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Original Research Article

Reliability Assessment of Transmission Power System: A Case Study of Ajaokuta 132/33 kV Substation Feeders

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ABSTRACT

The reliability of power supply at the load points has become a global phenomenon owing to ever increasing load demand occasioned by industrial revolution, high standard of living and introduction of high tech equipment for several applications. Reliability is an important tool to measure the ability of power system to perform its intended functions under stated environmental condition for a specified period of time. The aim of this study is to carry out a reliability assessment of transmission power system using Ajaokuta 132/33kV feeder substation as a case study. The exponential distribution model and reliability block diagram are adopted in this study to assess the reliability of substation feeders and associated components. It can be established from the study that confluence feeder has the highest outage frequency and outage duration of 117 and 700.6 hrs while steel plant feeder has the lowest outage frequency and outage duration of 24 and 152.27 hrs. The reliability performance metrics of the substation such as failure rate, availability, meant time before failure and mean time to repair are computed to be 0.06278 f/hr, 0.99983, 49672 hrs and 83.70 hrs. The results show that the substation is not reliable and has poor feeders' availability. The major causes of outage were earth fault, open circuit fault, ageing components and over load. The substation is underutilized; therefore there is need for the expansion of distribution networks. The results of the research can serve as a model to determine the reliability of any substation on the global note.

1. INTRODUCTION

With the increasing reliance of industries, agriculture and day to day household comfort upon the continuous supply of electricity, the reliability of electrical power system has assumed a tremendous importance.

Electricity supply authorities are under obligation to make power available to its numerous consumers either metered or unmetered with quality of service and continuity at affordable price. For this reason, reliability of power system must be coordinated properly (Kothari and Nagrath, 2009). Nigeria power supply reliability depends on the ability of the generation companies, Transmission Company of Nigeria and Distribution Companies to expand the capacities of generation, transmission and distribution networks respectively. Nigeria transmission and distribution network has long been very weak in country electricity value chain. Despite humongous investment on power transmission upgrades and privatization of power distribution, Transmission Company of Nigeria has not been able to transmit up to 6000 MW of electricity on daily basis. The national grid network frequently suffers from system collapses and regularly fails to transmit and evacuate available power generated by generation companies thereby resulted into nationwide power outages (Precious, 2020). The need for reliability of an engineering system has become an important issue during their design, construction and operation because of the increasing dependence of our day to day lives schedule on the optimal functioning of these systems. Typical examples of these systems are power system installations which have a number of components assembled to make up a substations be it generation, transmission or distribution substations. Most of these components if not all must perform normally to have a power system that is efficient, stable, affordable and reliable. The required reliability of engineering system is specified in the design specification and this is carefully implemented during construction (Dhillon, 2006).

Reliability is the probability that a system or an item or an event will perform its desired or intended or expected functions under stated conditions for a specified or stated period of time subject to specified environmental conditions (Oroge, 2000 and Billinton *et al.*, 2003). Reliability is the most generally acceptable standard that is rational for determining the best design in terms of reduced total tariff of life of electrical system. A power system is cost effective ways of providing electricity in any nation. The subsystems of power system are; generation, transmission, distribution and utilization. Because of the complexity of power system, it is advisable to practically carry out the reliability of each component of power system independently Billinton *et al.* (1996). A power system network that is reliable and effective will bring development to any country. In order to bring about meaningful development in Nigeria, electricity supply authority must provide sustainable energy that is cost reflective and accessible for reasonable hours in a day (Adefarati *et al.,* 2014). The essence of power system is to provide electricity to its consumers with minimum interruption. The reliability of the power system is determined by the number of interruptions or outages that occur while the system performs its desired functions well by the quality of electricity delivered. Consumers' satisfactions depend on unhindered supply of electricity at assessable and affordable cost while the satisfaction of supply authority is the ability to get return on investment (Raji *et al.*, 2022). The improvement in the performance of electricity supply is paramount for economic and social developments. Several efforts have been made over the years to improve the performance of Nigeria electricity supply to meet consumers demand and satisfactions. Techniques of reliability analysis have been gradually accepted globally as a standard tool for the planning, design, operation, management and maintenance of electric power system (Jibril and Ekundayo, 2013).

Transmission Company of Nigeria (TCN) Ajaokuta 132/33 kV substation is not insulated from power system interruption which pervaded the electric power system and substations in Nigeria. TCN reported that as at 2021 not less than 85 million Nigerians lack access to electricity. Different categories of electricity consumers who have access to National grid have faced or experienced electricity supply that is not only unreliable but also insufficient. Electricity supply gap is mostly compensated with reliance on fossil fuel which is costly and causes pollution. TCN reported that between 2013 and 2023, the records of partial or total grid collapse were 4, 13, 10, 29, 21, 13, 11, 4, 4, 7 and 3 respectively, thereby thrown part of or the entire nation into total blackout. It should be noted that nature and frequency of power outages vary from one substation to another. The substation under review provides power supply to 5x33 kV outgoing feeders which are domestic and industrial consumers who sometimes experience frequent outages due to one reason or the other. Many communities within this power facility are sometimes either in black out or not connected to power at all. This is the challenge that the proposed study seeks to resolve. The transmission power system consists of various types of interconnected components such as lines, transformers, circuit breakers and isolators to enable the system to function. The system is constantly subjected to failures in its interconnected components, caused by lightning, overloading, storms, human errors, sabotage and aging equipment. The scope of this research is mainly to assess reliability analyzes of substation feeders and major equipment in the substation which includes transformers, circuit breakers, station storage batteries, relays, bus bars and instrument transformers. The importance of reliability assessment cannot be underestimated because it is impossible to determine if a system meets all the required functionality and safety expectations without consistent tools for measuring results. The research will also provide the transmission system operators additional inputs to the decision making in the planning of the system.

It is very essential to review similar works on this study so as to keep abreast of the existing work on reliability analysis and evaluation and numerous solutions it has provided to power system globally. Adefarati *et al*., (2014) conducted research on reliability evaluation of Ayede 330/132kV substation using reliability and customer oriented indices such as system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), customer average duration index (CAIDI), customer average interruption frequency index (CAIFI), momentary average interruption frequency index, customer interrupted per interruption index and average system availability index (ASAI) to determine the optimum performance of power system. Muhammad *et al.,* (2022) carried out reliability analysis of high voltage power equipment in Ajaokuta steel company limited using fault tree analysis. Reliability of the substation was determined using exponential distribution models and development of reliability block diagram method. The study revealed that earth fault and equipment ageing and delay in maintenance were the causes of unavailability of power to the customer. Jibril and Ekundayo, (2013) conducted research on reliability assessment of 33kV Kaduna electricity distribution feeders, Northern region, Nigeria. The research revealed that the rural feeders have the highest failure rate. High forced outage was discovered which indicated unreliable performance. Sonwane and Kushare, (2015) worked on the distribution system reliability as compared to previous research mostly on generation and distribution. The study also beamed a searchlight on the effect of different components failure modes. Okozi *et al.,* (2018) presented a research paper that assessed reliability assessment of Nigeria power systems, case study of 330 kV transmission lines in Benin sub-region. The research work showed the weakness of the system in frequent failures that occurred on six out of the thirteen circuit breakers of the work centre and the poor maintenance of others.

The literature review presented has shown that several studies have been carried out by numerous researchers in the field of reliability assessment of power system, utilizing different techniques for the analyses. This indicates that there has been an extensive research on reliability analyses and evaluation but no verifiable research publication at present on the reliability assessment of transmission power system using Ajaokuta 132/33kV substation as a case study. The present study presented reliability block diagram and exponential distribution model that can be used to predict the reliability of substation utilizing theoretical and historical data.

2. METHODOLOGY

2.1. Reliability Evaluation

Reliability evaluation is the process of determining whether an existing power system has achieved a specified level of operational reliability. Reliability evaluation is an important element of reliability engineering and it has to do with ensuring that engineering equipment is reliable. Researchers have developed many reliability evaluation methods or techniques over the year (Dorji, 2009; Malamati and Angelos 2010). The reliability of the power system is classified into adequacy and security as presented in Figure 1.

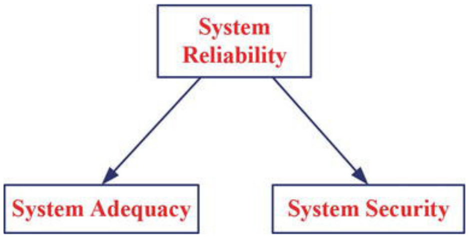

Figure 1: Reliability of power system (Kumar *et al.*, 2018)

The power system adequacy is a measure of the probability of power to supply the load in all the steady states in which the power system may exist by considering standard conditions Billinton *et al.,* (1996). Power system security is the ability of the system network to withstand faults or changes and remain in its secure state. The scope of this work is limited to adequacy evaluation of the power system. The primary methods utilized for evaluation of adequacy are based on their segmental applications in the entire power system Billinton *et al.,* (1994). The segments of the power system are classified into three functional zones such as generation, transmission and distribution in Figure 2 (Liu *et al.*, 2009). Hierarchical levels consist of different functional zones of the power system. The reliability evaluation at hierarchical level 1 (HL-1) is the generation capability of the power plants and their ability to match the consumption on the power system. The reliability evaluation at hierarchical level 11 (HL-11) is a combination of generation and transmission facilities. This hierarchical level can be used to assess the potential of the composite power system to deliver bulk power supply at the respective load points. The last hierarchical level is hierarchical level 111 (HL-111) that consists of all the three functional segments such as generation, transmission and distribution.

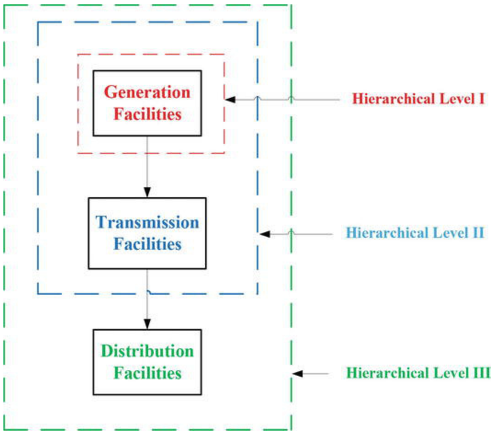

Figure 2: Structure of hierarchical level (Kumar *et al.*, 2018)

2.1.1. Analytical method

The reliability evaluation in this method is carried out based on assumptions with respect to statistical distributions of repair times and failure rates. The failure mode analysis or minimum cut-set analysis is the most common evaluation technique using a set of approximate equations.

2.1.2. Simulation technique

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. The simulation process is intended for examining and predicting the stochastic behavior of a system in simulated time (O'onnor and Kleyner, 2011; Uhunmwangho and Omorogiuwa, 2014).

2.2. Reliability Analysis Method

The reliability analysis method used in this research work is fault tree analysis and reliability block diagram. The basic reliability expressions in this method are as discussed below.

2.2.1. Fault tree analysis and fault tree diagram

The fault tree diagrams are logic block diagram that display the state of a system (top event) in terms of its components (basic events). It consists of gates (OR and AND gates) and events connected with lines. The various types of symbols commonly used by fault tree diagram are circle, rectangle, OR gate and AND gate. The circle represents a basic fault event or failure of elementary components. The rectangle represents a fault event that arises from the combination of fault events through the input of a logic gate. The OR gate represents that an output fault occurs if one or more of the input fault events occur. Lastly, AND gate indicates that an output fault events occur only if all the input fault events occur. In the fault tree diagram shown in Figure 3, A and C are OR gates while B is AND gate. Failure of output of A will occur when failure of either event 1 or 2 or both events 1 and 2 occurred. Similarly, failure of output of B will occur when failure of both events 3 and 4 occurred. Failure of top event occurs when failure of either event (A or B) or both occurred.

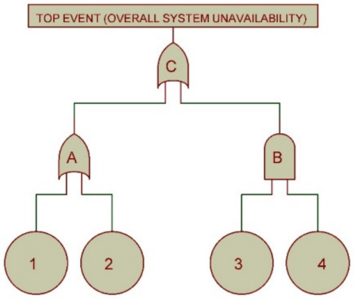

Figure 3: Fault tree analysis diagram

2.2.2. Reliability block diagram

The reliability block diagram (RBD) is a method of modeling how components and subsystem failures combine to cause a system failure. The reliability block diagrams are representation of components, subsystem and system as a series of block in such a way that equipment failure rates, operating philosophies and maintenance strategies can be quantitatively assessed in terms of the impact they are expected to have on system performance. The reliability block diagram can be calculated in series, parallel and combination of series and parallel.

i. Series connection

Series probability is calculated by multiplying the reliability or probability of the series components as shown in Figure 4. That is, the system reliability is equal to the product of the reliabilities of its constituent components. The equation for series reliability connection is presented in Equation (1).

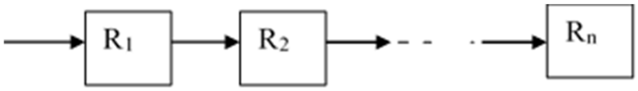

Figure 4: Series reliability connections

$$R_s = R_{1(t)} x R_{2(t)} x ------ R_{n(t)} \quad (1)$$

$$R_s = \prod_{i=1}^{n} R_i \quad (2)$$

ii. Parallel connection

Parallel reliability can be estimated by multiplying the unreliability (Q) of the parallel components as shown in Figure 5. The equation for parallel reliability connections is shown in Equation (3).

$$R_p = 1 - Q_{(s)} = 1 - (Q_1 . Q_2 . - - - Q_n) \tag{3}$$

$$R_p = 1 - [(1 - R_1)(1 - R_2) - - - (1 - R_n)] \tag{4}$$

$$R_p = 1 - \prod_{i=1}^{n}(1 - R_i) \tag{5}$$

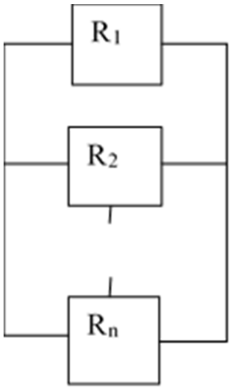

Figure 5: Parallel reliability connection

The probabilities of the occurrence of the output fault events of logic gates OR and AND are given in Equation (6).

$$P(E_0) = 1 - \prod_{i=1}^{n}[1 - P(E_1)] \tag{6}$$

Where $P(E_0)$ is the probability of occurrence of the OR gate output fault event E_0, n is the number of independent input fault events and $P(E_1)$ is the probability of AND gate.

$$P(Y_0) = \prod_{i=1}^{n} P(Y_1) \tag{7}$$

Where $P(Y_0)$ is the probability of occurrence of input fault event Y_0 and $P(Y_1)$ is the probability of occurrence of input fault eventY_1 for n=1,2---n.

2.3. Reliability Indices

The electric utility industry has developed several indicators to measure reliability performance of the power system. The reliability indices are used by utilities and other power system operators to assess the performance of their systems and to identify areas for improvement. The basic reliability indices, energy oriented reliability indices and customer oriented reliability indices are used in the study to estimate the reliability of the power system.

2.3.1. Basic reliability indices

The basic reliability can be used to estimate the reliability of the distribution system. The continuity of power supply at the supply points can be assessed by using the basic reliability indices that are briefly explained as follows:

- **Reliability**

The context of reliability is the ability of the power system to provide uninterrupted electricity to its customers. The reliability of the power is varying due to ageing of its basic components.

$$R(t) = e^{-\lambda t} \tag{8}$$

Where λ is the failure rate and *t* is time in hours.

$$R(t) + Q(t) = 1 \tag{9}$$

Failure Probability can be expressed in Equation (10) as

$$\text{Q(t)} = 1 - e^{-\lambda t} = \lambda T \tag{10}$$

Where T is average down time per failure and λ is failure rate.

- **Failure rate**

Failure rate can be defined as the anticipated number of times that an item fails in a specified period of time.

$$\lambda = \frac{Total\ number\ of\ outages}{Total\ operating\ hours} \quad \text{(f/hr)} \tag{11}$$

- **Mean Time between Failures**

The meant time before failure (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 (Oroge, 2000). It is expressed as ;

$$MTBF = \frac{Total\ System\ Operating\ Hours}{Number\ of\ Failures} \tag{12}$$

$$MTBF = \frac{1}{Failure\ Rate} = \frac{1}{\lambda} \tag{13}$$

- **Mean Time to Repair**

The mean time to repair (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 (Oroge, 2000). It is expressed in Equation (14):

$$MTTR = \frac{Total\ Duration\ of\ Outage}{Total\ Frequency\ of\ Outage} \tag{14}$$

$$Failure\ Frequency\ (f) = \frac{1}{MTBF+MTTR} \tag{15}$$

- **Availability**

Availability is the probability that an item is available for use when required. It is expressed in Equation (16).

$$Availability = \frac{MTBF}{MTBF+MTTR} \tag{16}$$

- **Unavailability**

Unavailability is the probability that a system is not available for use when required. It is expressed in Equation (17).

$$Unavailability = \frac{MTTR}{MTBF+MTTR} = \frac{fxMTTR}{8760} \tag{17}$$

2.3.2. Energy oriented reliability indices

The energy oriented indices provide value information regards to the reliability performance and improvements of the existing power system by using the following indicators: expected energy not supplied, expected interruption cost index and interruption energy assessment rate indices. The abovementioned indicators can be used to describe the overall performance of the power system.

- **Expected Energy not supplied**

Expected energy not supplied (EENS) is the expected amount of the energy that is not delivered at the consumer load points owing to an unexpected power outage or power interruption. The EENS is expressed in Equation (18) as Adefarati *et al.*, (2017b):

$$EENS = LU \text{ (kWhr/yr)} \tag{18}$$

Where L is the average load and U is the annual outage duration.

- **Average Energy not Supplied**

Average energy not supplied is the average value of energy not supplied by the system that affects customers on annual basis. The AENS is presented in Equation (19) as Adefarati *et al.*, (2017b):

$$AENS = \frac{Total\ Energy\ Not\ Supplied}{Total\ Number\ of\ Customers\ Served} \text{ (kWhr/Customer/yr)} \tag{20}$$

- **Expected Interruption Cost Index**

The practical method that can be used to estimate The reliability worth of the power system can be estimated based on the evaluation of the expected interruption cost index (ECOST). The ECOST provides substantial information that can be used for planning and design of the power system.

$$ECOST = \sum_{i=1}^{n} P_i f_i D \text{ (₦/hr)} \tag{21}$$

where f_i is the cost of interruption (₦/kWhr), P_i is the average load (kW) and D is the annual outage duration (hr).

- **Interruption Assessment Rate Index**

The interruption assessment rate index can be used by the power utilities to estimate the expected annual economic damage bear by customers. The interruption assessment rate index can be expressed by using Equation (22) Adefarati *et al.*, (2017a):

$$IEAR = \frac{ECOST}{EENS} \text{ (kWhr/Customer/yr)} \tag{22}$$

2.3.3. Customer oriented reliability indices

The customer oriented indices are introduced in this study to assess the impacts of power interruptions at the load points. The customer-oriented indices are the most usually utilized reliability indices that provide significant information about the performance of the power system. The following customer oriented indices are taking into account in this study:

- **System Average Interruption Duration Index**

The SAIDI describes the total duration of the average customer interruption. It is calculated by multiplying the average duration of customer interruptions by their total number and then dividing by the total number of customers in the system. It is expressed in hours per customers (hrs/customers) Adefarati *et al.*, (2017b).

$$SAIDI = \frac{Total\ Outage\ Durations\ in\ Hours}{Number\ of\ Customers\ Supplied} \text{ (hr/customer/yr)} \tag{23}$$

- **System Average Interruption Frequency Index**

The SAIFI describes how often the average customer experiences an interruption. It is calculated by dividing the total number of customers interrupted by an outage by the total number of customers in the system Adefarati *et al.*, (2017b).

$$SAIFI = \frac{Frequency\ of\ Outage}{Number\ of\ Customers\ Supplied}\ \text{(failure/customer/yr)} \tag{24}$$

- **Customer Average Interruption Duration Index**

The CAIDI describes the average time required to restore service. It is calculated as total duration of customer interruption divided by the total number of customers interrupted .

$$CAIDI = \frac{Sum\ of\ Customers\ Interuption\ Durations}{Total\ Number\ of\ Customers\ Interrupted} = \frac{SAIDI}{SAIFI}\ \text{(hour/customer interruption)} \tag{25}$$

- **Customer Average Interruption Frequency Index**

The CAIFI describes how many interruptions each impacted customer experiences. Therefore, it helps detect whether problems are being resolved effectively or left vulnerable to recurrence. It is calculated by dividing the number of interruptions by the number of customers experiencing interruptions Adefarati *et al*., (2017b).

$$CAIFI = \frac{The\ number\ of\ customer\ interruption}{Total\ number\ of\ Customers\ Interrupted} \tag{26}$$

Average Service Availability Index

ASAI has to do with a measure of the average availability of the distribution system that serves customers. It is usually represented in percentages. It is expressed as Adefarati *et al*., (2017a):

$$ASAI = \frac{Customers\ Hours\ Service\ Availability}{Customers\ Hours\ Service\ Demanded} \tag{28}$$

$$ASAI = \frac{(Number\ of\ Customers\ x\ 8760) - (Number\ of\ Customers\ x\ Duration\ of\ Outage)}{Number\ of\ Customers\ x\ 8760} \tag{29}$$

- **Average Service Unavailability Index**

ASUI has to do with the fraction of time customers are without electricity throughout the predefined interval of time. It is expressed as Adefarati *et al*., (2017b):

$$ASUI = \frac{Duration\ of\ Outages\ in\ Hours}{Total\ Hours\ Demanded} \tag{30}$$

$$ASUI = 1 - ASAI \tag{31}$$

2.4. Overview of Transmission Company of Nigeria Ajaokuta 132/33 kV Substation

The overview and schematic diagram of the Transmission Company of Nigeria Ajaokuta 132/33 kV Substation is presented in Fig. 6. The list of the components or equipment that makes up the substation are: 1x60 MVA and 1x30 MVA 132/33 kV power transformers, grounding or earthing transformer, 5x 33 kV, 2000 A, SF6 circuit breakers, isolators, 132 kV and 33 kV bus bars, 600 AH, 110 V rectifier unit and storage batteries, 1x132 kV incoming feeder, 5x33 kV outgoing feeders, instrument transformers (voltage and current transformers), relays protection (earth fault and over current relay) and bus bars. The basic information about the substation feeders are presented in Table 1.

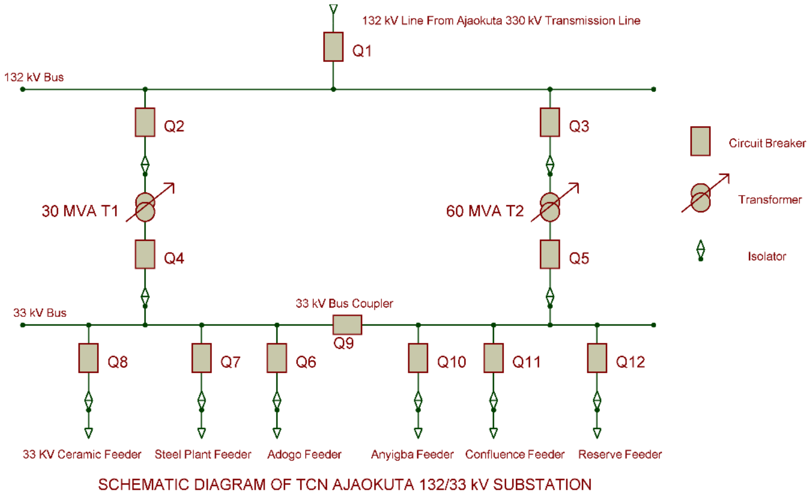

Figure 6: Schematic diagram of TCN Ajaokuta 132/33kV substation

Table 1: Basic Information of Ajaokuta 132/33kV substation

Feeder name	Feeder length (km)	Average load demand (MW)	Feeder band	Consumer
132 kV incoming feeder	10			
33 kV outgoing steel plant feeder	10.2	1.2	Industrial	West Africa Ceramics
33 kV outgoing ceramics feeder	10	0.5	Industrial	BN Ceramics
33 kV outgoing Ayingba feeder	78	20	Domestic	Nine LGA of Kogi State
33 kV outgoing Lokoja feeder	35	12	Domestic	Part of Ajaokuta and Lokoja L.G.A.
33 kV outgoing Adogo feeder	36	1.2	Domestic	Part of Ajaokuta L.G.A

2.5. Fault Tree Diagram of TCN Ajaokuta 132/33kV Substation

The fault tree diagram of Transmission Company of Nigeria, Ajaokuta 132/33kV Substation is presented in Figure 7. The diagram contains the failure rate of each component assembled to make up the substation. From the diagram, it should be noted that, failure of the top event (unavailability of substation) will only occur whenever one or more of the input failed.

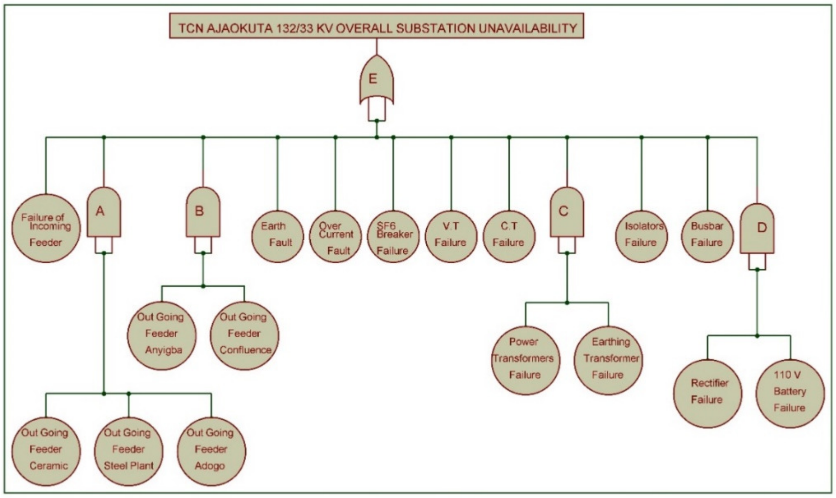

Figure 7: Fault tree analysis diagram of TCN Ajaokuta 132/33kV substation

2.6. Reliability Block Diagram of TCN Ajaokuta 132/33 kV Substation

The block diagram shown in Figure 8 is the reliability block diagram of the proposed substation. The system is made up of seventeen blocks connected in both series and parallel to form a single reliability block diagram. It is shown in the diagram that outgoing feeders' steel plant, ceramics and Adogo are all connected to a single busbar and are said to be connected in parallel. Outgoing feeders' confluence and Anyigba are both connected to a common busbar and are said to be connected in parallel. The two power transformers are connected to a common busbar and are said to be connected in parallel. Batteries and rectifier units are connected in parallel. The rest of the components are connected in series with those parallel connections.

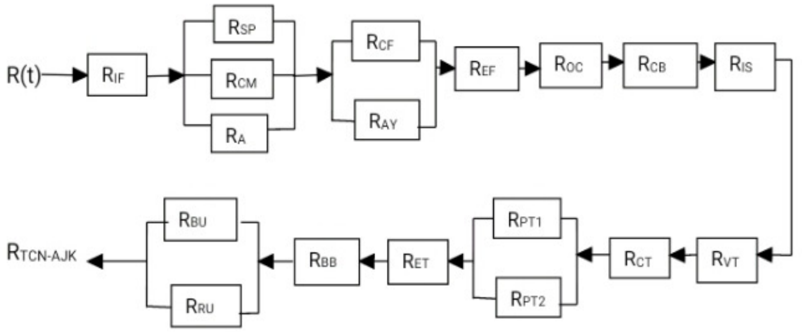

Figure 8: Reliability block diagram of TCN Ajaokuta 132/33kV substation

From the reliability block diagram shown in Figure 8, the reliability of each component is represented thus; Where, R_{IF} is the reliability of incoming feeder, R_{SP} is the reliability of outgoing feeder steel plant, R_{CM} is the reliability of outgoing feeder ceramic, A_{AD} is the reliability of outgoing feeder Adogo, R_{CF} is the reliability of outgoing feeder confluence, R_{AY} is the reliability of outgoing feeder Anyigba, R_{AD} is the reliability of outgoing feeder Adogo, R_{EF} is the reliability of earth fault relay, R_{OC} is the reliability of over current relay, R_{CB} is the reliability of sulphur hexafluoride circuit breaker, R_{IS} is the reliability of isolator, R_{VT} is the reliability of voltage transformer, R_{CT} is the reliability of current transformer, R_{PT1} is the reliability of power transformer T1, R_{PT2} is the reliability of power transformer T2, R_{ET} is the reliability of earthing transformer, R_{BU} is the reliability of storage battery unit, R_{RU} is the reliability of rectifier unit and R_{BB} is the reliability of bus bar.

2.7. Reliability Block Diagram Development Model of Substation

From Figure 8, total reliability block diagram of Transmission Company of Nigeria Ajaokuta 132/33kV Substation is computed as:

$$R_{TCN-AJK} = \{R_{IF} \cdot (R_{SP} \,//\, R_{CM} \,//\, R_{AD}) \cdot (R_{CF} \,//\, R_{AY}) \cdot R_{EF} \cdot R_{OC} \cdot R_{CB} \cdot R_{IS} \cdot R_{VT} \cdot R_{CT}(R_{PT1} \,//\, R_{PT2}) \cdot R_{EF} \cdot R_{BB} \cdot (R_{BU} \,//\, R_{RU})\} \tag{32}$$

The reliability block diagram above which contain an independent series and parallel subsystems configurations can be simplified to an equivalent units using reliability network reduction method.

$$R_{TCN-AJK} = \{R_{IF}(1-(1-R_{SP})(1-R_{CM})(1-R_{AD})) \cdot (1-(1-R_{CF})(1-R_{AY})) \cdot R_{EF} \cdot R_{OC} \cdot R_{CB} \cdot R_{IS} \cdot R_{VT} \cdot R_{CT}(1-(1-R_{PT1})(1-R_{PT2})) \cdot R_{EF} \cdot R_{BB} \cdot (1-R_{BU})(1-R_{RU})\} \tag{33}$$

By applying Equation (32) and substitute for the failure rate of each component in Equation (33), the reliability equation of the substation becomes Equation (34) which is the reliability equation developed for Transmission Company of Nigeria Ajaokuta 132/33kV Substation derived from the RBD of the substation shown in Figure 8. Reliability of the substation can be calculated at any time by substituting for the value of failure rate of each component. The model can be utilized to predict the reliability of Ajaokuta 132/33kV substation over a period of years.

$$R_{TCN-AJK} = \left\{e^{-\lambda_{IF}t}\left(1-(1-e^{-\lambda_{SP}t})(1-e^{-\lambda_{CM}t})(1-e^{-\lambda_{AD}t})\right) \cdot \left(1-(1-e^{-\lambda_{CF}t})(1-e^{-\lambda_{AY}t})\right) \cdot e^{-EFt} \cdot e^{-\lambda_{OC}t} \cdot e^{-\lambda_{CB}t} \cdot e^{-\lambda_{IS}t} \cdot e^{-\lambda_{RV}t} \cdot e^{-\lambda_{CT}t}\left(1-(1-e^{-\lambda_{PT1}t})(1-e^{-\lambda_{PT2}t})\right) \cdot e^{-\lambda_{EF}t} \cdot e^{-\lambda_{BB}t} \cdot \left(1-e^{-\lambda_{BU}t}\right)\left(1-e^{-\lambda_{RU}t}\right)\right\} \tag{34}$$

2.8. Exponential Distribution Model

Exponential distribution model of finding reliability is used because during the useful life of substation and its components, the failure rate is assumed to be constant. The failure rate of each component of the proposed substation can be inserted in Equation (35) to estimate the general reliability of the power system. The exponential distribution model is applied in this paper to predict the reliability of the substation over a period of time. The mathematical representation of the entire transmission substation reliability can be represented by using Equation (35).

$$R_{TCN} = e^{-\lambda_{TCN} t} \tag{35}$$

Where λ_{TCN} is the total (constant) failure rate of the entire Ajaokuta 132/33kV substation at time *t*.

3. RESULTS AND DISCUSSION

This section presents an elaborate reliability analysis of the studied secondary transmission substation. The data which was collected from Ajaokuta 132/33kV substation and Nigeria Electricity Regulatory Commission was used to assess the substation components failure rate, overall reliability of substation, availability, customer oriented reliability indices, load and energy oriented indices and reliability cost. Table 2 shows the outage frequency of an incoming feeder and outgoing feeders such as steel plant, ceramics, Anyigba, confluence and Adogo respectively from July 2022 to June 2023. It is discovered that confluence feeder has the highest number of outage of 117 while the incoming feeder has the lowest number of outage of 2. Table 3 shows the outage durations of incoming and outgoing feeders from July 2022 to June 2023. It is discovered that outgoing confluence feeder has the highest number of outage duration of 700.60 hrs while the incoming feeder has the lowest number of outage duration of 8.12 hrs. Table 4 shows the summary of basic reliability indices of incoming 132kV feeder. There were two cases of outage on this feeder in April and May 2023 with 8.12 hours outage duration. There is failure rate of 0.001389 f/hr in April and 0.001344 f/hr in May 2023. There was no failure for the rest of the month. Overall failure rate of the incoming feeder for the year under review was 0.000228 f/yr. The MTBF is 4380 hrs, MTTR is 4.06 hrs and availability of incoming feeder is 99.907%.

Table 2: summary of outage frequency from July 2022 to June 2023

Month	Incoming Feeder	Steel Plant Feeder	Ceramic Feeder	Anyigba Feeder	Confluence Feeder	Adogo Feeder
July	-	1	-	1	2	4
August	-	-	1	4	8	6
September	-	4	10	30	21	12
October	-	5	6	13	21	7
November	-	1	1	6	16	4
December	-	1	1	2	8	1
January	-	5	8	7	10	5
February	-	2	1	1	2	3
March	-	3	3	7	8	6
April	1	1	1	4	9	3
May	1	-	-	4	9	7
June	-	1	3	1	3	2
Total	2	24	35	80	117	60

Table 3: summary of outage duration from July 2022 to June 2023

Month	Incoming Feeder	Steel Plant Feeder	Ceramic Feeder	Anyigba Feeder	Confluence Feeder	Adogo Feeder
July	-	8.03	-	5.57	24.52	42.18
August	-	-	1.83	58.55	39.52	41.63
September	-	38.83	93.77	94.65	88.07	70.02
October	-	3.50	23.5	65.87	48.73	35.52
November	-	3.50	3.5	64.70	84.60	56.15
December	-	15.95	15.95	18.75	95.48	15.93
January	-	9.73	49.82	54.80	36.82	55.13
February	-	12.02	5.73	20.28	2.50	9.57
March	-	47.57	18.93	90.60	31.67	37.37
April	4.50	4.68	4.62	21.88	156.63	24.05
May	3.62	-	-	5.87	61.58	48.73
June	-	8.45	48.62	8.52	30.48	19.27
Total	8.12	152.26	266.27	510.04	700.60	455.55

Table 4: Summary of incoming feeder basic reliability indices

Month	Frequency of outage	Outage duration (hrs)	Total operating hours	Failure rate (f/hr)	MTBF (hrs)	MTTR (hrs)	Availability
July	-	-	744	-	-	-	-
August	-	-	744	-	-	-	-
September	-	-	720	-	-	-	-
October	-	-	744	-	-	-	-
November	-	-	720	-	-	-	-
December	-	-	744	-	-	-	-
January	-	-	744	-	-	-	-
February	-	-	672	-	-	-	-
March	-	-	744	-	-	-	-
April	1	4.5	720	0.001389	720	4.5	0.99379
May	1	3.62	744	0.001344	744	3.62	0.99516
June	-	-	720	-	-	-	-
Total	2	8.12	8760	0.000228	4380	4.06	0.99907

In the Table 5, there are 24 outages occurrence with 152.26 hrs outage duration on steel plant feeder for the period under review. The failure rate, MTBF, MTTR and availability of the steel plant feeder were calculated to be 0.00274 f/y, 365 hrs, 6.34 hrs and 98.292% respectively. There is no record of outages on this feeder in August 2022 and May 2023. October 2022 and January 2023 have the highest outage frequencies of 5. March 2023 has the highest outage duration of 47.57 hrs on this feeder. The availability of steel plant feeder is 98.292%.

Table 5: Summary outgoing steel plant feeder basic reliability indices

Month	Frequency of outage	Outage duration (hrs)	Total operating hours	Failure rate (f/hr)	MTBF (hrs)	MTTR (hrs)	Availability
July	1	8.03	744	0.00134	744	8.03	0.98932
August	-	-	744	-	-	-	-
September	4	38.83	720	0.00556	180	9.71	0.94883
October	5	3.5	744	0.00672	148.8	0.7	0.99532
November	1	3.50	720	0.00139	720	3.5	0.99516
December	1	15.95	744	0.00134	744	15.95	0.97901
January	5	9.73	744	0.00672	148.8	1.95	0.98709
February	2	12.02	672	0.00298	336	6.01	0.98243
March	3	47.57	744	0.00403	248	15.86	0.93990
April	1	4.68	720	0.00139	720	4.68	0.99354
May	-	-	744	-	-	-	-
June	1	8.45	720	0.00139	720	8.45	0.98840
Total	24	152.26	8760	0.00274	365	6.34	0.98292

Table 6 shows the basic reliability indices of ceramics feeder. There were 35 outage occurrences with 266.27 hours outage durations. Failure rate, MTBF, MTTR and availability were calculated to be 0.004 f/hr, 250.29 hrs, 7.61 hrs and 97.05% respectively. There were no outages in July 2022 and May 2023 on this feeder. September 2022 has the highest outage frequency of 10 with outage duration of 93.77 hrs. Availability of ceramic feeder is 97.05%.

Table 6: Summary of outgoing ceramics feeder basic reliability indices

Month	Frequency of outage	Outage duration (hrs)	Total operating hours	Failure rate (f/hr)	MTBF (hrs)	MTTR (hrs)	Availability
July	-	-	744	-	-	-	-
August	1	1.83	744	0.00134	744	1.83	0.99755
September	10	93.77	720	0.01389	72	9.38	0.88477
October	6	23.5	744	0.00806	124	3.92	0.96938
November	1	3.5	720	0.00139	720	3.50	0.99516
December	1	15.95	744	0.00134	744	15.95	0.97901
January	8	49.82	744	0.01075	93	6.23	0.93724
February	1	5.73	672	0.00149	672	5.73	0.99155
March	3	18.93	744	0.00403	248	6.31	0.97519
April	1	4.62	720	0.00139	720	4.62	0.99362
May	-	-	744	-	-	-	-
June	3	48.62	720	0.00417	240	16.21	0.93674
Total	35	266.27	8760	0.00400	250.29	7.61	0.97050

Table 7 shows the basic reliability indices of outgoing Anyigba feeder. There were 80 outages with 510.04 hrs outage duration. Failure rate, MTBF, MTTR and availability of the feeder were calculated to be 0.00913 f/y, 109.50 hrs, 6.38 hrs and 94.498%. September has the highest outage frequency and outage duration of

30 with 94.65 hrs respectively while July has the least outage frequency and duration of 1 and 5.57 hrs respectively. Availability of outgoing Anyigba feeder is 94.498%.

Table 7: Summary of outgoing Anyigba feeder basic reliability indices

Month	Frequency of outage	Outage duration (hrs)	Total operating hours	Failure rate (f/hr)	MTBF (hrs)	MTTR (hrs)	Availability
July	1	5.57	744	0.00134	744	5.57	0.99257
August	4	58.55	744	0.00538	186	14.64	0.92705
September	30	94.65	720	0.04167	24	3.16	0.88382
October	13	65.87	744	0.01747	57.2308	5.07	0.91867
November	6	64.70	720	0.00833	120	10.78	0.91755
December	2	18.75	744	0.00269	372	9.38	0.97542
January	7	54.80	744	0.00941	106.286	7.83	0.93140
February	1	20.28	672	0.00149	672	20.28	0.97071
March	7	90.60	744	0.00941	106.286	12.94	0.89145
April	4	21.88	720	0.00556	180	5.47	0.97051
May	4	5.87	744	0.00538	186	1.47	0.99217
June	1	8.52	720	0.00139	720	8.52	0.98831
Total	80	510.04	8760	0.00913	109.5	6.38	0.94498

Table 8 shows the basic reliability indices of outgoing confluence feeder. There were 117 cases of power outages with total outage duration of 700.60 hrs. September and October 2022 have the highest outage frequencies of 21 each while July 2023 has the least outage of 2. April 2023 has the highest outage durations of 156.63 hrs with 9 outages. February 2023 has the least outage duration s of 2.5 hrs. The feeder failure rate, MTBF, MTTR and availability were calculated to be 0.01336 f/hr, 74.87 hrs, 5.99 hrs and 92.595% respectively.

Table 8: Summary of outgoing confluence feeder basic reliability indices

Month	Frequency of outage	Outage duration (hrs)	Total operating hours	Failure rate (f/hr)	MTBF (hrs)	MTTR (hrs)	Availability
July	2	24.52	744	0.00269	372.00	12.26	0.96809
August	8	39.52	744	0.01075	93.00	4.94	0.94956
September	21	88.07	720	0.02917	34.29	4.19	0.89101
October	21	48.73	744	0.02823	35.43	2.32	0.93853
November	16	84.60	720	0.02222	45.00	5.29	0.89485
December	8	95.48	744	0.01075	93.00	11.94	0.88626
January	10	36.82	744	0.01344	74.40	3.68	0.95284
February	2	2.50	672	0.00298	336.00	1.25	0.99629
March	8	31.67	744	0.01075	93.00	3.96	0.95917
April	9	156.63	720	0.01250	80.00	17.40	0.82133
May	9	61.58	744	0.01210	82.67	6.84	0.92356
June	3	30.48	720	0.00417	240.00	10.16	0.95939
Total	117	700.60	8760	0.01336	74.87	5.99	0.92595

Table 9 shows the basic reliability indices of outgoing 33 kV Adogo feeder. There were 60 cases of power outages with 455.55 hours outage duration on the feeder. The failure rate, MTBF, MTTR and availability of Adogo feeder were calculated to be 0.00685 f/hr, 146 hrs, 7.59 hrs and 95.057% respectively. In Table 10, fault on confluence feeder contributed most to the substation failure with total outage frequency and outage duration of 117 and 700.60 hours respectively. Another component of the substation that contributed to the interruption of electricity at the load points is earth fault relay with outage frequency of 173, outage duration of 1057.56 hr and failure rate of 0.01975 f/hr. The least component that contributed to power interruption in the substation is earthing transformer with outage frequency of 1, outage duration of 2 and failure rate of

0.00011 f/hr for the period under review. The failure rate, MTBF, MTTR and availability of the substation are 0.06278 f/hr, 49672 hrs, 83.70 hrs and 0.9983% respectively.

Table 9: Summary of outgoing Adogo feeder basic reliability indices

Month	Frequency of outage	Outage duration (hrs)	Total operating hours	Failure rate (f/hr)	MTBF (hrs)	MTTR (hrs)	Availability
July	4	42.18	744	0.00538	186.00	10.55	0.94635
August	6	41.63	744	0.00806	124.00	6.94	0.94701
September	12	70.02	720	0.01667	60.00	5.84	0.91137
October	7	35.52	744	0.00941	106.29	5.07	0.95443
November	4	56.15	720	0.00556	180.00	14.04	0.92766
December	1	15.93	744	0.00134	744.00	15.93	0.97904
January	5	55.13	744	0.00672	148.80	11.03	0.93101
February	3	9.57	672	0.00446	224.00	3.19	0.98596
March	6	37.37	744	0.00806	124.00	6.23	0.95217
April	3	24.05	720	0.00417	240.00	8.02	0.96768
May	7	48.73	744	0.00941	106.29	6.96	0.93853
June	2	19.27	720	0.00278	360.00	9.64	0.97393
Total	60	455.55	8760	0.00685	146.00	7.59	0.95057

Table 10: Summary of substation components basic reliability

Descriptions	Outage Frequency	Outage Duration (hrs)	Failure Rate (f/hr)	MTBF (hrs)	MTTR (hrs)	Availability
Incoming Feeder	2	8.12	0.000228	4380	4.06	0.9991
Steel Plant Feeder	24	152.26	0.00274	365	6.34	0.9829
Ceramics Feeder	35	266.27	0.004	250.29	7.61	0.9705
Anyigba Feeder	80	510.04	0.00913	109.5	6.38	0.9450
Confluence Feeder	117	700.60	0.01336	74.87	5.99	0.9260
Adogo Feeder	60	455.55	0.00685	146	7.59	0.9506
Power TransformerT_1	1	5.0	0.00011	8760	5.0	0.9994
Power TransformerT_2	3	10.5	0.00034	2920	3.5	0.9988
Earthing Transformers	1	2	0.00011	8760	2.0	0.9998
Circuit Breakers	5	49	0.00057	1752	9.8	0.9944
Isolators	2	9.5	0.00023	4380	4.75	0.9989
Batteries and Rectifier	1	3	0.00011	8760	3.0	0.9997
Earth Fault Relay	173	1057.56	0.01975	50.64	6.11	0.8923
Overcurrent Relay	43	336.28	0.00491	203.72	7.82	0.9630
Instrument Transformers	2	4.5	0.00011	4380	2.25	0.9995
Bus bars	2	3.0	0.00023	4380	1.5	0.9997
Total	551	3573.18	0.06278	49672	83.70	0.9983

The exponential distribution model presented in Equation (35) is used with the failure rate of each component to predict ten years reliability of the substation as presented in Figure 9. The reliability of the substation is estimated to be 0.939150 by using exponential distribution model. This shows that the reliability of the substation is 93.9150. The RBD model is also used to predict ten years reliability of the substation. Therefore, the system overall reliability as obtained from the reliability block diagram of Transmission Company of Nigeria Ajaokuta 132/33kV Substation is 0.974076 as shown in Figure 9. This means that the reliability of the substation for the period under review is 97.4076%. The proposed 132/33kV substation is partially stable with availability of 99.83% which is below the IEEE standard of 0.9999. The reliability of the substation for the year 2023 and the predicted reliability indices from 2024 to 2033 are presented in Figure 9. By comparing RBD and exponential distribution model, it can be seen that the two models have the same reliability trend. On the other hand, the predicted values of RBD model are slightly more than the exponential distribution model that depends on the failure rate of each component of the proposed substation. It can be concluded from the comparison that the substation has a poor reliability performance when the failure rate of each component that makes up the substation is considered as against the standard failure rate.

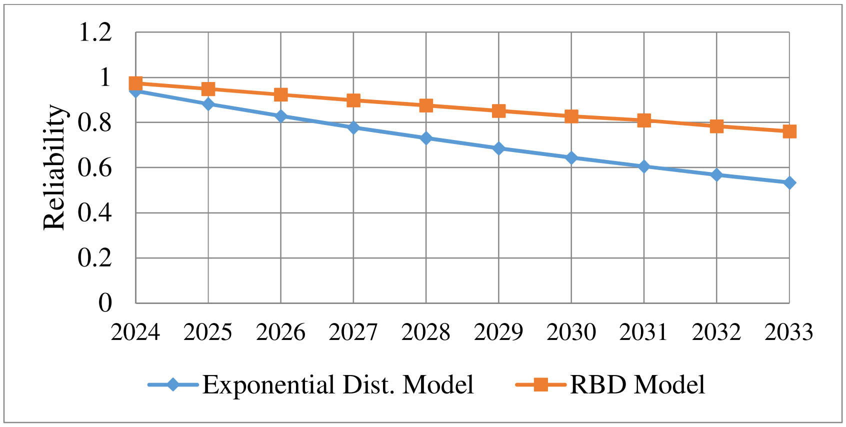

Figure 9: Predicted reliability indices utilizing RBD and exponential distribution model

The cost of outage on outgoing 33kV feeders is presented in Table 11. The table contains feeder name, feeder band, outage duration, maximum load demand, EENS, ECOST and IEAR. The ECOST of steel plant, ceramics, Anyigba, confluence and Adogo feeders are ₦12,759,616.92, ₦18,593,634.10, ₦443,848,507.20, ₦348,394,368 and ₦31,811,056.50 naira respectively. Steel plant feeder has the least ECOST of ₦12,759,616.92 while Anyigba feeder has the highest ECOST of outage of ₦443,848,507.20. The EENS, ECOST and IEAR of the substation are 13649764 kWhr/yr, ₦855,407,182.72/yr and ₦62.67/kwh respectively.

Table 11: Summary of load and energy oriented indices

Feeder Name	Feeder Band	Outage Durations (hrs)	Maximum load demand P (kW)	Unit Price (₦/kWh)	EENS (kWhr/yr)	ECOST(₦/yr)	IEAR (₦/kWh)
Steel Plant	A	152.27	1200	69.83	182724		
Ceramic	A	266.27	1000	69.83	266270		
Anyigba	D	510.03	14000	62.16	7140420		
Confluence	D	700.60	8000	62.16	5604800		
Adogo	A	455.55	1000	69.83	455550		
Total		2084.72	25200		13649764		

From Table 12, industrial ceramics feeder has the highest values of SAIDI, SAIFI and CAIDI of 266.27 hrs/customer, 35 interruption/customer and 7.6077 hrs/interruption while Anyigba feeder has the lowest values of SAIDI, SAIFI and CAIDI of 5.667 hrs/customer, 0.889 interruption/customer and 6.375 hrs/interruption. The values of SAIDI, SAIFI, CADI, ASAI and ASUI of Transmission Company of Nigeria Ajaokuta 132/33kV are 14.739 hrs/customer, 2.239 interruption/customer, 6.582 hrs/interruption, 0.7611 and 0.2389. From the Table 12, SAIDI for each customer which was served is 14.739 hrs/customer for a period of one year. This is slightly above the IEEE standard 1366-2003 which gives a value for North American utility to be 1.5 hrs. This is a region in which the power system generation is not only sufficient but also robust and secured. With reference to the standard, performance of this substation is poor, but there is room for improvement. The month of September 2022 has the highest value of SAIDI followed by March 2023 with each having SAIDI value of 2.71 hrs/customer and 1.59 hrs/customer. The least value of SAIDI was in February 2023 followed by July 2022 with the value of 0.35 hrs/customer and 0.57 hrs/customer. Customers on this feeder experience the least duration of outage in February 2023 followed by July 2023 and highest duration of outage in September 2022. The SAIDI value for steel plant, ceramic, Anyigba, confluence and Adogo feeders are 152.27, 266.27, 5.667, 28.024 and 22.778 hrs/customer. The substation overall SAIDI is 14.738 hrs/customers. In Tables 12 and 13, the SAIFI of the substation explain the occurrence of sustained interruption. The month of July 2022 has the least value of SAIFI of 0.006 interruptions/customer followed by February 2023 with SAIFI of 0.006 interruptions/customer. Customers experience the least interruption in the month of July 2022 and experience the highest interruption in the month of September 2022 with SAIFI of 0.54 interruption/customer. Ceramic feeder has the highest occurrence of sustained interruption with SAIFI of 35 interruptions per customer while Adogo feeder has the least value of sustained interruption with SAIFI of 3 interruption/customer. On the other hand, the SAIFI values for steel plant, ceramic, Anyigba, confluence and Adogo Feeders are 24, 35, 0.889, 4.68 and 3 interruption/customer. The overall SAIFI of the substation is 2.239 interruption/customer. The CAIDI values for steel plant, ceramic, Anyigba, confluence and Adogo feeders are 6.3446, 7.6077, 6.3754, 5.988 and 7.5925 hr/customer interruption. Ceramic feeder has the highest value of CAIDI while confluence feeder has the least value of CAIDI, this means that ceramic feeder experience the highest number of continuous interruption while confluence feeder experience the least continuous interruption. The substation CAIDI value is 6.582 hr/customer interruption. In Table 13, December 2022 has the highest value of CAIDI of 12.67 while October 2022 has the least value of CAIDI of 5.02 hr/customer interruption. This means that customer experience the highest continuous interruption in December 2022 and least continuous interruption in October 2022. The ASAI values for steel plant, ceramic, Anyigba, confluence and Adogo feeders are 98.26%, 96.96%, 94.18%, 92% and 94.8% as shown in Table 12. The overall ASAI of the substation is 76.2 percent. The entire feeders are relatively stable. Steel plant feeder is the most stable with highest value of ASAI of 98.26% while confluence feeder is the least stable with ASAI value of 92%. The ASUI values for steel plant, ceramic, Anyigba, confluence and Adogo feeders are 0.0174, 0.0304, 0.0582, 0.0800 and 0.0520 respectively. Among the five outgoing feeders, steel plant feeder has the highest availability follow by ceramic feeder while confluence feeder has the least availability. ASUI has the least value of 0.0746 in February 2023 and highest value of 0.5352 in September 2022 as shown in 13.

Reliability benchmarking is the standard in which the reliability of a power system transmission or distribution is measured against. It allows for easy comparison between multiple metrics. The reliability benchmark of some countries as compared to Nigeria TCN Ajaokuta 132/33kV substation. It can be seen in Table 14 that SAIDI and SAIFI of the substation are poor when compared to developed countries and there is a need for improvement. The substation ASAI value of 76.11% is too low as compared to developed countries ASAI values.

Table 12: Summary of customer oriented indices

Feeder Name	No of customers	Outage duration (hrs)	Outage frequency	SAIDI (hrs/Cus.)	SAIFI (Int/Cus.)	CAIDI (hr/int.)	ASAI	ASUI
Incoming feeder	5	8.12	2	1.62	0.400	4.050	0.9991	0.0009
Steel plant	1	152.27	24	152.27	24.000	6.3446	0.9826	0.0174
Ceramics	1	266.27	35	266.27	35.000	7.6077	0.9696	0.0304
Anyigba	90	510.03	80	5.667	0.889	6.375	0.9418	0.0582
Confluence	25	700.60	117	28.024	4.680	5.988	0.9200	0.0800
Adogo	20	455.55	60	22.778	3.000	7.592	0.9480	0.0520
Total	142	2092.84	318	14.738	2.239	6.582	0.7611	0.2389

Table 13: Customer oriented reliability indices on monthly basis

Month	Outage frequency	Outage durations (hrs)	No of Customers	SAIDI (hrs/Cus.)	SAIFI (Int/Cus.)	CAIDI (hr/int.)	ASAI (%)	ASUI (%)
July	8	80.30	142	0.57	0.06	9.50	0.8921	0.1079
August	19	141.53	142	1.00	0.13	7.69	0.8098	0.1902
September	77	385.33	142	2.71	0.54	5.02	0.4648	0.5352
October	52	177.12	142	1.25	0.37	3.38	0.7619	0.2381
November	28	212.45	142	1.50	0.20	7.50	0.7049	0.2951
December	13	162.07	142	1.14	0.09	12.67	0.7822	0.2178
January	35	206.30	142	1.45	0.25	5.80	0.7227	0.2773
February	9	50.10	142	0.35	0.06	5.83	0.9254	0.0746
March	27	226.13	142	1.59	0.19	8.37	0.6961	0.3039
April	19	216.37	142	1.52	0.13	11.69	0.6995	0.3005
May	21	119.80	142	0.84	0.15	5.60	0.8390	0.1610
June	10	115.33	142	0.81	0.07	11.57	0.8399	0.1601
Total	318	2092.83	142	14.74	2.24	6.58	0.7611	0.2389

Table 14: Comparison of reliability indices with international benchmark

Countries	SAIDI (hrs/Cus.)	SAIFI (Int/Cus.)	ASAI (%)
Austria	0.59	0.59	99.9
Belgium	0.7	0.9	99.99
France	0.89	1.21	99.99
Germany	0.62	0.27	99.99
Britain	1.17	0.77	99.99
Netherland	0.46	0.38	99.99
Barcelona city	1.79	2.28	99.99
Sweden	1.65	2.07	99.98
USA	1.36	0.97	99.98
Finland	3.04	4.06	99.97
Ireland	3.93	1.34	99.97
Spain	2.55	2.98	99.97
Italy	3.38	3.83	99.96
Norway	3.63	2.73	99.96
Nigeria IBDC, Osun	2470.16	695.16	71.88
TCN Ajaokuta 132/33 kV substation	14.74	2.24	76.11

4. CONCLUSION

The reliability assessment of 132/33 kV transmission power system has been carried out in this paper to identify the major components that are responsible for power outages at each feeder. It can be deduced from the results obtained from the study that conference outgoing feeder has the highness number of power outages, this shows that the feeder contributed outage frequency of 700.60, outage duration of 117 and failure rate of 0.01336 to the entire substation. Conversely, steel plant outgoing feeder has the least values of outage frequency of 24, outage duration of 152.26 and failure rate of 0.09274 f/hr when compared with other five outgoing feeders. There were 318 cases of outage with total outage duration of 2092.84 hours. The failure rate, MTBF, MTTR and availability of the substation are 0.0363014 f/hr, 27.5421 hrs, 6.58126 hrs and 0.80713. Overall reliability of the substation was calculated to be 0.939150 and 0.974076 using both exponential distribution model and reliability block diagram. The result showed that reliability block diagram model of calculating reliability has better result as compared to exponential distribution model. Overall SAIDI, SAIFI, CAIDI, ASAI and ASUI of the substation are 14.74 hr/customer, 2.24 interruption/customer, 6.5812 hr/customer interruption, 0.7611 and 0.2380. The EENS, ECOST and IEAR of the substation are 136,49764 kWhr, ₦855,407182.72/yr and ₦62.67/kWhr. The results shows that the substation is not reliable when compared to the standard reliability indices obtained from several countries.

The major causes of outage were earth fault, open circuit fault, generation capacity shortage due to gas constraint and grid constraints. The substation is underutilized; therefore there is need for the expansion of distribution networks by Abuja Electricity Distribution Company to make power accessible to numerous consumers. With reference to the work done in this research work, it is recommended that appropriate and routine inspection of utility facilities like transformers, poles and circuit breakers must be carried out periodically to increase the reliability of the substation. The channel used for reporting outages should be enhanced to ensure prompt reports and prompt action.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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