American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-1, pp-180-188
www.ajer.org
Research Paper Open Access

Reliability and Fault Analysis of Electrical Distribution System: A Case Study of Kafanchan Distribution Substation in Kaduna State, Nigeria.

Obatola Samuel Ololade[1], Prof. Tang Junjie[2] andIbrahim Sinneh Sinneh[3]
[1, 2 & 3]*(School of Electrical Engineering, Chongqing University, China)*
Corresponding Author: Obatola Samuel Ololade

ABSTRACT: *This paper looks to address the reliability of distribution systems in Nigeria, using the monthly fault report data of the load points. By using the analytical method and network reduction technique, the substation reliability was analyzed based on the outage data gotten from the utility company.*

KEYWORDS*Reliability, Electricity, Distribution System, Reliability Indices, Distribution Substation, PHCN, Transformers*

Date of Submission: 15-01-2020 Date of acceptance: 31-01-2020

I INTRODUCTION

Electricity is the bedrock and arguably the most fundamental basis of any developed and advanced nation. Inconsistent electric power supply results in uneasiness, mental discomfort, as well as stifled productivity. As a result of its massive importance, electricity is the driving force behind the growth of any nation both economically and industrially as well as diverse other sectors (1). Electricity in our present-day is an index used to measure or depict the standard and quality of living as well as the scale of industrialization in which nations are measured.

One of the main setbacks ravaging Nigeria as a whole is the issue of ineffective management when compared with other developed nations of the world as well as its position amongst contemporary black nations, Nigeria is being plagued in the aspect of electricity distribution.

Nigeria's power supply is characterized by prodigious unreliability and appears to be currently in an epileptic state from the perspective of the consumer. Notwithstanding the vast and massive funds disbursed for the procurement of new equipment and mending of existing equipment, it has been acknowledged that despite increment in installed capacity, available capacity is often adverse. The deficiency in power systems which causes current to be distracted or maligned from an intended path is called FAULT. (2)

From the perspective of optimum performance of electric power distribution in delivering consistent and quality electricity to consumers, the core of this research is on reliability and fault analysis of electrical power distribution in Nigeria. Faults at the distribution level that causes power failure to the consumers may be due to any of the following effect on the system.

- Blown of fuses in the feeder pillar and J & P fuses holders.
- Damages to poles and underground cables
- Low tensions lines cut down
- Breakdown of insulation and cross arms
- Service wire cut down
- Tripping of circuit breaker
- Burning of transformer windings.

The faults data extracted from the PHCN fault report logbook for the case study considered in this project, are classified under the above seven types of faults. This paper attempt to solve this problem, through making use of the monthly fault report data at the load point (system interruption records) on a given electrical distribution system to evaluate the system reliability indices. The reliability indices evaluated in this work include SAIDI, SAIFI, ASAI, ASUI, CAIFI and CAIDI. The systems failure rate, MTTR, MBTF and availability were also determined. The results will further aid substation designers and operators, thereby ensuring the availability of quality power supply by getting the most out of power generated and transmitted which will culminate in higher profits for the distribution company as consumers only pay for energy supplied since the sole aim of every organization is to maximize profit.

II PREVIOUS WORKS

A recent survey by the Electric Power Research Institute in the US established that owing to interruptions in electric power distribution, about $104 billion to $164 billion is lost annually by organizations and businesses, and a further $15 billion to about $24 billion is lost yearly arising from other power quality glitches (3).

Reference (4) evaluated reliability assessment of electric power in Nigeria precisely on distribution system using Ekpoma network, Edo, as a reference point. Outage data was collected for January 2012 to December 2012, and the average availability using underlying reliability indices was evaluated for Iruekpen, Irrua, and Express feeders which are distribution feeders in Ekpoma. The outages were classified based on type, frequency, as well as outage duration and the result, calculated showed that there is a daily occurrence of disruptions and irregularities in the distribution feeders. Earth fault, supply failure, planned outage for maintenance, and load shedding were identified to be the possible causes for interruptions on the feeders.

The paper presented by (5) investigated and discussed the faults that impact a typical 11-kV feeder located in Southern metropolis of Kaduna city.By using NEPLAN simulation software, a software tool that helps in assessing the configurations of a power system, in the paper by (6) a method is presented for evaluation and prediction of distribution system reliability using Choba in Rivers state as a case study. NEPLAN power system software was used to perform an offline simulation of the distribution network considering outage time, incoming energy, outgoing voltages (kV) rating and three-phase current rating.

Most distribution systems are affected by outages which could be due to consequences from weather conditions, vegetation and animals. Furthermore, utilities can't shield its equipment from these factors completely.According to (7), reliability improvement is attainable by increased investment bringing about a decrease in the utility outage cost of the system. This outage cost can usually be computed by multiplying the energy cut to the consumer by the price of the kWh not supplied.

III METHODOLOGY

The approach presented is applicable in manual calculations or included in a digital computer program. The quantitative technique, which involves the collection of data, is adopted in this project. This technique describes the historical performance of existing systems and utilizes the past performance to predict the effects of changing conditions on system performance. The present system reliability indices shall have been evaluated by making use of the twelve month's data collected on the system. The reliability indices to be assessed are explained, and the formulae to be used are shown. Failure in the system is unavoidable; however, the effects could be lowered by carrying out proper analysis and planning, which is also the reason for evaluation. In this project, the analytical method, namely, network modelling, will be used.

3.1 Series System

From a reliability standpoint, each component comprising a series system must work simultaneously to guarantee system success as the failure of any single part leads to the failure of the entire system. Hence, this connotes that a system in series is a non – redundant system. The figure 1 below describes a series system:

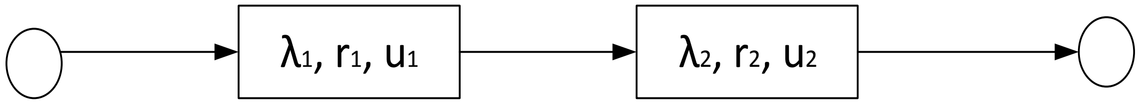

Figure 1:Typical Diagram of a Series System

(8) provided the formulae used in the calculations involved in the series system shown in figure 1 above and are given in equations (1) to (3);

Where, λ = expected failure rate

U = the annual outage time

r = average outage time

$$\lambda_s = \lambda_1 + \lambda_2 \quad = \sum_{i=1}^{2} \lambda_i \qquad (1)$$

$$U_s = \lambda_1 r_2 + \lambda_2 r_2 = \sum_{i=1}^{2} \lambda_i r_1 \qquad (2)$$

$$r_s = \frac{u_s}{\lambda_s} \qquad (3)$$

3.2 Parallel System

System components are said to be in parallel from a reliability point of view if only one needs to be working for system success or all must fail for system failure. This system is fully redundant.

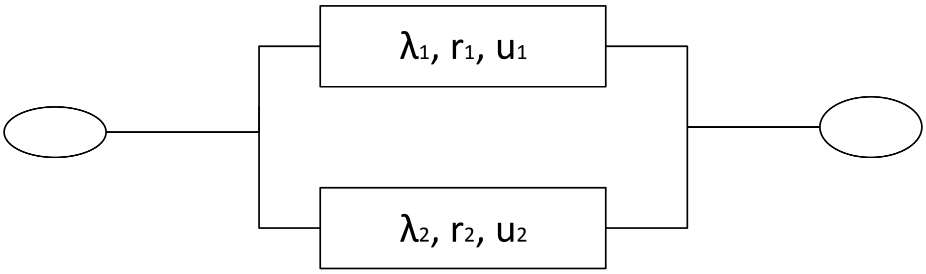

Figure 2:Typical Diagram of a Parallel System

The calculations involved in the parallel system shown in figure 2 above are given in equations (4) to (6);

$$\lambda_p = \lambda_1 \lambda_2 (r_1 + r_2) \qquad (4)$$

$$U_p = \lambda_1 \lambda_2 r_1 \qquad (5)$$

$$r_p \frac{u_p}{\lambda_p} \qquad (6)$$

The above equations (1) to (6) are sufficient for simple radial systems, and more indices are computed for global distribution systems. Network technique using the series system is used in calculating the rate of failure for all components making up the distribution system.

Also, the following reliability parameters in equations (7) to (10) will be used in determining the availability of each component and the overall availability of the substation using the data collected.

Mean Down Time (MDT) or Mean Time to Repair (MTTR): It describes the average time whereby a component is out of service due to fault before it is restored to normal operation (9). It is expressed as

$$MTTR = \frac{Total\ Duration\ of\ Outages}{Frequency\ of\ Outage} \qquad (7)$$

Failure Rate:

$$\lambda = \frac{Number\ of\ outages\ on\ component\ in\ a\ given\ period}{Total\ time\ component\ \text{is in}\ operation} \qquad (8)$$

Mean Time between Failures (MTBF): is also the time that elapsed before when a component, assembly, or network fails, under the circumstance of a persistent failure rate. It describes the total time the element is in operation (9). It is expressed as

$$MTBF = \frac{Total\ System\ Operating\ hours}{Number\ of\ Failures} \qquad (9)$$

Availability

Availability is the measure of the duration for which the component is in operation at any time. It deals with the period for which the system is entirely functional for its specific function (9). It is expressed as

$$\text{AVAILABILITY} = \frac{\text{MTBF}}{MTBF + MTTR} \qquad (10)$$

A general way of determining reliability is by computing the customer and load-based indices (9). Reference (7) provided the index used in the calculations, equations (11) to (15) below, (4) also cited.

Average Service Unavailability Index (ASUI)

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

$$\text{ASUI} = \frac{Duration\ of\ Outages \text{ in } Hours}{Total\ Hours\ Demanded} \qquad (11)$$

System Average Interruption Duration Index (SAIDI)

This index helps the utility to report for how many minutes' customers would have been out of service if all customers were out at one time. It is expressed as

$$\text{SAIDI} = \frac{Total\ Outage\ Duration\ in\ Hours}{Number\ of\ Customers\ Supplied} \qquad (12)$$

System Average Interruption Frequency Index (SAIFI)

This is the average sum of times whereby a customer experiences interruption during a stated duration of time. The resultant unit is "interruptions per customer". It is expressed as

$$SAIFI = \frac{\text{Frequency of Outages}}{Number\ of\ Customers\ Supplied} \qquad (13)$$

Average Service Availability Index (ASAI)

This is a degree of the average availability of the power distribution system that serves customers. It is often expressed in percentages. It is expressed as

$$\text{ASAI} = \frac{Customer\ Hours\ Service\ Availability}{Customers\ Hours\ Service\ Demanded} \qquad (14)$$

Customer Average Interruption Duration Index (CAIDI)

The index provides utilities with the basis to account for the average duration for a typical customer outage concerning affected customers. It is expressed as

$$CAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customers\ Interrupted} \qquad (15)$$

3.3 Basic Design Layout

The distribution substation on which the study is carried out forms an integral part of a secondary distribution network, and it is mostly referred to as secondary distribution substation or customer substation. The typical configuration used in most distribution substations owned by PHCN is the single-end fed network which has overcurrent fault as well as earth fault protection upstream, and the secondary substation typically has step-down transformer usually protected by HRC fuse. In some other designs, the secondary substation may include central ring units and a high voltage circuit breaker. The single-end radial fed arrangement has the lowest supply security as an outage of any component results in customers loss of power supply although it has the benefit of been effortlessly coordinated, no idle part and it is relatively cheaper to implement.

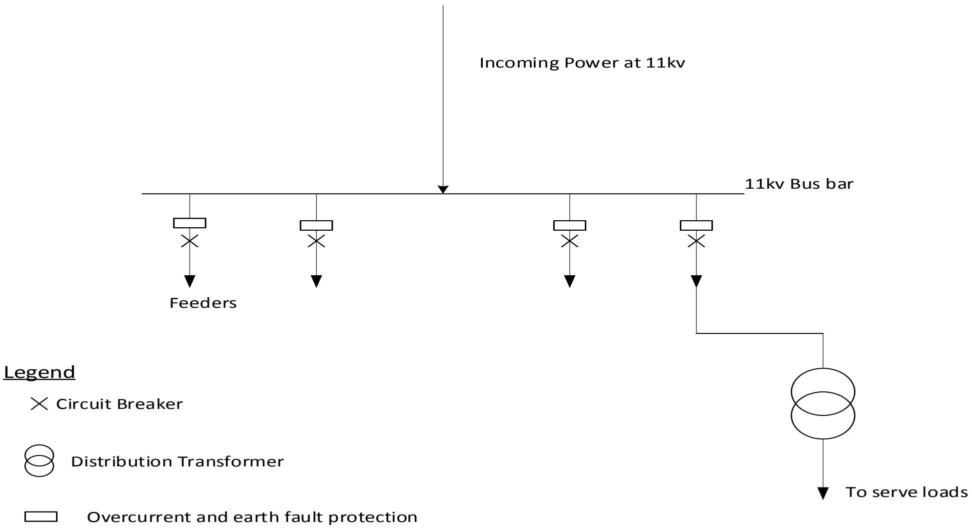

Figure 3: A Typical Single-End Radial Network Configuration

IV RESULTS AND DISCUSSION

Table 1: Basic Reliability Indices on Each Component

Component	Failure Rate (f/yr) λ	Average Outage Time Time (Hours)	Annual Outage Time (Hours)
Transformer	0.0031	38.1667	0.1181
Switch gear	0.0044	6.4167	0.0280
Supply line (Incoming)	0.0022	5.8333	0.0126
Bus bars	0.00046322	1.6667	0.00077203
Circuit Breakers	0.00068324	2.0833	0.0014
Fuses	0.0061	15.1667	0.0927
Switches	0.00045923	1.3333	0.00061231
Outgoing Feeder	0.0045	13.25	0.0593
Overcurrent relay	0.00023547	0.2083	0.000049057
Earth fault relay	0.00011201	0.1667	0.000018668
Surge Arrester	0	0	0

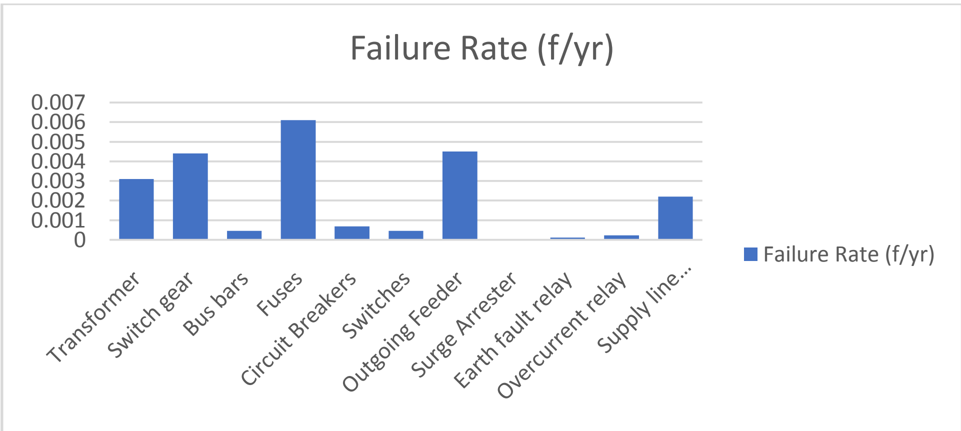

Figure 4: Bar Chart Showing the Failure Rate of Each Component

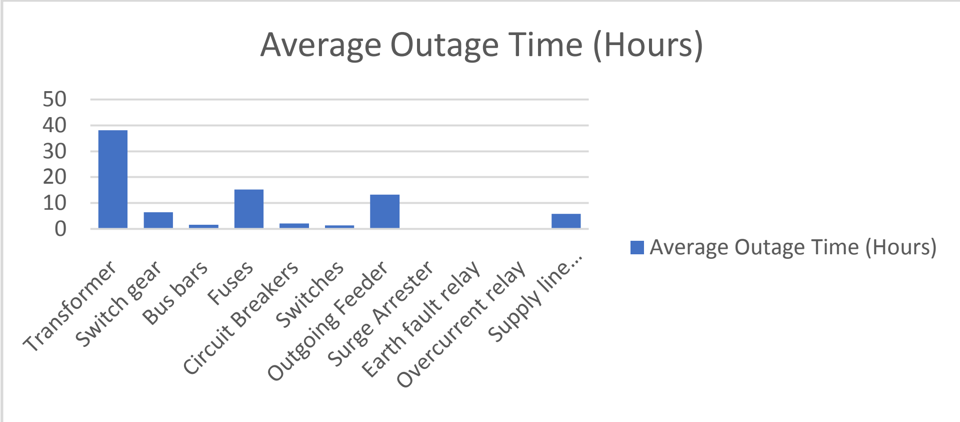

Figure 5: Bar Chart Showing the Average Outage (Hours) Time of Each Component

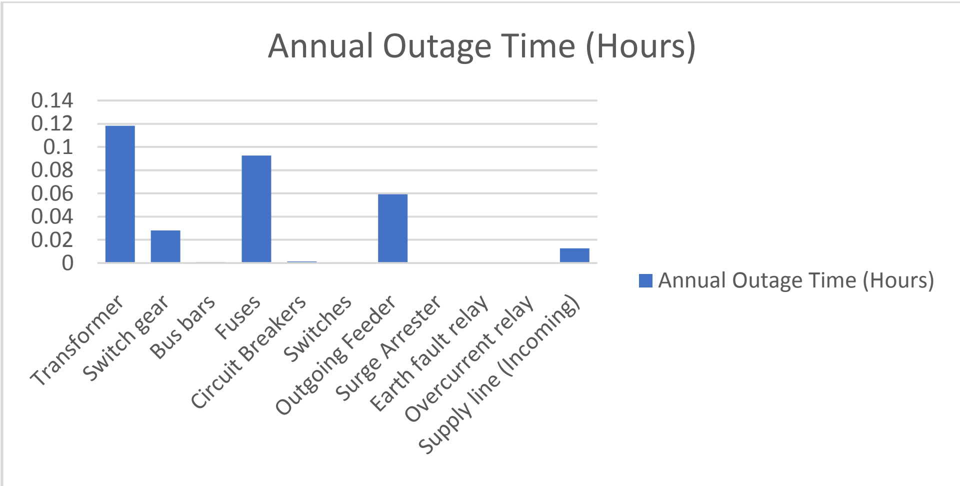

Figure 6: Bar Chart Showing the Annual Outage (Hours) Time of Each Component

From the above results, using table 1 which reflects the yearly outage time/components unavailability (U), it can be deduced that the transformer having a value of 0.1181 is the principal component which contributes the most to substation interruption hence affecting the delivery and supply of power to customers. The fuse seconds the transformer with 0.0927 and then followed by the outgoing feeder with a value of 0.0593.

Earth fault relay and overcurrent relay has lower values of unavailability, 0.000049057 and 0.000018668, respectively. The bus bar and breaker also had small amounts of unavailability of 0.00077203 and 0.0014, respectively**.**

Table 4.13: Additional Basic Reliability Indices

Component	Number of Failures	Outage (Hours)	Total (Hours)	Failure Rate (f/yr)	MTBF	MTTR	Availability
Transformer	27	458	8784	0.0031	325.3333	16.9630	0.9504
Switch gear	38	77	8784	0.0044	231.1579	2.0263	0.9913
Supply line (Incoming)	19	70	8784	0.0022	462.3158	3.6842	0.9921
Bus bar	4	20	8784	0.00046322	2196	5.0000	0.9977
Circuit Breaker	6	25	8784	0.00068324	1464	4.1667	0.9972
Fuses	54	182	8784	0.0061	162.6667	3.3704	0.9982
Switches	4	16	8784	0.00045923	2196	4.000	0.9822
Outgoing Feeder	39	159	8784	0.0045	225.2308	4.0769	0.9997
Overcurrent Relay	2	2.5	8784	0.2083	4392	1.2500	0.9998
Earth Fault Relay	1	2	8784	0.1667	8784	2.0000	
Surge Arrester	0	0	8784	0	-	-	-
Total	194	1011.5	8784		45.2784	5.2139	0.8967

Table 3: Computed Customer Orientation Indices, January to December 2018 on Kafanchan Substation

Month	Frequency of Interruptions	Duration of Interruption	Total Hours	No. of Customers	SAIDI (hrs/cust)	SAIFI (int/cust)	CAIDI (hrs/cust)	ASAI (p.u)	ASUI (p.u)
January	38	260	744	268	0.9701	0.1418	6.8421	0.6505	0.3495
February	32	268	696	268	1.0000	0.1194	8.3750	0.6149	0.3851
March	19	76	744	268	0.2836	0.0709	4.0000	0.8978	0.1022
April	22	96.5	720	268	0.3601	0.0821	4.3864	0.8660	0.1340
May	10	31	744	268	0.1157	0.0373	3.1000	0.9583	0.0417
June	8	28	720	268	0.1045	0.0299	3.5000	0.9611	0.0389
July	10	44	744	268	0.1642	0.0373	4.4000	0.9409	0.0591
August	13	48	744	268	0.1791	0.0485	3.6923	0.9355	0.0645
September	9	33	720	268	0.1231	0.0336	3.6667	0.9542	0.0458
October	15	70	744	268	0.2612	0.0560	4.6667	0.9059	0.0941
November	13	47	720	268	0.1754	0.0485	3.6154	0.9347	0.0653
December	5	17	744	268	0.0634	0.0187	3.4000	0.9772	0.0228
Total	194	1018.5	8784	268	3.8004	0.7239	5.2500	0.8841	0.1159

A CAIDI value of 5.25 implies that from the customer end, there was no supply of electricity for 5.25 hours every day for the whole year, i.e. on the average, it takes 5.25 hours to restore power supply whenever there is an interruption. From the results in Table 3, the distribution substation has a service or system reliability index, and ASAI value of 88.41%. Utilities have been recorded to have a value of 99.99% or four nines, which means a SAIDI of 52 minutes per annum or 0.866 hours per year. The ASUI value gives the complement of ASAI by providing the value of the substation unavailability. The system has an ASUI of 0.1159.

The average outage duration, SAIDI, for each customer served is 3.8004 hours for the whole year. This is over twice the IEEE standard 1366-2003 which gives a value of 1.5 hours for North American Utility. This is a region that has sufficient power generation and robust system security. Therefore, according to the standard, the performance of thisdistribution substation system is low. The month of February had the highest SAIDI value followed by January with each having SAIDI value of 1.0000 and 0.9701 respectively.

This substation has a very acceptable low value of SAIFI for the year. This means that the frequency of interruptions spread across the year is low.

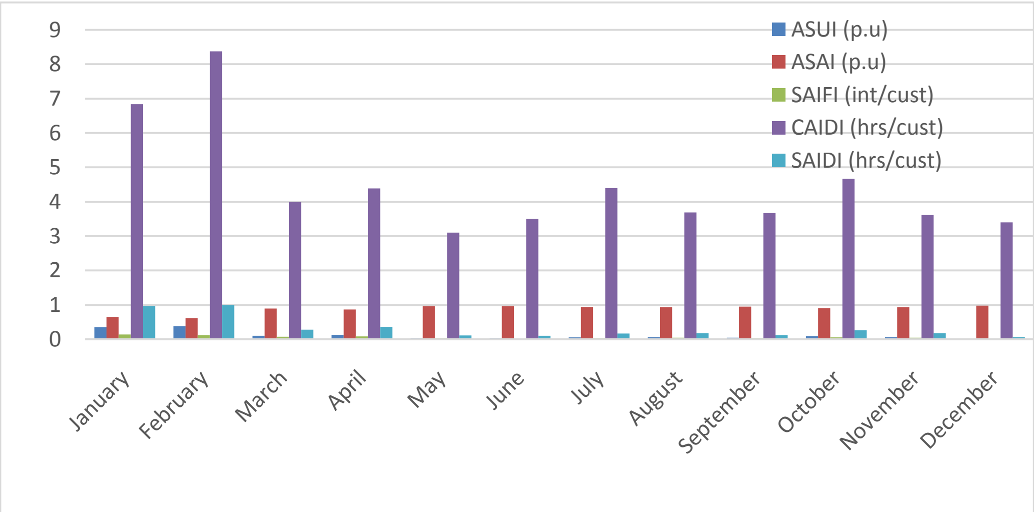

Figure: 7 Annual SAIDI, ASAI, SAIFI, CAIDI, ASUI bar Chart

4.1: Comparison of This Dissertation's Results with Reliability Benchmark

The standard with which the reliability of a distribution system is measured against is known as reliability benchmarks. The rules are given to offer justification and provide an acceptable margin for the reliability performance of distribution networks. Based on IEEE Guide, the benchmarks for nine countries were computed for power distribution reliability, as shown in Table 4.

Table 4: Reliability Indices Benchmark (Rouse and Kelly 2018)

Country	SAIDI (Minutes/year)	SAIFI (Interruptions/Customer)	CAIDI (Minutes/Outage	ASAI (%)
United States	240	1.5	123	99.91
Uk	90	0.8	100	99.964
Italy	58	2.2	106	99.9991
Spain	104	2.2	114	99.968
Austria	72	0.9	112	99.97
Netherlands	33	0.3	75	99.97
Denmark	24	0.5	70	99.981
France	62	1	58	99.97
Kafanchan (Nigeria)	**228**	**0.7239**	**315**	**88.41**

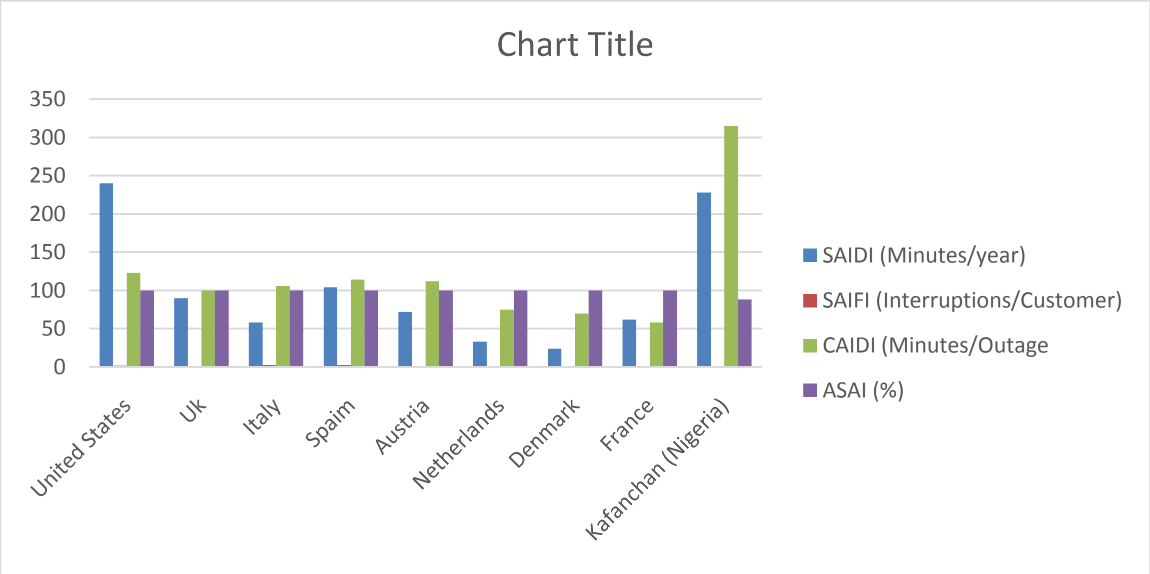

Fig 8. Bar Chart Showing Compared Reliability Indices

V. CONCLUSION

In this paper, Kafanchan substation, Kaduna South was chosen as a secondary distribution substation to study to evaluate the reliability of a typical substation in Nigeria. To achieve this, the substation was viewed to be in isolation from the rest of the power system. That is, the effect of insufficient generation was not considered, and the impact of transmission subsystem failure. This paper, by using Kafanchan substation as a case study for carrying out reliability evaluation of a secondary distribution system in Nigeria, has been able to identify transformer as the component contributing most to consumer reliability problems followed by the fuse and the outgoing feeder.

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

a. The utility company should continue to keep an accurate record of interruptions, the causes and durations as these will help to carry out concise research work.

b. Also, efforts should be put in place to see that when there is a component outage, the duration is significantly reduced in order to achieve a more reliable system. And this can be done by ensuring that the customers have a means of reporting outages to the utility company and speedy response whenever outages are reported.

d. The customers should be enlightened to see the substation as their property as this will foster quick reportage of failures. This will also aid in the protection of the substation from vandals.

f. The design of the substation can be improved to be a double-end fed radial system to ensure a better supply of electricity which automatically enhances the reliability of the substation.

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

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Obatola Samuel Ololade, et.al. "Reliability and Fault Analysis of Electrical Distribution System: A Case Study of Kafanchan Distribution Substation in Kaduna State, Nigeria.". *American Journal of Engineering Research (AJER)*, vol. 9(01), 2020, pp 180-188.