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RELIABILITY ASSESSMENT ON SECONDARY DISTRIBUTION NETWORK: CASE STUDY OF KARU SUBSTATION IN ABUJA, NIGERIA

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Abstract: *The Power system design normally provides function effectively to the consumers. Therefore the interruptions cannot be avoided which cause power unavailability which affect the generation of electricity for high quality achievement. This research paper analyzes the reliability system of Karu substation in Abuja for proper system planning and design in the power network using network reduction and analytical method. The analysis was done using MATLAB 2015 software. The paper analysis shows that overloading and transformer failure are the most unavailable to the substation. Finally the total reliability analysis of the distribution system showed that the substation performance is poor with 88.46% compare with the standard benchmark.*

Keywords: *Reliability, Power system, substation, MATLAB*

1. Introduction

The electric power system is normally design to supply electricity without or little interruptions to the customers. The number of interruptions in the system is basically determined through the total reliability of the system. The quality of electricity supply depends on reliability of the system. Moreover, when the power system is operating on continuously, it means that the customer are specifically satisfied through electricity that gives better favorably returns to the investment of supplying electricity. Thus, there is a need to supply electricity that will be more reliable for the development of technology and also enhanced the modern society. So, reliability is very important in power system in order to improve the productivity of electricity. There are three subsystems in power system i.e generation, transmission and distribution. In generating station, the generation and transmission of electricity is through high voltage transmission lines to distribution network substations. The network of distribution system substation is normally between the sub-transmission system and the transmission line to the end-user (consumer meter) i.e transmission of 11kV to 0.415 kV (Theraja and Theraja, 2005).

The distribution substation are always located very near the customers in order to deliver effectively, substation maintenance and monitoring the system which gives the network to the secondary distribution substation and also to customer.

Hence, there are losses in power generation which causes very serious problems in transmitting to the environment and society. When these losses occur, the productivity of electricity will be very low due to poor performance on transmission lines to distribution system.

Thus, when disturbance occurs in the system it causes failure in the distribution outages system. Analysis of the customer failure statistics of most electricity companies shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer (Gonen, 2014). In effect, the purpose of establishing generating stations and the hurdles overcome to transmit electricity is defeated when it does not get to the user end as a result of distribution system failure. This makes distribution system to be highly important. The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability (Billinton and Jonnavithula, 1996). The important of power system is to provide electricity to the customers but this can be done when the components are in a good condition and can operate well for long period of time. Therefore, the distribution reliability is very crucial due to sensitive increase on cost of electricity.

2.0 Reliability principles

The principles of Reliability electric power system normally based on the probability that the system will steadily produce electricity to its consumers without affecting the power quality dissipated (Bhavaraju et al., 2005). It can determine the measure of electricity that users needs at a particular time. (Wang, 2012). The reliability of primary distribution system are based on consumer interruptions and equipment outages.

Reliability according to IEE means that ability of a component or system to perform its particular functions at a particular period of time. Therefore, power system reliability as a states in which the electricity is being transfer to customers within accepted standards (Kueck et al., 2004). The outages of the system component and power supply interruption always occurs due to scheduled and unscheduled planning. The scheduled events are normally occurs when there is a maintenance operations on the equipment, construction, consumer request, and usually consumers do get notice of interruption of supply in advance.

The unscheduled events may be as a result of oversights during installation or maintenance operations, component failures and faults.

2.1 Review of Power system Reliability

The researcher (Adegboye and Dawal, 2012) analyze the effect of fault on 11-kV feeder for Kaduna town. The substation has four 30-MVA outgoing feeders. The researcher study the reliability of the substation through the data collected from power holding company. The researcher (Okorie and Abdu, 2015) evaluate the reliability outage for kano distribution company. The study focus on 33- kV feeder distribution system which involves underground and overhead distribution system. The researchers analyze critically the causes of outages in power system in the network. The researchers (Okorie, 2016) study the reliability performance of Kaduna Disco in Abakpa distribution network. The author performed thorough analysis on how to achieve better reliability system performance. The research was conducted for the period of three years (2010-2012). Finally the researcher was able to compute outage rate, failure rate, and also the time of repair within a specific duration and outages frequency. The researcher Sonwane and Kushare (2015) prepare analysis technique that can be applied in reliability system. The researcher aims is to develop precise and accurate model which can study the behavior of the power system network.

3. 0 Method and Materials

The data collection were analyze for twelve month at Karu substation in Abuja, from January 2018 to December 2018. The data collected from PHCN for karu substation analyze the outage component duration. The MATLAB 2015 software was used to perform the analysis on the substation.

The reliability analysis formula used for this research paper is explained below:

The Failure Rate λ

$$\lambda = \frac{\text{Number of outages on component in a year}}{\textit{Total time component is in operation}}$$

Mean Time Between Failure

$$\text{MTBF} = \frac{\text{Total system operating Hours}}{\textit{Number of Failures}}$$

Mean Time To Repair (MTTR)

$$\text{MTTR} = \frac{\text{Total Duration of Outage}}{\textit{Frequency of Failure}}$$

Availability

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

Customer Reliability Indices

System Average Interruption Duration Index (SAIDI)

$$\text{SAIDI} = \frac{\text{Total Outage Duration (hours)}}{\textit{Number of Customers Supplied}}$$

System Average Interruption Frequency Index (SAIFI)

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

Customer Average Interruption Frequency Index (CAIDI)

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

Average Service Availability Index (ASAI)

$$\text{ASAI} = \frac{\text{Customer Hours Service Available}}{\textit{Customers Hours Service Demanded}}$$

Average Service Availability Index (ASUI)

$$\text{ASUI} = \frac{\text{Duration of Outages (hours)}}{\textit{Customers Hours Service Demanded}}$$

4.0 Result and Discussion

The monthly component reliability indices for the 33KV K2 feeder at Karu substation in Abuja for a period of twelve month from January 2018 to December 2018. The MATLAB 2015 software was used to analyze and evaluate the presented data.

Table 1 and 2 show the basic reliability indices of each component. Figures 1 through 4 shows the graphical representation of the reliability indices of each component for the whole year. The surge protector has the lowest failure rate with no failure throughout the year; hence, it is the most reliable. On the other hand, the least reliable component in the distribution system is the fuses, having an annual failure rate of 0.0055/year. Again, the fuses have their mean time between failure (MTBF) to be 179.2653 hours, which is the lowest of all the components in the system, hence showing that they are the most prone to failure, thus least reliable. The surge protector has the highest MTBF with 8784 hours for the year. The entire system's average MTBF is 46.23 hours which mean that the system could fail on an average of 46.23 hours interval. Over-current Relay has the lowest MTTR with a value of 1.5 hours while the transformer has the highest MTTR with 16.667 hours to between failure and repair. The average MTTR for the whole distribution system is about 4.685 hours. This depicts that in case of occurrence of any failure on the system, it takes an average of 4.685 hours to repair or restore the system back to its normal operation.

Table 1: Basic Reliability Indices on Each Component

COMPONENT	Failure Rate (f/yr)	Average Outage Time (Hours)	Annual Outage time (hours)
Transformer	0.003100	37.50	0.1160000
Switchgear	0.004100	6.25	0.0259000
Supply line	0.002300	5.75	0.0131000
Busbars	0.000463	1.50	0.0006948

Circuit breakers	0.000795	2.25	0.0018000
Fuses	0.005500	14.75	0.0818000
switches	0.000575	1.67	0.0009583
Outgoing Feeder	0.004500	13.58	0.0608000
Overcurrent relay	0.000235	0.25	0.0000589
Earth fault Relay	0.000112	0.25	0.0000280
Surge Arrester	0.000000	0.00	0.0000000

Table 2: Additional Basic Reliability Indices

COMPONENT	**No. of failures**	**Outage Time (Hours)**	**Failure Rate (f/yr)**	**MTBF (Hours)**	**MTTR (Hours)**	**Availability**
Transformer	27	450	0.003100	325.3333	16.6667	0.9513
Switchgear	36	75	0.004100	244	2.0833	0.9915
Supply line	20	69	0.002300	439.2	3.45	0.9922
Busbars	4	18	0.000463	2196	4.5	0.998
Circuit breakers	7	27	0.000795	1254.9000	3.8571	0.9969
Fuses	49	177	0.005500	179.2653	3.6122	0.9802
switches	5	20	0.000575	1756.8000	4	0.9977
Outgoing Feeder	39	163	0.004500	225.2308	4.1795	0.9818
Overcurrent relay	2	3	0.000235	4392	1.5	0.9997
Earth fault Relay	1	3	0.000112	8784	3	0.9997
Surge Arrester	0	0	0.000000	65535	-	-
Total	190	1005		46.23157	4.68488	0.899

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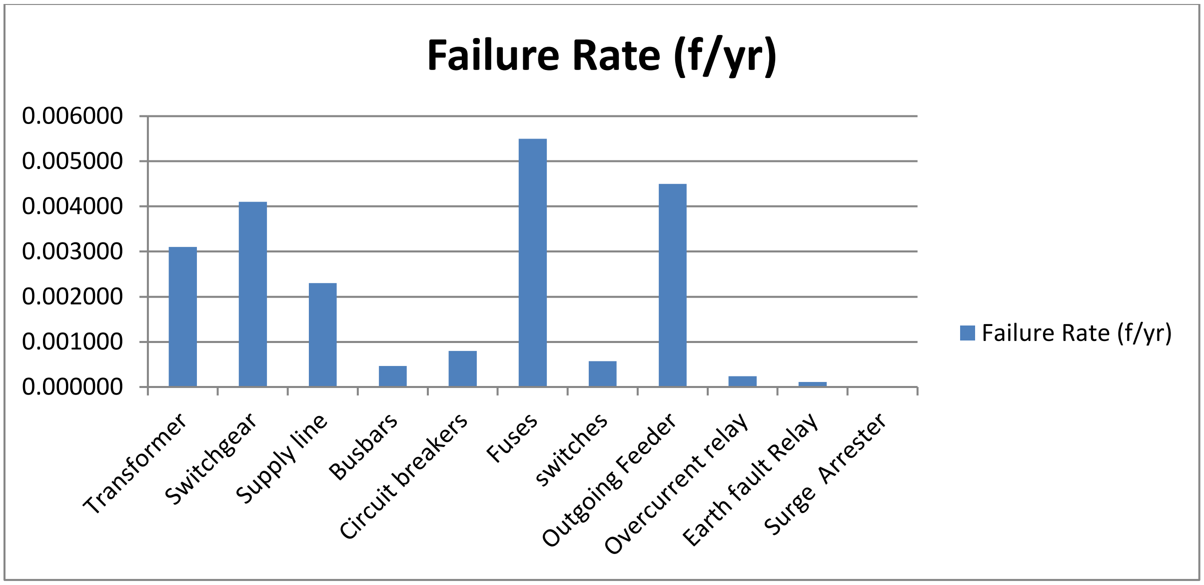

Figure 1: Bar Chart of Failure Rate for each component

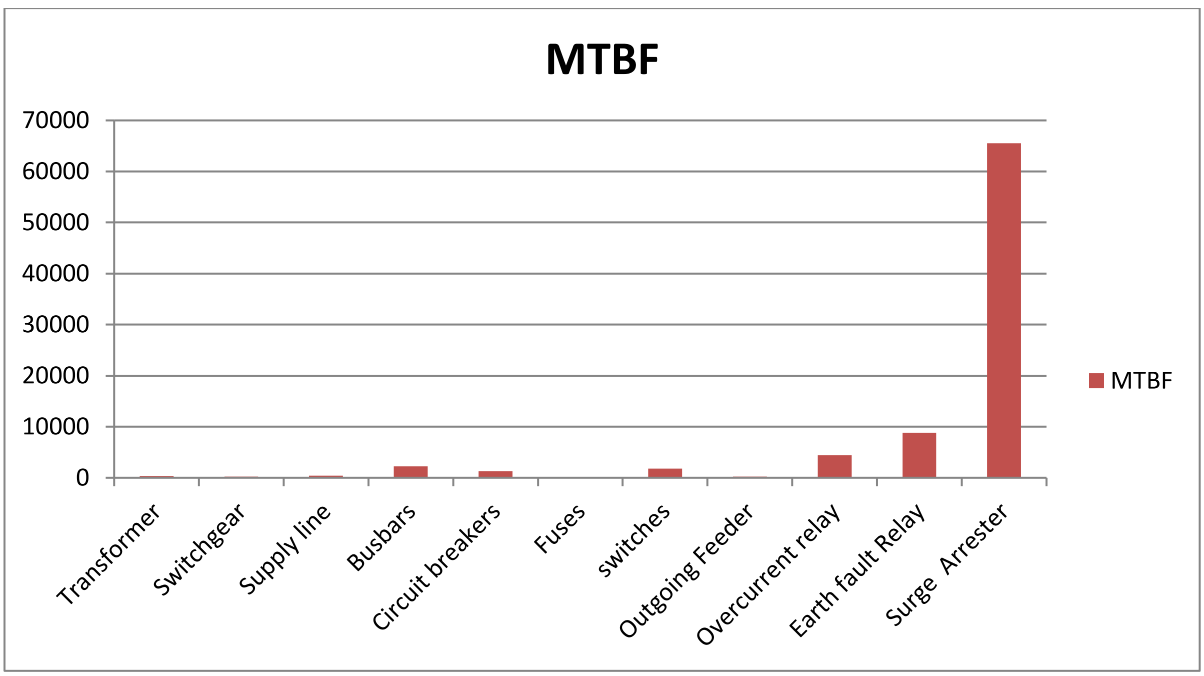

Figure 2: Bar Chart of MTBF for each component

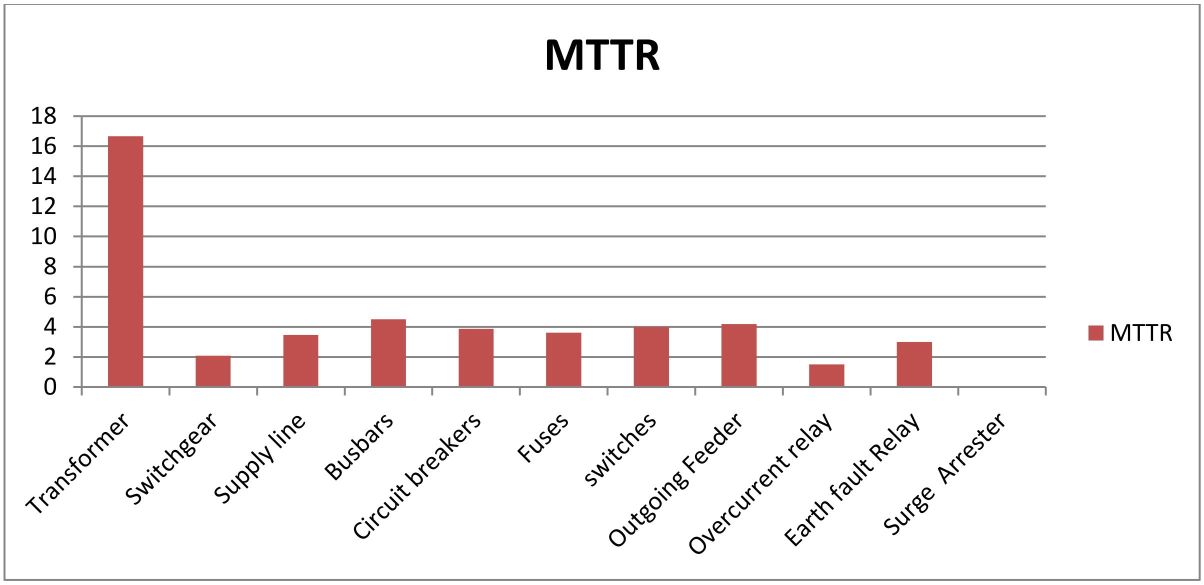

Figure 3: Bar Chart of MTTR for each component

Figure 4: Bar Chart of Availability for each component

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Interpretation of Customer Reliability Evaluation Results

Table 3 presents the customer orientation indices for the Karu substation. Figure 5 through 9 show the compares the monthly SAIDI, SAIFI, CAIDI, ASAI and ASUI of the distribution network.

Table 3: Computed Customer Orientation Indices Karu in Abuja substation **from January to December 2018**

Month	Frequency of Interruption	Duration of Interruption (hours)	Total Hours	No. of Customers	SAIDI (hrs/cust)	SAIFI (int/cust)	CAIDI (hrs/cust)	ASAI (p.u)	ASUI (p.u)
January	37	253	744	268	0.944	0.1381	6.8378	0.6599	0.3401
February	32	264	696	268	0.9851	0.1194	8.25	0.6207	0.3793
March	18	72	744	268	0.2687	0.0672	4	0.9032	0.0968
April	22	99	720	268	0.3694	0.0821	4.5	0.8625	0.1375
May	9	32	744	268	0.1194	0.0336	3.5556	0.957	0.043
June	7	25	720	268	0.0933	0.0261	3.5714	0.9653	0.0347
July	10	40	744	268	0.1493	0.0373	4	0.9462	0.0538
August	11	43	744	268	0.1604	0.041	3.9091	0.9422	0.0578
September	8	33	720	268	0.1231	0.0299	4.125	0.9542	0.0458
October	14	70	744	268	0.2612	0.0522	5	0.9059	0.0941
November	16	54	720	268	0.2015	0.0597	3.375	0.925	0.075
December	6	20	744	268	0.0746	0.0224	3.3333	0.9731	0.0269
Total	190	1005	8784	268	3.75	0.709	4.5381	0.8846	0.1154

The system has very high SAIDI values in February (0.9851) and January (0.944) which indicates a relatively high interruption duration. On the other hand, December (0.0746) and June (0.0933) had the lowest SAIDI. Annual SAIDI per customer served is calculated to be 3.75 hours which is about two and half times the IEEE standard 1366-2003 value of 1.5hours for North American Utility. In contrast with the standard SAIDI value, the Karu substation is said to be less efficient.

The SAIFI value of the system is considerably low, polling a total of 0.709 interruptions per customer. The system has a low SAIFI compared with the IEEE Standard 1366-1998 value of 1.10 for North American Utilities. This indicates that the system has a lower index of interruptions per customer compared with the Standard value. Considering SAIFI alone, the system could be said to be reliable.

The annual average of CAIDI is 4.5381 which imply that the average time to restoration of power to customer is 4.5381 hours per customer. This is more than three times the IEEE Standard 1366-1998 of 1.36 hours for North

American utilities, thus indicating that the system is less reliable.

The ASAI value of the system is 0.8846 or 88.46%. This indicates that the utility is available for 88.46% time of the expected operational time. Comparing the system's ASAI value with the globally expected ASAI value of four nines i.e 99.99%, this system is less reliable. ASUI value of 0.1154 shows that the system is unavailable for 11.54% of the expected operational time.

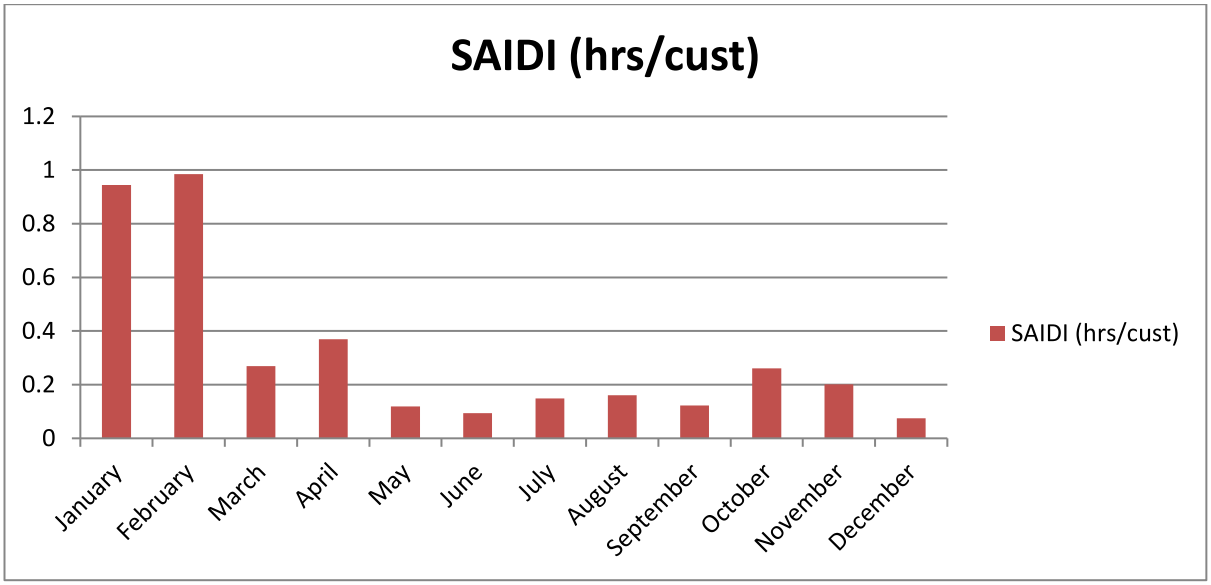

Figure 5: Bar Chart of SAIDI for Twelve Months

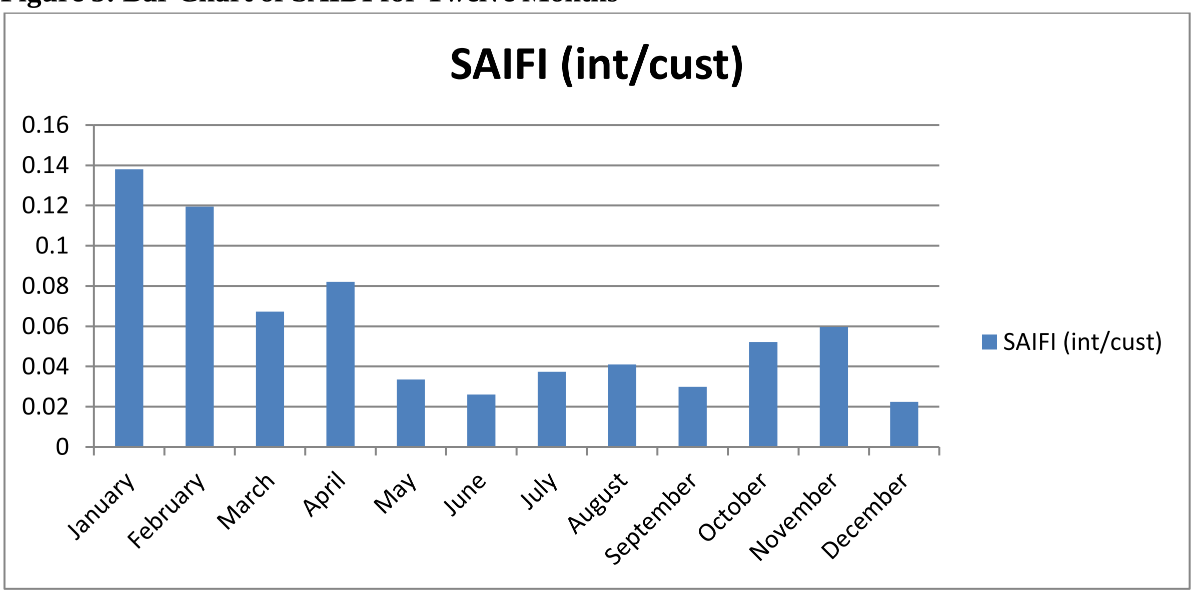

Figure 6: Bar Chart of SAIFI for Twelve Months

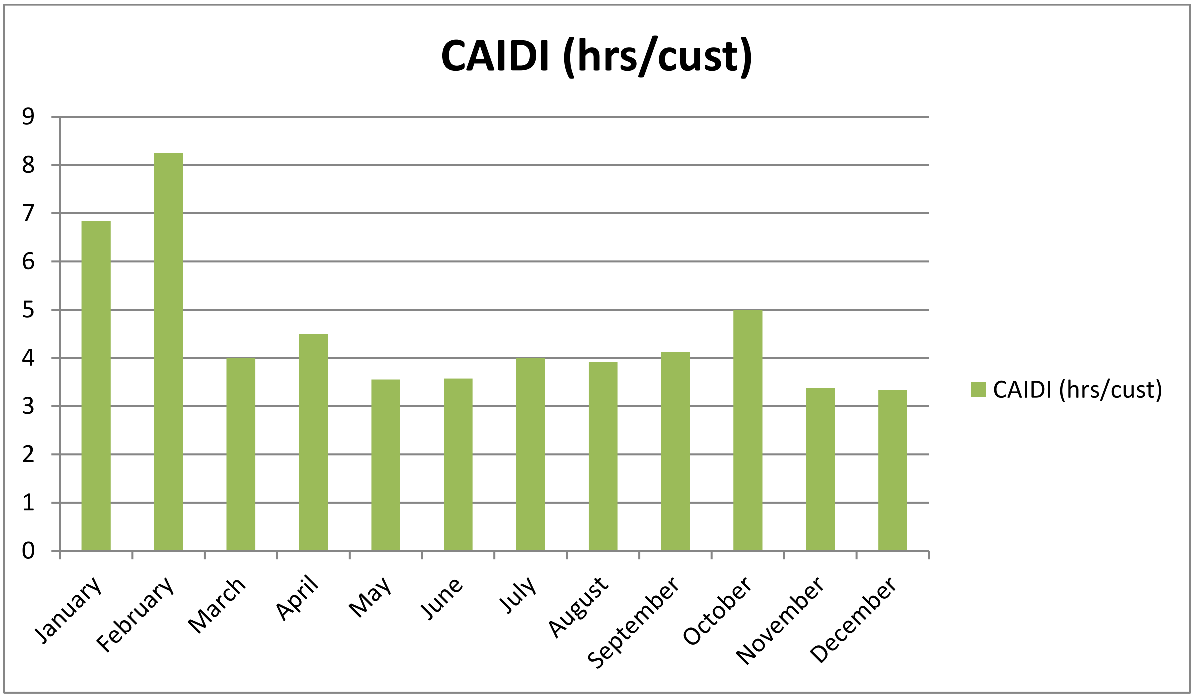

Figure 7: Bar Chart of CAIDI for Twelve Months

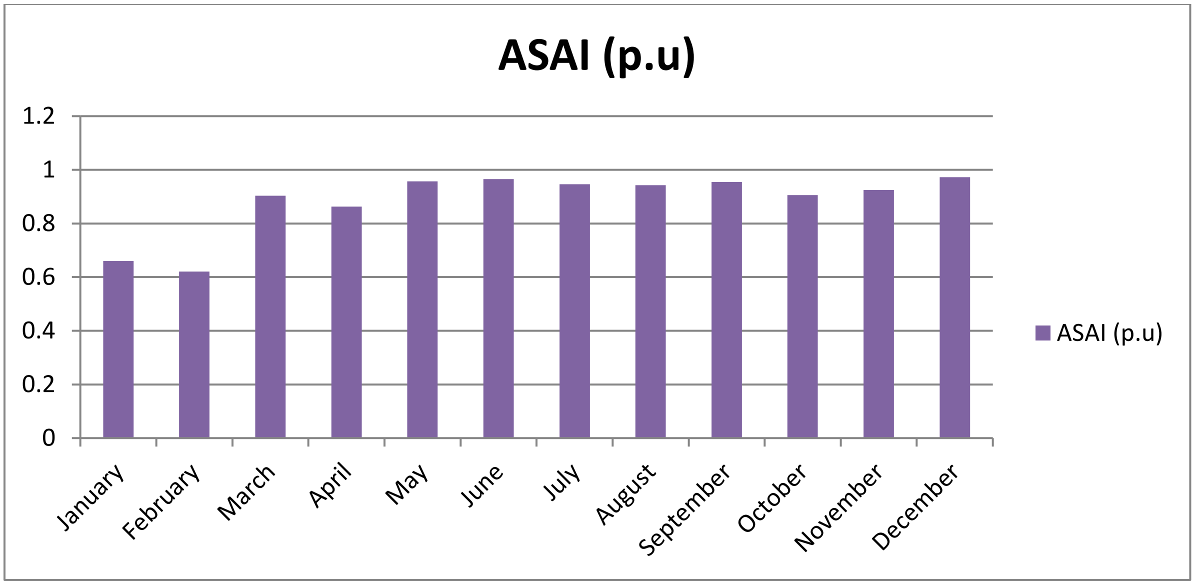

Figure 8: Bar Chart of ASAI for Twelve Months

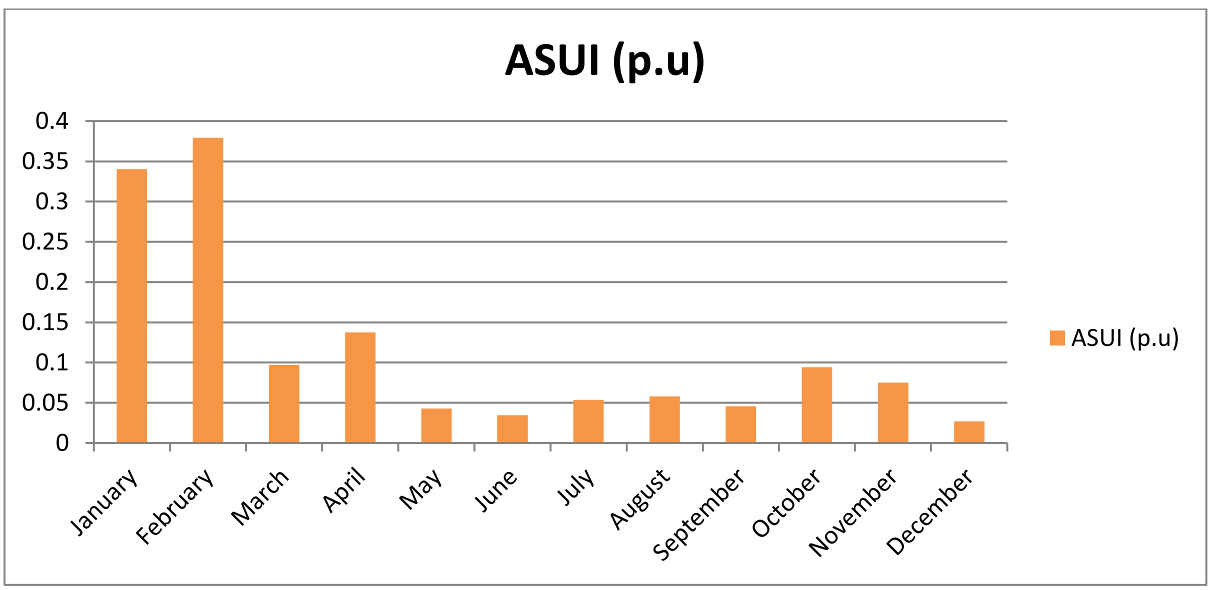

Figure 9: Bar Chart of ASUI for Twelve Months

Comparison of Results with Reliability Benchmark Indices

Reliability of a system is ethically ascertained by comparing it with the generally and professionally acceptable standard indices. Going by the IEEE standard which was developed from reports obtained from countries with relatively reliable systems, this work will compare the reliability of this case study distribution system with that of the standard systems. Comparison shall also be made with reliability results of Ayetoro 1 Substation, Aguda, Lagos, Nigeria (Akintola, 2017).

Table 4 shows the countries standards for SAIDI, SAIFI, CAIDI and ASAI. The considered substation has a SAIDI of 225 minutes/year which is ranked third highest when compared with others on the table, just behind United States and Ayetoro 1(Nigeria). The SAIFI of 0.709 interruptions per customer is the second lowest just behind Denmark with 0.5 interruptions/customer. This indicates that the substation has an acceptable SAIFI. CAIDI value of 272.286 minutes/outage which is more than twice United States value of 123 minutes/outage implies that the substation has a very high CAIDI value just behind Ayetoro 1(Nigeria) with 315 minutes/outage. The substation ASAI of Karu in Abuja substation is 88.46% made it just better than only Ayetoro 1(Nigeria) with 88.41% but performed very poorly when compared with other Utilities.

Since the substation has a good SAIFI value, but poor SAIDI and CAIDI values, the substation engineers should focus on reducing outage duration in order to improve SAIDI and CAIDI.

Table 4: Reliability Indices Benchmark (Rouse and Kelly 2011)

Country	SAIDI (Minutes/year)	SAIFI (Interruptions/Customer)	CAIDI (Minutes/Outage)	ASAI (%)
United States	240	1.5	123	99.91
UK	90	0.8	100	99.964
Italy	58	2.2	106	99.9991
Spain	104	2.2	114	99.968
Austria	72	0.9	112	99.97
Denmark	24	0.5	70	99.981
France	62	1	58	99.97
Ayetoro 1 (Nigeria)	**228** 228	**0.7239** 0.7239	**315** 315	**88.41** 88.41
Karu in Abuja substation (Nigeria)	225	0.709	272.286	88.46

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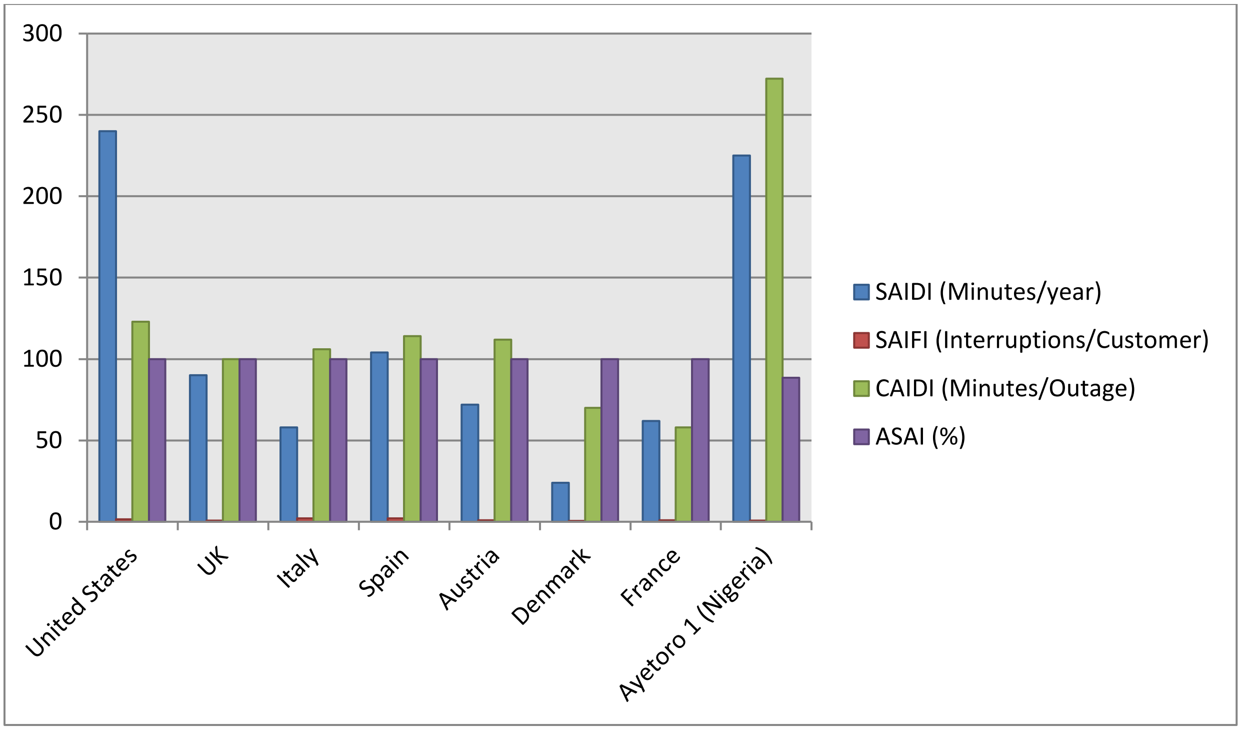

Figure 10: Bar Chart Showing Compared Reliability Indices

Conclusion

The analysis of Karu substation was carried out for 12 months from January to December 2018 based on component outage frequency and its duration. The method used for the reliability analysis is done using analytical and network reduction, also the model was carry out using **MATLAB 2015** software. The design of substation is single-end fed radial network that gives only one failure mode. Therefore this failures in the system can cause power supply interruption. The result shows that overloading and transformer failure are the most unavailable to the substation. Finally the overall reliability of the distribution system showed that the substation performance is poor with 88.46% compare with the standard benchmark.

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