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Modeling and Evaluation of System Reliability for Auchi Distribution Network

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ABSTRACT: The Auchi distribution network is an important component of the Nigerian power sector and its reliability is critical in ensuring uninterrupted power supply to consumers. This paper presents the modeling and assessment of the reliability of the Auchi distribution network using reliability indices such as the system average interruption duration index (SAIDI), the system average interruption frequency index (SAIFI) and the customer average interruption duration index (CAIDI). These indices use the interruption duration in time, the interruption frequency and the total number of feeders based on the data obtained from the grid. The analysis results show that in 2016 and 2018, based on SAIFI and SAIDI, the AUCHI feeder was more reliable than the GRA feeder. However, in 2017, the two feeders had the same index. In 2019, 2020, and 2021, the Auchi feeder tends to be more reliable than the GRA feeder based on SAIDI and SAIFI. Likewise, using the customer average interruption duration Index (CAIDI) in 2016, 2018 Auchi feeder is more reliable than the GRA feeder. In 2017, the CAIDI was the same for the two feeders. Furthermore, in 2019, 2020, and 2021, the CAIDI in Auchi Feeder was higher than in GRA Feeder. This means that more consumers are disrupted in Auchi Feeder than in GRA during this time period. Initial reliability data extraction and analysis revealed the reasons of interruptions and their contributions to the Auchi and GRA feeder and system reliability indices. From 2016 to 2021, the most common causes of disruption on the Auchi and GRA feeders were vegetation and J&P rupture, while conductor breakdown was the least common. The network was simulated using the highest transformer loading, which was around 80% of the rated amount. The study's findings give vital information for power sector decision-makers looking to increase system dependability and reduce downtime, ultimately improving the overall performance of the Auchi Distribution system.

Keywords: Reliability, interruption, distribution, faults, feeders
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INTRODUCTION

An electric power system can be described as a network of electrical components that generate, transmit, distribute and use electricity. Traditional power systems are constructed in such a way that electricity generation sources, such as hydro-electric power dams, coal fired power plants etc. produce electricity and are normally located in distant areas from consumer areas. The electricity produced is supplied to the consumers by a large transmission and passive distribution network system, comprising high voltage (HV), medium voltage (MV) and Low Voltage (LV) networks. Power passes through all the above three network stages (generation, transmission and distribution) before it gets to the final consumer (Ayodele et al., 2016). The consumer utilizes the power as required with the level of consumer demand varying among different consumers. The conventional concept of power systems as shown in (Figure 1), considers one direction of power flow i.e. from the sources of generation through the large and extensive transmission and distribution system, to consumers (load) in a radial distribution network (Kabir, 2015). The demand for electricity has increased with increase in world population and development in technology (Ayodele *et al.*, 2016), thereby reviving the interest in connecting more generation to the power system, and evaluating the reliability of existing power system equipment.

Power system is a system that delivers to its costumer's electric energy at an acceptable level of reliability. Facts have revealed that a country's power system is directly tied to its economic development because the majority of its economic agents depend on this kind of energy to increase their activity (Melodi *et al.,* 2017). Reliability and quality have been considered to be the two important aspects of any electrical power supply

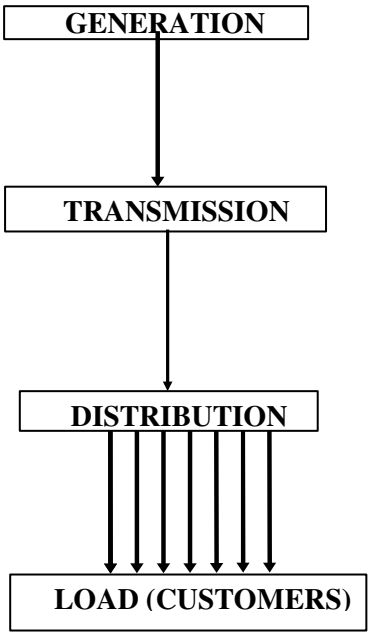

Figure 1: Conventional concept of power system (Kabir, 2015).

system. The distribution network system is operated in a manner such that the availability of power (reliability) is the important factor in supplying electricity to the consumers without consideration for the quality of the delivered power due to the linear nature of the electrical loads. With the increasing penetration of non-linear loads in the distribution system, the quality of the delivered power is degraded and has become important factor in power delivery due to the effects of the power quality problems introduced in the distribution system which affect both the utility and the consumers. The quality of the delivered power simply describes the quality of the voltage and the quality of the current that will ensure safe operation of all electrical equipment connected to the distribution network. Power quality is the combination of voltage quality and current quality. Therefore, power quality is concerned with deviations of voltage and/or current from the ideal. Power is said to be of good quality if the supply is stable, the voltage magnitude and the frequency are within the recommended statutory limits and waveform is a distortion-less sinusoidal signal (Adebisi *et al.,* 2017). Power quality problems exist if there is any voltage, current or frequency deviation from its sinusoidal waveform at nominal frequency. The widespread application of non-linear loads utilizing power electronic devices pollutes the quality of power in the distribution system due to injected harmonics and increased reactive power demand. Deficient quality of delivered power results in performance degradation, reduced life expectancy of an equipment, mal-operation or failure of consumer equipment, increased system losses and financial losses.

Power quality problem is not only a technical problem but also an economic problem therefore developing economies like Nigeria which continues to struggle with lack of robust utility infrastructure and stable power supply are lagging in terms of their preparedness for a good power quality environment and continue to absorb techno-economic losses caused by poor power quality. Poor investments have been reported to be one of the causes of poor power quality in the distribution network (Melodi *et al*, 2017).

Reliability assessment of real size electrical power systems is a complex problem. Therefore understanding how the electric power systems works is essential to assess its reliability (Idoniboyeobu, 2018). Taking into account this mentioned facts, it is usual to divide the electric power systems in their main functional zones. These are: Generation, Transmission and Distribution. This division was first proposed by (Billinton and Allan, 1982; Idoniboyeobu, 2018), introducing the concept of hierarchical levels.

The hierarchical level one, HLI, refers to generation facilities and their ability to supply the system demand; the hierarchical level two, HLII, refers to transmission systems and its capacity to deliver energy to the bulk supply points; the hierarchical level three, HLIII, refers to the complete system including distribution and its amplitude to assure the power and the energy demand of the individual consumers. This partition allows the development of specific techniques to quantify reliability according to their characteristics. In practice, the reliability assessment of a power system is carried out by separately investigating the reliabilities of its different

stages or sub systems i.e Generation, Transmission and Distribution (Billinton and Allan, 1982). This simplification allows assessment of the reliability of power system generation and helps draw conclusions on each hierarchy.

The necessity is clear for reliability studies whose main objective is to obtain performance indices for the behaviour of the power systems, which can be used in the decision making process. However one must distinguish between reliability adequacy and reliability security. Reliability adequacy is related to the existence of sufficient resources within the system to meet the customer demand and the system operational requirements. This includes resources for generation, transmission and distribution needed to “carry” the energy to the individual consumption points (Nweke, Gusau, & Isah, 2020).

Reliability indices can be placed in two categories, local indices or load point indices, and global or system indices. Load point indices measures the impact to the individual customer, while the system indices measures the overall reliability of the system (Balijepalli N, 2004). This paper focuses on the system indices mainly from the customer viewpoint. Despite many different reliability indices, it is fairly common to use the standard IEEE reliability indices like Customer average interruption duration index (CAIDI), System average interruption frequency indices (SAIFI), and System average interruption duration indices (SAIDI) to track and benchmark reliability performance. These reliability indices include measures of outage duration, frequency of outages, system availability and response time. The evaluation of reliability indices for a composite system is very much computational demanding given the overall behaviour of the system (Strongman, 2004).

This paper will focus on the model and evaluation of the system reliability of the Auchi township distribution network using SAIDI, SAIFI and CAIDI.

Power system distribution network reliability

Power distribution system is the largest part of the power system. It consists of substations, primary feeder, transformer, distributors and service mains and it is to distribute power to various electricity consumers at a safe voltage and quality as well as at minimal cost (Melodi and Ogunboyo, 2011). Power reliability and quality involve how sinusoidal is the voltage waveform and having a constant frequency supply. It is the responsibility of the utilities to provide a clean and reliable supply to the consumer.

Traditional loads such as lighting, heating and motors are less sensitive to variations in the supply voltage but modern electrical devices and equipment in industrial, commercial and domestic facilities equipment are more sensitive to variations in supply voltage due to the increased use of power electronics and microprocessor-based technologies in equipment and appliances. Power electronic devices that have rapid and frequent load variations have become abundant today due to their many process control related and energy saving benefits. However, they also bring a few major drawbacks to electrical distribution systems such as harmonics and rapid change of reactive power requirements. Power system reliability describes the overall ability of the power system to perform its function. Typically power system reliability assessments are divided into two separate aspects, adequacy and security (Aprajita and Slipi, 2014).

i. Adequacy is the ability of the power system to supply the aggregate electric power energy requirement of the customer at all times, taking into account scheduled and unscheduled outages.
ii. Security is the ability of the power system to withstand sudden disturbances such as electric short circuits or non-anticipated loss of system components (Kundur, 2004).

Reliability in electric power transmission system is generally defined as the ability of the system to adequately transport electric power from the points of generation to the points of load (Hayes, 1976) . For this research, "adequacy" implies that all network elements are within specified limits. In reliability analysis, power *quality is* usually disregarded. Power is seen to be either delivered (within acceptable quality limits), or not supplied (also including the case of the power quality being unacceptable low). Specifically, the conditions for adequate operation are: no lines are overloaded, all buses are within voltage limits, all generators are operating within real and reactive power limits, and all loads are satisfied (Ahmad & Hussein, 2014). Many techniques as been used by researcher’s to ensure that the power system network parameters operates within the acceptable limit, such as voltage, frequency in which failure out of acceptable limit can cause contingencies in the power system which invariably can reduce system reliability.

Power system reliability assessment

Reliability assessment techniques help to analyze the complex conditions in power systems and enhance the quality of service for the system's operations. The reliability calculation methods are classified into deterministic, probabilistic and intelligent methods, as shown in (Figure 2). Many researchers have adopted these methods, and the simulation tools supporting reliability studies have also been analyzed in many research works.

Reliability assessment of real size electrical power systems is a complex problem. The reason for this complexity is due to the number of components and functional zones it has. This simplification helps to assess

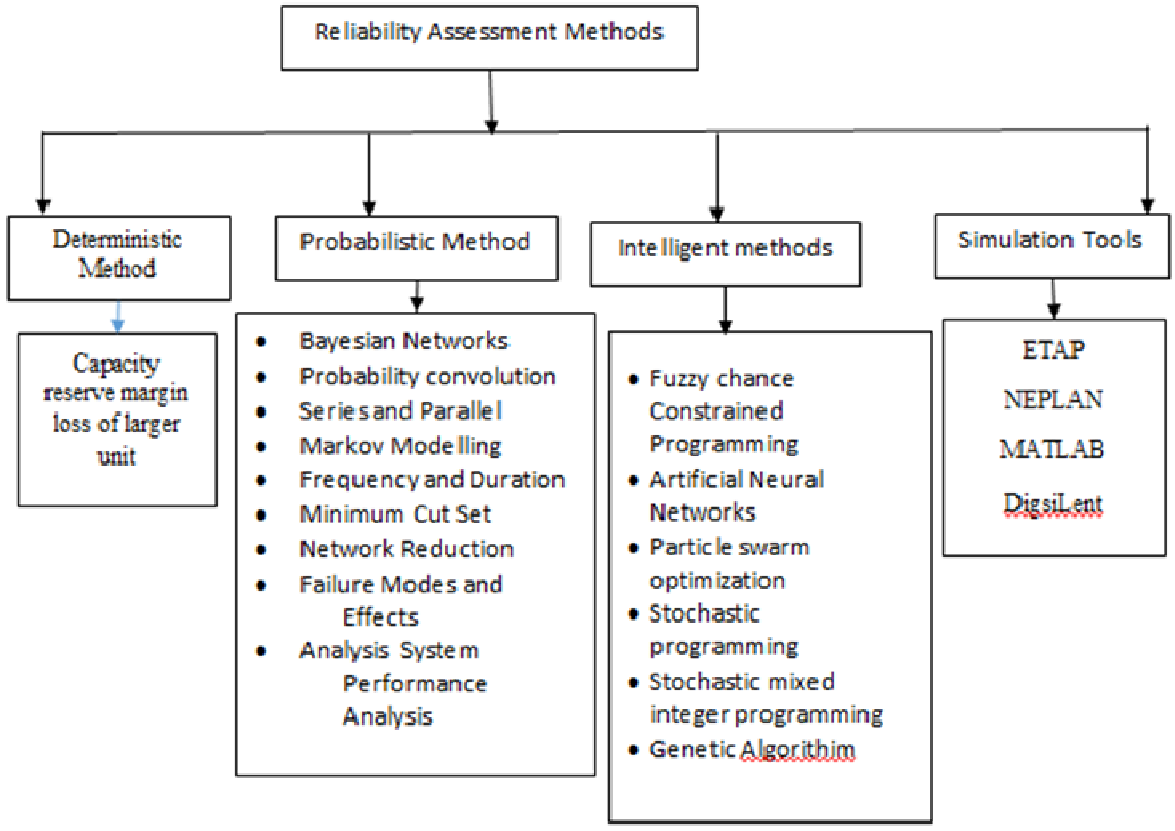

Figure 2: Reliability Assessment Methods.

the reliability of the transmission system. If the transmission system is not properly sized or reliable, a large amount of customers may not be supplied even though the generation is considered reliable. Therefore care must be taken in the application of a specific technique because the results provided are only valid in the scope of problem formation and its simplification. Several techniques have been developed in assessing the power system adequacy. Two approaches were identified by Carvalho (2008) but Okwe and Iyama (2013) however included a third approach. This third approach mentioned was the fuzzy set concept in modeling system uncertainties. Example given was the fuzzy numbers been used to model uncertainties in system component failure and repair rates, fuzzy load duration curves are developed using a fuzzy number in each time step , and fuzzy power flow models are developed to identify possible system behaviours given specified uncertainties. These fuzzy representations of system uncertainties are then integrated into the probabilistic evaluation procedure (Brown R. E., 1998; Melodi et al., 2017). It was however pointed out that by using this fuzzy probabilistic method, the computational burden increases significantly without a commensurate gain in the quality of results. The two other techniques mentioned by them all was the traditional deterministic to the more current probabilistic approach (Uhunmwangbo & Omorogiuwa, 2014).

Reliability adequacy indices

Reliability indices can be classified into two categories: indices used to measure the historical performance of the existing system or equipment and indices used to estimate the reliability level of a future system with various changes, including load growth, change in operation conditions, modification or enhancement in network configuration, and addition or retirement of facilities in the system.

Adequacy indices in HLIII

There are three basic load-point indices in distribution system adequacy assessment. They are load-point failure rate A, load-point outage duration r, and load-point annual unavailability U(IEEE, 2012). Overall distribution system performance indices can be calculated using the three basic load-point indices. The definitions and formulas for the system performance indices are as follows. These indices can be used to indicate the past or future performance of the system and are defined by (IEEE, 2012) as follows;

(i)SAIFI-System Average Interruption Frequency Index (interruptions/system customer/yr).

$$SAIFI = \frac{\sum \lambda_i N_i}{N_T} \quad (1)$$

where λ_i is the failure rate, N_i is the number of customers for location i and N_T is the total number of customers served.
In other words,

$$SAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customer served}} \quad (2)$$

SAIFI is measured in units of interruptions per customer. It is usually measured over the course of a year.

(ii)CAIFI-Customer Average Interruption Frequency Index (interruptions / customer affected/yr)

$$CAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customer affected}} \quad (3)$$

This index differs from SAIFI only in the value of the denominator. It is particularly useful when a given calendar year is compared with other calendar years since, in any given calendar year, not all customers will be affected and many will experience complete continuity of supply. The value of CAIFI therefore is very useful in recognizing chronological trends in the reliability of a particular distribution system. In the application of this index, the customers affected should be counted only once, regardless of the number of interruptions they may have been experienced in the year.
(iii) SAIDI-System Average Interruption Duration Index (hr/system customer/yr).

$$SAIDI = \frac{\sum U_i N_i}{N_T} \quad (4)$$

In other words,

$$SAIDI = \frac{\text{sum of all customer interruption durations}}{\text{total number of customer served}} \quad (5)$$

Where is the number of customers and U_i is the annual outage time for location , and N_T is the total number of customers served.
(iv) CAIDI-Customer Average Interruption Duration Index (hr/customer interruption)

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \quad (6)$$

CAIDI can also be viewed as the average restoration time. CAIDI is measured in units of time, often minutes or hours. It is usually measured over the course of a year. The values of SAIDI and SAIFI calculated in equation 1.2 and 1.4 was be used in evaluating the value for CAIDI.
In other words,

$$CAIDI = \frac{\text{sum of all customer interruption durations}}{\text{total number of customer interruptions}} = \frac{SAIDI}{SAIFI} \quad (7)$$

(v) Average service availability index, ASAI

$$ASAI = \frac{\text{customer hours of available service}}{\text{customer hours demanded}} \quad (8)$$

where 8760 hours(number of hours in a calendar year) is the customer hours demanded year.

(vi) Average service unavailability index, ASUI

$$ASUI = \frac{\text{customer hours of unavailable service}}{\text{customer hours demanded}} \quad (9)$$

where 8760 hours(number of hours in a calendar year) is the customer hours demanded year.

vii) Energy not supplied index, ENS

$$ENS = \sum_{i \in s} P_{ai} U_i \quad (10)$$

Where P_{ai} is the average load (in kW) connected to load point i and U_i is the annual outage time (in hr/yr) at the load point. ENS is the total energy not supplied by the system

(viii) AENS-Average Energy Not Supplied (kWh/customer/yr)

$$AENS = \frac{ENS}{\sum_{i \in s} N_i} \quad (11)$$

(ix) ACCI-Average Customer Curtailment Index (kWh/customer affected/yr)

$$ACCI = \frac{ENS}{\sum_{i \in s} M_i} \quad (12)$$

This index differs from AENS in the same way that CAIFI differs from SAIFI. It is therefore a useful index for monitoring the changes of average energy not supplied between one calendar year and another. Conclusively, it has been established that the power system reliability assessment includes two aspects: adequacy and security. Of the two, adequacy assessment has been the

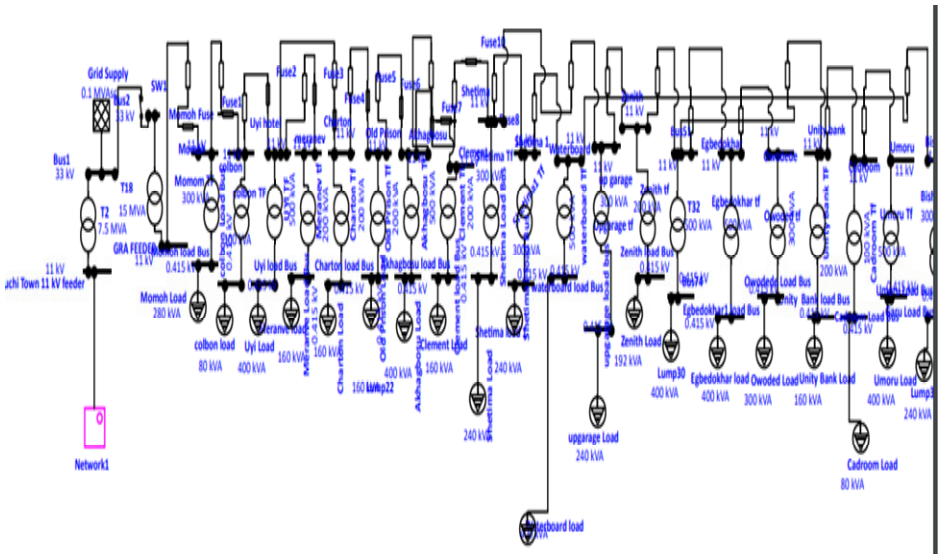

Figure 3a: Etap Model for Auchi Network (Auchi Town Feeder).

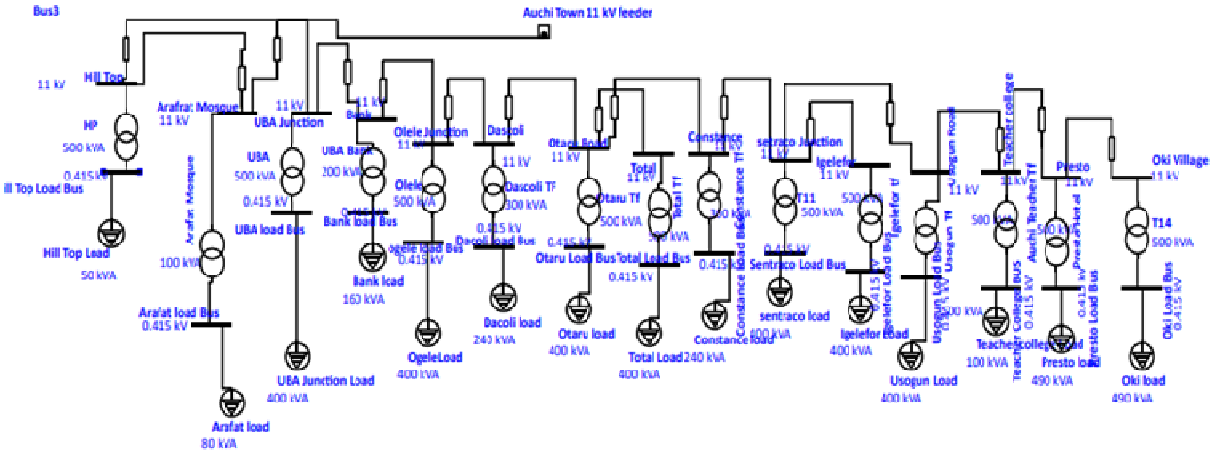

Figure 3b: Etap Model for Auchi Town Network (Auchi Town Feeder).

major concern. Research has focused on both analytical and simulation techniques and has found the former superior to the latter procedures. The current bulk power system reliability assessment techniques reveals following facts:

(1) The probabilistic modeling method has become the most promising means to represent practical system behaviour,
(2) The analytical technique is superior to the Monte Carlo simulation technique in performing reliability.

Therefore this paper will be centred on adequacy analysis of bulk power system using the analytical technique. A comprehensive approach for bulk power system reliability assessment of the Auchi Distribution Network using the customer oriented reliability indices will be evaluated.

METHODOLOGY

The Auchi network is supplied by two 11kv feeders to various 11/.415 kV substation as shown in Figure 3(a) and (b) while (Figure 3) shows the flow chart for the comparison of tests. In order to perform the reliability simulation on ETAP the single line diagram of Auchi network will be obtained and load data, fault frequency, Uptime and downtime data will also be obtained for all the feeders and load point in Auchi network. The ETAP will be used to obtain the average failure rate, Annual outage duration and average outage duration of the feeders and the load points of Auchi Network.

Reliability evaluation processes

The reliability evolution of a power system can be

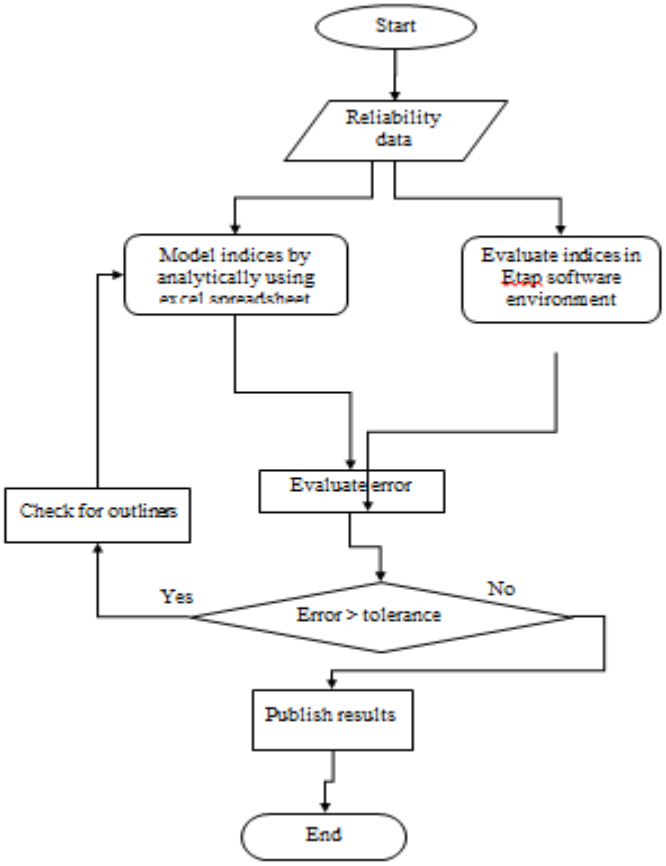

Figure 4: Flow chart of comparison testing.

Figure 5: Reliability Processing.

described by a six-step procedure as shown in Figure 5. Step I represents the component constants and capabilities. Steps II and III represent the possible component outages and the definition of possible system failure modes resulting from single or multiple component outages. Step IV represents the possible realizations of the component performance which may be actual or simulated. Step V describes the system model, where the system performance is obtained. The techniques used for such analysis are selected based on their accuracy and

speed to suit either planning or operation studies. At step VI the system model results are analyzed to evaluate the system reliability.

Evaluation of SAIDI, SAIFI and CAIDI of the Auchi distribution network

The evaluation of the SAIDI, SAIFI and CAIDI of the Auchi Distribution Network will be done for a time frame of 6 years (January 2016 to December 2022). This evaluation will be done analytically and the formulas to be used in evaluating the SAIDI, SAIFI and CAIDI for the feeders are as shown below.

$$\mathbf{SAIDI} = \frac{\sum \mathbf{U_i N_i}}{\mathbf{N_T}} \quad (13)$$

$$\mathbf{SAIFI} = \frac{\sum \lambda_i \mathbf{N_i}}{\mathbf{N_T}}$$

$$\mathbf{CAIDI} = \frac{\sum \mathbf{U_i N_i}}{\sum \lambda_i \mathbf{N_i}} \quad (14)$$

Where N_i is the number of customers, $\mathbf{U_i}$ is the annual outage time for location $\mathbf{i}$, λ_i is the failure rate, and $\mathbf{N_T}$ is the total number of customers served.

Calculation concepts and expression

Applying Equations 15 to 17 pose the following difficulties: outage durations and frequency for feeders are unavailable. Available data are respective times of occurrence and restoration of faults. To surmount this problem, the following approach and algorithm was proposed and applied:

1. The outage data includes time of occurrence of fault (t_s) and restoration (t_r) for each line connected to the feeder. Outage duration for (i-jth) link or line is obtained as shown in Equation 15.

$$Dij = (t_r - t_s)_{ij} \quad (15)$$

2. To obtain D_i of the feeder in the j^{th} year, which could not be extracted from outage data, the following approach was conceptualized and applied as in equation 16:

$$D_i = U_i T_a = (1 - R_i) \quad (16)$$

and is unavailability and availability (or reliability) of power respectively of the feeder in given year. is hours in a year (8760 hrs).

In order to obtain the unavailability (U) of power at i^{th} $feed$, the lines connected to the i^{th} $feed$ is considered as a parallel system i.e U of feeder will depend on U values of i -ith links in a parallel structure function. This is considered so since for power to be available at a DP, at least one of the i - links must be energised. The concept of success structure function is described in Cutello, Montero,andYanez (1996). Therefore in view of these considerations is defined as in Equation (17)

$$R_i = 1 - \prod_{j=1}(U_{ij}) ; \Rightarrow U_i = \prod_{j=1}(U \quad (17)$$

For kth year, the notations of Equations 3.5 and 3.6 are adjusted to become:

$$D_{ik} = U_{ik} T_a ; \; U_{ik} = U_i \; for \; U_{ij} \; \epsilon \; C \quad (18)$$

Where O is obtained outage data for year k

This model is applied to obtain outage duration and unavailability values for all DPs. The obtained and are applied in Equations (17) to (18)

3. Available outage data is a count of the entries of time of interruption occurrences or fault restorations on each transmission line, and consolidated for each month or year of the data period. No recorded interruption on delivery points. This leads to the following approach to determine the SAIFI: Let the outage or failure rate FR, λ) of i^{th} feeder of the grid be denoted as λ_i. The FR of the i^{th} feeder depends on the FRs of the connected lines in a parallel structure function. Also the value of each line is independent; FR of the feeder is obtained as follows. Firstly, the reliability () of DP for N number of parallel links is modelled as:

Table 1: Obtained SAIDI, SAIFI and CAIDI (2016-2021).

	AUCHI FEEDER			GRA FEEDER			AUCHI DISTRIBUTION NETWORK		
YEAR	SAIDI (hrs)	SAIFI	CAIDI	SAIDI (hrs)	SAIFI	CAIDI	SAIDI (hrs)	SAIFI	CAIDI
2016	7.27	33.95	0.21	7.75	33.95	0.22	15.02	67.90	0.22
2017	15.76	32.94	0.48	8.37	32.94	0.25	24.13	65.88	0.36
2018	7.25	48.88	0.15	5.03	28.96	0.17	12.29	77.84	0.15
2019	7.85	29.47	0.27	6.36	29.95	0.21	14.21	59.42	0.23
2020	9.39	45.90	0.20	9.74	67.76	0.14	19.13	113.66	0.16
2021	3.95	25.97	0.15	4.55	25.97	0.18	7.90	51.936	0.15
TOTAL	51.48	217.11	1.46	41.82	233.50	1.13	92.70	436.65	1.30
Average (2006-2021)	8.58	36.18	0.24	6.97	38.92	0.19	15.45	72.77	0.21
Averag (2006-2022)	zax						7.72	36.38	0.10

$$R_i = 1 - \prod_j^N (1 - R_{ij}) = 1 - \prod_j^N (1 - e^{-\lambda_{ij} r}) \quad (19)$$

Where R_{ij} and λ_{ij} are respective availability and failure rate for an in-parallel line connecting i to sending end bus j, N is the number of parallel lines being connected to i.

Secondly applying basic definition of mean time to failure (MTTF) (Dhillon, 2006),

$$MTTF_i = \int_0^\infty R_i dt = \int_0^\infty e^{-\lambda_{ij} r} dt = \frac{1}{\lambda_\perp}; \lambda_i = \frac{1}{MTTF_i} \quad (20)$$

Considering the adopted models of reliability for parallel systems, FR and MTTF relationships as defined in Equation
(19) and (20), the number of interruption for i[th] bus can be defined as:

$$M_i = \lambda_i \times T_a \quad (21)$$

For k^{th} year

$$M_{ik} = M_i \; for \; \lambda_{ij} \epsilon \; OD_k \quad (22)$$

4. Customer Average Interruption duration Index also known as system average restoration index can also be evaluated using Equation (23)
5.

$$CAIDI = \frac{\sum_{k=1}^{N_y} \Omega_{ik}}{\sum_{k=1}^{N_y} M_{ik}} = \frac{SAIDI}{SAIFI} \quad (23)$$

Evaluation of analytical SAIDI, SAIFI and CAIDI of the Auchi distribution network

The applied analytical algorithm yields the following results, which are presented in (Table 1):
i) For Auchi Feeder, SAIDI i_is (3.95-15.76) hr(s)/yr with an average of 8.58 hrs/yr with 2021 as the lowest and 2017 as the highest, SAIFI_i is (25.97- 48.88) int (s)/yr with an average of 36.18 ints/yr with 2021 as the lowest and 2018 as the highest, and CAIDI_i is (0.15-0.48) hrq(s)/int. with 2021 as the lowest and 2017 as the highest.

ii For GRA Feeder, SAIDI_iis (4.55-9.74) hr(s)/yr with an average of 6.87 hrs/yr with 2021 as the lowest and 2020 as the highest, SAIFI_i is (28.96- 67.76) int (s)/yr with an average of 38.92 ints/yr with 2018 as the lowest and 2020 as the highest, and CAIDI_i is (0.11-0.25) hrq(s)/int. with2021 as the lowest and 2017 as the highest.

iii For the Auchi Township Distribution Network, SAIDI is (7.90-24.13) hr(s)/yr with 2021 as the lowest and 2017 as the highest, SAIFI is (51.94- 113.66) int (s)/yr with 2021 as the lowest and 2020 as the highest, and CAIDI is (0.15-0.36) hrq (s)/int. with2021 as the lowest and 2017 as the highest.

Figures 6 to 10 present graphs of SAIDI, SAIFI and CAIDI for the years and the averages for the entire period. In 2013, a spike in TSAIDI of 3.84 hrs./DP was observed, which was above the system's decade average of 2.03 hrs./DP/yr. The year 2004 experienced a high TCAIDI of 3.84 hrs./int., indicating a possible instance of aggravated inadequacy in post fault repair and power supply restoration apparatus or mechanism in the transmission grid.

In the year 2016, SAIDI for Auchi and GRA had 48% and 52% contribution to Auchi Distribution Network. In 2017, Auchi and GRA had 65% and 35% contribution. In 2018, 2019, 2020, and 2021, Auchi feeder had 59%, 55%, 49% and 50% contributions to Auchi Distribution Network. However, for SAIFI, Auchi feeder had 50%,50%, 63%, 50%, 40%, and 50% contribution for 2016, 2017, 2018, 2019, 2020, and 2021 respectively while GRA had 50%, 50%, 37%,50%,60%and 50% contribution for 2016,2017,2018,2019,2020, and 2021. Table 2 shows the Percentage Contribution of Saidi and Saifi for Auchi and GRA Feeder on Auchi Distribution Network.

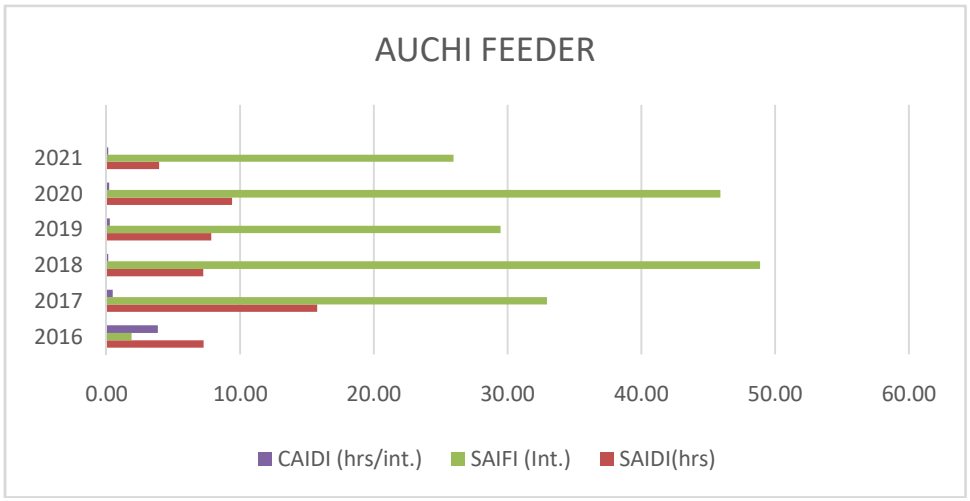

Figure 6: Evaluated SAIDI, SAIFI, AND CAIDI for Auchi Feeder from 2016-2021.

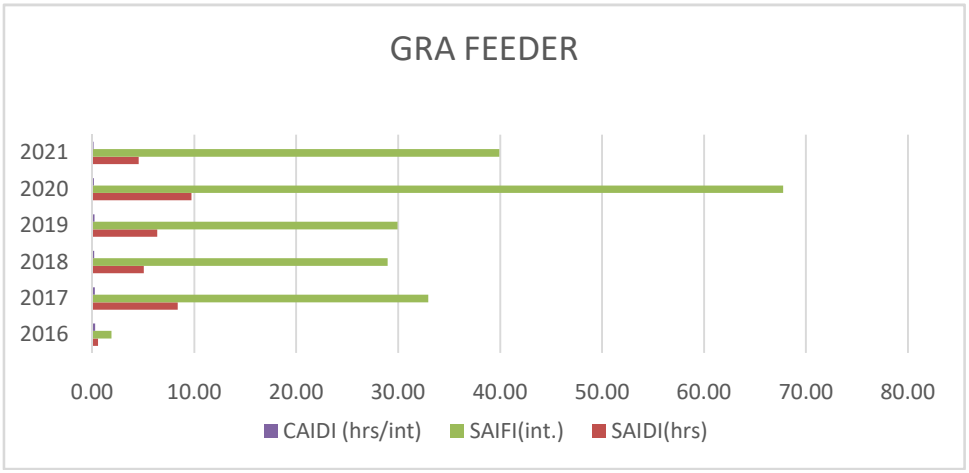

Figure 7: Evaluated SAIDI, SAIFI, AND CAIDI of GRA Feeder from 2016-2021.

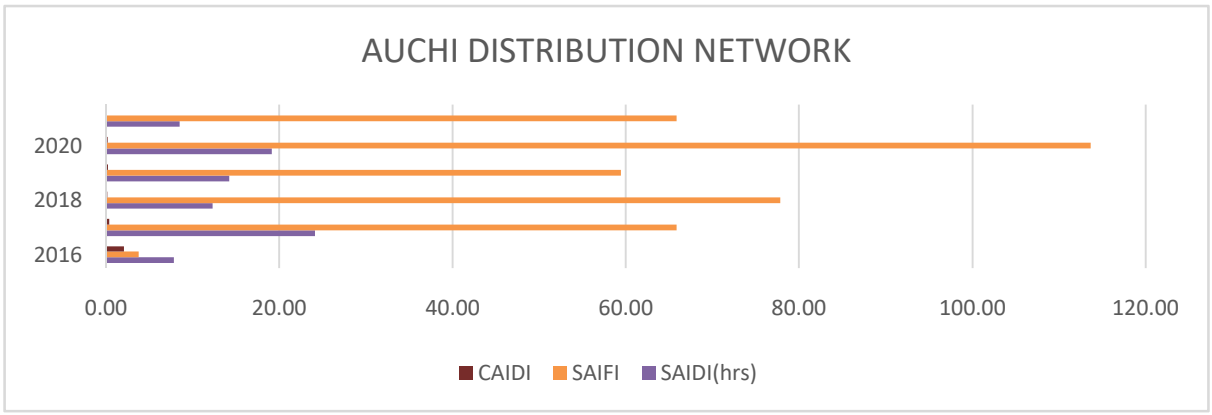

Figure 8: Evaluated SAIDI, SAIFI, AND CAIDI of Auchi Distribution Network

Table 2: Percentage contribution of Saidi and Saifi for Auchi and GRA Feeder on Auchi distribution Network.

YEAR	AUCHI- SAIDI(hrs)	GRA SAIDI(hrs)	AUCHI-SAIFI	GRA-SAIFI
2016	0.48	0.52	0.50	0.50
2017	0.65	0.35	0.50	0.50
2018	0.59	0.41	0.63	0.37
2019	0.55	0.45	0.50	0.50
2020	0.49	0.51	0.40	0.60
2021	0.50	0.50	0.50	0.50

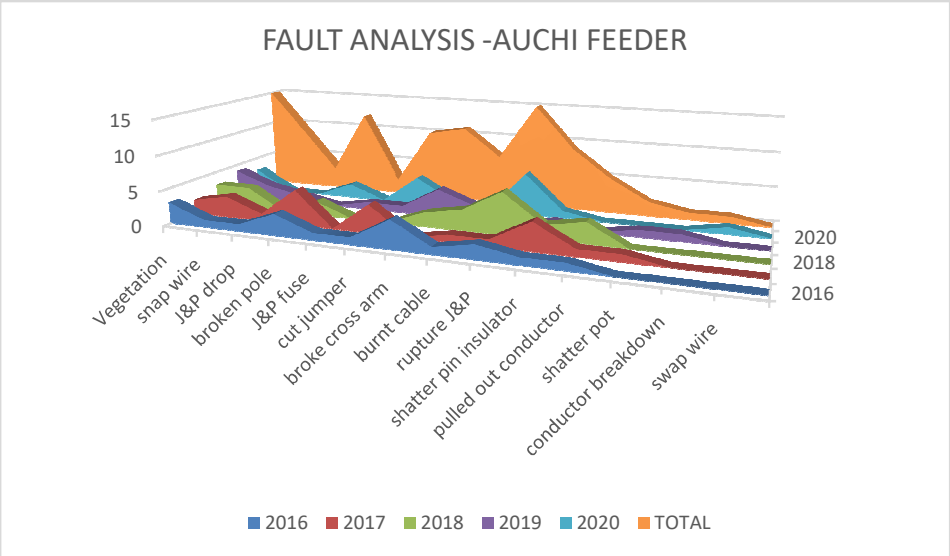

Figure 9: Fault Analysis - Auchi Feeder.

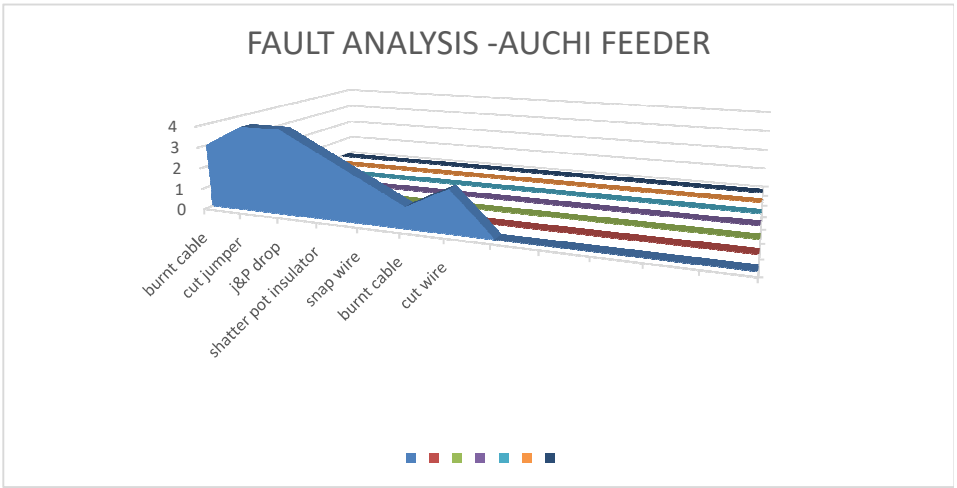

Figure 10: Fault Analysis - GRA Feeder

Interruption causes and contributions

Interruption causes and their contributions to Auchi and GRA feeder and system reliability indices, obtained from initial reliability data extraction and analysis, are presented in (Figures 9 and 10) .Figure 10 show that vegetation and ruptured J&P were the highest cause of interruption while conductor breakdown was the lowest cause of interruption on Auchi feeder from 2016 to 2021.

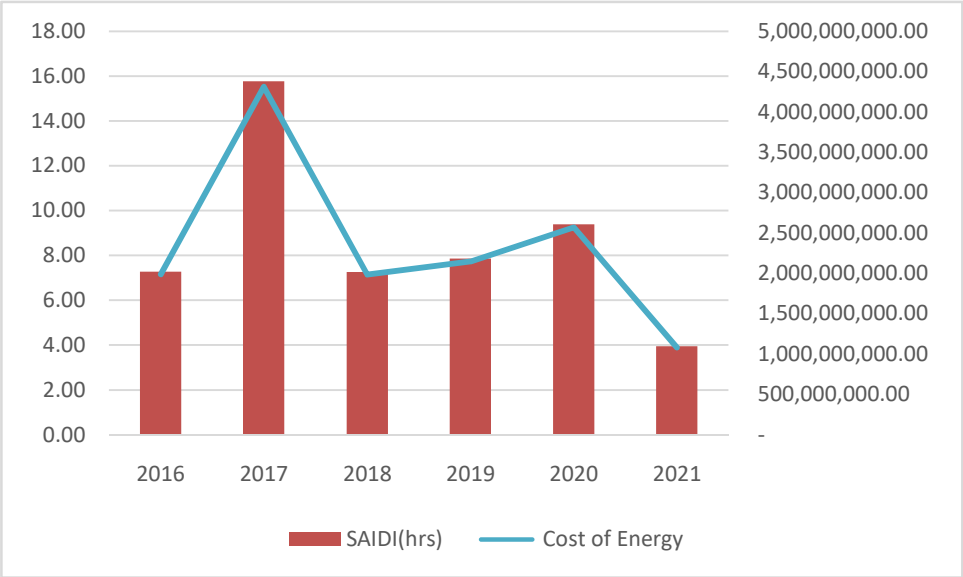

Figure 11: Graph of COUR and Its Corresponding SAIDI (2016-2021) For Auchi Feeder.

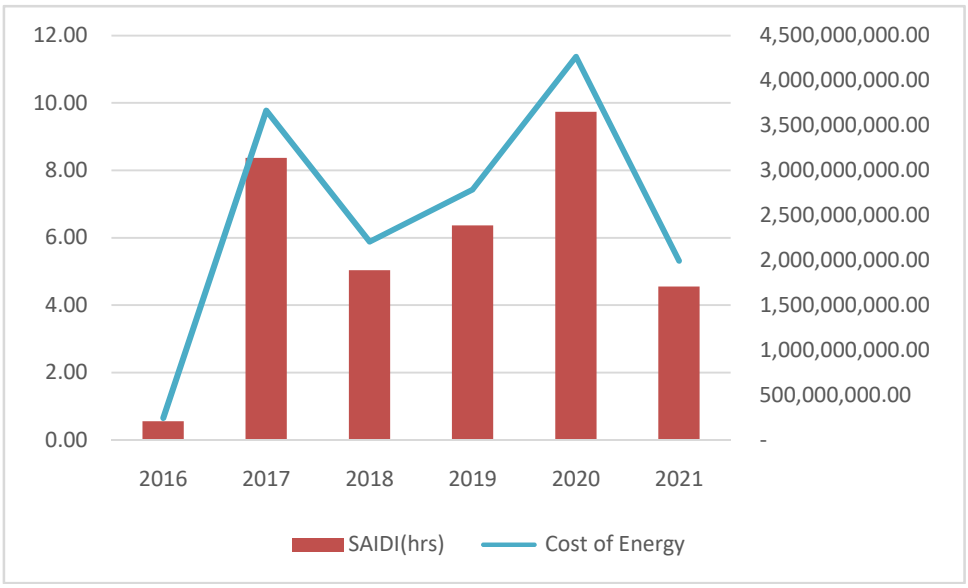

Figure 12: Graph of COUR and its Corresponding SAIDI (2016-2021) for GRA feeder.

Figure 10 shows that vegetation and ruptured J&P were the highest cause of interruption while cut conductor was the lowest cause of interruption on GRA feeder from 2016 to 2021.

Evaluation of the cost of reliability and unreliability of the Auchi distribution network

Figure 11 and 12 show that the cost of unreliability (COUR) and its corresponding SAIDI for year 2016 to 2021. A high value of TSAIDI implies a high value of cost of unreliability, as both are directly proportional. The cost of unreliability for a year is also dependent on the average injected power of the feeders for that year.

Simulation results of reliability indices

The results of the reliability of Auchi township distribution network (Auchi Feeder and GRA feeder) based on the data obtained from 2016 to 2021 is presented in (Table 3). The network was simulated based on the outage of the lines in the network and the active failure rate (due to Fault) was only considered while the passive failure rate (load shedding and planned maintenance) was assumed

Table 3: Analytical Results of AUCHI Township Network.

Year	AUCHI FEEDER			GRA FEEDER		
	SAIDI	SAIFI	CAIDI	SAIDI	SAIFI	CAIDI
2016	7.2727022	33.95072	0.214214	7.752671	31.9505	0.242646
2017	8.3736564	32.94765	0.25415	8.373656	32.94765	0.25415
2018	7.25172	48.88281	0.148349	0.251977	1.448106	0.174005
2019	7.8511854	29.47084	0.266405	6.362736	29.95654	0.212399
2020	9.3902295	45.89796	0.204589	9.741393	67.76464	0.143753
2021	3.9534381	25.96829	0.152241	4.549013	39.91984	0.113954

Table 4: Simulation Results of AUCHI Township Network.

	AUCHI FEEDER			GRA FEEDER		
YEARS	SAIDI	SAIFI	CAIDI	SAIDI	SAIFI	CAIDI
2016	7.0599	0.9155	7.712	6.4223	0.8988	7.146
2017	7.709	0.9072	6.9934	6.3656	0.8917	7.139
2018	6.8834	0.8934	7.705	6.3088	0.8846	7.132
2019	6.8168	0.8851	7.702	6.2232	0.8739	7.121
2020	6.3947	0.8332	7.675	5.6452	0.8183	6.898
2021	6.3946	0.8332	7.675	5.6448	0.8182	6.899

Table 5: Comparison of Simulation and Analytical Reliability Results of Auchi Feeder.

	AUCHI FEEDER Simulation			AUCHI FEEDER Analytical		
YEARS	SAIDI	SAIFI	CAIDI	SAIDI	SAIFI	CAIDI
2016	7.0599	0.9155	7.712	7.2727022	33.95072	0.214214
2017	7.709	0.9072	6.9934	8.3736564	32.94765	0.25415
2018	6.8834	0.8934	7.705	7.25172	48.88281	0.148349
2019	6.8168	0.8851	7.702	7.8511854	29.47084	0.266405
2020	6.3947	0.8332	7.675	9.3902295	45.89796	0.204589
2021	6.3946	0.8332	7.675	3.9534381	25.96829	0.152241

Table 6: Comparison of Simulated and Analytical Reliability Results of GRA Feeder.

GRA FEEDER Simulation			GRA FEEDER Simulation		
SAIDI	SAIFI	CAIDI	SAIDI	SAIFI	CAIDI
6.4223	0.8988	7.146	7.752671	31.9505	0.242646
6.3656	0.8917	7.139	8.373656	32.94765	0.25415
6.3088	0.8846	7.132	0.251977	1.448106	0.174005
6.2232	0.8739	7.121	6.362736	29.95654	0.212399
5.6452	0.8183	6.898	9.741393	67.76464	0.143753
5.6448	0.8182	6.899	4.549013	39.91984	0.113954

to be zero. The three basic reliability indices average failure rate, average outage duration and average outage time are important to evaluate system reliability but sometimes they don't present complete picture of system. Customer oriented indices like System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI) are used for evaluating reliability of distribution system, these indices as shown give complete picture of system.

The analytical results presented in (Table 3) shows that in year 2016, 2018, based on SAIFI and SAIDI shows that AUCHI feeder is more reliable compared to GRA feeder. However, in Year 2017 the two feeder has the same index. In year 2019, 2020 and 2021, Auchi feeder tends to be more reliable than GRA feeder based on SAIDI and SAIFI. Likewise using the customer average interruption duration Index (CAIDI) in year 2016, 2018 Auchi feeder is more reliable compared to GRA feeder, in year 2017 the CAIDI is the same for the two feeder. Moreso, in year 2019, 2020 and 2021 the CAIDI is higher in Auchi Feeder compared to GRA Feeder this implies that more customers are interrupted in Auchi Feeder compared to GRA during this period.

The simulation results presented in (Table 4) shows that in year 2016 to 2021 based on system interruption

(SAIFI and SAIDI) shows that GRA feeder is more reliable compared to Auchi feeder GRA this may be due to the tariff band of Customers under the feeder, because based on Nigeria Electricity regulation Commission (NERC) the hours of supply to consumer depend on the tariff bands. However, the results based on customer interruption shows that in Auchi feeder customers were more interrupted compared to GRA feeder for all the years except 2017.

The results of the simulation and Analytical approach for Auchi feeder presented in (Table 5) shows that there is similarity between the SAIDI while there is a difference between the SAIFI and CAIDI but this may be due to the data obtained based number of customers associated to each of the feeder. Also, failure rate of other equipment (Transformer and Feeder Pillar or load point) associated to the network were not considered in the analytical approach this may cause the difference in the value obtained.

Also the comparison presented in (Table 6) shows that there is similarity between the SAIDI while there is a difference between the SAIFI and CAIDI. This may also be due to the data obtained based number of customers associated to each of the feeder and failure rate of other equipment (Transformer and Feeder Pillar or load point) associated to the network that were not considered in the analytical approach this may cause the difference in the value obtained. It Also, the Network was simulated based on the maximum loading of the transformers which is 80% of the rated value.

Conclusion

The study has considered the basic delivery point reliability indices definitions, adapted its algorithm and demonstrated its application to obtaining model values of applied reliability indexes. From the analysis of the result, the following conclusions were made:

i. Interruption causes and their contributions to Auchi and GRA feeder and system reliability indices, obtained from initial reliability data extraction and analysis shows that vegetation and ruptured J&P were the highest cause of interruption while conductor breakdown was the lowest cause of interruption on Auchi feeder from 2016 to 2021.

ii. For GRA feeder, vegetation and ruptured J&P were the highest cause of interruption while cut conductor was the lowest cause of interruption on GRA feeder from 2016 to 2021.

iii. Annual and cumulative unreliability costs for present and future grids are prohibitive and correlate with system load. The DPs with only one circuit sources contributes mainly to these costs. More active redundant links to the affected DPs should be installed respectively.

iv. With reference to the model future indices, an additional circuit to weak delivery point reduces the system outage duration, thereby increasing the system reliability.

By implementing the recommendations derived from our model, it is possible to enhance the overall performance of the system and ensure reliable electricity supply for consumers.

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