RELIABILITY ANALYSIS OF HIGH VOLTAGE POWER EQUIPMENT IN AJAOKUTA STEEL COMPANY LIMITED (ASCL)

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF ENGINEERING (M. Sc.) DEGREE IN ELECTRICAL ENGINEERING

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NOVEMBER, 2021

DECLARATION

I, Raji Enesi MUHAMMAD hereby declare that this dissertation titled "Reliability Analysis of High Voltage Power Equipment in Ajaokuta Steel Company Limited (ASCL)" has been carried out by me under the supervision of Prof. Yusuf Jibril, Dr. Gaddafi Sani Shehu and Dr. Abubakar Abdulkarim as part of the requirements for the award of Master of Engineering (M.Sc.) Degree in Electrical Engineering. To the best of my knowledge, this work has never been submitted anywhere for the award of any certificate. All literatures used are cited in this research and duly acknowledged by means of references.

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Muhammad, Raji Enesi	Date

CERTIFICATION

This Dissertation titled "RELIABILITY ANALYSIS OF HIGH VOLTAGE POWER EQUIPMENT IN AJAOKUTA STEEL LIMITED (ASCL)" meets the requirements for the award of Master of Engineering Degree in Power System Engineering, in Electrical Engineering by Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literacy presentation.

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DEDICATION

I dedicate the achievement of this Project/Research work, and the M.Sc. Programme as a whole to ALLAHU, RABBIY, who decreed its successfulness to be. So, my Prayers, other forms of Worshipping of mine, Living and Death are for ALLAHU, (SWT), the LORD of the Universe. I associate none with HIM. On this Establishment I declare my Willing Submission to HIM.

Equally, I dedicate this Favour to the Authorities of Ahlil-Wasilah (the Personalities that Guide for Seeking Nearness and Showing Love) to ALLAHU, (SWT). Once more, I declare: I am please with ALLAHU, as the LORD, with Al-Islam as the Religion, with Muhammad (SAW), as the Prophet and the Messenger (SAW). And I am please with the Awliya'ALLAHU (the Friends of ALLAH).

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ABSTRACT

Reliability of power equipment in Ajaokuta Steel Company Limited (ASCL), Ajaokuta, Kogi State is as important as the company as a whole. The study presents the reliability analysis of critical Power Equipment in Ajaokuta Steel Company Limited (ASCL), using one of the distribution substation, 7DS (Engineering Shops & Auxiliaries including Housing Estates) as a case study, for the purpose of assessing how frequent the failure of power equipment were experienced within the period of January to December 2020. To achieve this, failure data of power equipment like 11kV, 630A Oil Circuit Breakers (OCB) of Incoming Feeder to the substation as well as Outgoing Feeder Cubicle 32 and Outgoing Feeder Cubicle 5, Earth Fault Relay PTN, Overcurrent Relay PT3, Current Cut-off Relay PT1, Pole Discrepancy Protection Relay (for Single Phasing Fault), Voltage Transformer, 3-phase, 11/0.415kV Sub Service Transformer, Current Transformers, Manual isolator on Outgoing Feeders, 110V DC Battery Unit and Rectifier Unit were calculated using Microsoft Excel software and analysed using Fault Tree Analysis method. The Reliability of the distribution substation was determined using exponential distribution model. A model was developed using the reliability block diagram (RBD) method. A 10-year prediction using the exponential distribution model and the RBD model was obtained and comparison between the models was carried out. The outages/unavailability records were obtained from the Logbook of MSDS 1 Control Room. The Case Study Substation, 7DS is an unmanned Distribution Substation under MSDS 1. As a result, all data regarding 7DS Substation were obtained from MSDS 1 Control Room. Results show that the outgoing feeder 32 (Township Feeder 1) has the highest annual outage time/unavailability, thus contributing most to the interruptions in the substation with a failure rate of 0.021474607 per hour and annual outage time of 0.9141 hour. Another major contributor to interruptions in the substation thereby affecting delivery of electricity to the customers was earth fault failures having a failure rate of 0.016765799 per hour and outage time of 0.5676 hour, followed by current cut-off failures 0.012860225 per hour and 0.42996 hour and the outgoing feeder 5 (Township feeder 2), 0.014417382 per hour and 0.38268 hour respectively. Sub-service transformers 1SST & 2SST, voltage transformers 1VT & 2VT as well as current transformer had the same failure rates of 0.000112007 per hour. The least contributor to interruption within the period under review was the sub-service transformer 1SST & 2SST with a value of 0.00000233348 hour. The reliability of the entire substation obtained using the exponential distribution model was 91.77%. Using reliability block diagram, the substation has a reliability of 95.22%. The reliability of the substation is low compared to the IEEE standard of 99.99% for distribution substation. Hence with the value calculated for this substation, the reliability is low. Comparing the result obtained with the available reliability benchmarks, it is obvious that the substation has performed poorly and needs to be improved upon to increase its reliability indices. Routine maintenance and right of way clearance on all outgoing feeders should be carried out to reduce the rate of earth fault and current cut off system tripping.

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LIST OF ABBREVIATIONS

ASAI	Average Service Availability Index
ASCL	Ajaokuta Steel Company Limited
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CT	Current Transformer
DS	Distribution Substation
FTA	Fault Tree Analysis
IEEE	Institute of Electrical and Electronics Engineering
MSDS 1	Main Step Down Substation 1
MSDS 2	Main Step Down Substation 2
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
P T & D	Power Transmission & Distribution
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TPP/TBS	Thermal Power Plant/Turbo Blower Station
TSS	Transmission Substation
VT	Voltage Transformer

CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

Reliability is defined as the probability that a system, product or service operates properly for a specific period of time under operating conditions without failures. Irrespective of the system configuration, the reliability of the system is the most important factor for system planners (Abdulkarim *et al.*, 2018).

Reliability of an electric power system is the probability that the system will continuously deliver electricity to its consumers without compromise on the quality of the power being delivered (Bhavaraju *et al*., 2005). Equipment outages and consumer interruptions are the primary focus of power system reliability. According to IEEE, the definition of reliability is simply the ability of a system or component to perform its intended functions under stated conditions for a specified period of time. Power reliability can be defined as the degree to which the performance of the elements in a bulk system results in electricity being delivered to customers within accepted standards and in the amount desired (Kueck *et al*., 2004).

Electric power system is basically set up to supply electricity with little or no interruptions to its customers. The number of interruptions that occur while the system performs its intended function is part of what determines the overall reliability of the system. The other factor that determines its reliability is the quality of electricity delivered. Furthermore, the capability of a power system to continuously deliver quality electricity means that the customers are satisfied and the electricity providers are having favorable returns on their investment as they continue their business of supplying electricity. As electricity consumption has become an important factor that affects the drive needed for technology to grow and to facilitate the development of modern society, it is very important therefore to take seriously the issue of reliability of an electric power system.

Generation, Transmission and Distribution are the three subsystems of an electric power system. At the generating station, electricity is generated and transmitted through the high voltage transmission lines to the distribution substations. The distribution substation system considered covers the electrical system between the substation fed by the sub transmission system and the supply lines to the consumers' meters i.e. 11kV to 0.415kV transformation (Theraja and Theraja, 2008). The distribution substations are usually sited relatively near the customers for effective delivery, monitoring and maintenance of the substation and the customer end and are usually referred to as secondary distribution substation system. Distribution systems basically serve as the link from the distribution substation to the customer. Reliable and safe transfer of electricity to the customers covered by the distribution area is ensured by this system and is the main subject studied in this dissertation. Another type of substation is the Transformer Substation (Switchgear Substation) whose main function is to change the voltage level of electric supply along the lines. These sub-stations receive power at some voltage level and deliver it at some other voltage level. The equipment in a switchgear includes: Bus-bars, Insulators, isolating switches, Circuit breakers, Power transformers, Instrument transformers, Metering and Indicating instruments, Fuses, etc.

Ajaokuta Steel Company Limited, Power System is not different. Voltage at 11.5kV level is generated at the 110 Megawatts Thermal Power Plant/Turbo Blower Station (TPP/TBS), which is stepped up to 132kV and transmitted at the Transmission Sub-Station (TSS). The Steel Company has two Main Step Down Substations (MSDS 1 & MSDS 2), equipped with 63MVA Transformers responsible for stepping down 132kV to 11.5kV and distributed to several other Distribution Substations (DSs) at 11.5kV and 6.6kV depending on the substations loads.

The performance characteristics of any system include its reliability, Failure Rate, Mean Time Between Failures (MTBF) for repairable system or Mean Time To Failure (MTTF) for non-repairable system. The failure rate is the frequency with which a plant, system or component fails, which is expressed in failures per hour. Though, in practice, failure rate is simply the inverse of the MTBF (David and Smith, 2005).

Ajaokuta Steel Company is made up of 43 individual Plants with substations (DSs) designed to handle the power needs of the individual plant among which are the Blast Furnace and Iron Making Plant (1 DS), Steel Making Shop (5DS &6DS), Coke Oven & By-Product Handling Plant (2DS & 22DS), Wire Rod Mill (15DS), Light Section Mill (14DS), Oxygen, Hydrogen and Nitrogen Plant (4DS), Billet Mill, Engineering Shops Auxiliaries (7DS) which includes Machines& Tools Shop, Power Equipment Repair Shop, Pattern Making Shop and Rubberizing shop, etc. Power supply to these plants must be steady and uninterrupted.

7DS substation is an 11kV substation originally designed to handle the power requirements of Engineering shops and its auxiliaries. The substation has two incoming feeders, one from MSDS 1 and another from MSDS 2, as well as outgoing feeders to several transformer substations; 7TS1, 7TS2, 7TS3, 7TS5, 7TS6, 7TS7, 7TS9, 7TS13, 7TS15, 7TS17, 7TS18, 7TS19 and 7TS20. These transformers are distribution transformers of Power Equipment Repair Shop, Forge & Fabrication Shop, Pattern Making Shop, Rubberizing shop as well as Machine & Tools shop. 7DS substation also a feeder to Foundry Shop (9DS) and 6 spare feeders. Over the past years, two of these spare feeders (feeders 5 & 32) have been converted to housing estates feeders. It is on this note that the reliability analysis of high voltage power equipment will be carried out, using 7DS as a case study.

1.2 Problem Statement

Ajaokuta Steel Company was designed to have access to uninterrupted power supply all year round due to the nature of load and power demands. In this regards, a 110MW thermal power plant was built to handle the power needs of the 43 individual plants in the steel company via distribution substations. However, over the years, failures of equipment have caused a continuous degradation in the reliability of these substations thereby hampering the steady supply of power to these substations. This has led to incessant power outages in some of the plants that have been fully commissioned and still operational. Using 7DS substation as a case study, an idea of the reliability of other substations including the transmission substation (TSS), main switch gear (MSG), main step down substation 1 (MSDS 1), main step down substation 2 (MSDS 2) as well as all other secondary distribution substations can be achieved.

1.3 Aim and Objectives

The aim of this study is to carry out the reliability analysis of High Voltage Power Equipment in Ajaokuta Steel Company Limited, using 7DS substation as a case study.

The objectives of the study are:

i. To determine the reliability of the entire Substation, 7DS, using Exponential Distribution Model.

ii. To development the reliability model of the entire substation, using Reliability Block Diagram (RBD) algebra.

iii. To compare analysis between the reliability indices of (i) and (ii).

1.4 Methodology

Power Equipment outage/unavailability duration for a twelve-month period was collected and analyzed. Outages/Unavailability records was obtained from logbook of MSDS 1 Control Room. The case study substation, 7DS is an unmanned Distribution Substation under MSDS 1. As a result, all data regarding 7DS substation was obtained from MSDS 1 Control Room. The collected data reflected permanent outages as a result of faults and failures. The data also captured the recorded monthly duration for each component's outage and the frequency of the outages. The components reliability indices were calculated using Microsoft Excel and analyzed using Fault Tree Analysis and the reliability block diagram of the substation was modelled. 14 power components were analyzed, out of which 10 were in series and 4 were in parallel. Details are presented in chapter three.

1.5 Scope of the Study

For the purpose of this study, failure data of 11kV, 630A Oil Circuit Breakers (OCB) of Incoming Feeder to the substation as well as Outgoing Feeder Cubicle 32 and Outgoing Feeder Cubicle 5, Earth Fault Relay PTN, Overcurrent Relay PT3, Current Cut-off Relay PT1, Pole Discrepancy Protection Relay (for Single Phasing Fault), Voltage Transformer, 3-phase, 11/0.415kV Sub Service Transformer, Current Transformers, Manual isolator on Outgoing Feeders, 110V DC Battery Unit and Rectifier Unit were analyzed. The data of a period of twelve months (January 2020 – December 2020) from 7DS substation was collected and analyzed. Data collected was used to investigate the reliability and maintainability of major power equipment in the substation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A modern electric power system is a very large and complex network consisting of Generator stations, Transmission Substations (TSS), Distribution Substations (DSs), and other devices. The purpose of the electric power system is to generate, transmit, distribute and use electric power. This power system is also known as the Grid and can be broadly divided into the generators that supply the power, mostly electricity generation comes from coal, natural gas, biomass, nuclear fission, wind, solar, and hydropower. The transmission system that carries the power from the generating centre to the load centre, and the distribution system that feeds the power to nearby homes and industries.

Power systems across the globe are built with the intent of providing for the energy needs of the modern times. A well-designed power system provides high-quality electric energy to the user instantly, constantly, and exactly in the amount that is needed. It would be, however, impractical or uneconomic to design and build a fault-proof power system. Thus power systems and their components need appropriate or reasonable protection against natural hazards and equipment failures, as well as human errors. The objectives of every electric power utility are to maintain network integrity and stability throughout, and to promote higher reliability of power supply to customers without interruption (Wang *et al.*, 2002).

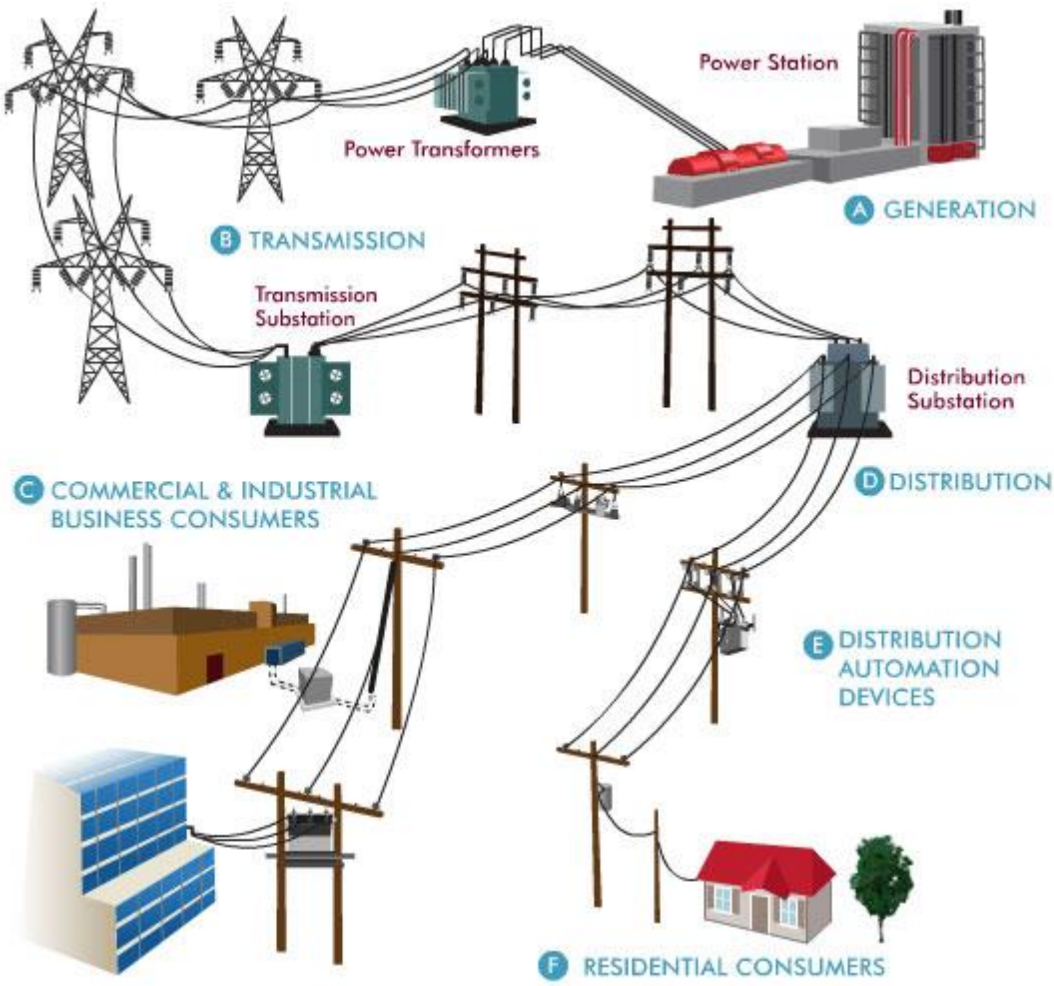

Figure 2.1 Power Generation and Distribution System.
Source: http://www.bravoprojects.co.in/transmission.php

Hence, it is understood that meeting the needs of the customers is the most important reason why a power system is established, with the profit coming along while doing the business. The significance of reliable high voltage power equipment in a power system cannot be over-emphasized; hence, this chapter looks at the principle behind reliability and also explains the different methods available in order to carry out reliability analysis of high voltage power equipment. In addition, review of empirical literature of current and past research papers was also carried out in this chapter.

2.2 Review of Fundamental Concepts

The section comprises review on concept of reliability engineering, power system reliability, types of interruption, reliability evaluation, and reliability indices amongst others.

2.2.1 Concept of Reliability Engineering

Reliability engineering is an engineering discipline for applying scientific know-how to a component, product, plant, or process in order to ensure that it performs its intended function, without failure, for the required time duration in a specified environment (Kiran, 2017). It emphasizes dependability in the lifecycle management of a product, which is the ability of a system or component to function under stated conditions for a specified period of time. In other words, reliability has two significant dimensions, the time and the stress. A product has to endure for several years of its life and also perform its desired function, despite all the threatening stresses applied to it, such as temperature, vibration, shock, voltage, and other environmental factors.

In quality management, this principle is applied to a component, product, plant, or process in order to assure that it performs its intended function, without failure, for the required time duration in a specified environment. This is called functional reliability and the application of these principles to achieve high product life is called reliability engineering.

Reliability engineering is an engineering framework that enables the definition of a complete production regime and deals with the study of the ability of the product to perform its required functions under stated conditions for a specified period of time. It characterizes measures and analyzes the failure and repair of the systems to improve their use by increasing their design life, mitigating defect risks, and reducing the likelihood of failures (Kiran, 2017).

2.2.2 Power System Reliability

Reliability of an electric power system is the probability that the system will continuously deliver electricity to its consumers without compromise on the quality of the power being delivered (Bhavaraju *et al*., 2005). It is also simply a measure of whether users have electricity when it is needed (Wang, 2012). Furthermore, according to IEEE, the definition of reliability is simply the ability of a system or component to perform its intended functions under stated conditions for a specified period of time. Power reliability can be defined as the degree to which the performance of the elements in a bulk system results in electricity being delivered to customers within accepted standards and in the amount desired (Kueck *et al*., 2004).

Scheduled and unscheduled events disrupt normal operating conditions and can lead to outages of the components in the system and interruptions to power supply. The unscheduled events may be as a result of oversights during installation or maintenance operations, component failures and faults. The scheduled events are usually as a result of the need to carry out maintenance operations on the equipment, construction, consumers' request, and usually consumers do get notice of interruption of supply in advance.

2.2.3 Types of Interruption

Momentary Interruption

This is a situation where a customer is without electricity supply from the utility for less than a few minutes. When power supply is interrupted and restored in less than 5 minutes, then the customer is said to have experienced momentary interruption according to IEEE 1366-2003 standard. The operation of a circuit breaker or reclosers, which opens the circuit momentarily to clear faults and closes back, brings about this interruption. Momentary interruptions sometimes affect power quality and sometimes lead to voltage sags (Short, 2004).

Temporary Interruption

This is usually categorized as interruptions that last a few hours. It is usually less in duration than a sustained interruption and higher than momentary interruption. This interruption usually requires an operator to put the system back on by manual operation. Hence, the duration is usually as determined by the unavailability of an operator to perform the switching operation immediately. This interruption is expected to last for less than two hours. Both momentary and temporary interruptions can be as a result of faults due to lightning, two conductors in contact when there is wind etc. (Gonen, 2014).

Sustained Interruption

This is a loss of supply to customers which is usually more than many hours and can sometimes last for days. A temporary fault can lead to sustained interruption if it is not taken care of as soon as possible. However, sustained interruption could be as a result of transformer failure, insulator failure, damaged wires etc.

Planned Interruption

This happens when deliberate action is taken on a component by removing it from service in order to carry out maintenance work or repair. This interruption usually accompanies scheduled outage. It is usually planned and the customers are aware of the loss of supply that ensues.

Unplanned Interruption

This type of interruption is basically as a result of system faults and failures which make a component to be unavailable to perform its function, hence system collapses.

From the above facts, the two major factors that affect the reliability of power distribution system are;

i. Capacity shortages
ii. Faults/Failures.

Capacity Shortages

The reliability of power systems is usually lowered by capacity shortage. This can be as a result of inability to meet market demands or inadequate planning to provide redundant element to ensure supply of power in case of unforeseen events. The situation above is sometimes caused when there is inadequate transmission or distribution capacity to ensure transfer of available electricity within the power system. For instance, the Transmission Company of Nigeria (TCN) is projecting an expansion of its wheeling capacity beyond the present level of 5,500MW to 10,000MW and 20,000MW by 2017 and 2020 respectively (Ezeolisah, 2015). The achievement of this project mentioned above will solve the capacity shortage problem being discussed. This will impact directly on electricity available for distribution utilities to serve their customers. Moreover, there is interruption in the delivery of electricity when there is capacity shortage as utility managers perform load-shedding to avoid overloading the system which means that some customers will experience outages because their loads will not be served. In addition, for a distribution system, power delivery will be hampered by unexpected additions of load when new customers join existing network thereby weakening the system and affecting its reliability.

Faults and Failures

Faults occur when there is short circuit between phases, or phase to ground faults leading to unintended opening of fuses or circuit breakers used for protection within a power system. A fault means that an accidental electrical connection is made between an energized component and something at a different potential leading to a short circuit (Meier, 2006). The failure of an electrical component is usually not influenced by external factors that may give rise to faults. Failures can be as a result of human error or due to malfunctioning of the equipment. There are several types of failure in electrical equipment and the common types that lead to short circuits include transformer windings, lightning arrestors, and high voltage bushings. Both faults and failures can cause outages which could last for few seconds if it is resolved quickly by operating programmed switching equipment. When an electrical component such as a transformer is damaged due to faults or failures, its replacement or repair usually takes time, sometimes hours or days and as such may lead to longer hours of service interruption to the consumers. In most cases, faults and failures instead of capacity deficiencies are the reasons for component outages in a power system.

2.2.4 Reliability Evaluation

Some of the main goals of reliability analysis according to Dorji (2009) include providing answers to questions such as “how reliable is the system?”, “which component contributes most to incessant interruptions?” and “which part of the system requires more financial commitment to better the system operations?”. Distribution system reliability can be divided into two general aspects, namely: System Adequacy and System Security.

System adequacy simply refers to static situation. It checks the capacity of the system to adequately deliver the energy demanded by the customers by carrying out evaluation based on the components or equipment being used. It simply implies that system adequacy focuses on the system design and structure and its installed component capacity (Billinton and Allan, 1996; Wang, 2012).

System security is the ability of the system to respond to any given contingency or disturbances such as faults (Billinton and Allan, 1996). Thence, the reliability that concentrates on the system security is called dynamic reliability, while the reliability that focuses on the system adequacy is defined as static reliability. The focus of this dissertation is on static reliability.

The two major methods used in carrying out the evaluation of distribution systems reliability are (Kjolle and Sand, 2002):

i. Analytical methods based on solution of mathematical models

ii. Simulation methods based on drawings from statistical distributions

Analytical Method

In this method, the evaluation is carried out based on assumptions with respect to statistical distributions of repair times and failure rates. Failure mode analysis or minimum cut-set analysis is the most common evaluation technique using a set of approximate equations. Compared to the simulation method, analytical method is less time consuming but in most cases does not represent repair times adequately. This method is further divided into Network technique and Markov modelling.

Network Technique

An electrical system can be viewed as a network of its components connected together either in series, parallel, meshed or a combination of these. The structural relationships between a system and its components are considered in this technique. Modelling the failure behaviour of the system is one of the major challenges in reliability analysis. However, according to Billinton and Allan (1996), analytical techniques of distribution systems and electrical networks when the generation sources are neglected are mainly based on a failure modes and effects analysis (FMEA), using minimal cuts sets and groups of equations for calculating the reliability indices of series and parallel systems. By carrying out analysis on each component that makes up the system, this approach presents all the imminent failure modes and then pin-points their resulting effects on the system. This method determines at least those components within a system which result in an interruption of service at the load-point of interest.

Markov Modelling

Stochastic modelling in reliability engineering is used to explain the functioning of a system with time. In most cases, the component failure and repair times are used as the random variables. A Markov model looks into the present event to determine the future event and does not consider the past event. In other words, the Markov model works solely on the assumption that a system’s behaviour in each state is memory-less. It therefore does not consider the process or event that led to the present event. However it is possible to generate a stochastic system that is related and similar to the original system or event. This technique requires a large number of states to generate the system to be modelled. This is because as the number of factors/parameters increases, there is exponential increase in the number of states. Hence, various assumptions must be made to ensure a controllable sized model.

Simulation Technique

The behaviour of a particular system could follow a random nature. Simulation in reliability analysis often concerns random events and are commonly referred to as Monte Carlo simulations. Simulation can be done using a sequential method in which events are chosen in a given order or random method in which events are chosen at random. In simulation, one of the aims is to make estimates of unknown parameters which will serve as real experiments after observing a simulation process for a specific period. The simulation process is intended for examining and predicting the stochastic behaviour of a system in simulated time. This technique takes time and it is expensive to implement because of the need to use huge number of failures to simulate. The statistical distribution of failure rates and outage times gives the fault contribution from each component. In simulation process, a number of runs are normally performed by the software so as to find the estimates of the means of the output parameters needed such as failure rate, mean repair time, and availability. This is usually done to have a converging result since simulation generates variable outcomes (O'Connor and Kleyner, 2011; Uhunmwangho and Omorogiuwa, 2014).

In a modelled system in which the events in the previous interval directly impact on the next interval, which is often the case in distribution system reliability studies where the action or inaction of one component may affect the performance of the other, then the sequential method is appropriate. In this method, events are set to occur at random times to obey specific probability distributions. The actual behaviour of the system is represented by distribution function gotten from the conversion of the random numbers used. The time-sequential simulation process can also be used to examine and predict behaviour patterns in simulated time. This method is an extension of the sequential method, only that, it uses an artificial history of up and down times of the system and it is included in the generation of the random chronological number as in sequential simulation. The relationship that exists between the element states and system states serves as template to generate the component histories which help in formulating the sequence of in-service, out-of-service cycles of the system (Faulin *et al.,* 2010).

2.2.5 Reliability Indices

Reliability indices are numerical parameters that reflect the capability of the system to provide its customers an acceptable level of electricity supply (Uhunmwangho and Omorogiuwa, 2014). By providing quantitative measures at different individual load points and for the whole system, these indices approximate system reliability. The most important of all the indices used in evaluation of power systems reliability are the duration of interruption and frequency of interruption. This is basically due to the fact that they indicate the expected frequency and the expected duration of interruption of power supply. The frequently used reliability indices for evaluation of systems include: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), Average Energy Not Served (AENS), System Expected Interruption Cost Index (ECOST), and Energy demanded but not supplied (EDNS). Failure rate, annual unavailability, and average outage duration are the basic indices associated with system load points. By collecting information on the past performance of a system, valuable insight is provided into the reliability profile of the existing system.

2.3 Reviews on Reliability Analysis Methods Development

One of the major methods that have been adopted in reliability analysis is the use of fault tree analysis (FTA). A fault tree translates the failure behaviour of a physical system into a visual diagram and a logical model (Johan, 2014). Fault Tree Analysis (FTA) was originally developed in 1962 at Bell Laboratories by H.A Watson, under a U.S Air Force Ballistics Systems Division contract to evaluate the Minuteman I Intercontinental Ballistic Missile (ICBM) Launch Control System (Isaac *et al.*, 2013). The use of fault trees has since gained wide-spread support and is often used as a failure analysis tool by reliability experts. Following the first published use of FTA in the 1962 Minuteman I Launch Control Safety Study, Boeing and AVCO expanded use of FTA to the entire Minuteman II system in 1963-1964 (Mohammad *et al.*, 2011). The Boeing Company improved the technique and introduced computer programs for both qualitative and quantitative fault tree analysis. At the 1965 Safety Symposium, sponsored by the University of Washington and the Boeing Company, several papers were presented that expounded the virtues of fault tree analysis.

The presentation of these papers marked the beginning of the wide-spread interest in using fault tree analysis as a system safety and reliability tool for complex dynamic system such as nuclear reactors (Josep, 2014). Since 1960, great efforts have been made in solving fault trees to obtain reliability information about complex systems. Following the lead of the aerospace industry, the nuclear power industry discovered the virtues and benefits of fault tree analysis, and began using the tool in the design and development of nuclear power plants (Ahmed *et al*., 2013). Many key individuals in nuclear power industry contributed to advancing fault tree theory and fault tree software codes. In fact, the nuclear power industry may have contributed more to the development of fault tree analysis than any other single user group. Many new evaluation algorithms were developed, along with software using these algorithms.

Today fault tree analysis is by far the most commonly used technique of risk and reliability studies. Fault tree analysis has particularly been used with success to analyze system in nuclear power station (Josep, 2014).

2.4 Reliability Analysis Method Used

The Reliability analysis method used in this dissertation is the fault tree analysis. The basic reliability expressions in this method are discussed.

2.4.1 Fault Tree Analysis

In this method, certain reliability expressions are analyzed for each of the power equipment under review in order to obtain the reliability indices for each of the equipment. Expressions to be analyzed include;

Reliability Expressions in Fault Tree Analysis

Reliability expressions are used in fault tree analysis to determine the failure rate probability of the basic and overall top events. The expressions include; Reliability ($R_{(t)}$), Failure Probability ($Q_{(t)}$), Failure rate (λ), Average down time per failure (T), MTBF (Mean time between failures), MTTR (Mean time to repair), Availability (A) and Unavailability (U).

Reliability, $R_{(t)} = e^{-\lambda t}$ (2.1)

$R_{(t)} + Q_{(t)} = 1$ (2.2)

Failure Probability, $Q_{(t)} = 1 - e^{-\lambda t}$ (2.3)

$Q_{(t)} = \lambda T$ (2.4)

where T is average down time per failure and λ is failure rate

$$\text{Failure rate}, \lambda = \frac{\text{Number of times failure occurred}}{\text{Number of unit} - \text{hours of operation}} \quad (2.5)$$

Mean Time Between Failures (MTBF)

Mean time between failures (MTBF) is one of the basic ways of measuring the reliability of repairable components in a power system. It is the expected unit of time between the occurrences of two consecutive failures for repairable systems. MTBF is also the time that elapsed before a component, assembly, or system fails, under the condition of a constant failure rate. It describes the total time the component is in operation (Gonen, 2014). It is expressed as:

$$\mathrm{MTBF} = \frac{\text{Total system operating hours}}{\text{Number of failures}} \tag{2.6}$$

Mean Time To Repair (MTTR)

MTTR is the average time it takes to identify the location of a failure and to repair that failure thereby restoring the component into normal operation. It describes the average time for which a component is out of service due to fault before it is restored to normal operation (Gonen, 2014). It is expressed as;

$$\mathrm{MTTR} = \frac{\text{Total duration of outages}}{\text{frequency of outage}} \tag{2.7}$$

$$\text{Failure frequency, f} = \frac{1}{\mathrm{MTBF} + \mathrm{MTTR}} \tag{2.8}$$

Availability

Availability is the measure of the duration for which the component is in operation at any time. It deals with the duration for which the system is fully operational for its specific function (Gonen, 2014). It is expressed as;

$$\text{Availability, A} = \frac{\mathrm{MTBF}}{\mathrm{MTBF} + \mathrm{MTTR}} \tag{2.9}$$

$$\text{Unavailability} = \frac{\mathrm{MTTR}}{\mathrm{MTBF} + \mathrm{MTTR}}$$

$$= \frac{\mathrm{f} \times \mathrm{MTTR}}{8760} \qquad (2.10)$$

Reliability Indices

Proposed Customer-based indices to be used include; System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer's Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI) and the Average Service Un-availability Index (ASUI).

System Average Interruption Frequency index (SAIFI)

This is defined as the average number of times that a customer is interrupted during a specified time period. The resulting unit is "interruptions per customer" and is expressed as;

$$\mathrm{SAIFI} = \frac{\text{Frequency of Outages}}{\text{Number of Customers Supplied}}$$

$$= \sum \frac{N_i}{N_T} \qquad (2.11)$$

System Average Interruption Duration index (SAIDI)

This is defined as the average interruption duration for customers served during a specified time period. The unit is "minutes". This index helps the utility to report for how many minutes customers would have been out of service if all customers were out at one time. It is expressed as;

$$\mathrm{SAIDI} = \frac{\text{Total Outage Duration in hours}}{\text{Number of Customers Supplied}}$$

$$= \sum \frac{r_i N_i}{N_T} \qquad (2.12)$$

Customer Average Interruption Duration Index (CAIDI)

This is defined as the average length of an interruption, weighted by the number of customers affected, for customers interrupted during a specific time period. The index enables utilities to report the average duration of a customer outage for those customers affected. It is expressed as;

$$\text{CAIDI} = \frac{\text{Sum of Customer Interruptions Durations}}{\text{Total Number of Customers Interrupted}}$$

$$= \frac{\text{SAIDI}}{\text{SAIFI}}$$

$$= \frac{\sum r_i N_i}{\sum N_T} \quad (2.13)$$

Average Service Availability Index (ASAI)

This is a measure of the average availability of the distribution system that serves customers. It is usually represented in percentages. It is expressed as;

$$\text{ASAI} = \frac{\text{Consumer Hours Service Availabilty}}{\text{Customers Hours Service Demanded}}$$

$$= \frac{N_T(no.of\ hrs/yr) - \sum r_i N_i}{N_T(no.of\ hrs/yr)} \quad (2.14)$$

Average Service Unavailability Index

It provides the fraction of time customers are without electricity throughout the predefined interval of time. It is expressed as;

$$\text{ASUI} = \frac{\text{Duration of Outages in Hours}}{\text{Total Hours Demanded}}$$

$$= \frac{\sum r_i N_i}{N_T(no.of\ hrs/yr)} \quad (2.15)$$

2.4.2 Fault Tree Diagram

Fault Tree Diagrams (or negative analytical trees) are logic block diagram that display the state of a system (top event) in terms of its components (basic events). Like reliability block diagrams, (RBDs), fault tree diagrams are graphical design technique, and as such provide an alternative methodology to RBDs (weibull.com, 2021).

An FTD is built top-down and in terms of events rather than blocks. It uses a graphic “model” of the pathways within a system that can lead to a foreseeable, undesirable loss event (or a failure). The pathways connect contributory events and conditions, using standard logic symbols (AND, NOR, etc.).

Figure 2.2 is an example of a simple fault tree diagram. In this figure, failure of the top event depends on an intermediate event and one basic event C combined by the “NOR” logic gate such that the intermediate event failure mode is activated by the failure of two basic events A and B combined by the “AND” logic gate. In this fault tree diagram example, failure of the top event occurs when either event C or both event A and B fails. If only event A fails, the entire system does not fails. Also, event B alone cannot lead to system failure. The system fails if both event A and event B failure occurs.

Fault Tree Analysis explicitly shows all different failure modes that are necessary to result in the top event and constructing the fault tree gives a thorough understanding of the logic and basic causes leading to the top event. FTA can give a qualitative evaluation of the system. Figure 2.2 shows the fault tree with “AND” gates, “NOR” gates, and events of the diagram. Based on this, the fault tree diagram of the substation under review was thereafter constructed.

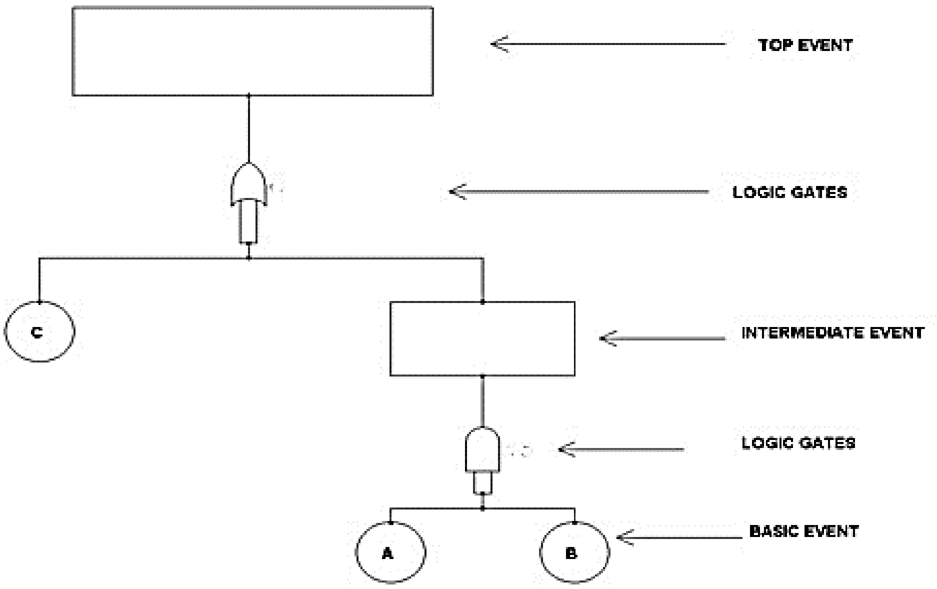

Figure 2.2 A Simple Fault Tree Diagram

2.4.3 Reliability Block Diagram (RBD)

Reliability Block Diagram (RBD) is a network diagram of a system that depicts the relationship of the subsystems that are required for successful operation of a system/network. In the RBD, each component/element of the system is represented as a block. The blocks are then connected in series, parallel, or m-out-of-n configurations based on the operational dependency between the components.

In reliability block diagram analysis, sometimes called block diagram decomposition, there are usually two steps in finding the system reliability indices, viz constructing the system reliability equation and analyzing the equation. System reliability equation accommodates the system configuration and its behaviours, with the answer relying on how accurately the system configuration and its behaviours are understood, and what assumptions are made and adopted. It also relies on what modelling method and tools are used.

The most fundamental difference between fault tree diagrams and RBDs is that you work in the "success space" in an RBD while you work in the "failure space" in a fault tree. In other words, the RBD looks at success combinations while the fault tree looks at failure combinations. In addition, fault trees have traditionally been used to analyze fixed probabilities (i.e. each event that composes the tree has a fixed probability of occurring) while RBDs may include time-varying distributions for the blocks' success or failure, as well as for other properties such as repair/restoration distributions (weibull.com, 2021).

For this project, the following assumptions were made:

i. The reliability of each individual block is known or can be estimated.

ii. Only hardware failures were considered.

iii. Failures of blocks are statistically independent.

iv. Blocks are bimodal, they either operate fully or fail completely (degradation of service is not allowed for).

v. The substation reliability is a function of reliability values of components that make up the system.

Given these assumptions, it is possible to determine the reliability of a system using RBD, from the component's failure rate. Exponential-time distribution model is used since the components failure rates are assumed constant. It is one of the simplest distribution forms to actually calculate the reliability value. The exponential failure density function f(t) is defined by;

$$f(t) = \lambda e^{-\lambda t} \qquad t \geq 0 \; \& \; t > 0 \tag{2.16}$$

where λ is the constant failure rate, and t is operating time. The reliability function R(t) is given by

$$R(t) = e^{-\lambda t} \tag{2.17}$$

2.4.3.1 Series Connection

From reliability block diagram reduction algebra, for a system consisting of two or more components connected in series with failure rates λ_1, λ_2, ….. λ_n, the system failure rate will be the sum of individual components' failure rates (i.e. $\lambda_1 + \lambda_2 + \ldots\lambda_n$). Because failure rates are constant, the component reliabilities R_1, R_2, …. R_n over a time of operation t, are exp (-λ_1t).exp(-λ_2t)…..exp(λ_nt). The overall reliability of the system is illustrated in Figure 2.3 is given by:

$$R = \prod_{i}^{n} R_i \qquad (2.18)$$

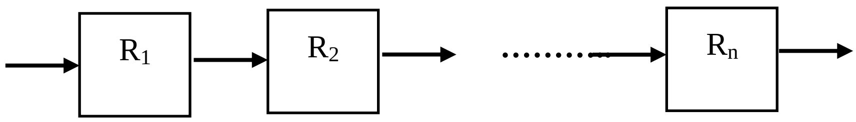

Figure 2.3 Reliability Block Diagram for Series Connection

2.4.3.2 Parallel Connection

From reliability block diagram reduction algebra, a system consisting of n simultaneously operating units connected in parallel with failure rates λ_1, λ_2, ….. λ_n, having component reliabilities R_1, R_2, …. R_n, is shown in Figure 2.4. In this system, satisfactory operation occurs if all units work normally for the successful operation of the system. Therefore, the reliability of the system R is equal to the probability of at least one of these units operating normally for system success.

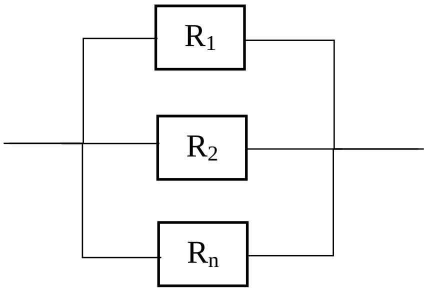

Figure 2.4 Reliability Block Diagram for Parallel Connection

The general expression for active parallel connection for constant failure case is given by

$$R = 1 - \prod_{i=1}^{n} (1 - R_i) \tag{2.19}$$

Where R_i is the reliability of the ith unit and n is the number of units connected in parallel. Redundancy is necessary when it is extremely important to keep a system alive in any case. These procedures were compared with military handbook of reliability, MIL-HDBK-338B (page 5.31 – 5.33).

2.4.4 Mean Time Between Failure (MTBF)

MTBF can be obtained for each component by operating the network system for specified period of time under specified conditions. The probability density function can thus be expressed as:

$$MTBF = \int_0^1 tf(t)dt \tag{2.20}$$

Based on the assumption that a component has a constant failure rate, equation (2.20) can be represented by:

$$MTBF = \frac{1}{\lambda} \tag{2.21}$$

where λ is the failure rate of each component of the network system. The mean time between failures for each component is obtained by substituting each component failure rate into equation (2.21).

2.5 Power System Failures and Faults

Failures in power system or at the electrical installations are eliminated under the supervision of a shift control engineer. In some instances, however, when it is necessary to take immediate measures, operators themselves may carry out the following operations;

i. Switch out any equipment if its operation endangers the life of men or it may be damaged;
ii. Switch out the failed equipment and ensure normal operation of other equipment;
iii. Connect immediately in parallel again, the generator and other equipment that have been obviously falsely disconnected;
iv. Restore the power supply of station auxiliaries;
v. Ensure self-synchronization of generators;
vi. Switch on the standby equipment.

Typical Failures and Faults

2.5.1 Failures and Faults of Transformers

One of the major causes of failure in a power system is failure of transformer. The most common causes of transformer failures are usually systematic overloading, leakage of short-circuit currents through the windings (due to the poor condition of distribution networks), discrepancy in protective devices, ingress of moisture into the transformer through poorly sealed bushings, low strength of oil tanks in some transformers, etc.

Failures are observed in the tap changers when transferring them from one position to another. These failures generally occur because of moisture ingress and disturbances in the attachment of tap changer mechanisms. There are cases when oil leaks from the oil conservator and gas relay, whereas the oil gauge indicates a proper oil level due to the clogged oil passages. The attending personnel should be particularly careful when inspecting the transformer oil system.

Transformer failures can lead to fire outbreak, as observed recently at one of the distribution substation in ASCL; 27 DS (Pump House and Sewerage Plant – 1). The 6.3MVA, 6.6 kV transformer was powered on no-load. Few hours later, it was reported that the transformer was in flames. Investigations are currently on-going to ascertain the cause of failure of the transformer. Falade *et al.* (2016) carried out the Reliability Assessment of Power Transformers for Oshogbo Area Control Center in Nigeria for a period of five years (2009 - 2013). The daily record of transformers' outages on the 330/132 kV and 132/33 kV transformers were obtained. Several indices were determined in order to evaluate the reliability of these transformers. The number and duration of transformers outages were investigated and analyzed, the MTTF for 132/33 kV transformers was 1.77 years and the failure rate was 0.5650 per year while the MTTF for 330/132 kV transformers was 2.30 years and the failure rate was 0.4348 per year.

2.5.2 Failure and Faults of Circuit Breakers

Another major power equipment that may fail is the circuit breaker. Damage to the oil circuit breakers may occur due to a failure to quench the arcs drawn between the contacts, faults in their contact systems (overheating and sticking of contacts), flashover across the internal and external insulating parts, malfunction in the operating and actuating mechanisms and breakage of insulation links.

The faults that are most frequently found in the air circuit breakers are caused primarily by an insufficient arc-control capacity when interrupting the short circuits and small load currents (unloaded lines and transformers), a flashover across the support insulator and air-blast pipe insulation, broken insulators and arc chutes, damaged contact systems and operating mechanisms, faulty rubber seals. Close attention should be given to the condition of a ventilating air flow rate indicator. There have been cases when in intensive blowing, the ball shut off the flow of ventilating air into the space and, the circuit breaker was damaged.

Failures may be caused by damaged contact systems as a result of scored rubbing surfaces and peeled silver coating due to the deformation of an arc chute mechanism body, etc. the air-blast and other valves are frequently wedged in the air-blast circuit breakers because of low quality of rubber seals. The contact of circuit breakers controlled by manual operating mechanisms wear out particularly quickly because their operation depends on the skill and expertise of the attending personnel. The paper presented by (Adegboye and Dawal, 2012) investigated and discussed the faults that impact a typical 11-kV feeder in the Southern part of Kaduna city. There are four outgoing feeders from the 30-MVA, 33/11-kV Peugeot injection substation and Coca-Cola feeder is one of them. The reliability of the case study, 11-kV Coca Cola feeder, was assessed by analyzing the data obtained from the Power Holding Company (PHCN). The data used was for January 2004 to December 2004 and it contains the type of fault, monthly peak load demand, outage duration, and power losses due to the outages on the feeder. The faults identified were earth fault and overcurrent faults. The earth fault however, contributes more to outages than overcurrent fault and its occurrence is higher during the rainy season than in the dry season. Hence, it was shown that the seasons of the year really affect the integrity of the substation. Amongst the many recommendations given in order to improve the reliability of the substation is that the distribution system's configuration should be redesigned to include ring system which means the consumers will now be supplied by two feeders. This thus removes dependency on just a single feeder. Also, iron cross arms should be used in place of wooden cross arms in order to reduce avoidable earth faults due to broken wooden cross arms. The paper only looked at the feeder distribution system and hence faults and failures that arise from the downstream of the secondary distribution were neglected.

Jibril and Ekundayo (2013) analyzed the reliability performance of the 33kV Kaduna Electricity Distribution Feeders, Northern Region, Nigeria. The monthly reliability parameters for the 33kV distribution feeders were calculated using the daily outage data of the feeders for 24 months (January, 2011 to December, 2012). The results of the analysis carried out show that the system availability is low compared to the IEEE standard of ASAI which is 0.99989.

2.5.3 Switchgear Failures

The faults observed in a switchgear installation occur due to the ingress of moisture, faulty sealings and failure to observe required insulating distances. Insulation breakdowns are generally caused by an increase of humidity over 80%, ingress of dust and dirt through poorly sealed joints and by application of textolite plates (instead of porcelain insulation) to secure busbars.

In some factory assembled switchgear installations, a close watch should be kept on the correct locking of the withdrawable truck of a circuit breaker, because an improper locking of the truck may lead to damage of cluster contacts and to the formation of arcing and a short circuit across the switchgear busbars.

2.5.4 Failures in Power System

The heaviest failures are those which lead to the break-up of the power system and loss of auxiliary supply. Such failures arise as a result of disturbances in the static and dynamic stability, fall of some components of power system out of synchronism, overload of transmission lines, improper operation of protection systems or failure of circuit breakers at short circuit. In the event of the above failures, the primary task of the attending personnel is to restore the auxiliary power supply. For this purpose, they may employ the outgoing lines to receive power from the neighbouring electrical installations as well as from the diesel-generators installed at some powerful power stations to start-up the most essential low-capacity station auxiliaries.

Onime and Adegboyega (2014) carried out reliability assessment of power distribution system in Nigeria using Ekpoma network, Edo, as a case study. Outage data were collected from January 2012 to December 2012 and the average availability using basic reliability indices was evaluated for Iruekpen, Irrua, and Express feeders which are distribution feeders in Ekpoma. The reliability indices used include: Mean Time Between Failure (MTBF), Mean

Down Time (MDT), and Availability. Customer-based indices used include: Customer's Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Average Service Availability Index (ASAI) and the Average Service Unavailability Index (ASUI). The outages were classified based on type, frequency and durations and the result calculated showed that outages occur in the distribution feeders daily. Earth fault, supply failure, planned outage for maintenance, and load shedding were identified to be the possible causes for interruptions on the feeders. From the study, load shedding was the major reason for interruptions. The study further showed that heat during the dry season and windstorms in the rainy season were factors that could increase the failure rate of the feeders. The researchers identified load shedding as the main cause of outages for the feeders analyzed. Planned outages due to maintenance work, supply failures and earth faults were also identified as causes for interruptions on the distribution feeders. The researchers made case for improvement of the reliability of the distribution but did not give any recommendations that can bring about this improvement. There were no interpretations for the values of the customer orientation indices computed with reference to reliability benchmark. However, the system has an ASAI value of 0.6147 which means the reliability is very low.

2.5.5 Failures in Station Auxiliaries

These failures occur due to disconnection of live isolators, wrong short-circuiting, application of temporary earth sets to the live equipment and the erroneous disconnection of station auxiliaries. In addition, some failures occur because of the imperfection of connection diagrams and defects of equipment. They are; unsatisfactory sectionalization of station auxiliaries busbars; lack, malfunction or improper selection of circuit breakers; lack of standby facilities for auxiliary power supply (automatic cut-in devices for auxiliary power supply, standby transformer automatic cut-in devices); failure in operation of station auxiliaries standby source automatic cut-in devices due to malfunction of breaker operating mechanisms; insufficient voltage across the d.c. control current busbars.

To maintain the rated voltage level on the d.c. control current busbars, station batteries should be equipped with all required automatic equipment. A trouble-free and reliable operation of all station auxiliaries can be ensured by a proper maintenance of their electric motors. Operating experience has shown that most of the motor failures (about 40%) were caused by an improper operation and maintenance and by a low quality of repair.

2.5.6 Failures Associated with improper Operation of Secondary Circuits

These failures are caused by damaged insulation and earth faults in the secondary circuits and by the improper actions of the attending personnel when handling the fuses, test sets, control switches and other devices during preventive maintenance and routine switching operations.

2.6 Literature Review

By employing analytical technique, the study carried out by Izuegbunam *et al.*, (2014) assessed the reliability of Onitsha Business Unit within the period of three years, 2009 to 2011. This technique requires the use of outage data which was obtained from the Power Holding Company (PHCN) for the various feeders in the Onitsha distribution system. The paper also presented the impact of having photovoltaic (PV)/inverter interconnected with the network in order to improve the reliability of the system. The researchers investigated the factors causing poor reliability performance, and possible ways to bring about improvements to the system. To analyze the effect of improving the reliability of the system by having alternative or complementary source (PV/inverter) interconnected at the 11-kV busbar, ETAP software was used. The algorithm used in the software was displayed and the simulation was carried out with a set-up having a self-driven fixed frequency inverter design connected to 11-kV distribution bus to supply the loads whenever there is outage in the utility. The results obtained showed 61.2%, 55.7% and 65.1% reductions in revenue loss for 2009, 2010, and 2011 respectively after the PV installation. The researchers concluded that reliability performance can be improved upon by introducing a complementary source and that by effectively utilizing solar technologies such as PV, there will be less erratic supply of power to consumers.

Samuel *et al.* (2013) presented a research paper that assessed the reliability of a 132kV transmission line protection scheme using fault tree analysis. Their paper focused on the application of fault tree analysis to enhance the reliability of a power transmission line. Fault tree diagrams were developed for the present protection scheme employed on the 150km-long 132kV transmission line in the Northern part of Nigeria of which Kano-Kankia power transmission line was used as case study. The protection scheme was analyzed and then compared with another newly developed scheme, by the researchers, which has an arrangement that made provision for redundancy. The new scheme revealed a significant improvement of about 51% in the availability of the transmission lines. In addition, the assessment revealed that relays, as a result of lack of automatic supervision, were the major weakness of the protection scheme.

The stochastic nature of failures of a distributed generation was analyzed with the distribution system using a method based on Bayesian Networks was a paper presented by Gao *et al.* (2014). The reliability analysis of the distribution system was done using test data from another research work. The analysis carried out determined the availability, location and the numbers of distributed generation and the effect it has on the overall distribution system performance.

Adefarati *et al.* (2014) presented a research work on the reliability assessment of Nigeria 330/132kV substations, using Ayede 330/132kV substation as a case study. In their work, the different reliability indices that can be used to determine optimum operation of a power system such as SAIDI, CAIDI, SAIFI, CAIFI, CIII, MAIFI and ASAI were deduced for the substation. Furthermore, their work reveals the necessity of optimizing power system failure rate since it affects availability, quality and quantity of electricity in the system. The analysis carried out looked into the criticality and sensitivities of the subsystems or components of the system for continuous improvement by analyzing only the substation feeders of the six districts being fed by it. The research further work presented suggestions on how to improve power system reliability.

By using NEPLAN simulation software, a software tool that helps in assessing the configurations of power system, Uhunmwanghoand Omorogiuwa (2014) a method was presented for evaluation and prediction of distribution system reliability using Choba in Rivers state as case study. NEPLAN power system software was used to perform an offline simulation of the distribution network considering outage time, incoming energy, outgoing voltages (kV) rating and three-phase current rating. The data for a period of six months was obtained from the Choba Injection substation and used to compute the reliability indices of the distribution system. Customers Average Interruption Duration Index (CAIDI), System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Frequency Index (CAIFI), Customer Interruptions per Interruption Index (CIII), Momentary Average Interruption Frequency Index (MAIFI) and Average Service Availability Index (ASAI) were used in estimating the reliability of the system. The results of the computed reliability indices showed that the distribution system averaged an availability of 99.98% which the researchers described as being very poor due to the fact that other utilities have set an ASAI goal of 99.99%. It was recommended that the utility company should be keeping detailed account of data and records which contains component outage time, component failure rate and total energy consumed which will help compute reliability indices such as Energy Demanded Not Supplied (EDNS).

Sonwane and Kushare (2015) presented an overview of useful methods used in reliability analysis. The inclusion of aging components when using conventional reliability analysis as a means to better the reliability evaluation of distribution network was done by Wang and Wu (2011). The analysis carried out presented the relationship between aging components and their limit age (time). Failure Mode and Effect Analysis (FMEA) was used to calculate the reliability indices. A simple distribution network was generated and used for the research and the focus was on supply lines.

In a similar research, researchers Amuda *et al.* (2016) carried out the Reliability Analyses of a Typical Mega-Water Pumping Station. A comparative study on the 2011 commissioned mega-water treatment and pumping stations in Kwara State was conducted using two reliability analyses techniques. The Weibull function was used to predict projected reliability for two decades from the year of installation. In the same way, the estimated reliability of the system for each year was obtained using exponential distribution. Based on the four pumping stations, the results show that on average, the intake pumping station has estimated reliability of 91.885% compare to projected reliability of 99.115%. Similarly, the lowlift pumping station has an estimated reliability of 67.1275% compare to projected reliability of 81.0375% and same pattern for the highlift and treatment stations. It was also discovered that, the current poor rating of the maintenance of some basic components of the plant can course a complete breakdown of the plant in less than 10 years after its commissioning. Component importance analysis was carried out in order to define rank of each unit to the system reliability. The analysis showed that some treatment plant components are at critical stage when considering reliability improvements. On the other hand, when planning a maintenance action lowlift unit is the most critical.

Okorie (2016) assessed and quantified the reliability performance of Abakpa distribution substation of Kaduna Disco. In addition, the author suggested ways of achieving better reliability performance. The distribution network was assessed with filed data collected from the substation's logbooks for a period of three years, 2010-2012. The substation's failure rate, outage rate, and repair rate were computed by using the duration and frequency of outages in the data. The following reliability indices were also computed: Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), Mean Time To Failure (MTTF), Availability and Reliability. The load outages and downtimes for each year were summed up for each year in order to avoid working with cumbersome data due to the large data involved. It is important to note that the Abakpa substation is a 132-kV/33-kV/11-kV transmission and distribution substation. The cumulative fault frequency, period of occurrence and total downtime for each year were computed and used to calculate the reliability indices mentioned earlier. The reliability indices were computed for components and for nature/causes of failure for each of the year understudied. Examples of the component faults include: earth leakage fault, switch gear related fault, fault tripping fault, faulty transformers, tree falling on line, failure on line due to jumpers, reactor faults, overcurrent etc. The result showed that contrary to one of the objectives of the paper, the author failed to suggest a distribution network design that will improve the reliability of the substation while it mentioned that simple overhead radial systems have poor reliability performance. The paper, however, discussed some of the factors that influence reliability such as vegetation, animals, and environmental factors. Circuit length was also pointed out as a factor that affects reliability as longer circuits are susceptible to interruptions.

Airoboman *et al.* (2017) researched on the reliability analysis of power system network using Transmission Company of Nigeria Benin City as case study. Data was collated from the daily operational log books of five feeders emanating from the Transmission Company of Nigeria, Benin City, Nigeria. The reliability indices were calculated and the results interpreted using a spreadsheet. A mathematical model was also developed for the network using the curve fitting tool in the MATLAB (2013) environment and a corresponding Simulink model was eventually developed from the mathematical model. The results show that the priority feeder has the highest reliability of 97.8% while the feeders characterized with obsolete equipment have the least reliability of 78.4%.

To ensure the power system operates safely and reliably, Li and Jianying (2017) reviewed the condition monitoring and diagnosis of power equipment, including transformer, gas insulated switchgear, cable, external insulation, generator, and power capacitor in recent years. The researchers observed that although much progress has been made in technologies of condition monitoring and fault diagnosis such as test accuracy, fast and accurate fault localization and recognition of fault types, there were still many deficiencies which needs further research work, including the reliability of signal collection from sensors, the accuracy of data treatment and analysis, anti-interference performance of test equipment, appropriate models used for condition evaluation. The prospective of condition monitoring and diagnosis technologies of power equipment were also presented in the study. They proposed that the application of big data, internet of things and cloud computing should be expected and given special attention in the near future.

Adelabu *et al.* (2018) carried out the reliability assessment of power equipment in the 33/11kVAnglo-Jos distribution substation of the Jos Electricity Distribution PLC using fault tree analysis (FTA) technique. The aim of the researchers was to analyze the reliability of power equipment in a distribution substation by using fault tree analysis. Using the data recorded in the substation’s log book was used as the field data which included frequencies of failures of power equipment in the substation and their respective durations of failures, the single line diagram and the fault tree diagram of the power equipment in the distribution substation was constructed. The FTA model showed the logical arrangement of the basic events in hierarchical form leading to the desired top event. The qualitative fault tree analysis was done to determine the minimal cuts of the basic events that could lead to the top event by using Boolean algebra and probability expressions. The quantitative fault tree analysis was carried out to determine the mean time between failures (MTBF), mean time to repair (MTTR) and unavailability of each power equipment by using reliability expressions. The power equipment with the best MTBF and MTTR were also identified and discussed. The result of the research identified the power equipment that should be upgraded so as to achieve reliable distribution substation and guarantee improved electricity delivery to consumers.

Li *et al.* (2018) analyzed the reliability of ultrahigh voltage AC/DC system combined with the quasi-Monte Carlo method and PSD-BPA simulation. By so doing, the researchers obtained the reliability model of various components as well as the system. This ensured that the simulation speed is improved with accuracy ensured. In order to ensure the compatibility and efficiency of the software, the researchers designed the BPA-Matpower data interface, and the data translation from BPA to Matpower was realized by fourth conversion. They further proposed an index system for reliability evaluation, concise and easy to compute, to reflect the reliability of the UHV grids and the characteristics of AC and DC systems. Based on actual regional powergrid, comparison between their model and the traditional sequential Monte Carlo method was carried out.

Puschkarsky *et al.* (2019) reviewed Silicon-Carbide (SiC) MOSFETs High-Voltage Device Reliability focusing on Threshold Voltage Instability. Measurement techniques for the characterization of the threshold voltage instabilities were compared and discussed. Modeling of the threshold voltage instabilities based on capture–emission-time (CET) maps was also discussed, taking into account the complete gate bias/temperature history.

Hamoud *et al.* (2020) compared the reliability of two deterministic criteria for planning high voltage auto-transformer. One criterion calls for designing the station to withstand the loss of one unit transformer (single contingency criterion) while the other calls for designing it to withstand the loss of two units (double contingency criterion). The system availability index and the loss of energy index were the two criteria utilized in this research. The study proposed a number of Markov models to evaluate the probability of system failures under each criterion.

Comparative analysis of the defect type recognition reliability in High-Voltage Power Transformers Oil using different methods of Dissolved Gas Analysis (DGA) was carried out by Shutenko and Kulyk (2020). In the research, the reliability of 9 most known methods of defect type recognition by DGA results was analysed. It was established that none of 9 analysed methods allowed the reliable recognition all 40 types of defects. The largest number of correct diagnoses for the analysed sample was obtained using the method of nomograms and Duval triangle. The smallest number of correct diagnoses was obtained using the gas ratios recommended by Rogers and Dornenburg methods. Thus, the same method has different reliability in respect to different diagnoses. In addition, diagnoses made using different methods for the same defect type differ significantly both from each other and from actual diagnoses. The values of diagnostic criteria (gas ratio values and gas percentage values) obtained as a result of the analysis for 40 defects of different types allow to increase the reliability of defect type recognition by DGA results.

2.7 Summary of the Review

Review has shown that a lot has been done by previous researchers in the area of reliability analysis of power equipment, adopting different methods of analysis. These researches have been majorly centered on power transformers, circuit breakers commonly referred to as feeders, as well as transmission and distribution substations. Methods of analysis that have been adopted include fault tree analysis, use of ETAP software and curve fitting tools in MATLAB. Reliability indices commonly analyzed are Mean Time Between Failure (MTBF), Mean Down Time (MDT), and Availability. Customer-based indices used include:

Customer's Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Average Service Availability Index (ASAI) and the Average Service Unavailability Index (ASUI). Furthermore, it can be seen that the existing models and most applied methods were not able to predict the reliability of the systems. Therefore, this work proposed a method that is capable of reliability prediction of high voltage power equipment using historical and theoretical data.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Collection of Data

The data of a period of twelve months (January – December 2020) from 7DS substation (refer to Appendix A) was collected and analyzed. Outages/Unavailability records were obtained from logbooks of MSDS 1 Control Room. The case study substation, 7DS is an unmanned Distribution Substation under MSDS 1. As a result, all data regarding 7DS substation was obtained from MSDS 1. The data also captures the recorded monthly duration for each component's outage and the frequency of the outages. An overview of the substation is shown in Plate 3.1 and a schematic diagram of Ajaokuta Steel Company Power Network is shown in Figure 3.1. The components on which data was collected are:

i. 11 kV Incoming Feeder, Cubicle 30 Section II

ii. 11 kV Outgoing Feeder Cubicle 32 Section II (Township Feeder 1)

iii. 11 kV Outgoing Feeder Cubicle 5 Section I (Township Feeder 2)

iv. Earth Fault Relay PTN (PT-40/0.2 – 04)

v. Overcurrent Relay PT3 (PT-40/20-04)

vi. Current Cut-off Relay PT1 (PT-40/20-04)

vii. 11 kV, 630A, Oil Circuit Breaker

viii. Pole Discrepancy Protection Relay (Single Phasing Fault)

ix. Voltage Transformer (1VT & 2VT)

x. 3-phase, 11/0.415kV Sub Service Transformer (1SST & 2SST)

xi. Current Transformers (Bus CTs & Cable CTs)

xii. Manual isolator on Outgoing Feeders

xiii. 110V DC Battery Unit

xiv. Rectifier Unit

Plate 3.1 Overview of 7DS Substation

In the substation overview (Plate 3.1), cubicles are arranged on the left hand side as well as the right hand side, each numbered and labelled accordingly for easy identification, operation and maintenance. Section 1 is on the left hand side while section 2 is on the right hand side with the sectionalizing breaker and isolator located at the extreme end of section 2 (right hand side).

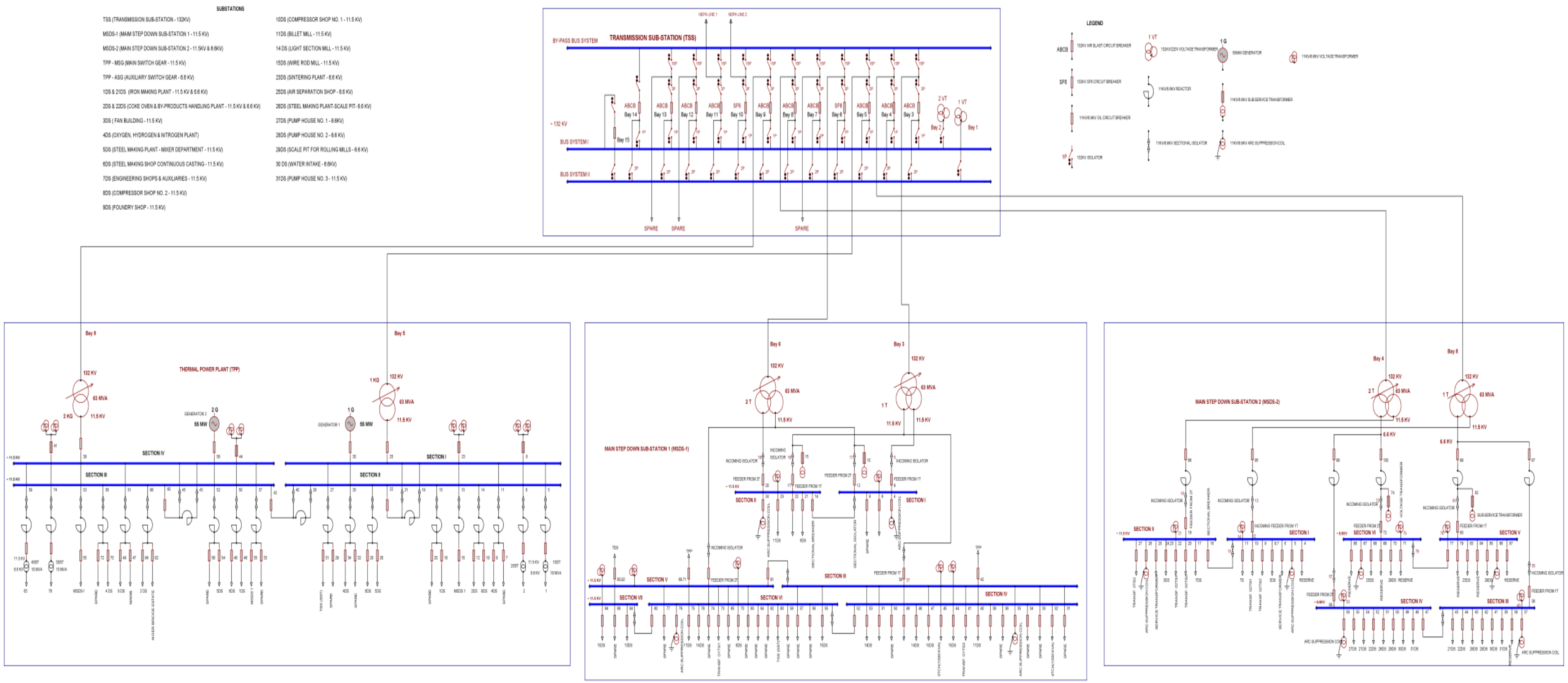

Figure 3.1 Schematic Diagram of ASCL Power System Network

Figure 3.1 shows the link between the transmission substation (TSS), main switch gear (MSG), main step-down substation 1 (MSDS 1), main step down substation 2 (MSDS 2) as well as the secondary distribution substation in each of the 3 major load centres.

3.2 Basic Design Layout

The distribution substation on which the study was carried out forms an integral part of the entire Power Transmission and Distribution Network of Ajaokuta Steel Company Limited Power System network. It is mostly referred to as secondary distribution substation or customer substation. The primary distribution network of Ajaokuta Steel Company Limited are the Main Step Down Substation 1 (MSDS 1), Main Step Down Substation 2 (MSDS 2) and Main Switch Gear (MSG).

The typical configuration used in most distribution substations of ASCL is the double-end fed network which has overcurrent, phase differential and earth fault protections. 7DS substation is an 11kV substation originally designed to handle the power requirements of Engineering shops and its auxiliaries. The substation has two incoming feeders, one from MSDS 1 and another from MSDS 2, as well as outgoing feeders to several transformer substations; 7TS1, 7TS2, 7TS3, 7TS5, 7TS6, 7TS7, 7TS9, 7TS13, 7TS15, 7TS17, 7TS18, 7TS19 and 7TS20. These transformers are distribution transformers of Power Equipment Repair Shop, Forge & Fabrication Shop, Pattern Making Shop, Rubberizing shop as well as Machine & Tools shop. 7DS substation also a feeder to Foundry Shop (9DS) and 6 spare feeders. Over the past years, two of these spare feeders (feeders 5 & 32) have been converted to housing estates feeders.

Figure 3.2 illustrates a one-line schematic diagram of 7DS substation. From the diagram, the substation has two sections (section 1 and section 2) linked with a sectionalizing feeder (cubicle 23) and an isolator (cubicle 22). The substation has two incoming feeders circuit breakers rated 1250 A, each from the two main distribution substations (cubicle 13 from

MSDS 2 and cubicle 30 from MSDS 1), two sub-service transformers (11/0.415 kV), one on each section, sub-service transformer 1 (cubicle 12) on section 1 and sub-service transformer 2 (cubicle 29) on section 2. Also available in the substation are voltage transformer 1 (cubicle 14) and voltage transformer 2 (cubicle 31). The substation has a total of 26 outgoing feeders, with 4 spares (cubicle 9, cubicle 17, cubicle 21 and cubicle 26), one feeder to another substation (9DS), two feeders to the housing estates (cubicle 5 and cubicle 32) and 19 outgoing feeders to various transformer substations (TSs).

As seen in Figure 3.2, the sub-service transformer which serves as the domestic transformer of the substation receives supply even before switching ON the substation incoming feeder. This is to ensure that the substation auxiliaries which includes the rectifier unit, the battery charging unit, the current control panel, lighting and ventilation as well as the power supply unit 1 & 2 are successfully powered immediately. The output voltage from the sub-service transformer is sent to the low voltage apparatus cubicle (cubicle 1) which serves as a distribution cabinet. All domestic loads are fed from this cubicle.

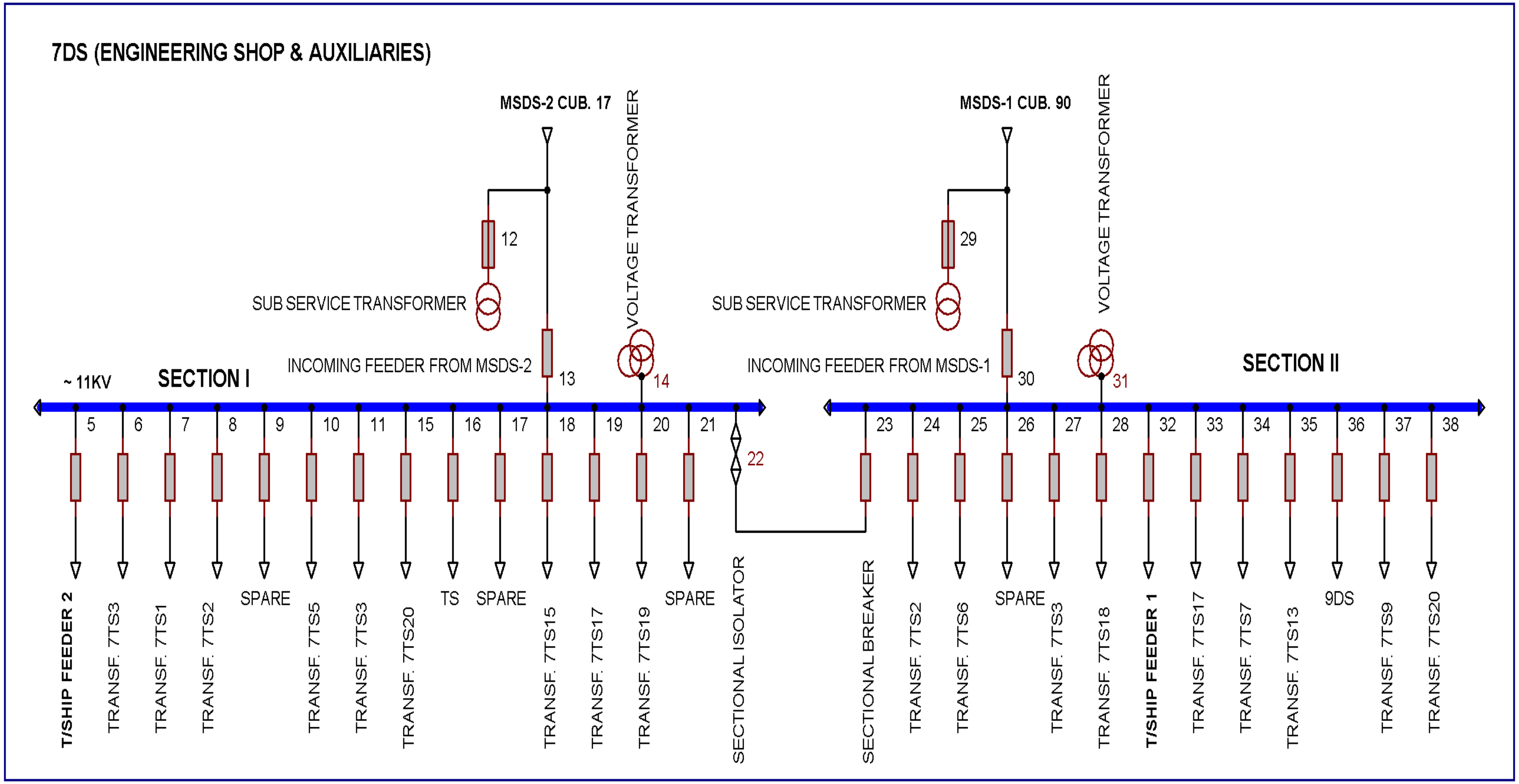

Figure 3.2 One Line Diagram of 7DS Substation

3.3 Fault Tree Diagram of the Substation, 7DS

Figure 3.3 illustrates the fault tree diagram of the substation. In this diagram, failure of the top event (unavailability of the substation) can only occur when failure of either the incoming feeder, outgoing feeder 5 and outgoing feeder 32 together, earth fault, over-current fault, current cut-off, OCB failure, single phasing, voltage transformer, sub-service transformer, current transformers, isolator failure, as well as battery failure and rectifier failure together. This implies that failure of rectifier alone cannot lead to substation unavailability. Likewise, failure of battery alone cannot lead to substation unavailability.

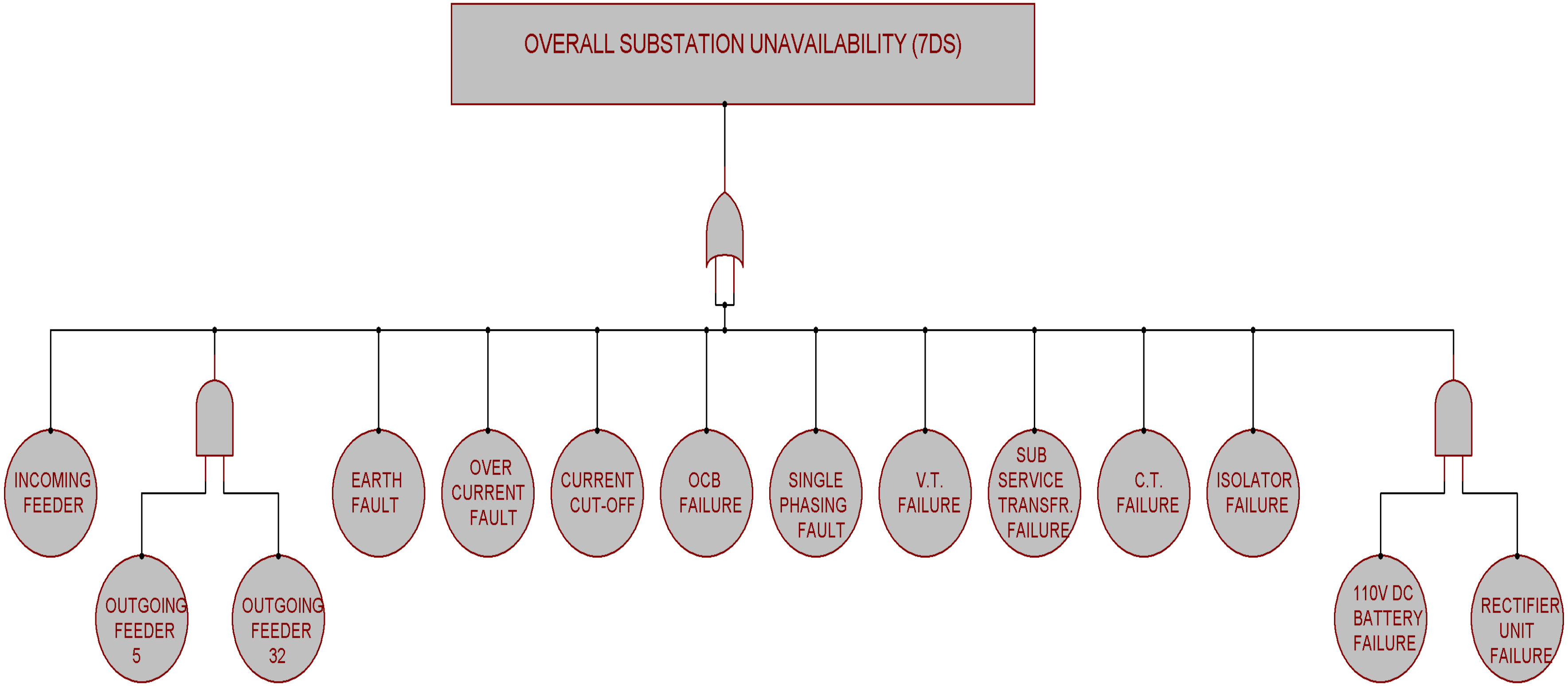

Figure 3.3 Fault Tree Diagram of 7DS Substation

3.4 Reliability Block Diagram (RBD) of 7DS Substation Components

The system consists of 14 blocks. The Incoming Feeder, Earth Fault Relay, Overcurrent Relay, Current Cut-off Relay, 11kV Oil Circuit Breaker, Pole Discrepancy Protection Relay (for Single Phasing Fault), Voltage Transformer, Sub Service Transformer, Current Transformers and Manual isolator on Outgoing Feeders can be considered to be connected in series because failure of one of these components results in the failure of the whole network (Figure 3.4). However, the Outgoing Feeder 5 and Outgoing Feeder 32 are in parallel. Also, the 110V DC Battery Unit and Rectifier Unit can be considered to be connected in parallel because failure of the battery unit cannot result to failure of the system except when there is no power to the substation itself. Also, failure of the rectifier unit cannot result to failure of the system as the battery backup immediately comes into play. Therefore, both battery unit and rectifier unit must fail before the entire network fails.

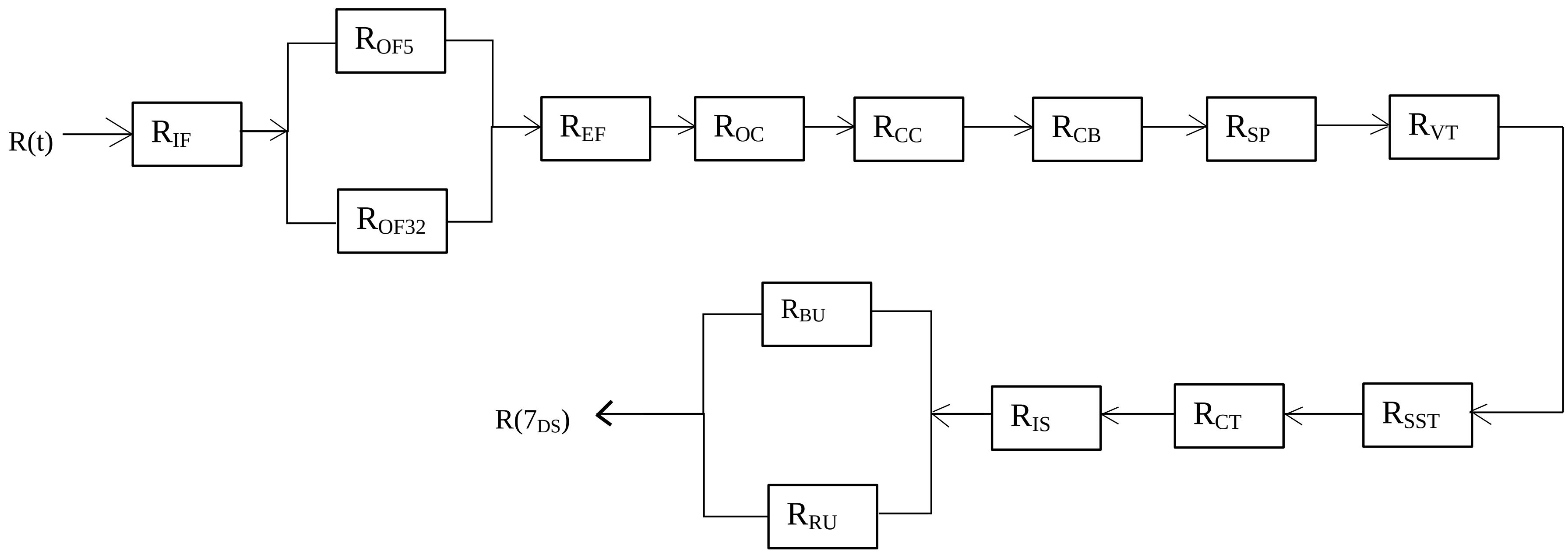

Figure 3.4 Reliability Block Diagram of 7DS Substation

The equivalent reliability block diagram of 7DS substation is represented in Figure 3.4

The reliability of each component is represented as;

R_{IF} = reliability of incoming feeder

R_{OF5} = reliability of outgoing feeder 5

R_{OF32} = reliability of outgoing feeder 32

R_{EF} = reliability of earth fault relay

R_{OC} = reliability of overcurrent relay

R_{CC} = reliability of current cut-off relay

R_{CB} = reliability of oil circuit breaker

R_{SP} = reliability of single phasing relay

R_{VT} = reliability of voltage transformer

R_{SST} = reliability of sub-service transformer

R_{CT} = reliability of current transformer

R_{IS} = reliability of isolator

R_{BU} = reliability of 110V battery unit

R_{RU} = reliability of rectifier unit

3.5 Development of Reliability Model of the Substation using RBD

The overall reliability of the substation from the block diagram can be expressed in equation 3.1;

$$R_{7DS} = R_{IF} \cdot (R_{OF5}//R_{OF32}) \cdot R_{EF} \cdot R_{OC} \cdot R_{CC} \cdot R_{CB} \cdot R_{SP} \cdot R_{VT} \cdot R_{SST} \cdot R_{CT} \cdot R_{IS} \cdot (R_{BU}//R_{RU}) \tag{3.1}$$

Using series, parallel and redundancy reliability block diagram theorems, the reliability model of the substation can be presented as

$$R_{7DS} = R_{IF} \cdot [1-(1-R_{OF5})(1-R_{OF32})] \cdot R_{EF} \cdot R_{OC} \cdot R_{CC} \cdot R_{CB} \cdot R_{SP} \cdot R_{VT} \cdot R_{SST} \cdot R_{CT} \cdot R_{IS} \cdot [1-(1-R_{BU})(1-R_{RU})] \tag{3.2}$$

From equation (2.17), it is assumed that the failure rate follows exponential distribution, therefore; substituting the components failure rates in equation (3.2), the general reliability equation of 7DS distribution substation can be generally expressed as:

$$\mathrm{R_{7DS}} = e^{-\lambda_{IF}t} \cdot \left[1 - \left(1 - e^{-\lambda_{OF5}t}\right)\left(1 - e^{-\lambda_{0F32}t}\right)\right] \cdot e^{-\lambda_{EF}t} \cdot e^{-\lambda_{OC}t} \cdot e^{-\lambda_{CC}t} \cdot e^{-\lambda_{CB}t} \cdot e^{-\lambda_{SP}t} \cdot e^{-\lambda_{VT}t} \cdot e^{-\lambda_{SST}t} \cdot e^{-\lambda_{CT}t} \cdot e^{-\lambda_{IS}t} \cdot \left[1 - \left(1 - e^{-\lambda_{BU}t}\right)\left(1 - e^{-\lambda_{RU}t}\right)\right] \quad (3.3)$$

Inserting the failure rate of the individual components that make up the substation,

$$\mathrm{R_{7DS}} = e^{-0.004652546t} \cdot [1 - (1 - e^{-0.014417382t})(1 - e^{-0.021474607t})] \cdot e^{-0.016765799t} \cdot e^{-0.011064377t} \cdot e^{-0.012860225t} \cdot e^{-0.002382534t} \cdot e^{-0.000451762t} \cdot e^{-0.000112007t} \cdot e^{-0.000112007t} \cdot e^{-0.000112007t} \cdot e^{-0.000119732t} \cdot [1 - (1 - e^{-0.001023514t})(1 - e^{-0.000336022t})] \quad (3.4)$$

Simplifying the above expression,

$$\mathrm{R_{7DS}} = e^{-(0.004652546)t} \cdot [1 - (1 - e^{-0.014417382t})(1 - e^{-0.021474607t})] \cdot e^{-(0.016765799+0.011064377+0.012860225+0.002382534)t} \cdot e^{-(0.000451762+0.000112007+0.000112007+0.000112007+0.000119732)t} \cdot [1 - (1 - e^{-0.001023514t})(1 - e^{-0.000336022t})]$$

$$\mathrm{R_{7DS}} = e^{-(0.004652546)t} \cdot [1 - (1 - e^{-0.014417382t})(1 - e^{-0.021474607t})] \cdot e^{-(0.043072935)t} \cdot e^{-(0.000907515)t} \cdot [1 - (1 - e^{-0.001023514t})(1 - e^{-0.000336022t})]$$

$$\mathrm{R_{7DS}} = e^{-(0.004652546+0.043072935+0.000907515)t} \cdot [1 - (1 - e^{-0.014417382t})(1 - e^{-0.021474607t})] \cdot [1 - (1 - e^{-0.001023514t})(1 - e^{-0.000336022t})]$$

$$\mathrm{R_{7DS}} = e^{-0.048632996t} \cdot [1 - (1 - e^{-0.014417382t})(1 - e^{-0.021474607t})] \cdot [1 - (1 - e^{-0.001023514t})(1 - e^{-0.000336022t})]$$

$$\mathrm{R_{7DS}} = e^{-0.048632996t} \cdot \left[1 - \left(1 - e^{-0.021474607t} - e^{-0.014417382t} + e^{-(0.014417382+0.021474607)t}\right)\right] \cdot \left[1 - \left(1 - e^{-0.000336022t} - e^{-0.001023514t} + e^{-(0.001023514+0.000336022)t}\right)\right]$$

$$\mathrm{R_{7DS}} = e^{-0.048632996t} \cdot [1 - (1 - e^{-0.021474607t} - e^{-0.014417382t} + e^{-0.035891989t})] \cdot [1 - (1 - e^{-0.000336022t} - e^{-0.001023514t} + e^{-0.001359536t})]$$

$$R_{7DS} = e^{-0.048632996t} \cdot [1 - 1 + e^{-0.021474607t} + e^{-0.014417382t} - e^{-0.035891989t}]$$
$$\cdot [1 - 1 + e^{-0.000336022t} + e^{-0.001023514t} - e^{-0.001359536t}]$$

$$R_{7DS} = e^{-0.048632996t} \cdot (e^{-0.021474607t} + e^{-0.014417382t} - e^{-0.035891989t})$$
$$\cdot (e^{-0.000336022t} + e^{-0.001023514t} - e^{-0.001359536t})$$

$$R_{7DS} = e^{-0.048632996t} \cdot (e^{-0.021474607t} + e^{-0.014417382t} - e^{-0.035891989t})$$
$$\cdot (e^{-0.000336022t} + e^{-0.001023514t} - e^{-0.001359536t})$$

$$R_{7DS} = (e^{-(0.048632996+0.021474607)t} + e^{-(0.048632996+0.014417382)t} - e^{-(0.048632996+0.035891989)t})$$
$$\cdot (e^{-0.000336022t} + e^{-0.001023514t} - e^{-0.001359536t})$$

$$R_{7DS} = (e^{-0.070107603t} + e^{-0.063050378t} - e^{-0.084524985t})$$
$$\cdot (e^{-0.000336022t} + e^{-0.001023514t} - e^{-0.001359536t})$$

$$R_{7DS} =$$
$$e^{-(0.070107603+0.000336022)t} + e^{-(0.070107603+0.001023514)t} - e^{-(0.070107603+0.001359536)t} +$$
$$e^{-(0.063050378+0.000336022)t} + e^{-(0.063050378+0.001023514)t} - e^{-(0.063050378+0.001359536)t} -$$
$$e^{-(0.084524985+0.000336022)t} - e^{-(0.084524985+0.001023514)t} + e^{-(0.084524985+0.001359536)t}$$

$$R_{7DS} = e^{-0.070443625t} + e^{-0.07113117t} - e^{-0.071467139t} + e^{-0.0633864t} + e^{-0.064073892t} -$$
$$e^{-0.064409914t} - e^{-0.08861007t} - e^{-0.085548499t} + e^{-0.085884521t} \quad (3.5)$$

The equation (3.5) is the system general reliability equation of 7DS, which is a function of time of the distribution substation.

3.6 Parts Count Method of Reliability Prediction

The parts count method is a prediction method used in the preliminary design stage when the number of parts in each generic type class such as capacitors, resistors, etc., are reasonably fixed and ' the overall design complexity is not expected to change appreciably during later stages of development and production. The parts count method assumes the time to failure of the parts is exponentially distributed (i.e., a constant failure rate).

The information needed to apply the method are;

i. generic part types (including complexity for microcircuits) and quantities,

ii. part quality levels, and

iii. equipment environment.

The equipment failure rate is obtained by looking up a generic failure rate in one of the following tables, multiplying it by a quality factor, and then summing it with failure rates obtained for other components in the equipment. The general mathematical expression for equipment failure rate with this method is:

$$\lambda_{EQUIP} = \sum_{i=1}^{i=n} N_i \left(\lambda_g \pi_Q\right)_i \qquad (3.6)$$

For a given equipment environment where;

λ_{EQUIP} = Total equipment failure rate (Failures/10^6 Hours)

λ_g= Generic failure rate for the i^{th} generic part (Failures/10^6 Hours)

π_Q = Quality factor for the i^{th} generic part

N_i = Quantity of i^{th} generic part

n = Number of different generic part categories in the equipment

Equation (3.6) applies if the entire equipment is being used in one environment. If the equipment comprises several units operating in different environments (such as avionics systems with units in airborne inhabited (A_L) and uninhabited (A_U) environments), then equation (3.6) is applied to the portions of the equipment in each environment (MIL-HDBK-217F). These “environment-equipment” failure rates should be added to determine total equipment failure rate.

The generic failure rate, λ_G, of each component that makes the system network (7DS substation) from military handbook, MIL.HNDBK-STD-1562 (page 357), using parts count method of reliability prediction. The results of this analysis are presented in table 3.1

Table 3.1 Generic Failure Rate (λ_G) of Components

S/N	Component Description	Symbol	$\lambda_G = \frac{f}{10^6} hours$
1	Incoming Feeder	λ_G (IF)	0.0150
2	Outgoing Feeder 5	λ_G (OF5)	0.0160
3	Outgoing Feeder 32	λ_G (OF32)	0.0170
4	Earth Fault Relay	λ_G (EF)	0.0140
5	Over-Current Relay	λ_G (OC)	0.0130
6	Current Cut-off Relay	λ_G (CC)	0.0130
7	11kV Oil Circuit Breaker	λ_G (CB)	0.0110
8	Single Phasing Fault	λ_G (SP)	0.0080
9	Voltage Transformer (1VT & 2VT)	λ_G (VT)	0.0080
10	Sub-Service Transformer (1SST & 2SST)	λ_G (SST)	0.0080
11	Current Transformers (CTs)	λ_G (CT)	0.0080
12	Manual Isolator	λ_G (IS)	0.0080
13	110V DC Battery	λ_G (BU)	0.0110
14	Rectifier Unit	λ_G (RU)	0.0080

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents detailed reliability analysis of the studied distribution substation (7DS). The data collected from the selected substation were used to estimate the reliability indices of the components in the substation. Finally, the overall reliability of the substation and the customer reliability indices of the system were determined.

4.2 Analysis of the Failure Data

4.2.1 Failure Rate Evaluation of the Components

The monthly component failure rates for 7DS substation were calculated using the formulae discussed in equation 3.5 using Microsoft Excel. The results of these analysis are shown in the Tables 4.1 to 4.14. Each of these tables contains the computed failure rates for the components highlighted earlier. Table 4.15 contains the basic reliability indices such as the annual failure rate, average outage time and the annual outage time or unavailability.

Table 4.1 Summary of Outages on Incoming Feeder

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	3	41.65	744	0.004032258
February	2	2.567	696	0.002873563
March	4	1.867	744	0.005376344
April	8	5.65	720	0.011111111
May	5	1.283	744	0.006720430
June	3	2.483	720	0.004166667
July	7	3.95	744	0.009408602
August	-	-	744	-
September	1	1.783	720	0.001388889
October	-	-	744	-
November	-	-	720	-
December	8	3.217	744	0.010752688

Table 4.1 shows the summary of outages on the incoming feeder for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month on the incoming feeder to the substation. No outage or failure on the incoming feeder for the months of August, October and November. The highest frequency of outages was recorded in April and December while the highest outage time was recorded in January.

Table 4.2 Summary of Outages on Outgoing Feeder 5

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	7	7.267	744	0.009408602
February	8	12.067	696	0.011494253
March	10	13.583	744	0.01344086
April	8	20.717	720	0.011111111
May	11	13.35	744	0.014784946
June	9	58.45	720	0.0125
July	10	25.3	744	0.01344086
August	11	35.983	744	0.014784946
September	8	15.283	720	0.011111111
October	22	64.2	744	0.029569892
November	10	43.667	720	0.013888889
December	13	8.65	744	0.017473118

Table 4.2 shows the summary of outages on the outgoing feeder 5 for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month on the outgoing feeder 5 (township feeder 2). The highest number of outages was recorded in October while the highest outage time was recorded in June.

Table 4.3 Summary of Outages on Outgoing Feeder 32

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	7	1.883	744	0.009408602
February	11	27.267	696	0.015804598
March	20	22.717	744	0.02688172
April	16	41.133	720	0.022222222
May	22	45.433	744	0.029569892
June	20	49.2	720	0.027777778
July	15	61.167	744	0.02016129
August	19	57.283	744	0.025537634
September	17	33.867	720	0.023611111
October	24	139.25	744	0.032258065
November	6	7.867	720	0.008333333
December	12	23.733	744	0.016129032

Table 4.3 shows the summary of outages on the outgoing feeder 32 for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month on the outgoing feeder 32 (township feeder 1). The highest number of outages as well as highest outage time was recorded in October.

Table 4.4 Summary of Outages Resulting from Earth Fault

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	5	2.767	744	0.00672043
February	8	23.983	696	0.011494253
March	15	19.767	744	0.02016129
April	6	17.583	720	0.008333333
May	12	14.95	744	0.016129032
June	6	28.217	720	0.008333333
July	13	41.3	744	0.017473118
August	21	52.117	744	0.028225806
September	11	23.95	720	0.015277778
October	29	129.25	744	0.038978495
November	11	44.433	720	0.015277778
December	11	7.967	744	0.014784946

Table 4.4 shows the summary of outages resulting from earth fault for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month as a result of earth fault. The highest number of outages as well as highest outage time was recorded in October.

Table 4.5 Summary of Outages Resulting from Over Current Protection

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	6	1.55	744	0.008064516
February	7	9.683	696	0.010057471
March	6	3.183	744	0.008064516
April	12	27.25	720	0.016666667
May	17	29.667	744	0.022849462
June	16	31.733	720	0.022222222
July	5	19.65	744	0.00672043
August	4	28.55	744	0.005376344
September	9	21.533	720	0.0125
October	9	70.383	744	0.012096774
November	2	0.833	720	0.002777778
December	4	0.783	744	0.005376344

Table 4.5 shows the summary of outages resulting from over current protection for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month as a result of overcurrent protection trippings. The highest number of outages was recorded in May while the highest outage time was recorded in October.

Table 4.6 Summary of Outages Resulting from Current Cut-Off Protection

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	8	6.217	744	0.010752688
February	7	9.683	696	0.010057471
March	6	3.183	744	0.008064516
April	11	27.117	720	0.015277778
May	18	34.717	744	0.024193548
June	17	73.617	720	0.023611111
July	10	55.217	744	0.01344086
August	5	33.217	744	0.00672043
September	8	17.033	720	0.011111111
October	13	112.05	744	0.017473118
November	4	6.867	720	0.005555556
December	6	22.283	744	0.008064516

Table 4.6 shows the summary of outages resulting from current cut-off protection for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month as a result of current cut-off protection trippings. The highest number of outages was recorded in May while the highest outage time was recorded in October.

Table 4.7 Summary of 11 kV Oil Circuit Breaker Failure

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	1	0.083	744	0.001344086
February	2	0.3	696	0.002873563
March	1	0.217	744	0.001344086
April	3	1.333	720	0.004166667
May	3	1.5	744	0.004032258
June	1	0.35	720	0.001388889
July	-	-	744	-
August	-	-	744	-
September	-	-	720	-
October	-	-	744	-
November	-	-	720	-
December	10	2.433	744	0.01344086

Table 4.7 shows the summary of outages resulting from oil circuit breaker failure for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month for oil circuit breaker (OCB) in the substation. The highest number of outages as a result of OCB failure as well as highest outage time was recorded in December. No outage as a result of failure of OCB was recorded between July and November 2020.

Table 4.8 Summary of Outages Resulting from Single Phasing

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	-	-	744	-
February	-	-	696	-
March	-	-	744	-
April	-	-	720	-
May	-	-	744	-
June	-	-	720	-
July	-	-	744	-
August	1	1.617	744	0.001344086
September	-	-	720	-
October	2	4.083	744	0.002688172
November	1	0.917	720	0.001388889
December	-	-	744	-

Table 4.8 shows the summary of outages resulting from single phasing faults for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month for single phasing faults. Single phasing occurred only in August, October and November. The highest number of outages as well as highest duration of outage as a result of this fault was recorded in October.

Table 4.9 Summary of Voltage Transformer (1VT & 2VT) Failure

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	-	-	744	-
February	-	-	696	-
March	1	20.167	744	0.001344086
April	-	-	720	-
May	-	-	744	-
June	-	-	720	-
July	-	-	744	-
August	-	-	744	-
September	-	-	720	-
October	-	-	744	-
November	-	-	720	-
December	-	-	744	-

Table 4.9 shows the summary of outages resulting from voltage transformer (VT) failure for the year 2020. During the year under review, only transformer 2VT was in use. The 1VT transformer was out of use. The table indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month for VT. Voltage transformer failure occurred only in March and lasted for 20.167 hours.

Table 4.10 Summary of Sub-Service Transformer (1SST & 2SST) Failure

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	-	-	744	-
February	-	-	696	-
March	1	0.25	744	0.001344086
April	-	-	720	-
May	-	-	744	-
June	-	-	720	-
July	-	-	744	-
August	-	-	744	-
September	-	-	720	-
October	-	-	744	-
November	-	-	720	-
December	-	-	744	-

Table 4.10 shows the summary of outages resulting from sub-service transformer (SST) failure for the year 2020. The table indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month for sub-service transformer. SST failure occurred only in March and lasted for 0.25 hours.

Table 4.11 Summary of Current Transformer (Bus CT & Cable CT) Failure

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	-	-	744	-
February	-	-	696	-
March	-	-	744	-
April	-	-	720	-
May	-	-	744	-
June	-	-	720	-
July	1	3	744	0.001344086
August	-	-	744	-
September	-	-	720	-
October	-	-	744	-
November	-	-	720	-
December	-	-	744	-

Table 4.11 shows the summary of outages resulting from current transformer (CT) failure for the year 2020. This includes failure resulting from failure of the bus current transformer and cable current transformer, also called zero sequence current transformer. The table indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month for CT. Current transformers failure occurred only in July and lasted for 3 hours.

Table 4.12 Summary of Manual Isolator Failure

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	-	-	744	-
February	1	0.917	696	0.001436782
March	-	-	744	-
April	-	-	720	-
May	-	-	744	-
June	-	-	720	-
July	-	-	744	-
August	-	-	744	-
September	-	-	720	-
October	-	-	744	-
November	-	-	720	-
December	-	-	744	-

Table 4.12 shows the summary of outages resulting from failure of manual isolator for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month on manual isolator. Failure occurred only in February and lasted for 0.917 hours.

Table 4.13 Summary of 110V DC Battery Failure

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	3	41.65	744	0.004032258
February	2	2.567	696	0.002873563
March	4	1.867	744	0.005376344
April	-	-	720	-
May	-	-	744	-
June	-	-	720	-
July	-	-	744	-
August	-	-	744	-
September	-	-	720	-
October	-	-	744	-
November	-	-	720	-
December	-	-	744	-

Table 4.13 shows the summary of outages resulting from DC battery failure for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month for the 110 V DC battery. Battery failure occurred only between January and March, with the highest number of outages occurring in March 2020. New batteries were supplied towards the end of March 2020 and no further outage was recorded.

Table 4.14 Summary of Rectifier Unit Failure

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
January	2	0.583	744	0.002688172
February	-	-	696	-
March	1	0.25	744	0.001344086
April	-	-	720	-
May	-	-	744	-
June	-	-	720	-
July	-	-	744	-
August	-	-	744	-
September	-	-	720	-
October	-	-	744	-
November	-	-	720	-
December	-	-	744	-

Table 4.14 shows the summary of outages resulting from rectifier unit failure for the year 2020. It indicates the number or frequency of outages, outage time and total hours for each of the 12 months in the year 2020. It also indicates the failure rate per month for the rectifier unit. Rectifier unit failure occurred only in January and March.

Table 4.15 Basic Reliability Indices on Each Component

Component	**Failure Rate (f/year) λ**	**Average Outage Time (Hrs)**	**Annual Outage Time (Hrs) (λ × t)**
Incoming Feeder	0.004652546	5.370833333	0.024988049
Outgoing Feeder 5	0.014417382	26.54308333	0.382681785
Outgoing Feeder 32	0.021474607	42.56666667	0.914102419
Earth Fault Relay	0.016765799	33.85700000	0.567639672
Over-Current Relay	0.011064377	20.39983333	0.225711448
Current Cut-off Relay	0.012860225	33.43341667	0.429961273
11kV Oil Circuit Breaker	0.002382534	0.518000000	0.001234153
Single Phasing Fault	0.000451762	0.551416667	0.000249109
Voltage Transformer (1VT & 2VT)	0.000112007	1.680583333	0.000188237
Sub-Service Transformer (1SST & 2SST)	0.000112007	0.020833333	0.00000233348
Current Transformers (CTs)	0.000112007	0.250000000	0.0000280018
Manual Isolator	0.000119732	0.076416667	0.00000914951
110V DC Battery	0.001023514	3.840333333	0.003930634
Rectifier Unit	0.000336022	0.069416667	0.0000233255

4.2.2 Interpretation of Component Reliability Evaluation Results

It is important to state here that the following assumptions were made in carrying out the reliability analysis of the distribution substation:

i. Only data of unplanned interruptions due to forced outage (or faults/failures outage) on the components were recorded.

ii. Component failures were repaired before the next fault occurs.

iii. Only one of the incoming feeders (cubicle 30 from MSDS 1) was considered as the second incoming (cubicle 13) from MSDS 2 was out of service during the period under review.

iv. Generation and transmission are highly reliable and in operation to perform their intended function.

From the results obtained in table 4.15, the outgoing feeder 32 (Township Feeder 1) has the highest annual outage time/unavailability, thus contributing most to the interruptions in the substation with an annual outage time of 0.9141 hour. Another major contributor to interruptions in the substation thereby affecting delivery of electricity to the customers was earth fault failures having a value of 0.5676 hour, followed by current cut-off failures 0.42996 hour and the outgoing feeder 5 (Township feeder 2), 0.38268 hour. The least contributor to interruption within the period under review was the sub-service transformer 1SST & 2SST with a value of 0.00000233348 hour.

Among other factors that affect the outgoing feeder, the foremost is right of way clearance. This has become a major challenge on the two housing estate feeders over time. Trees and shrubs have encroached on the overhead lines leading from the substation all the way to the housing estates which are located several kilometers from the steel plant. Also, lines become anneal and eventually break as a result of reduced tensile strength brought about by higher currents flowing through the lines making them to exceed their thermal capacity. The least component that fails is the sub-service transformer with a record of one failure which lasted for only 15 minutes (0.25 hours). This implies that the substation 0.415kV supply for own needs was steady during the period under review.

The 11 kV oil circuit breaker and the manual isolator on the outgoing feeders had lower values of unavailability, 0.001234153 hour and 0.0000091495 hour respectively. This implies that their contribution to loss of supply was minimal and this may be due to the fact that these components were maintained periodically by the maintenance units.

The voltage transformer (1VT & 2VT) responsible for the substation measuring devices and the current transformers (bus CTs and Cable CTs) also had low values of unavailability of 0.000188237 hour and 0.0000280 hour respectively.

4.3 Reliability Indices Evaluation of the Substation, 7DS

4.3.1 Exponential Distribution Model

Table 4.16 Total Failure Rate of the Substation

Component	Failure Rate (f/year) λ
Incoming Feeder	0.004652546
Outgoing Feeder 5	0.014417382
Outgoing Feeder 32	0.021474607
Earth Fault Relay	0.016765799
Over-Current Relay	0.011064377
Current Cut-off Relay	0.012860225
11kV Oil Circuit Breaker	0.002382534
Single Phasing Fault	0.000451762
Voltage Transformer (1VT & 2VT)	0.000112007
Sub-Service Transformer (1SST & 2SST)	0.000112007
Current Transformers (CTs)	0.000112007
Manual Isolator	0.000119732
110V DC Battery	0.001023514
Rectifier Unit	0.000336022
Total	**0.085884521**

The mathematical expression of the reliability of the entire power substation can be represented using exponential distribution model. That is,

$$R_{7DS} = e^{-\lambda^{T}7_{DS}t} \quad (4.1)$$

Where $-\lambda^{T}7_{DS}$ is the total failure rate of the entire power substation. This can be expressed as;

$$R_{7DS} = e^{-0.085884521t} \quad (4.2)$$

This can be used to predict the reliability of the system over time, as shown in table 4.17. The predicted reliability for the next ten years is computed in Table 4.17

Table 4.17 Predicted System Reliability from 2020 to 2029 using Exponential Distribution Model

Year	Reliability of 7DS
2020	0.9177002
2021	0.842173657
2022	0.772862934
2023	0.709256469
2024	0.650884804
2025	0.597317115
2026	0.548158036
2027	0.503044739
2028	0.461644258
2029	0.423651028

4.3.2 Reliability Block Diagram Model

From equation 3.5, the reliability expression obtained from the reliability block diagram of the distribution substation, R_{7DS} is given as;

$$R_{7DS} = e^{-0.070443625t} + e^{-0.07113117t} - e^{-0.071467139t} + e^{-0.0633864t} + e^{-0.064073892t} - e^{-0.064409914t} - e^{-0.08861007t} - e^{-0.085548499t} + e^{-0.085884521t} \quad (4.3)$$

For the year, 2020, t = 1 year.

Substituting for t = 1 in equation 4.3,

$$R_{7DS} = e^{-0.070443625} + e^{-0.07113117} - e^{-0.071467139} + e^{-0.0633864} + e^{-0.064073892} - e^{-0.064409914} - e^{-0.08861007} - e^{-0.085548499} + e^{-0.085884521}$$

$$R_{7DS} = 0.952240643$$

The overall reliability of the system as obtained from the reliability block diagram is 0.952240643. This implies that the substation reliability for the year 2020 was 95.22%. This result agrees with one of the examples for a system of combined configuration network of series and parallel components in Military Handbook, MIL-HDBK-338B (Page 5.35).

This expression in equation 4.3 can be used to predict the reliability of the system over time, for example, the next 5 years or more. The predicted reliability for 2020 to 209 is computed in Table 4.18

Table 4.18 Predicted System Reliability from 2020 to 2029 using RBD

Year	Reliability of 7DS
2020	0.952240643
2021	0.90622923
2022	0.861959784
2023	0.819418117
2024	0.778583059
2025	0.739427542
2026	0.701919568
2027	0.666023065
2028	0.631698648
2029	0.598904283

4.3.3 Comparison of the Predicted Reliability Indices of the Substation using Exponential Distribution Model and the RBD Model

The predicted reliability values obtained from the exponential distribution expression and the reliability block diagram expression computed in table 4.17 and 4.18 respectively were plotted. The reliability plots (figure 4.1) represent the substation reliability for the year 2020 as well as the predicted reliability indices from 2021 to 2029.

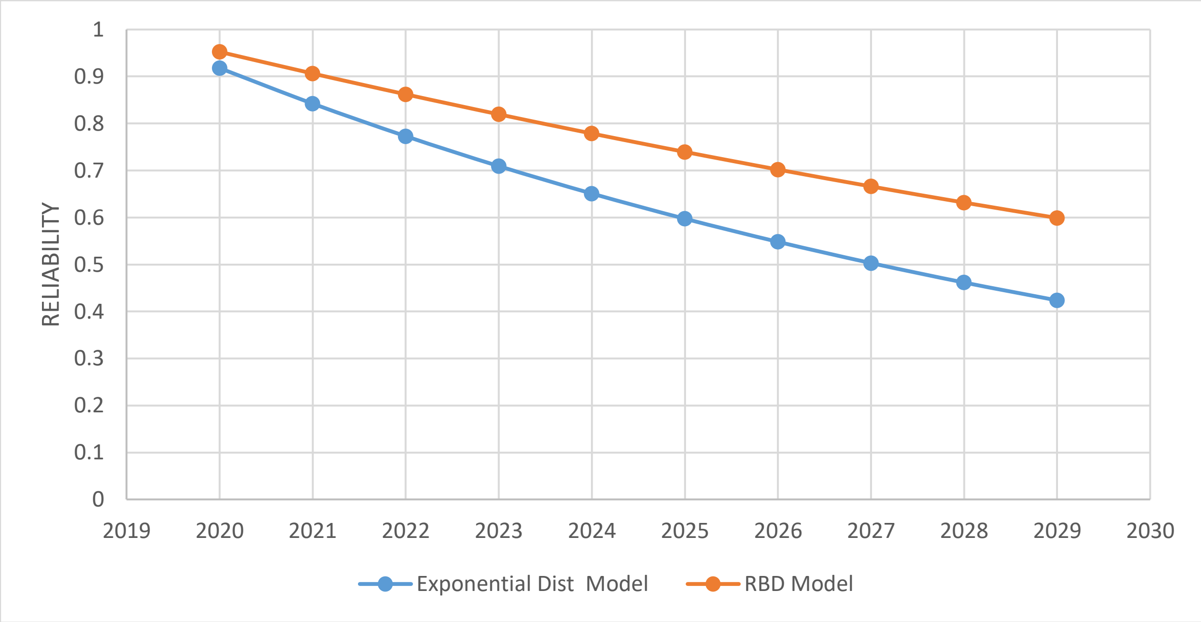

Figure 4.1 Predicted Reliability Indices using Exponential Distribution Model and RBD

From the reliability plots in Figure 4.1, the two models have approximately the same reliability figures. However, the RBD model has slightly higher predicted values than the exponential distribution model which is a function of the failure rate of the components that make up the substation, 7DS.

4.4 Comparison Between the Generic Reliability Data and the Present System Network (7DS) Reliability Data

A comparison between the expected reliability data and the present system network (7DS) reliability data was carried out. The expected reliability data as obtained from Military Handbook, MIL-HNDBK-STD-1562 (page 357) was compared with the obtained from 7DS substation. The result of this analysis is presented in tables 4.19 and 4.20 respectively.

The reliability functions from the tables all have approximately the same expected reliability figures. This means that each component as connected in the busbar system arrangement of the substation has insignificant effect on the overall reliability indices of the distribution substation, 7DS.

Table 4.19 Expected Reliability Data modelled using the Generic Failure Rate

S/N	Component Description	Symbol	$\lambda_G = \frac{f}{10^6} hours$	$MTBF = \frac{1}{\lambda_G}$	Expected Component Reliability
1	Incoming Feeder	λ_G (IF)	0.0150	66.6667	0.98511194
2	Outgoing Feeder 5	λ_G (OF5)	0.0160	62.5000	0.98412732
3	Outgoing Feeder 32	λ_G (OF32)	0.0170	58.8235	0.983143685
4	Earth Fault Relay	λ_G (EF)	0.0140	71.4286	0.986097544
5	Over-Current Relay	λ_G (OC)	0.0130	76.9231	0.987084135
6	Current Cut-off Relay	λ_G (CC)	0.0130	76.9231	0.987084135
7	11kV Oil Circuit Breaker	λ_G (CB)	0.0110	90.9091	0.989060279
8	Single Phasing Fault	λ_G (SP)	0.0080	125.0000	0.992031915
9	Voltage Transformer (1VT & 2VT)	λ_G (VT)	0.0080	125.0000	0.992031915
10	Sub-Service Transformer (1SST & 2SST)	λ_G (SST)	0.0080	125.0000	0.992031915
11	Current Transformers (CTs)	λ_G (CT)	0.0080	125.0000	0.992031915
12	Manual Isolator	λ_G (IS)	0.0080	125.0000	0.992031915
13	110V DC Battery	λ_G (BU)	0.0110	90.9091	0.989060279
14	Rectifier Unit	λ_G (RU)	0.0080	125.0000	0.992031915

Table 4.20 Present System (7DS) Reliability Values

S/N	Component Description	Symbol	$\lambda = \frac{f}{8784} hrs$	$MTBF = \frac{1}{\lambda}$	Present Component Reliability
1	Incoming Feeder	λ_{IF}	0.004652546	214.9361	0.99535826
2	Outgoing Feeder 5	λ_{OF5}	0.014417382	69.3607	0.985686051
3	Outgoing Feeder 32	λ_{OF32}	0.021474607	46.5666	0.978754331
4	Earth Fault Relay	λ_{EF}	0.016765799	59.6452	0.983373965
5	Over-Current Relay	λ_{OC}	0.011064377	90.3801	0.988996608
6	Current Cut-off Relay	λ_{CC}	0.012860225	77.7591	0.987222114
7	11kV Oil Circuit Breaker	λ_{CB}	0.002382534	419.7212	0.997620302
8	Single Phasing Fault	λ_{SP}	0.000451762	2213.5549	0.99954834
9	Voltage Transformer (1VT & 2VT)	λ_{VT}	0.000112007	8928.0134	0.999887999
10	Sub-Service Transformer (1SST & 2SST)	λ_{SST}	0.000112007	8928.0134	0.999887999
11	Current Transformers (CTs)	λ_{CT}	0.000112007	8928.0134	0.999887999
12	Manual Isolator	λ_{IS}	0.000119732	8351.9861	0.999880275
13	110V DC Battery	λ_{BU}	0.001023514	977.0262	0.99897701
14	Rectifier Unit	λ_{RU}	0.000336022	2975.9956	0.999664034

4.5 Customer Reliability Indices Evaluation

The computed customer reliability indices, SAIFI, SAIDI and CAIDI were calculated using equations 2.11, 2.12 and 2.13 respectively. The results are computed in table 4.21. The major assumption in computing the indices, in addition to the ones stated previously, is that the number of customers supplied from the substation was considered using the number of 11/0.415kV distribution transformers on all outgoing feeders of the substation. This was obtained to be 200 in total.

Table 4.21 Computed Customer Reliability Indices, January to December 2020 on 7DS Substation

Month	**Frequency of Interruptions**	**Duration of Interruption**	**Total Hours**	**No. of Customers**	**SAIDI (hrs/cust.)**	**SAIFI (int./cust.)**	**CAIDI (hrs/int.)**
January	42	103.650	744	200	0.518250	0.210	2.467857143
February	48	89.034	696	200	0.445170	0.240	1.854875000
March	69	87.051	744	200	0.435255	0.345	1.261608696
April	64	140.783	720	200	0.703915	0.320	2.199734375
May	88	140.900	744	200	0.704500	0.440	1.601136364
June	72	244.050	720	200	1.220250	0.360	3.389583333
July	61	209.584	744	200	1.047920	0.305	3.435803279
August	61	208.767	744	200	1.043835	0.305	3.422409836
September	54	113.449	720	200	0.567245	0.270	2.100907407
October	99	519.216	744	200	2.596080	0.495	5.244606061
November	34	104.584	720	200	0.522920	0.170	3.076000000
December	64	69.066	744	200	0.345330	0.320	1.079156250
Total	**756**	**2030.134**	**8784**	**200**	**10.15067**	**3.78**	**2.685362434**

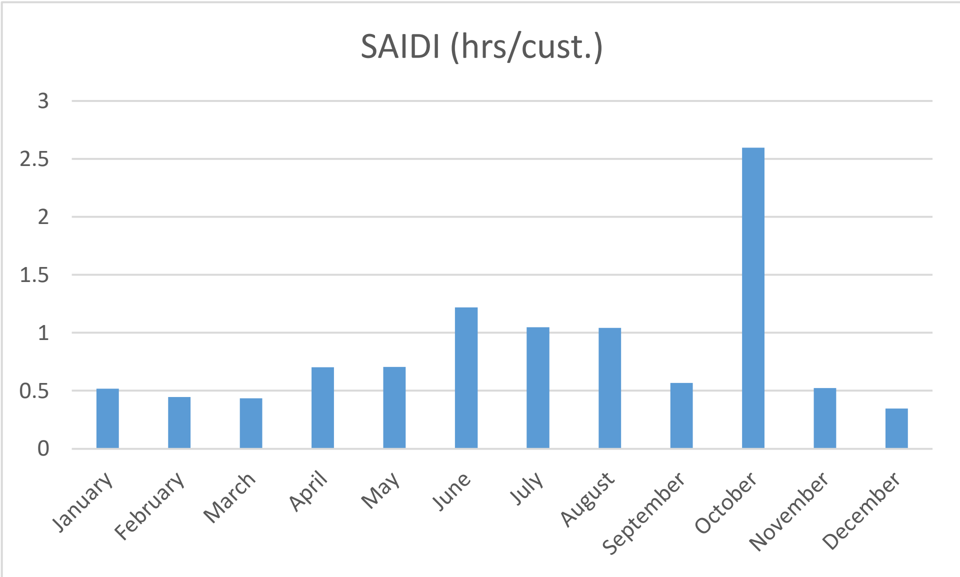

Figure 4.2 System Average Interruption Duration Index (SAIDI) for the Year 2020

Figure 4.2 illustrates the substation SAIDI for the year 2020. The month of October had the highest average interruption duration index for the year while December had the least.

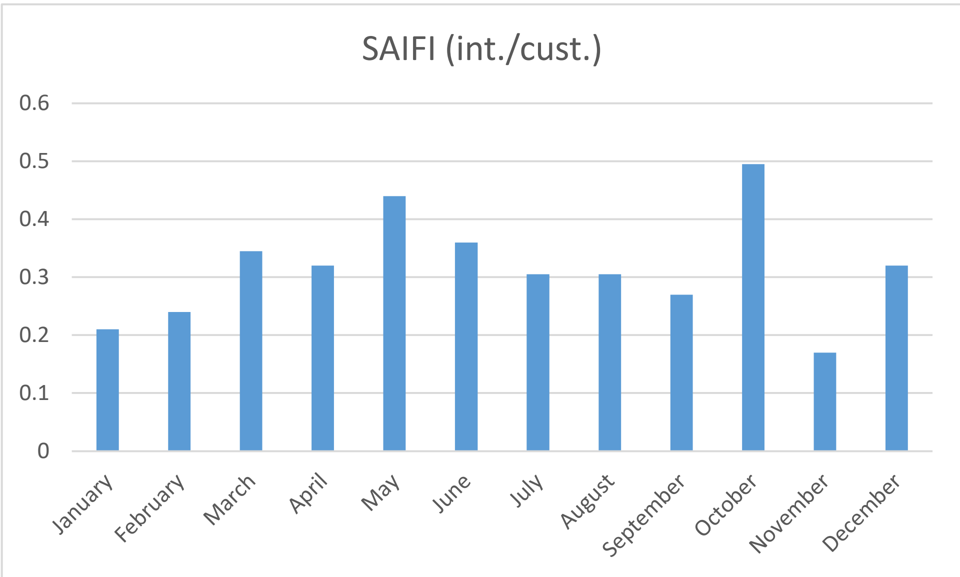

Figure 4.3 System Average Interruption Frequency Index (SAIFI) for the Year 2020

Figure 4.3 illustrates the substation SAIFI for the year 2020. The month of October had the highest average interruption frequency index for the year while November had the least.

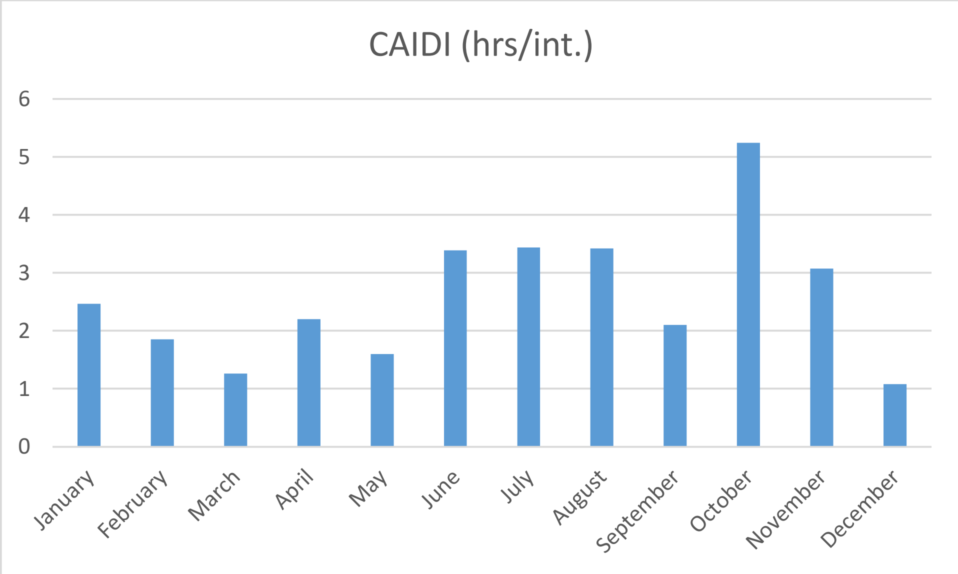

Figure 4.4 Customer's Average Interruption Duration Index (CAIDI) for the Year 2020

Figure 4.4 illustrates the substation CAIDI for the year 2020. The month of October had the highest customer average interruption duration index for the year while December had the least.

4.5.1 Interpretation of Customer Reliability Evaluation Results

The average outage duration, SAIDI, for each customer served is 10.15067 hours for the whole year. This is almost 7 times the IEEE standard 1366-2003 which gives a value of 1.5 hours for North American Utility. This is a region that has sufficient power generation and robust system security. Therefore, according to the standard, the performance of this distribution substation system is low. The month of October had the highest SAIDI value followed by June with each having SAIDI value of 2.596080 hours and 1.220250 hours respectively. However, the month of December had the least value of SAIDI followed by March with each having SAIDI values of 0.345330 hour and 0.435255 hour respectively. This implies that the causes of interruptions were quickly identified and the faults cleared early enough in December and March.

This substation has a very acceptable low value of SAIFI for the year, with a value of 3.78. This means that the frequency of interruptions spread across the year is actually low. Considering the SAIFI value alone, the system could have been mistaken to be very reliable which is not so. October and May have highest values of 0.495 and 0.440 respectively whilst November followed by January had lowest values of 0.170 and 0.210 respectively.

A CAIDI value of 2.6854 implies that from the customer end, there was no supply of electricity for 2.6854 hours every day for the whole year i.e. on the average; it takes 2.6854 hours to restore power supply whenever there is interruption. In other words, any interruption lasts for an average of 2.6854 hours throughout the year. The month of October had the highest monthly CAIDI followed by July with each having CAIDI value of 5.24461 hours and 3.43580 hours respectively which implies that in October it takes an average of 5.24461 hours to restore power supply while for July it takes an average of 3.43580 hours. The month of December had the lowest CAIDI followed by March with each having a CAIDI value of 1.079156 hours and 1.2616087 hours respectively.

4.5.2 Comparison of Results with Reliability Benchmark Indices

The standard with which reliability of a distribution system is measured against is known as reliability benchmarks. The standards are given in order to provide a justification and give acceptable margin for the reliability performance of distribution networks. Based on IEEE Guide, the benchmarks for nine countries were computed for power distribution reliability as shown in Table 4.22

Table 4.22 Reliability Indices Benchmark (Rouse and Kelly 2011)

Country	**SAIDI (Minutes/ year)**	**SAIFI (Interruptions/Customer)**	**CAIDI (Minutes/Outage)**	**ASAI (%)**
United States	240	1.5	123	99.91
UK	90	0.8	100	99.964
Italy	58	2.2	106	99.9991
Spain	104	2.2	114	99.968
Austria	72	0.9	112	99.97
Netherlands	33	0.3	75	99.97
Denmark	24	0.5	70	99.981
France	62	1	58	99.97
7DS (ASCL)	609	3.78	161	95.22

From Table 4.22, 7DS substation has a SAIDI of approximately 609 minutes per year, SAIFI of 3.78, CAIDI of 161 minutes per outage and an ASAI of 95.22%. This substation has a fairly high value of SAIFI which means not too many interruptions and a high value of SAIDI which means longer duration of outages. The ASAI value also shows that the availability of the system is very low. Comparing this with the average reliability indices computed, it is obvious that the substation has worse performance and needs to be improved upon to increase its reliability indices. Figure 4.5 gives a graphical representation of the comparison.

These results imply that there is need to work on reducing the duration of the outages, SAIDI and CAIDI as well as the frequency of outages even though it is not too high. The main challenge, therefore, is that the substation maintenance personnel need to intensify efforts in reducing the length or duration of outages in order to improve the availability and reliability of the substation. It therefore becomes evident that it is not just component outages that affect the substation reliability but the duration it takes to restore the components back to service.

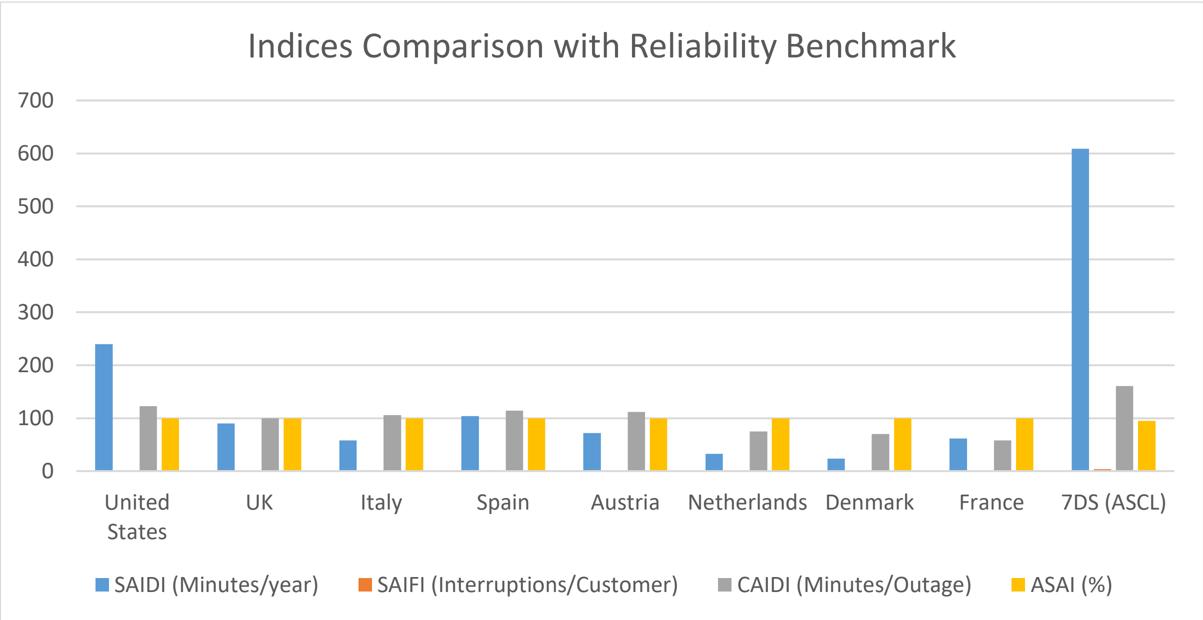

Figure 4.5 Comparison of Results with Reliability Benchmark Indices

This figure illustrates the performance comparison of the substation with global reliability benchmark indices.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Failures and faults that may occur in the electric power stations and substations are not only fraught with serious damages and outages of various units of electrical equipment but they may lead to the interruption of power supply to the customers and therefore may cause heavy economic losses. The cost of power not supplied as a result of interruption in power supply is usually very high, especially in the case of Ajaokuta Steel Company. Efforts must be made and regular maintenance must be ensured to minimize outages as a result of faults and failures of power equipment as much as possible.

This dissertation, by using 7DS substation (Engineering Shops & Auxiliaries including Housing Estates) as case study for carrying out reliability evaluation of a secondary Distribution Substation in Ajaokuta Steel Company, has been able to identify that the outgoing feeder 32 (Township Feeder 1) has the highest annual outage time/unavailability, thus contributing most to the interruptions in the substation with a failure rate of 0.021474607 per hour and annual outage time of 0.9141 hour. Another major contributor to interruptions in the substation thereby affecting delivery of electricity to the customers was earth fault failures having a failure rate of 0.016765799 per hour and outage time of 0.5676 hour followed by current cut-off failures 0.012860225 per hour and 0.42996 hour and the outgoing feeder 5 (Township feeder 2), 0.014417382 per hour and 0.38268 hour respectively. Sub-service transformers 1SST & 2SST, voltage transformers 1VT & 2VT as well as current transformer had the same failure rates of 0.000112007 per hour. The least contributor to interruption within the period under review was the sub-service transformer 1SST & 2SST with a value of 0.00000233348 hour.

The reliability of the entire substation obtained using the exponential distribution model was 91.77%. Using reliability block diagram, the substation has a reliability of 95.22%. The reliability of the substation is low compared to the IEEE ASAI standard of 99.99% for distribution substation. Hence with the values calculated for this substation, the reliability is low. Procedures as well as results obtained were compared with those of Military Handbook of Reliability, MIL-HDBK-338B (page 5.33 – 5.35), and were found to be in order.

Comparing the two reliability models employed in this dissertation, it was observed that the results were approximately the same. However, the predicted reliability indices for the years 2020 to 2029 using the RBD model was slightly above the exponential distribution model. These predictions indicate that the substation requires urgent attention so as to prevent a complete breakdown of the substation power system.

7DS substation has a SAIDI of approximately 609 minutes per year, SAIFI of 3.78 and CAIDI of 161 minutes per outage. This substation has a fairly high value of SAIFI which means not too many interruptions and a high value of SAIDI which means longer duration of outages. The ASAI value also shows that the availability of the system is very low. Comparing this with the average reliability indices computed, it is obvious that the substation has worse performance and needs to be improved upon to increase its reliability indices.

5.2 Recommendations

Based on the work done in this dissertation, the following recommendations are made:

i. The operation unit of P,T&D (Power Transmission & Distribution) sub-division should ensure to keep accurate record of interruptions in all the substations in the entire steel plant, the causes and durations as these will really help to carry out concise research work.

ii. Channel of reporting outages should be improved to enhance timely report and speedy response whenever outages are reported.

iii. There should be conscious effort to ensure that duration of outages is reduced to the lowest minimum as possible as this will help improve the reliability of the substation. This can be ensured by scheduling routine maintenance on the major power equipment under review.

iv. Right of way clearance on all outgoing feeders should be carried out to reduce the rate of earth fault and current cut off system tripping.

v. Proper and regular inspection of utility facilities like poles will also improve reliability of the substation.

vi. The management of Ajaokuta Steel Company should embark on carrying out the reliability analysis of all other substations in the steel plant.

5.3 Significance

i. The reliability data and performance of 7DS substation for the year 2020 was achieved.

ii. The obtained data will be useful in planning maintenance and system overhauling.

iii. The findings can be used as a template for other distribution substations in the steel plant.

iv. The findings will serve as a base for further research as regards power equipment in Ajaokuta Steel Company Limited.

REFERENCES

Abdulkarim, A., Faruk, N., Oloyede, A. O., Olawoyin, L. A., Akorede, M. F., Madugu, I. S., Abdelkader, S. M., Morrow, J. D. and Adediran, Y. A. (2018). Reliability Study of Stand-alone Hybrid Renewable Energy Microgrids.*Iran Journal of Science and Technology Transfer in Electrical Engineering*; **1**(1), pp. 1-15

Adefarati, T., Babarinde, A. K., Oluwole, A. S. and Olusuyi, K, (2014). Reliability Evaluation of Ayede 330/132KV Substation.*International Journal of Engineering and Innovative Technology (IJEIT)*; **4**(4), pp. 86-91.

Adegboye, B. A. andDawal, E. (2012). Outage Analysis and System Integrity of an 11kV Distribution System. Advanced Material Research; **367**, pp. 151-158.

Adelabu, A. J., Haruna, Y. S. and Aliyu, U. O. (2018). Reliability Assessment of Power Equipment in a Distribution Substation Using Fault Tree Analysis.*Global Scientific Journal*; **6**(2), Pp. 249 - 259

Ahmed, A., Ruzli, R. and Buang, A. (2013). Reliability analysis using fault tree analysis: A review. *International Journal of Chemical Engineering and Applications*; **4**(3).

Airoboman, A. E., Ogujor, E. A. and Okakwu, I. K. (2017). Reliability Analysis of Power System Network: a Case Study of Transmission Company of Nigeria, Benin City. *Conference Paper at IEEE PES-IAS Power Africa.*

Al-Qur'anul Karim. English-Sahih International.

Amuda, S. A. Y., Afolabi, L. O. and Abdulkarim, A. (2016). Reliability Analyses of a Typical Mega-Water Pumping Station. USEP: *Journal of Research Information in Civil Engineering*; **13**(3), pp. 1014-1030

Becker, J. A. and Sohne (2009). Operating Manual SV 2400/40, SV 2400/50. Edition; 01/2009

Bhavaraju, M. P., Billinton, R., Brown, R. E., Endrenyi, J., Li, W., Meliopoulos, A. P. and Singh, C. (2005). IEEE Tutorial on Electric Delivery System Reliability Evaluation.*IEEE Power Engineering Society (PES).*

David D. and Smith, J. (2005). Reliability, Maintainability and Risk, 7th edition, *Published by Elseiver Butterworth-Heinemann*, Oxford, United Kingdom.

Dorji, T. (2009). Reliability Assessment of Distribution Systems- Including a case study on Wangdue Distribution System in Bhutan. *Master Thesis, Department of Electrical Power Engineering,* Norwegian University of Science and Technology.

Ezeolisah, C. (2015). TCN Transmission News between July and December.*In-House Journal of Transmission Company of Nigeria*; **4**, pp. 1-76.

Falade, A. J., Fabiyi, S. D. and Abdulkarim, A. (2016). Reliability Assessment of Power Transformers for Oshogbo Area Control Center in Nigeria. USEP: *Journal of Research Information in Civil Engineering*; **14**(1), pp. 1066-1081

Faulin, J., Juan, A. A., Martorell, S. and Ramirez-Marquez, J. (2010). Simulation Methods for Reliability and Availability of Complex Systems. London: Springer-Verlag London Limited.

Gao, L., Zhou, Y., Li, C. and Huo, L. (2014). Reliability Assessment of Distribution Systems With Distributed Generation Based on Bayesian Networks. *Engineering Review*; Vol. **34**(1), pp. 55-62.

Gonen, T. (2014). Electric Power Distribution Engineering. Boca Raton: CRC Press, Taylor and Francis Group.

Gupta, S., Pahwa, A., Zhou, Y., Das, S. and Brown, R. E. (2005). An Adaptive Fuzzy Model for Failure Rates of Overhead Distribution Feeders. *Electric Power Components and Systems*; **33**(11), pp. 1175-1190.

Hamoud, G. A., Nahas, E. and Faried, S. O. (2020). Reliability Comparison of Two Deterministic Criteria for Planning High Voltage Auto-transformer Stations. *IEEE Xplore;* Pp. 1 -11.

Isaac, A., Awelewa, A., Katende, J. and Odigwe, I. (2013). Fault tree-based reliability assessment of a 132-kV transmission line protection scheme. *American Journal of Engineering Research*; **2**, pp. 100-106.

Jibril, Y. and Ekundayo, K. (2013). Reliability Assessment of 33kV Kaduna Electricity Distribution Feeders, Northern Region, Nigeria.*Proceedings of the World Congress on Engineering and Computer Science,* San Francisco, USA. pp. 3-7

Johan, K. (2014). Analyzing substation automation system reliability using probabilistic relational models and enterprise architecture, KTH, *Dissertation, Royal institute of technology, Stockholm, Sweden*, March, 2014.

Josep, S. (2014). Failure Analysis of Power Transformer Based on Fault Tree Analysis, *Ph D. Dissertation, Kyoto University Research Repository.*

Kiran, D. R. (2017). Total Quality Management Key Concepts and Case Studies. Published by Elsevier Inc. Accessed through https://www.sciencedirect.com/science/book/9780128110355

Kjolle, G. and Sand, K. (2002). RELRAD-an Analytical Approach for Distribution System Reliability Assessment. *IEEE Transactions on Power Deliver*; **7**(2), pp. 809-814.

Kueck, J. D., Brendan, J. K., Philip, N. O. and Markel, L. C. (2004). Measurement Practices for Reliability and Power Quality. Tennessee: Oak Ridge National Laboratory.

Li, S. and Jianying, L. (2017). Condition Monitoring and Diagnosis Of Power Equipment: Review and Prospective. *The Institute of Engineering and Technology Journals;* **2;** Pp. 82 – 91.

Li, Y., Yuan, S., Liu, W., Zhang, G., Teng, Y. and Chen, X. (2018). A Fast Method for Reliability Evaluation of Ultra High Voltage AC/DC System Based on Hybrid Simulation. *IEEE Access;* **6**, pp. 19151 – 19160.

Meier, A. V. (2006). Electric Power System. Hoboken, New Jersey: John Wiley & Sons, Inc.

Min-Gui, Pahwa, A. and Das, S. (2009). Analysis of Animal-Related Outages in Overhead Distribution Systems with Wavelet Decomposition and Immune Systems-Based Neural Networks.*IEEE Transactions on Power Systems*; **24**(4), pp. 1765-1771.

MIL-HDBK-338B (1998). General Guidelines for Electronic Equipment. Department of Defense Handbook.

MIL-HDBK-217 (1978). Reliability Prediction of Electronic Equipment. . Department of Defence Information Analysis Center.

MIL.HNDBK-STD-1562. (1976). Reliability Design Handbook. Department of Defence Information Analysis Center.

Mohammad, J., Nobakht, A. and Meskarbashee, A. (2011). Fault Tree Analysis Approach in Reliability Assessment of Power System. *International Journal of Multidisciplinary Sciences and Engineering*; **2**(6).

O'Connor, P. D. T. and Kleyner, A. (2011).Practical Reliability Engineering. West Sussex, UK: John Wiley and Sons Ltd.

Okorie, P. U. (2016). Reliability Assessment of Power Distribution of Abakpa Network Sub-Station of Kaduna Disco. *International Journal of Innovative Research in Education, Technology and Social Strategies*; **2**(1), pp. 78-84.

Onime, F. and Adegboyega, G. A. (2014). Reliability Analysis of Power Distribution System in Nigeria; a Case Study of Ekpoma Network, Edo State.*International Journal of Electronics and Electrical Engineering*; **2**(3), pp. 175-182

Puschkarsky, K., Grasser, T., Aichinger, T., Gustin, W. and Reisinger, H. (2019). Review on SiC MOSFETs High-Voltage Device Reliability Focusing on Threshold Voltage Instability. *IEEE Transactions on Electron Devices*; Pp. 1 - 13

Samuel, I. A., Awelewa, A. A., Katende, J. and Odigwe, I. A. (2013). Fault Tree-Based Reliability Assessment of a 132-kV Transmission Line Protection Scheme. *American Journal of Engineering Research*; **2**(10), pp. 100-106.

Short, T. A. (2004). Electric Power Distribution Handbook. Boca Raton, Florida: CRC Press LLC.

Shutenko, O. and Kulyk, O. (2020). Comparative Analysis of the Defect Type Recognition Reliability in High-Voltage Power Transformers Using Different Methods of DGA Results Interpretation. *IEEE Xplore;* Pp. 1 – 6.

Sonwane, P. M. and Kushare, B. E. (2015). Distribution System Reliability: An Overview. *International Journal of Innovations in Engineering and Technology (IJIET)*; **5**(3), pp. 148-153.

Theraja, B. L. and Theraja, A. K. (2008). A Textbook of Electrical Technology. New Delhi: S. Chand & Company Ltd.

Uhunmwangho, R. and Omorogiuwa, E. (2014). Reliability Prediction of Port Harcourt Electricity Distribution Network Using NEPLAN.*The International Journal Of Engineering and Science (IJES)*; **3**(12), pp. 68-79.

Wang, F. (2012). Reliability Evaluation of Substations Subject to Protection Failures. *Master of Science Thesis, Department of Electrical Engineering, Mathematics and Computer Science, Division of Electrical Power System*, Delft University Of Technology, Delft, the Netherlands.

Wang, M., Vandermaar, A. J. and Srivastava, K, D. (2002). Review of Condition Assessment of Power Transformers in Services. *IEEE Electrical Insulation Magazine*; **1**

APPENDIX A

FAILURE RATE DATA OF 7DS POWER EQUIPMENT

S/N	DATE OF FAULT OCCURED	TIME OF FAULT OCCURED	TYPE OF FAULT OCCURRED	DATE AND DURATION PERIOD OF THE RESTORATION (AFTER FAULT CLEARANCE)		REMARK: (ON OPERATION AND MAINTANCE CARRIED OUT).
1.	01/01/2020	21:12	FEEDER 5 TRIPPED ON EARTH FAULT	01/01/2020	22:00 (45 MINS)	THE FAULT WAS CLEARED AND THE RESTORATION WAS SUCCESSFUL.
2	03/01/2020	14:30 14:33 14:40	FEEDER 5 OCB CLOSE BUT NO POTENTIAL, FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF. AND FEEDER 30 TRIPPED ON CURRENT CUT OFF.	03/01/2020	14:55 (25 MINS)	ALL THE FAULT WERE CLEARED AND POWER RESTORED SUCESSFULLY.
3.	04/01/2020	07:35	FEEDER 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF.	SAME DAY		THE FAULT WAS CLEARED AND RESTORATION WERE SUCCESSFUL.
4.	09/01/2020	07:14	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CUREENT PROTECTION.	SAME DAY AT 07:45	(31 MINS)	BOTH FAULT WERE CLEARED AND GIVES A TRIAL CLOSING AND IT SUCCESSFUL.

5.	09/01/2020	15:29	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	SAME DAY AT 15:36	(7 MINS)	THE RELAY WAS RESET AND THE BREAKER WAS CLOSED SUCCESSFULLY.
6.	10/01/2020	01:37	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	SAME DAY		RESET WAS EFFECTED AND THE FEEDER WAS CLOSE AND STAYED.
7	14/01/2020	06:35	FEEDER 5 TRIPPED ON EARTH FAULT	14/01/2020	07:03 (28 MINS)	THE EARTH FAULT RELAY WAS RESET AND POWER WAS RESTORED SUCCESSFULLY.
8	16/01/2020	04:37	FEEDER 32 TRIPPED ON CURRENT CUT OFF.	16/01/2020	04:55 (18 MINS)	THE SIGNAL RELAY WAS RESET AND THE BREAKER CLOSED AND STAYED.
9	22/01/2020	02:41	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION	22/01/2020	02:51 (10 MINS)	THE RELAY WAS RESET AND THE FEEDER WAS RESTORED SUCCESSFULLY.
10	24/01/2020	06:35	FEEDER 5 TRIPPED ON CURRENT CUT OFF DUE TO OIL LEAKAGE IN ONE OF THE OIL CHAMBERS OF OCB (PHASE C).	24/01/2020	10:55 (4HRS 20MINS)	THE OIL LEAKAGE WAS ARRESTED AND THE FAULT CLEARED AND POWER RESTORED SUCCESSFULLY.

11	26/01/2020	13:20	TRANSFORMER TWO TX2 TAP CHANGER WAS FAULTY.	27/01/2020	06:00	THE TAP CHANGER OF TX2 RECTIFIED BY ETL TEAM.
12	30/01/2020	05:45	FEEDER 5 TRIPPED ON EARTH FAULT.	30/01/2020	06:29	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
13	01/02/2020	21:30	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	01/02/2020	21:30	THE FAULT WAS CLEARED AND THE FEEDER REDTORED SUCCESSFUL.
14	06/02/2020	06:08	FEEDER 5 TRIPPED ON EARTH FAULT	06/02/2020	06:20	THE FEEDER WAS GIVEN A TRIAL CLOSING AND IT WAS SUCCESSFUL.
15	06/02/2020	17:15	HEAVY SPARK ON ISOLATOR NOTICED AT THE CLOSURE OF FEEDER 5, THEN FEEDER 5 WAS OPEND.	06/02/2020	18:10	THE FEEDER WAS GIVEN A TRIAL SWITCHING AFTER WORKING ON THE ISOLATOR AND STAYED SUCCESSFULLY.
16	08/02/2020	13:15	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	08/02/2020	13:50	POWER WAS RESTORED AFTER FAULT CLEARANCE.
17	09/02/2020	04:55	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	09/02/2020	05:06	THE SIGNAL RELAY WERE RESET AND TRIAL SWITCHING WAS GIVEN AND IT STAYED.

18	10/02/2020	04:30	FEEDER 32 TRIPPED ON EARTH FAULT.	10/02/2020	04:51	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
19	12/02/2020	04:35	NO FAULT INDICATION SEEN BUT FEEDER 5 TRIPPED.	12/02/2020	04:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
20	13/02/2020	15:35	FEEDER 5, 30, 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	13/02/2020	15:48	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
21	16/02/2020	08:58	FEEDER 5 TRIPPED ON EARTH FAULT	16/02/2020	09:19	THE EARTH FAULT SIGNAL WAS CLEARD AND RESTORATION SUCCESSFUL.
22	16/02/2020	15:30	FEEDER 5 TRIPPED ON EARTH FAULT	16/02/2020	15:38	THE EARTH FAULT SIGNAL WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
23	17/02/2020	14:33	FEEDER 5 TRIPPED ON EARTH FAULT			THE OPERATION WAS SUSPENDED
24	18/02/2020	11:31 13:12	FEEDER 32 CLOSED AND TRIPPED ON EARTH FAULT. FEEDER 5 CLOSED AND TRIPPED ON EARTH FAULT.	18/02/2020	16:29 18:55	FEEDER 32 WAS CLOSED AND STAYED, FEEDER 5 WAS CLOSED AND STAYED AFTER FAULT CLEARANCE.

25	20/02/2020	22:01	FEEDER 32 TRIPPED ON EARTH FAULT.	20/02/2020	05:50	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
26	21/02/2020	02:54	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	21/02/2020	03:07	THE SIGNAL WAS RESET AND RESTORATION WAS SUCCESSFUL.
27	27/02/2020	22:00	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	27/02/2020	22:20	THE FEEDER WAS RESTORED SUCCESSFUL AFTER FAULT CLEARED.
28	29/02/2020	01:03	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	29/02/2020	01:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
29	01/03/2020	21:35	FEEDER 32 TRIPPED ON EARTH FAULT.	01/03/2020	21:52	THE SIGNAL RELAY WAS RESET AND THE BREAKER STAYED.
30	02/03/2020	06:40	FEEDER 32 TRIPPED ON OVER CURRENT AND CURRENT CUTT OFF.	02/03/2020	06:57	THE SIGNAL WAS RESET AND RESTORATION WAS SUCCESSFUL.
31	05/03/2020	19:30	FEEDER 5, 32 TRIPPED ON EARTH FAULT	05/03/2020	19:45	BOTH FEEDER WERE RESTORED AFTER CLEARING THE FAULT.
32	06/03/2020	21:00	FEEDER 32 TRIPPED ON EARTH FAULT.	06/03/2020	21:25	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.

33	06/03/2020	22:12	FEEDER 5, 32 BOTH TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	06/03/2020	22:45	BOTH FEEDER WAS RESTORED AFTER CLEARED SUCCESSFULLY.
34	06/03/2020	03:45	FEEDER 32 TRIPPED ON EARTH FAULT.	06/03/2020	04:09	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
35	07/03/202	07:10	FEEDER 32 TRIPPED ON EARTH FAULT.	07/03/2020	08:17	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
36	07/03/2020	11:00	FEEDER 32 TRIPPED ON EARTH FAULT.	07/03/2020	16:35	THE FAULT WAS CLEARED AFTER SEVERAL TRIALS.
37	12/03/2020	00:08	FEEDER 5, 32 BOTH TRIPPED ON EARTH FAULT.	12/03/2020	00:20	FEEDER WAS CLOSED SUCCESSFULLY AND FEEDER 32 TRIPPED AGAIN.
38	13/03/2020	00:08	FEEDER 32 TRIPPED ON EARTH FAULT.	13/03/2020	11:20	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
39	13/03/2020	14:45	FEEDER 32 TRIPPED ON EARTH FAULT.	13/03/2020	15:00	THE SIGNAL RELAY WAS CLEARED AND RESTORATION SUCCESSFUL.
40	18/03/2020	18:16	FEEDER 32 TRIPPED ON EARTH FAULT.	18/03/2020	18:28	THE SIGNAL RELAY WAS RESET AND RESTORATION WAS SUCCESSFUL.

41	22/03/2020	12:59	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	22/03/2020	13:03	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
42	23/03/2020	16:50	FEEDER 5, 32, 30 TRIPPED AS A RESULT OF TREE BRANCH THAT FELL ON THE LINE.	23/03/2020	17:25	
43	23/03/2020	11:25	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION, FEEDER 30 INCOMING FEEDER TRIPPED ON NO FAULT SIGNAL.	23/03/2020	00:25	FEEDER 30 AND 32 WAS RESTORED SUCCESSFULLY AFTER FAULT CLEARED.
44	23/03/2020	00:27	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	23/03/2020	03:29	THE EARTH FAULT SIGNAL WERE CANCELLED AND A TRIAL SWITCHING WERE GIVEN TO THE FEEDER, FEEDER 32 STAYED AND 5 TRIPPED AGAIN.
45	24/03/2020	15:36	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF, OVER CUREENT PROTECTION.	24/03/2020	16:06	THE SIGNAL RELAYS WERE RESET AND TRIAL SWITCHING WERE GIVEN. FEEDER 32 WAS CLOSED SUCCESSFULLY WHILE 5 TRIPPED AGAIN.

46	24/03/2020	16:08	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF, WHICH ALSO TRIPPED FEEDER 30 AND 90.	24/03/2020	18:16	THE FAULT WAS CLEARED ALL THE FEEDER WERE RESTORED SUCCESSFULLY.
47	27/03/2020	10:00	FEEDER 5 TRIPPED ON NO FAULT SIGNAL.	27/03/2020	10:13	A TRIAL SWITCHING WAS GIVEN AND IT STAYED.
48	27/03/2020	17:12	FEEDER 5 TRIPPED ON NO FAULT WHILE 32 TRIPPED CURRENT CUT OFF AND OVER CURRENT PROTECTION, WHILE 30 ALSO TRIPPED ON OVER CURRENT PROTECTION.	27/03/2020	18:20	THE FAULT WAS CLEARED AND ALL THE FEEDER WERE RESTORED SUCCESSFULLY.
49	29/03/2020	14:30	FEEDER 32 TRIPPED ON EARTH FAULT.	27/03/2020	14:45	FEEDER 32 WAS RESTORED AFTER THE RESET OF SIGNAL RELAY.
50	30/03/2020	20:37	FEEDER 5 TRIPPED ON EARTH FAULT.	30/03/2020	20:51	THE FAUL WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
51	31/03/2020	23:14	FEEDER 5 TRIPPED ON NO FAULT WHILE 32 TRIPPED ON EARTH FAULT.	31/03/2020	23:25	THE FAULT WAS CLEARED AND BOTH FEEDER RESTORED SUCCESSFULLY.
			FEEDER 5 TRIPPED ON NO FAULT			A TRIAL SWITCHING WAS GIVEN AND THE

52	01/04/2020	08:29	SIGNAL	01/04/202	08:45	BREAKER STAYED.
53	01/04/2020	14:20	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	01/04/2020	14:38	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
54	02/04/2020	22:25	FEEDER 90 TRIPPED ON OVER CURRENT PROTECTION AND IT TRIPPED 5 AND 32.	02/04/2020	22:50	THE FAULT WAS CLEARED AND THE FEEDERS WERE RESTORED.
55	06/04/2020	06:02	FEEDER 32 TRIPPED ON NO SIGNAL FAULT.	06/04/2020	06:38	A TRIAL SWITCHING WAS GIVEN AND IT STAYED.
56	10/04/2020	22:32	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	10/04/2020	23:20	THE FAUL WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
57	14/04/2020	00:45	FEEDER 32 TRIPPED ON EARTH FAULT.	14/04/2020	01:06	THE FAUL WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
58	14/04/2020	04:35	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND EARTH FAULT.	14/04/2020	04:48	THE SIGNAL RELAY WAS RESET AND THE FAUL WAS CLEARED.

59	18/04/2020	17:25	FEEDR TRIPPED ON EARTH FAULT AND 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	18/04/2020	17:55	FEEDER 32 WAS RESTORED AND FEEDER 5 TRIPPED AGAIN.
60	18/04/2020	18:04 18:55	FEEDER 5 TRIPPED AGAIN ON EARTH FAULT WHILE GIVEN A TRIAL. FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	18/04/2020	19:11	TRIAL CLOSING WAS GIVEN TO THE BOTH FEEDERS BUT TRIPPED IMMIDATELY. WHILE FEEDER 32 BREAKER EXPLODED AND OPEN BAY6 AT TSS.
61	18/04/2020	19:18	FEEDER 90 TRIPPED ON OVER CURRENT PROTECTION.	18/04/2020	20:09	BAY6 WAS CLOSED AND FEEDER 90 WAS RESTORED SUCCESSFUL.
62	19/04/2020	12:49	FEEDER 90 TRIPPED ON EARTH FAULT.	19/04/2020	13:34	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
63	19/04/2020	14:30	FEEDER 5 TRIPPED ON EARTH FAULT.	19/04/2020	15:06	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
64	19/04/2020	19:05	FEEDER 5 TRIPPED ON NO FAULT INDICATION.	19/04/2020	19:28	THE FEEDER WAS GIVEN A TRIAL AND IT STAYED.

65	19/04/2020	22:05	FEEDER 90 TRIPPED ON OVER CURRENT PROTECTION.	19/04/2020	01:20	THE FAUL WAS CLEARED AND RESTORATION SUCCESSFUL.
66	21/04/2020	09:36	FEEDER 32 TRIPPED ON EARTH FAULT AND OVER CURRENT PROTECTION.	21/04/2020	09:42	THE SIGNAL RELAY WAS RESET AND RESTORATION WAS SUCCESSFUL.
67	21/04/2020	00:48	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	21/04/2020	00:57	THE SIGNAL RELAYS WERE RESET AND FEEDER WAS RESTORED SUCCESSFULLY.
68	25/04/2020	22:01	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	21/04/2020	23:05	THE SIGNAL RELAY WAS RESET AND A TRIAL SWITCHING WAS GIVEN AND IT WAS SUCCESSFUL.
69	28/04/2020	12:55	FEEDER 90 WAS OPEND AS A RESULT OF SMOKE.	26/04/2020	10:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
70	26/04/2020	12:23	FEEDER 5 TRIPPED ON EARTH FAULT.	26/04/2020	14:15	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
71	26/04/2020	16:04	FEEDER 5 TRIPPED ON EARTH FAULT.	27/04/2020	11:35	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

72	27/04/2020	12:28	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	27/04/2020	12:48	THE SIGNAL RELAY WAS RESET AND THE FAULT WAS CLEARED.
73	28/04/2020	06:49	FEEDER 5 TRIPPED ON EARTH FAULT.	28/04/2020	12:25	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
74	28/04/2020	14:46	FEEDER 90 LOST POTENTIAL AND FEEDER 5 TRIPPED ON CURRENT CUT OFF	28/04/2020	17:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
75	28/04/2020	11:25 11:27	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION. FEEDER 5 TRIPPED ON CURRENT CUT OFF.	28/04/2020	16:52 17:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
76	30/04/2020	05:15	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	30/04/2020	05:22	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
77	01/05/2020	11:31	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	01/05/2020	11:40	THE SIGNAL RELAY WAS RESET AND RESTORATION WAS SUCCESSFUL.

78	01/05/2020	12:18	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	01/05/2020	15:17	POWER WAS RESTORED AFTER FAULT CLEARED.
79	02/05/2020	03:25	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	02/05/2020	03:44	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
80	03/05/2020	02:50	FEEDER 5 AND 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	03/05/2020	03:38	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
81	04/05/2020	07:48	FEEDER 90 TRIPPED ON OVER CURRENT PROTECTION.	04/05/2020	07:56	FEEDER 90 WAS RESTORED SUCCESSFULLY AFTER FAULT CLEARED.
82	04/05/2020	08:42	FEEDER 32 TRIPPED ON EARTH FAULT.	04/05/2020	14:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
83	09/05/2020	01:28	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF. WHILE FEEDER 30 TRIPPED ON NO FAULT INDICATION.	09/05/2020	02:04	BOTH FEEDER WERE RESTORED SUCCESSFULLY AFTER FAULT CLEARED.

84	10/05/2020	06:00	FEEDER 32 TRIPPED ON EARTH FAULT.	10/05/2020	06:45	SIGNAL RELAY WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
85	10/05/2020	23:45	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	10/05/2020	00:05	SIGNAL RELAY WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
86	12/05/2020	18:44	FEEDER 5 TRIPPED ON NO FAULT SIGNAL.	12/05/2020	18:59	A TRIAL SWITCHING WAS GIVEN AND IT STAYED.
87	12/05/2020	21:15	FEEDER 90 TRIPPED ON OVER CURRENT PROTECTION.	12/05/2020	21:31	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
88	12/05/2020	21:40	FEEDER 5 TRIPPED ON NO FAULT SIGNAL AND FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION.	12/05/2020	21:50	BOTH FEEDERS WAS CLOSED SUCCESSFULLY AFTER FAULT WAS CLEARED.
89	12/05/2020	03:44	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION, EARTH FAULT.	13/05/2020	10:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

90	13/05/202	14:32	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	13/05/2020	21:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
91	15/05/2020	23:35	FEEDER 90 TRIPPED ON OVER CURRENT PROTECTION AND FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION AND FEEDER 30 TRIPPED ON NO FAULT INDICATION.	16/05/202	11:47	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
92	16/05/2020	14:09	FEEDER 32 TRIPPED ON EARTH FAULT.	16/05/2020	14:21	THE SIGNAL RELAY WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
93	16/05/2020	04:54	FEEDER 5 TRIPPED ON EARTH FAULT.	17/05/2020	05:05	THE SIGNAL RELAY WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
94	17/05/2020	06:30	FEEDER 5 TRIPPED ON EARTH FAULT.	17/05/2020	06:40	THE SIGNAL RELAY WAS RESET AND RESTORATION WAS SUCCESSFUL.

95	17/05/2020	02:48	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	17/05/2020	02:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
96	17/05/2020	03:50	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	17/05/2020	03:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
97	18/05/2020	17:40	FEEDER 5 TRIPPED ON EARTH FAULT.	18/05/2020	17:45	THE SIGNAL RELAY WAS CLEARED AND RESTORATION SUCCESSFUL.
98	18/05/2020	22:01	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	18/05/2020	22:03	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
99	18/05/2020	03:47	FEEDER 32 TRIPPED ON EARTH FAULT AND OVER CURRENT PROTECTION.	19/05/2020	09:20	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
100	19/05/2020	09:02	FEEDER 32 TRIPPED ON A TRIAL CLOSING AND TRIPPED 90.	19/05/2020	12:45	THE FAULT WAS CLEARED AND BOTH FEEDERS RESTORED SUCCESSFULLY.
101	20/05/2020	19:07	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	20/05/2020	19:50	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

102	24/05/2020	14:20	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	24/05/2020	14:32	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
103	24/05/2020	16:01	FEEDER 5 TRIPPED ON EARTH FAULT AND FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	24/05/2020	16:06	THE FAULT WAS CLEARED ON BOTH FEEDER AND RESTORATION WAS SUCCESSFUL.
104	24/05/2020	23:35	FEEDER 5 TRIPPED ON EARTH FAULT.	24/05/2020	23:53	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
105	24/05/2020	23:56	FEEDER 5 TRIPPED ON EARTH FAULT	25/05/2020	10:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
106	24/05/2020	00:05	FEEDER 32 TRIPPED ON EARTH FAULT.	25/05/2020	03:00	THE FAULT CLEARED AND RESTORATION WAS SUCCESSFUL.
107	25/05/2020	22:15	FEEDER 5 TRIPPED ON EARTH FAULT.	25/05/2020	22:35	THE FAULT WAS CLEARD AND RESTORATION WAS SUCCESSFUL.
108	26/05/2020	09:33	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	26/05/2020	09:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

109	26/05/2020	10:45	FEEDEF 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF.	26/05/2020	11:12	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
110	27/05/2020	04:15	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	27/05/2020	05:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
111	28/05/2020	06:20	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	28/05/2020	07:15	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
112	31/05/2020	21:20	FEEDER 5 TRIPPED ON EARTH FAULT.	31/05/2020	21:25	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
113	01/06/2020	24:01	FEEDER 32 TRIPPED ON CURRRENT CUT OFF AND OVER CURRENT PROTECTION.	01/06/2020	02:52 08:54	A TRIAL SWITCHING GIVEN BUT TRIPPED THE ENTIRE STATION AS WELL AS BAY6. THE FAULT WAS CLEAED AND RESTORATION WAS SUCCESSFUL.

114	02/06/2020	02:48	A REQUEST FROM HAUSING ESTATE TO OPEN FEEDER 5 AS A RESULT OF SHORT CIRCUIT BY A LIVING BAT.	03/06/2020	01:11	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
115	04/06/2020	02:30	FEEDER 5 TRIPPED AND 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	04/06/2020	02:50	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
116	05/06/2020	04:02	FEEDER 32 TRIPPED ON EARTH FAULT.	05/06/2020	04:30	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
117	06/06/2020	17:10	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	07/06/2020	02:22	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
118	06/06/2020	18:00	FEEDER 5 TRIPPED ON CURRENT CUT OFF.	07/06/2020	01:17	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
119	08/06/2020	08:34	FEEDER 5 TRIPPED ON NO FAULT AND 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	08/06/2020	08:55	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
120	08/06/2020	14:38	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	08/06/2020	15:54	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.

121	08/06/2020	22:32	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	08/06/2020	22:50	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
122	09/06/2020	07:45	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	09/06/2020	12:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
123	10/06/2020	14:07	FEEDER 32 TRIPPED ON EARTH FAULT.	10/06/2020	14:30	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
124	11/06/2020	15:44	FEEDER 5 TRIPPED ON CURRENT CUT OFF WHILE FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	11/06/2020	16:04	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
125	12/06/2020	12:40	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	12/06/2020	16:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
126	13/06/2020	19:15	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	13/06/2020	19:38	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

127	14/06/2020	21:30	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	14/06/2020	10:30	THE FAULT WAS CLEARED AND RESTORATION SUCCESSFUL.
128	17/06/2020	01:41	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	17/06/2020	02:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
129	18/06/2020	07:20	FEEDER 32 TRIPPED ON CURRENT CUT OFF ANF OVER CURRENT PROTECTION.	18/06/2020	08:20	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
130	19/06/2020	02:00	FEEDER 32 TRIPPED ON EARTH FAULT.	19/06/2020	02:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
131	20/06/2020	19:30	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	20/06/2020	19:43	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
132	21/06/2020	04:55	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	21/06/2020	05:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
133	22/06/2020	08:38	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	22/06/2020	12:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

134	24/06/2020	04:28	FEEDER 5 AND 32 TRIPPED ON OVER CURRENT PROTECTION.	24/06/2020	05:02	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
135	26/06/2020	04:25	FEEDER 5 TRIPPED ON EARTH FAULT.	26/06/2020	04:43	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
136	27/06/2020	21:40	FEEDER 5 TRIPPED ON EARTH FAULT	29/06/2020	20:54	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
137	30/06/2020	09:45	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	30/06/2020	10:18	THE FAUL WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
138	01/07/2020	06:15	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION.	01/06/2020	06:50	THE FAUL WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
139	03/07/2020	05:05 20:40	FEEDER 5 TRIPPED ON EARTH FAULT FEEDER 32 TRIPPED BAY6	03/07/2020 04/07/2020	05:08 04:36	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL. THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
140	04/07/2020	14:10	FEEDER 5 AND 32 TRIPPED ON CURRENT CUT OFF AND EARTH FAULT.	04/07/2020	14:42	THE FAUL WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

141	05/07/2020	16:54	FEEDER 5 AND 32 TRIPPED ON CURRENT CUT OFF AND EARTH FAULT.	05/07/2020	19:17	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
142	05/07/2020	21:09	FEEDER 5 AND 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION, AND EARTH FAULT.	05/07/2020 06/07/2020	22:04 11:20	THE FAULT WAS CLEARED AND THE BOTH FEEDER WERE RETORED.
143	07/07/2020	08:34	FEEDER 32 TRIPPED ON CURRENT CUT OFF. AND FEEDER 5 TRIPPED ON EARTH FAULT.	07/07/2020	13:38	THE FAULT WAS CLEARED AND BOTH FEEDERS WERE RESTORED.
144	08/07/2020	23:35	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND EARTH FAULT.	09/07/2020	14:08	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
145	10/07/2020	11:47	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	10/07/2020	15:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
146	12/07/2020	11:10	FEEDER 32 TRIPPED ON CURRENT CUT OFF.	12/07/2020	13:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

147	12/07/2020	20:00	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	12/07/2020	21:05	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
148	13/07/2020	09:26	FEEDER 32 TRIPPED ON EARTH FAULT.	13/07/2020	09:29	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
149	13/07/2020	15:30	FEEDER 32 AND 5 BOTH TRIPPED ON EARTH FAULT.	13/07/2020	19:22	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
150	15/07/2020	00:13	FEEDER 5 TRIPPED ON CURRENT CUT OFF.	16/07/2020	12:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
151	16/07/2020	18:45	FEEDER 5 TRIPPED ON EARTH FAULT.	16/07/2020	19:06	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
152	19/07/2020	12:30	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	19/07/2020	12:35	THE FAULT WAS CLEARED AND RESTORATION SUCCESFUL.
153	20/07/2020	04:46	FEEDER 5 AND 32 BOTH TRIPPED ON EARTH FAULT.	20/07/2020	04:49	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
154	23/07/2020	02:55	FEEDER 5 TRIPPED ON EARTH FAULT.	23/07/2020	03:13	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

155	24/07/2020	05:15	FEEDER 32 TRIPPED ON EARTH FAULT.	24/07/2020	05:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
156	03/08/2020	01:45	FEEDER 32 TRPPED ON EARTH FAULT.	03/08/2020	05:52	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
157	05/08/2020	16:53	FEEDER 32 TRIPPED ON EARTH FAULT.	05/08/2020	17:05	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
158	05/08/2020	20:33	FEEDER 5 TRIPPED ON EARTH FAULT.	05/08/2020	20:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
159	06/08/2020	16:45	FEEDER 32 TRIPPED ON EARTH FAULT.	06/08/2020	17:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
160	06/08/2020	20:50	FEEDER 5 TRIPPED ON EARTH FAULT.	06/08/2020	21:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
161	07/08/2020	11:04	FEEDER 32 OPENS FOR SINGLE PHASING OR LOW VOLTAGE.	07/08/2020	12:41	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
162	07/08/2020	20:07	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	08/08/2020	11:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

163	08/08/2020	05:55	FEEDER 5 TRIPPED ON CURRENT CUT OFF.	08/08/2020	11:07	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
164	08/08/2020	12:34	FEEDER 32 TRIPPED ON EARTH FAULT.	08/08/2020	13:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
165	09/08/2020	04:55	FEEDER 5 TRIPPED ON CURRENT CUT OFF WHILE 32 TRIPPED ON OVER CURRENT PROTECTION.	10/08/2020	10:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
166	13/08/2020	08:15	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	13/08/2020	09:52	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
167	14/08/2020	20:10	FEEDER 32 TRIPPED ON EARTH FAULT.	14/08/2020	20:16	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL
168	14/08/2020	01:50	FEEDER 32 TRIPPED ON EARTH FAULT.	14/08/2020	02:02	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
169	17/08/2020	22:05	FEEDER 5 TRIPPED ON EARTH FAULT.	17/08/2020	22:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
170	17/08/2020	04:25	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	17/08/2020	04:42	THE FAULT WAS CLEARED AND RESORATION WAS SUCCESSFUL.

171	20/08/2020	20:08	FEEDER 5 TRIPPED ON EARTH FAULT.	20/08/2020	22:12	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
172	21/08/2020	17:52	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	21/08/2020	19:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
173	21/08/2020	21:04	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	21/08/2020	21:16	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
174	22/08/2020	06:15	FEEDER 32 TRIPPED ON EARTH FAULT.	22/08/2020	15:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
175	22/08/2020	20:45	FEEDER 5 TRIPPED ON EARTH FAULT.	22/08/2020	21:00	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
176	24/08/2020	1:20	FEEDER 5 TRIPPED ON EARTH FAULT.	24/08/2020	1:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
177	25/08/2020	06:38	FEEDER 32 TRIPPED ON EARTH FAULT.	25/08/2020	06:58	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFFUL.
178	26/08/2020	07:24	FEEDER 32 TRIPPED ON EARTH FAULT.	26/08/2020	07:35	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

179	26/08/2020	15:38	FEEDER 5 TRIPPED ON EARTH FAULT FEEDER 32 TRIPPED ON CURRENT CUT OFF.	26/08/2020	19:27 10:09	FEEDER 5 WAS CLEARED AND RESTORED SUCCESSFUL FEEDER 32 WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
180	27/08/2020	20:47	FEEDER 32 TRIPPED ON EARTH FAULT.	27/08/2020	20:58	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
181	27/08/2020	22:36	FEEDER 32 TRIPPED ON EARTH FAULT.	28/08/2020	09:01	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
182	30/08/2020	23:18	FEEDER 5 TRIPPED ON EARTH FAULT AND OVER CURRENT PROTECTION.	31/08/2020	18:21	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
183	31/08/2020	17:30	FEEDER 32 TRIPPED ON EARTH FAULT.	31/08/2020	18:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
184	01/09/2020	11:07	FEEDER 32 TRIPPED ON EARTH FAULT.	01/09/2020	13:09	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
185	04/09/2020	17:15	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	04/09/2020	18:03	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

186	04/09/2020	19:58	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	04/09/2020	20:05	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
187	05/09/2020	14:00	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	05/09/2020	14:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
188	09/09/2020	14:03	FEEDER 32 TRIPPED ON CURRENT CUT OFF.	09/09/2020	14:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
189	11/09/2020	06:28	FEEDER 32 TRIPPED ON EARTH FAULT.	11/09/2020	12:56	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
190	12/09/2020	15:30	FEEDER 5 TRIPPED ON OVER CURRENT PROTECTION AND FEEDER 32 TRIPPED ON EARTH FAULT.	12/09/2020	19:17	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
191	12/09/2020	01:56	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	12/09/2020	02:13	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
192	13/09/2020	15:07	FEEDER 5 TRIPPED ON EARTH FAULT.	13/09/2020	21:11	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

193	14/09/2020	02:20	FEEDER 5 TRIPPED ON CURRENT CUT OFF AND FEEDER 32 TRIPPED ON EARTH FAULT.	14/09/2020	02:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
194	16/09/2020	22:15	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	16/09/2020	22:28	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
195	17/09/2020	06:33	FEEDER 5 TRIPPED ON CURRENT CUT OFF AND FEEDER 32 TRIPPED ON EARTH FAULT.	17/09/2020	06:43	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
196	18/09/2020	18:00	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION.	18/09/2020	19:32	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
197	20/09/2020	08:00	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	20/09/2020	20:05	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
198	21/09/2020	19:45	FEEDER 32 TRIPPED ON EARTH FAULT.	21/09/2020	19:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
199	24/09/2020	12:10	FEEDER 5 TRIPPED ON EARTH FAULT.	24/09/2020	14:25	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

200	26/09/2020	06:20	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	26/09/2020	08:34	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
201	28/09/2020	21:45	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	28/09/2020	22:17	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
202	29/09/2020	30:06	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	29/09/2020	05:02	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
203	01/10/2020	08:45	FEEDER 5 TRIPPED ON EARTH FAULT.	01/10/2020	12:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
204	03/10/2020	07:24	FEEDER 5 TRIPPED ON EARTH FAULT.	03/10/2020	12:48	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
205	04/10/2020	06:07	FEEDER 5 TRIPPED ON EARTH FAULT.	04/10/2020	09:32	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
206	04/10/2020	09:28	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND EARTH FAULT.	04/10/2020	09:32	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
207	04/10/2020	14:47	FEEDER 5 TRIPPED ON EARTH FAULT.	04/10/2020	15:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

208	04/10/2020	15:32	FEEDER 32 TRIPPED ON EARTH FAULT.	04/10/2020	16:44	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
209	04/10/202	22:38	FEEDER 32 TRIPPED ON EARTH FAULT.	04/10/2020	06:38	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
210	05/10/2020	22:01	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	05/10/2020	22:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
211	06/10/2020	10:05	FEEDER 5 SINGLE PHASING FAULT.	06/10/2020	12:35	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
212	06/10/2020	18:05	FEEDER 32 TRIPPED ON EARTH FAULT.	06/10/2020	12:14	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
213	06/10/2020	03:31	FEEDER 5 TRIPPED ON CURRENT CUT OFF.	06/10/2020	14:09	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
214	07/10/2020	17:20	FEEDER 5 TRIPPED ON CURRENT CUT OFF AND EARTH FAULT.	07/10/2020	17:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
215	07/10/2020	17:20	FEEDER 32 TRIPPED ON EARTH FAULT.	07/10/2020	17:38	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
216	08/10/2020	06:55	FEEDER 5 TRIPPED ON EARTH FAULT.	08/10/2020	07:05	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

217	08/10/2020	07:20	FEEDER 5 HAS SINGLE PHASING ON THE LINE.	08/10/2020	08:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
218	08/10/2020	08:20	FEEDER 32 TRIPPED ON CURRENT CUT OFF	08/10/2020	08:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
219	08/10/2020	18:17	FEEDER 5 TRIPPED ON EARTH FAULT.	08/10/2020	18:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
220	09/10/2020	06:15	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	09/10/2020	06:20	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
221	09/10/2020	07:49	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	09/10/2020	09:59	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
222	09/10/2020	15:38	FEEDER 5 AND 32 TRIPPED ON EARTH FAULT.	09/10/2020	15:50	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
223	10/10/2020	07:10	FEEDER 32 TRIPPED ON EARTH FAULT ALONG WITH FEEDER 5.	10/10/2020	08:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

224	11/10/2020	09:15	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	11/10/2020	19:01	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
225	12/10/2020	19:30	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	13/10/2020	18:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
226	13/10/2020	04:45	FEEDER 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF AND OVER CURRENT PROTECTION.	14/10/2020	10:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
227	14/10/2020	16:10	FEEDER 32 TRIPPED ON EARTH FAULT AND OVER CURRENT PROTECTION.	14/10/2020	20:43	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
228	15/10/2020	20:45	FEEDER 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF.	15/10/2020	22:48	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
229	16/10/2020	13:08	FEEDER 5 TRIPPED ON EARTH FAULT AND FEEDER 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF.	16/10/2020	13:12	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

230	16/10/2020	19:05	FEEDER 5 TRIPPED ON EARTH FAULT.	17/10/2020	09:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
231	17/10/2020	12:20	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	17/10/2020	12:40	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
232	17/10/2020	03:55	FEEDER 5 TRIPPED ON EARTH FAULT.			THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
233	18/10/2020	01:00	FEEDER 5 TRIPPED ON EARTH FAULT.	18/10/2020	01:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
234	20/10/2020	20:13	FEEDER 5 TRIPPED ON EARTH FAULT.	20/10/2020	20:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
235	20/10/2020	03:01	FEEDER 5 TRIPPED ON EARTH FAULT.	20/10/2020	03:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
236	24/10/2020	12:32	FEEDER 32 TRIPPED ON EARTH FAULT.	24/10/202	12:47	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
237	24/10/2020	03:03	FEEDER 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF.	25/10/2020	12:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

238	25/10/2020	15:15	FEEDER 5 AND 32 BOTH TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	25/10/2020	16:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
239	27/10/2020	06:30	FEEDER 5 TRIPPED ON EARTH FAULT.	27/10/2020	06:48	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
240	29/10/2020	12:15	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	29/10/2020	13:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
241	31/10/2020	12:43	FEEDER 32 TRIPPED ON EARTH FAULT AND CURRENT CUT OFF.	31/10/2020	12:53	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
242	31/10/2020	16:40	FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION.	31/10/2020	17:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
243	01/11/2020	09:50	FEEDER 32 SINGLE PHASING PROBLEM.	01/11/2020	10:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
244	01/11/2020	18:50	FEEDER 5 TRIPPED ON EARTH FAULT.	01/11/2020	19:02	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

245	02/11/2020	22:10	FEEDER 5 TRIPPED ON EARTH FAULT.	02/11/2020	22:55	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
246	03/11/2020	06:30	FEEDER 5 TRIPPED ON EARTH FAULT.	03/11/2020	12:39	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
247	04/11/2020	07:40	FEEDER 32 TRIPPED ON EARTH FAULT AND OVER CURRENT PROTECTION.	04/11/2020	08:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
248	05/11/2020	02:26	FEEDER 32 TRIPPED ON EARTH FAULT AND OVER CURRENT PROTECTION.	05/11/2020	03:27	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
249	06/011/2020	06:25	FEEDER 5 TRIPPED ON EARTH FAULT.	06/11/2020	06:45	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
250	09/11/2020	08:33	FEEDER 5 TRIPPED ON EARTH FAULT AND FEEDER 32 TRIPPED EARTH FAULT AND CURRENT CUT OFF.	09/11/2020	13:18	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
251	11/11/2020		FEEDER 32 TRIPPED ON EARTH FAULT.	12/11/2020	06:31	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

252	12/11/2020	07:42	FEEDER 5 TRIPPED ON EARTH FAULT.	12/11/2020	12:12	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
253	12/11/2020	15:46	FEEDER 5 TRIPPED ON EARTH FAULT.	13/11/2020	07:20	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
254	13/11/2020	12:38	FEEDER 5 TRIPPED ON EARTH FAULT.	13/11/2020	14:07	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
255	15/11/2020	05:10	FEEDER 5 TRIPPED ON EARTH FAULT.	15/11/2020	05:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
256	17/11/2020	15:00	FEEDER 5 TRIPPED ON EARTH FAULT.	17/11/2020	15:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
257	19/11/2020	07:24	FEEDER 5 TRIPPED ON EARTH FAULT.	19/11/2020	11:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
258	01/12/2020	06:29	FEEDER 5 TRIPPED ON EARTH FAULT.	01/12/2020	06:30	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
259	02/12/2020	07:30	FEEDER 5 TRIPPED ON EARTH FAULT.	02/12/2020	07:50	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

260	06/12/2020	16:00	FEEDER 5 TRIPPED ON CURRENT CUT OFF WHILE FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	06/12/2020 07/12/2020	16:25 13:23	FEEDER 5 WAS CLEARED AND STAYED WHILE FEEDER 32 WAS RESTORED ON THE FELLOWING DAY.
261	06/12/2020	22:50	FEEDER 5 TRIPPED ON EARTH FAULT.	06/12/2020	22:57	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
262	07/12/2020	17:14	FEEDER 5 TRIPPED ON EARTH FAULT.	07/12/2020	17:20	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
263	08/12/2020	07:15	FEEDER 5 AND 32 LOST POTENTIAL DUE TO FEEDER 90 THAT TRIPPED ON OVER CURRENT PROTECTION.	08/12/2020	08:10 13:09	FEEDER 90 WAS CLEARED AND RESTORATION SUCCESSFUL. FEEDER 5 WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
264	08/12/2020	08:20	FEEDER 30 AND 32 TRIPPED ON CURRENT CUT OFF AND FEEDER 90 TRIPPED ON OVER CURRENT PTOTECTION.	08/12/2020	09:03 09:20	FEDER 90 WAS CLOSED AND STAYED. FEEDER 30 AND 32 WAS CLOSED AND STAYED.
265	09/12/2020	17:12	FEEDER 32 TRIPPED ON EARTH FAULT.	09/12/2020	17:28	THE SIGNAL RELAY WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

266	13/12/2020	06:33	FEEDER 32 TRIPPED ON EARTH FAULT.	13/12/2020	07:15	THE SIGNAL RELAY WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
267	13/12/2020	07:20	FEEDER 30 TRIPPED ON NO FAULT INDICATION AND FEEDER 32 TRIPPED ON OVER CURRENT PROTECTION AND CURRENT CUT OFF.	13/12/2020	17:25	BOTH FEEDERS WAS RESTORED SUCCESSFULLY.
268	13/12/2020	22:00	FEEDER 5 TRIPPED ON EARTH FAULT.	13/12/2020	22:10	THE SIGNAL RELAY WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
269	14/12/2020	21:06	FEEDER 5 AND 32 LOST POTENTIAL AND 30 TRIPPED ON NO FAULT.	14/12/2020	21:22	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
270	14/12/2020	04:02	FEEDER 90 AND 5, 32 LOST POTENTIAL. FEEDER 30 MET ON OFF POSITION.	14/12/2020	04:17	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
271	15/12/2020	08:05	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND OVER CURRENT PROTECTION.	15/12/2020	08:08	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

272	15/12/2020	03:10	FEEDER 32 TRPPED ON EARTH FAULT.	15/12/2020	03:25	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
273	18/12/2020	09:05	FEEDER 32 TRIPPED ON CURRENT CUT OFF AND EARTH FAULT.	18/12/2020	09:10	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
274	18/12/2020	01:46	FEEDER 30 TRIPPED ON NO FAULT INDICATION ALONG FEEDER 5 AND 32.	18/12/2020	01:50	FEEDER 30 WAS RESTORED AND 5, 32 WAS ALSO RESTORED SUCCESSFUL.
275	19/12/2020	11:30	FEEDER 32 TRIPPED ON EARTH FAULT.	19/12/2020	11:31	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
276	19/12/2020	04:28	FEEDER 30 AND OUTGOING FEEDER TRIPPED ON NO FAULT INDICATION RELAY SIGNAL.	19/12/2020	04:47	FEEDER 30 WAS CLOSED AND STAYED AND OTHER FEEDER RESTORED SUCCESSFUL.
277	21/12/2020	04:38	FEEDER 5 AND 32 DID’NT TRIPPED BUT FEEDER 30 TRIPPED ON NO FAULT INDICATION.	21/12/2020	04:45	FEEDER 30 WAS CLOSED AND STAYED AND FEEDER 5, 32 RESTORED SUCCESSFULLY.
278	27/12/2020	10:25	FEEDER 30 TRIPPED ON NO FAULT INDICATION AND 5, 32 LOST POTENTIAL.	27/12/2020	10:49	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.

279	27/12/2020	11:00	FEEDER 30 TRIPPED ON NO FAULT INDICATION AND 5, 32 LOST POTENTIAL.	27/12/2020	11:09	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
280	27/12/2020	14:12	FEEDER 30 TRIPPED ON NO FAULT INDICATION AND 5, 32 LOST POTENTIAL.	27/12/2020	14:25	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
281	27/12/2020	15:03	FEEDER 30 TRIPPED ON NO FAULT SIGNALS. FEEDER 5 AND 32 WERE AT ON POSITION.	27/12/2020	15:13	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
282	28/12/2020	07:14	FEEDER 5 TRIPPED ON EARTH FAULT.	28/12/2020	07:15	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.
283	31/12/2020	06:15	FEEDER 5 TRIPPED ON NO FAULT INDICATION.	31/12/2020	07:05	A TRY WAS GIVEN AND IT STAYED.
284	31/12/2020	04:20	FEEDER 5 TRIPPED ON NO FAULT INDICATION.	31/12/2020	04:27	THE FAULT WAS CLEARED AND RESTORATION WAS SUCCESSFUL.