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 16:53:00	0.283333333
	NS22	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 16:53:00	0.283333333
	NS25	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 16:53:00	0.283333333
	NS27	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 16:53:00	0.283333333
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 17:25:00	0.816666667
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 17:25:00	0.816666667
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 17:25:00	0.816666667
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 17:25:00	0.816666667
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 17:25:00	0.816666667
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 18:03:00	1.45
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.9 16:36:00	2018.08.9 17:59:00	1.383333333
	NS6	15kV Power Outage	Substation Power Outage	Municipal 400V Outage	2018.08.10 19:03:00	2018.08.10 21:18:00	2.25
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.12 6:51:00	2018.08.12 10:06:00	3.25
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.12 6:51:00	2018.08.12 12:20:00	5.483333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 5:31:00	2018.08.15 7:34:00	2.05
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 5:31:00	2018.08.15 7:34:00	2.05
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 5:31:00	2018.08.15 7:34:00	2.05
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 5:31:00	2018.08.15 7:34:00	2.05
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 3:18:00	2018.08.15 5:31:00	2.216666667
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 8:20:00	2018.08.15 8:34:00	0.233333333
	NS6	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 8:20:00	2018.08.15 8:34:00	0.233333333
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 8:20:00	2018.08.15 8:34:00	0.233333333
	NS10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 8:20:00	2018.08.15 8:34:00	0.233333333
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 8:20:00	2018.08.15 8:34:00	0.233333333
	NS14	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.15 8:20:00	2018.08.15 9:51:00	1.516666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.08.19 8:23:00	2018.08.19 8:41:00	0.3
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.08.22 3:44:00	2018.08.22 10:15:00	6.516666667
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.27 18:26:00	2018.08.27 18:36:00	0.166666667
	EW10	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.27 18:26:00	2018.08.27 18:36:00	0.166666667
	EW18	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.08.27 18:26:00	2018.08.27 18:36:00	0.166666667
	TOTAL						**42.93333333**
September	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.09.2 15:56:00	2018.09.2 19:05:00	3.15
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.09.5 6:52:00	2018.09.5 14:00:00	7.133333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.6 4:10:00	2018.09.6 11:13:00	7.05
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.6 4:10:00	2018.09.6 11:13:00	7.05
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.7 6:04:00	2018.09.7 7:02:00	0.966666667
	NS10	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.8 4:07:00	2018.09.8 5:22:00	1.25
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.8 15:15:00	2018.09.8 16:10:00	0.916666667
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.8 15:15:00	2018.09.8 16:10:00	0.916666667
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.8 15:15:00	2018.09.8 16:10:00	0.916666667
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.9 0:39:00	2018.09.9 9:51:00	9.2
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.9 0:39:00	2018.09.9 9:51:00	9.2
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.9 0:39:00	2018.09.9 9:51:00	9.2
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.11 20:56:00	2018.09.11 23:51:00	2.916666667
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.12 18:07:00	2018.09.12 18:30:00	0.383333333
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.12 20:34:00	2018.09.13 2:53:00	6.316666667
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.14 18:05:00	2018.09.14 21:53:00	3.8
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.15 10:49:00	2018.09.15 23:20:00	12.51666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.15 10:49:00	2018.09.15 16:20:00	5.516666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.15 10:49:00	2018.09.15 16:20:00	5.516666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.18 5:19:00	2018.09.18 16:56:00	11.61666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.18 5:19:00	2018.09.18 6:16:00	0.95

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.18 5:19:00	2018.09.18 6:16:00	0.95
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.18 11:23:00	2018.09.18 11:43:00	0.333333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.18 11:23:00	2018.09.18 11:43:00	0.333333333
	NS10	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.09.18 14:58:00	2018.09.18 18:30:00	3.533333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.09.19 13:46:00	2018.09.19 17:05:00	3.316666667
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.20 11:44:00	2018.09.20 22:46:00	11.03333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.20 20:32:00	2018.09.21 0:32:00	4
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.21 6:30:00	2018.09.21 13:15:00	6.75
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.09.21 9:17:00	2018.09.21 10:16:00	0.983333333
	Kality depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.24 4:12:00	2018.09.24 8:17:00	4.083333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.09.25 12:16:00	2018.09.25 14:38:00	2.366666667
	EW18	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.09.25 17:16:00	2018.09.25 17:48:00	0.533333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.09.26 7:33:00	2018.09.26 15:05:00	7.533333333
	TOTAL						**152.2333333**
October	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.3 21:39:00	2018.10.4 0:08:00	2.45
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.5 8:22:00	2018.10.5 10:12:00	1.833333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.8 20:33:00	2018.10.8 21:00:00	0.45
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.8 22:33:00	2018.10.9 5:00:00	6.45
	NS6	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.8 22:33:00	2018.10.9 5:00:00	6.45

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.8 22:33:00	2018.10.9 5:00:00	6.45
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.8 22:33:00	2018.10.9 5:00:00	6.45
	NS12	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.12 4:21:00	2018.10.12 9:57:00	5.6
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.13 12:00:00	2018.10.13 12:21:00	0.35
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.13 12:00:00	2018.10.13 12:21:00	0.35
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.13 12:00:00	2018.10.13 12:21:00	0.35
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.16 18:45:00	2018.10.16 22:20:00	3.583333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.17 8:08:00	2018.10.17 12:05:00	3.95
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.18 12:37:00	2018.10.18 13:20:00	0.716666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.18 14:00:00	2018.10.18 16:02:00	2.033333333
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.19 11:26:00	2018.10.19 17:19:00	5.883333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.19 11:26:00	2018.10.19 17:19:00	5.883333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.19 11:26:00	2018.10.19 17:19:00	5.883333333
	NS10	400V Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.19 16:17:00	2018.10.19 17:19:00	1.033333333
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.23 21:03:00	2018.10.24 10:37:00	13.56666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.24 7:12:00	2018.10.24 9:02:00	1.833333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.24 13:14:00	2018.10.24 15:36:00	2.366666667
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.24 8:25:00	2018.10.24 9:07:00	0.7
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.24 8:25:00	2018.10.24 9:07:00	0.7

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.24 8:25:00	2018.10.24 9:07:00	0.7
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.10.25 22:37:00	2018.10.26 7:09:00	8.533333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.26 21:32:00	2018.10.27 2:20:00	4.8
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.28 20:37:00	2018.10.28 21:48:00	1.183333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.30 2:18:00	2018.10.31 21:50:00	19.53333333
	EW5	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.30 22:30:00	2018.10.31 11:03:00	12.55
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.30 22:30:00	2018.10.31 11:03:00	12.55
	EW13	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.30 22:30:00	2018.10.31 0:07:00	1.616666667
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.10.30 22:30:00	2018.10.31 0:07:00	1.616666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.31 15:50:00	2018.10.31 16:50:00	1
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.31 15:50:00	2018.10.31 16:50:00	1
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.10.31 15:50:00	2018.10.31 16:50:00	1
	TOTAL						**151.4**
November	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.11.2 9:22:00	2018.11.2 10:43:00	1.35
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.11.6 9:36:00	2018.11.6 11:21:00	1.75
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.11.14 16:32:00	2018.11.14 22:22:00	5.833333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.11.14 16:32:00	2018.11.14 22:22:00	5.833333333
	NS10	400V Power Outage	Substation Power Outage	Ring network Cable Failure	2018.11.14 16:47:00	2018.11.14 17:40:00	0.883333333
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.11.15 1:12:00	2018.11.15 4:24:00	3.2

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.11.15 1:12:00	2018.11.15 4:24:00	3.2
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.11.15 19:34:00	2018.11.15 23:37:00	4.05
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.11.15 20:36:00	2018.11.15 23:37:00	3.016666667
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.11.15 20:36:00	2018.11.15 23:37:00	3.016666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.11.21 11:14:00	2018.11.21 13:45:00	2.516666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.11.24 22:17:00	2018.11.25 5:52:00	7.616666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.11.27 12:26:00	2018.11.27 12:50:00	0.4
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.11.27 12:26:00	2018.11.27 12:50:00	0.4
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.11.27 12:26:00	2018.11.27 12:50:00	0.4
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.11.27 12:26:00	2018.11.27 12:50:00	0.4
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.11.27 12:26:00	2018.11.27 12:50:00	0.4
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.11.27 16:10:00	2018.11.27 16:44:00	0.566666667
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.11.27 16:10:00	2018.11.27 16:44:00	0.566666667
	TOTAL						**45.4**
December	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.12.2 5:58:00	2018.12.2 8:31:00	2.55
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.3 9:51:00	2018.12.3 11:31:00	1.666666667
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.3 9:51:00	2018.12.3 11:31:00	1.666666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.5 9:13:00	2018.12.5 9:25:00	0.2
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.5 9:13:00	2018.12.5 9:25:00	0.2

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.9 13:48:00	2018.12.9 14:48:00	1
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.9 13:48:00	2018.12.9 14:48:00	1
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 12:52:00	1.966666667
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 12:52:00	1.966666667
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 11:25:00	0.516666667
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 11:25:00	0.516666667
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 11:25:00	0.516666667
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 11:25:00	0.516666667
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 11:25:00	0.516666667
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.10 10:54:00	2018.12.10 11:25:00	0.516666667
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.15 11:34:00	2018.12.15 14:48:00	3.233333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.15 11:34:00	2018.12.15 14:48:00	3.233333333
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.19 4:33:00	2018.12.19 5:40:00	1.116666667
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.19 4:33:00	2018.12.19 5:40:00	1.116666667
	Ayat depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW1	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW2	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW5	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW13	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW18	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW20	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	EW22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:52:00	8.333333333
	Kality depot	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS6	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS7	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS10	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS12	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS14	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	EW16	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS22	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS25	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	NS27	15kV Power Outage	Substation Power Outage	EEU Power Mains Outage	2018.12.19 9:32:00	2018.12.19 17:13:00	7.683333333
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.20 3:01:00	2018.12.20 14:01:00	11
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.20 3:01:00	2018.12.20 14:01:00	11
	EW1	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.22 3:23:00	2018.12.22 6:00:00	2.616666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.12.22 22:01:00	2018.12.23 7:14:00	9.216666667

Month	Substation	Failure Cause	Failure Mode	Analysis	Occurring Date & Time	Restoration Date & Time	Outage Duration (hrs)
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.23 10:13:00	2018.12.23 11:33:00	1.333333333
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.23 10:13:00	2018.12.23 11:33:00	1.333333333
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.12.24 8:05:00	2018.12.24 14:00:00	5.916666667
	EW20	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.25 16:02:00	2018.12.25 16:19:00	0.283333333
	EW13	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.25 16:02:00	2018.12.25 16:21:00	0.316666667
	NS10	400V Power Outage	Substation Power Outage	Municipal 400V Outage	2018.12.26 13:39:00	2018.12.26 14:28:00	0.816666667
	EW2	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.28 8:36:00	2018.12.28 9:55:00	1.316666667
	EW7	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.28 8:36:00	2018.12.28 9:55:00	1.316666667
	Ayat depot	15kV Power Outage	Substation Power Outage	Ring network Cable Failure	2018.12.29 4:15:00	2018.12.29 6:30:00	2.25
	TOTAL						**232.9**

TableA.6: 2018 Power Interruption frequency and effect on operation (Trips Cancelled)

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
January						
2018.01.9					1	0
2018.01.12					1	1
2018.01.16					1	7
2018.01.17		1	5		2	0
2018.01.23					1	5
2018.01.24		1	0			
2018.01.26		1	0			
2018.01.30		1	7		1	9
Total	**0**	**4**	**12**	**0**	**7**	**22**
February						
2018.02.4					1	4
2018.02.5		1	1		1	0
2018.02.8					1	0
2018.02.9		1	0		1	0
2018.02.10		1	0		1	2
2018.02.11					1	0
2018.02.13		1	0			
2018.02.14					1	0
2018.02.16					1	2
2018.02.20					1	0
2018.02.24					1	0
2018.02.27					1	0
2018.02.28					1	0
Total	**0**	**4**	**1**	**0**	**12**	**8**
March						
2018.03.2					1	5
2018.03.3					1	0
2018.03.4					1	1
2018.03.6					1	0
2018.03.8		1	1			
2018.03.10		2	8		1	7
2018.03.11		1	2			
2018.03.18					1	0
2018.03.24		1	0		1	9
2018.03.27		1	29			
2018.03.28					1	2

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	**External**	**Effect on Operation (Trips Cancelled)**	**Internal**	**External**	**Effect on Operation (Trips Cancelled)**
Total	**0**	**6**	**40**	**0**	**8**	**24**
April						
2018.04.3					3	13
2018.04.4					1	0
2018.04.5					5	5
2018.04.7		1	0			
2018.04.9		1	7			
2018.04.10	1		0			
2018.04.14		1	4			
2018.04.15					1	0
2018.04.18		1	11		1	7
2018.04.20					1	5
2018.04.23				1		0
2018.04.26					1	8
2018.04.28		1	10		2	14
2018.04.29					1	2
2018.04.30		3	29		4	36
Total	**1**	**8**	**61**	**1**	**20**	**90**
May						
2018.05.1	1	1	46		1	49
2018.05.4		1	9			
2018.05.8			6		1	3
2018.05.11					1	2
2018.05.12				1	1	3
2018.05.19					1	0
2018.05.21					1	3
2018.05.23					1	0
2018.05.24		1	0			
2018.05.31					1	0
Total	**1**	**3**	**61**	**1**	**8**	**60**
June						
2018.06.1					1	16
2018.06.3					1	4
2018.06.4		1	55		1	31
2018.06.6					2	0
2018.06.8		1			1	2
2018.06.10		1	7		1	8
2018.06.13					1	1

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
2018.06.16		1	2		1	5
2018.06.18					3	13
2018.06.20		2	0		3	20
2018.06.23					3	0
2018.06.24					1	4
2018.06.25		1	31			
2018.06.26		1	56		1	7
2018.06.27		1	0		1	
Total	**0**	**9**	**151**	**0**	**21**	**111**
July						
2018.07.2			4		3	9
2018.07.3			8		1	8
2018.07.4		1	2		2	7
2018.07.5		1	0		1	0
2018.07.11					2	2
2018.07.16					1	1
2018.07.17		1	60			
2018.07.20					1	0
2018.07.22			80		1	78
2018.07.26					1	17
2018.07.31		2	1		2	3
Total	**0**	**5**	**155**	**0**	**15**	**125**
August						
2018.08.2					1	1
2018.08.4		1	0			
2018.08.9		1	1		1	4
2018.08.10					1	1
2018.08.12					1	0
2018.08.15			12		3	23
2018.08.19					1	0
2018.08.22					1	22
2018.08.27		1	0			
Total	**0**	**3**	**13**	**0**	**9**	**51**
Septembe r						
2018.09.2					1	0
2018.09.5					1	16
2018.09.6					1	0

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
2018.09.7					1	12
2018.09.8					2	11
2018.09.9					1	37
2018.09.11		1	0			
2018.09.12		1	6		1	4
2018.09.14		1	0			
2018.09.15		1	19			
2018.09.18		2	15		1	14
2018.09.19					1	12
2018.09.20		1	0		1	3
2018.09.21		1	14		1	3
2018.09.24			25		1	27
2018.09.25		1	0		1	8
2018.09.26					1	24
Total	**0**	**9**	**79**	**0**	**15**	**171**
October						
2018.10.3					1	0
2018.10.5					1	2
2018.10.8					2	0
2018.10.12					1	0
2018.10.13		1	0			
2018.10.16					1	0
2018.10.17					1	14
2018.10.18					1	12
2018.10.19		1	0		1	0
2018.10.23		1	0			
2018.10.24		1			2	0
2018.10.25					1	o
2018.10.26		1	0		1	
2018.10.27		1	0			
2018.10.28		1	0			
2018.10.30		2	18			
2018.10.31		1	13		0	2
Total	**0**	**10**	**31**	**0**	**13**	**30**
November						
2018.11.2			8		1	3
2018.11.6			16		1	12
2018.11.14		1	17		1	7
2018.11.15		2	11		1	10

Date	**EW Line Power Interruption**			**NS Line Power Interruptions**		
	Internal	**External**	**Effect on Operation (Trips Cancelled)**	**Internal**	**External**	**Effect on Operation (Trips Cancelled)**
2018.11.21					1	4
2018.11.24					1	0
2018.11.27		2	0		1	0
Total	**0**	**5**	**52**	**0**	**7**	**36**
December						
2018.12.2					1	0
2018.12.3		1	42			
2018.12.5		1	0			
2018.12.9		1	0			
2018.12.10		1	8		1	1
2018.12.15		1	1			1
2018.12.19		2	87		1	64
2018.12.20		1	85			
2018.12.22		1	8		1	0
2018.12.23		1	7			
2018.12.24					1	12
2018.12.25		1	0			
2018.12.26					1	0
2018.12.28		1	7			
2018.12.29		1	20			
Total	**0**	**13**	**265**	**0**	**6**	**78**
		2018 SUMMARY				
January	0	4	12	0	7	22
February	0	4	1	0	12	8
March	0	6	40	0	8	24
April	1	8	61	1	20	90
May	1	3	61	1	8	60
June	0	9	151	0	21	111
July	0	5	155	0	15	125
August	0	3	13	0	9	51
September	0	9	79	0	15	171
October	0	10	31	0	13	30
November	0	5	52	0	7	36
December	0	13	265	0	6	78
Total	**2**	**79**	**921**	**2**	**141**	**806**
	NS & EW COMBINED					

Date	EW Line Power Interruption			NS Line Power Interruptions		
	Internal	External	Effect on Operation (Trips Cancelled)	Internal	External	Effect on Operation (Trips Cancelled)
	Total power interruption: Internal	Total power interruption: External	Total number of Trips Cancelled			
	4	220	1727			

TableA.7: Summary for frequency of interruptions, outage duration and trips cancelled in the years 2016, 2017 and 2018

Year	Month	Frequency	Outage duration [hr]	Trips Cancelled
2016	January	7	81.36666667	135
	February	3	31.7	17
	March	7	33.86666667	4
	April	5	13.05	0
	May	8	139.75	31
	June	4	21.85	4
	July	5	56.03333333	32
	August	10	51.01666667	0
	September	10	147.2833333	20
	October	10	40.81666667	12
	November	4	102.3	12
	December	14	228.4166667	145
	Total	**87**	**947.45**	**412**
2017	January	8	17.98333333	0
	February	7	75.96666667	72
	March	10	94.63333333	41
	April	12	39.73333333	22
	May	9	72.81666667	53
	June	13	95.45	138
	July	12	65.58333333	94
	August	16	122.7166667	136
	September	13	318.3833333	312
	October	21	116.7	900
	November	7	79.4	109
	December	9	40.08333333	50
	Total	**137**	**1139.45**	**1927**
2018	January	11	37.23333333	34
	February	16	35.66666667	9
	March	14	78.98333333	64
	April	30	157.1833333	151
	May	13	155.55	121

Year	Month	Frequency	Outage duration [hr]	Trips Cancelled
	June	30	227.35	262
	July	20	86.7	280
	August	12	42.93333333	64
	September	24	152.2333333	250
	October	23	151.4	61
	November	12	45.4	88
	December	19	232.9	343
	Total	**224**	**1403.533333**	**1727**

APPENDIX B

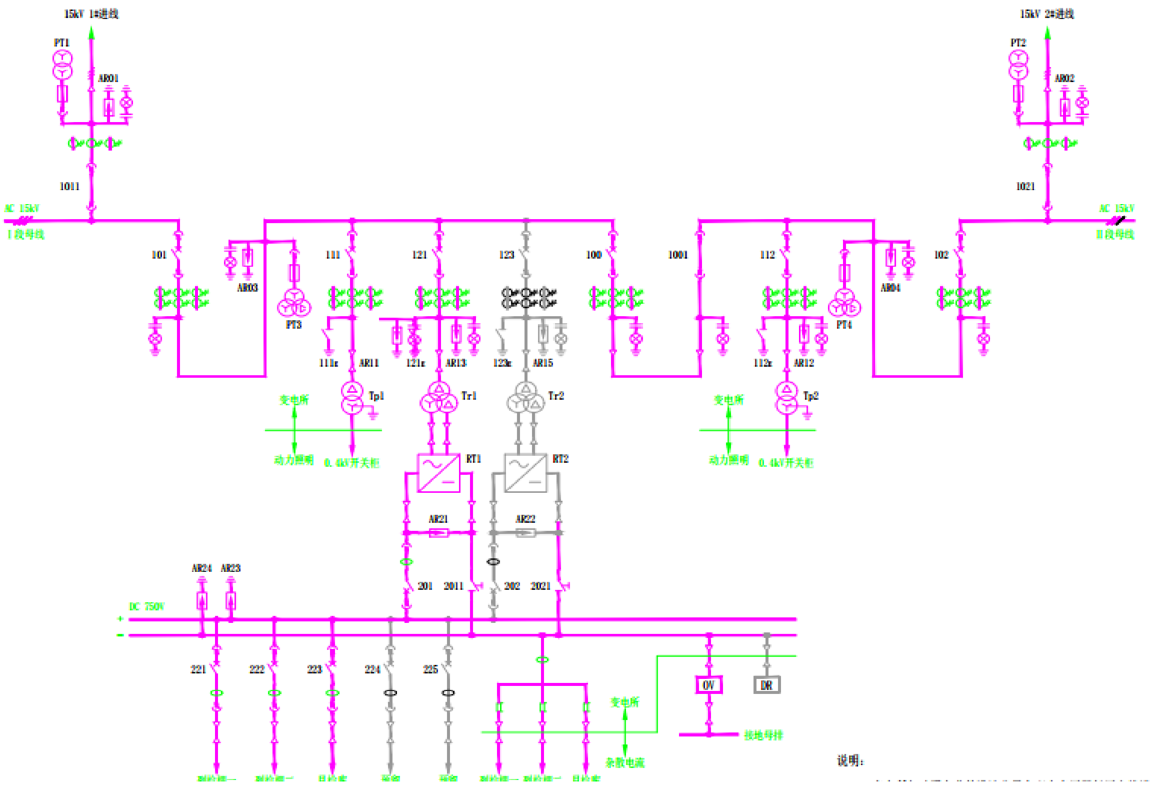


Figure B.1: Typical AALRT traction power substation- rectifier substation layout

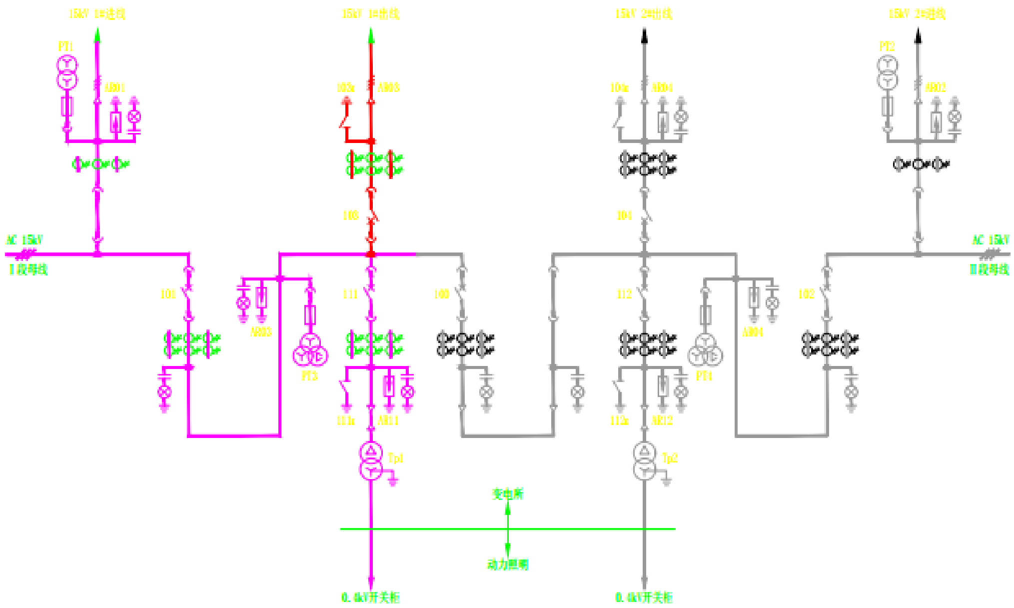


Figure B.2: EW 18 substation layout