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Reliability Evaluation of Secondary Distribution System in Garki–Area Three F.C.T, Abuja 33/11kV Distribution Substation

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ABSTRACT

This research work is centered on reliability assessment of the power apparatus of Garki – Area three 33/11KV distribution Substation as a case study. The aim is to established the frequency and the duration of the outages. Data were collected for the period of 12month (from April 2020 to March 2021) from the substation daily log book. We used Historical category of reliability analysis in assessing reliability of the distribution system. Hence, all data collected were computed and analyzed using fault tree analysis method, reliability block diagram and exponential modeling method. The results obtained shows that the total failure rate of the substation within the study period was 0.773896146. Feeder 5 with failure rate of 0.16874 has the highest outage of all the feeders. The reliability of the substation within the period of study was 0.461212611 which shows poor performances as compare to a standard bench mark of 0.999. The worst period of outages was in the month of May, 2020 due to rainy, windy and storm was at its peak. The total interruption as at May 2020 was 225.60 hours which is approximately 9 days total black out for the period of the study. While the best month was October 2020 with 96% availability of 92.11hours approximately 3days black out within the period of study. The substation is an injection substation originally design for 30MVA capacity with 2x 15MVA main power transformer, but during the period of this study one of the 15MVA Transformer was out of it service due to fault. Consequently, the major problem affecting the reliability of this substation is capacity shortage. Therefore, the substation needs to be improved and substation equipment need to be upgraded.
be provided for indexing purpose.

Keywords: reliability, failure rate, outage, frequency, duration, substation, distribution network

1.0. Introduction

The electric power distribution networks are constantly subjected to events that beget interruptions in the supply of energy to the end users. Such events which can be caused by a variety of factors such as bad weather conditions, contact between trees and live wires, equipment failure, unpredictable accidents and many more Sonoda, et al. (2018). These interruptions decrease the quality indices of the distribution infrastructures, causing poor reliability performances. It has therefore become imperative to develop techniques to improve the process of fault location in distribution networks. This work therefore emphatic a methodology for fault location in electric power distribution systems through the installation of fault indicators. The primary distribution network system used to convey the electrical power is called a feeder. Typically, in order to make it simpler to identify, feeders are named individually corresponding to the load area supplied Ramesh, et al. (2023). Selection of network system must meet the standards of requirements Mawengkang, et al. (2023): Electrical power systems provide electricity to humongous population around the world. There are three main processes to deliver electricity to end users. They are generation, transmission, and distribution entities. They work as a chain process, where each entity is required to pursue a reliable, secure, and stable service. Therefore, there is an increased interest for developing tools that allow the security evaluation of power systems, and ensure high levels of quality, reliability, and availability. By implication, available and uninterrupted electrical power at high quality is essential to the economic and industrial progress of a nation Salman et al. (2023). Regardless of the system arrangement, the reliability of power system is the most significant aspect of system planning Abdulkarim et al. (2018).

According to the NERC Act 2004 annual report NERC (2022), equipment failures are responsible for about 23% of major disturbances whilst protection mal operations are involved in about 42% of major disturbances whilst 35% of major disturbances are caused by human/ environmental factors. Thus, the protective system plays an important role in power system operation and in causing cascading events. In recent years, huge investments have been committed to technological advancements in protective systems.

Power distribution network system established mainly to provide adequate electricity supply to customers as economically as possible with reasonable assurance of reliability. Nowadays, the power distribution networks have grown exponentially in term of size and technology over the past few years. As a result, utility company must strive to ensure that the customer's reliability requirements are met with optimum strategic planning and lowest possible cost. The ability of the system to provide adequate supply of electricity energy determine by the term reliability. Reliability analysis of distribution network is not a new topic in electric power industries, a lot of studies and research have been carried out due to the increasing cost of blackouts and fault outages.

The availability of a reliable power supply at reasonable cost is crucial for the economic growth and development of a country Escalera, et al. (2018). Power Utilities Company nowadays try to enhance and develop their own strategies based on experience, trending, research, and studies to meet customer demands as economically as possible at reasonable service of reliability. An analysis throughout the world shows that around 90% of all customer reliability problems are due to the problem in distribution system. Thus, improving distribution reliability is the key to improving customer reliability Soma and Olalekan (2021). The concept of power-reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. Reliability assessment method for distribution system fall into two classes: simulation and analytical Li, et al. (2022). Simulation is the most flexible method but require extensive time in computational and uncertainty in precision. Analytical method can be further divided into network modelling and Markov modelling.

Abuja FCT distribution system is served from the Shiroro Transmission Station, presently known as North South Power Company Limited (NSPSL) Shiroro Hydo-Electric Station via 330 kV double circuit line to Abuja and 132 kV double circuit line which passes through Minna District as an alternative supply to the FCT Ikwu. (2005). Because Abuja metropolis distribution system is very strategic to the nation's prosperity and security, there is need to focus research attention on its reliability evaluation and how best to improve the quality of electricity delivery to consumers.

Abuja distribution network is undergoing a period of significant and fundamental reform in order to become competitive in the commercial market place. As a consequence, in 2006, additional Business Units were established to bring the services nearer to customers in the zone. These are Gwagwalada, Kubwa, and Karu Business units and Special Project Areas (SPAs) were created within the Abuja metropolis to improve service delivery. Thus, Abuja territorial area network has many districts and special project areas with several substations and injection substations. The core business of Abuja Electricity Distribution Company (ADC) is the delivery of electrical energy to its customers via continually expanding distribution network facilities, and the 33/11kV distribution substation is among the several substations/ injection substations being operated by ADC that the study being carried out.

2.0 Methodology

The Garki, Area 3 distribution substation in which the study was carried out is an indoor substation which forms an integral part of the entire Power Transmission and Distribution Network of Abuja Electricity Distribution Company Power System network. It is mostly referred to as secondary distribution substation or customer substation**.** Figure 1 present the schematic diagram of Garki Area 5 substation power system network.

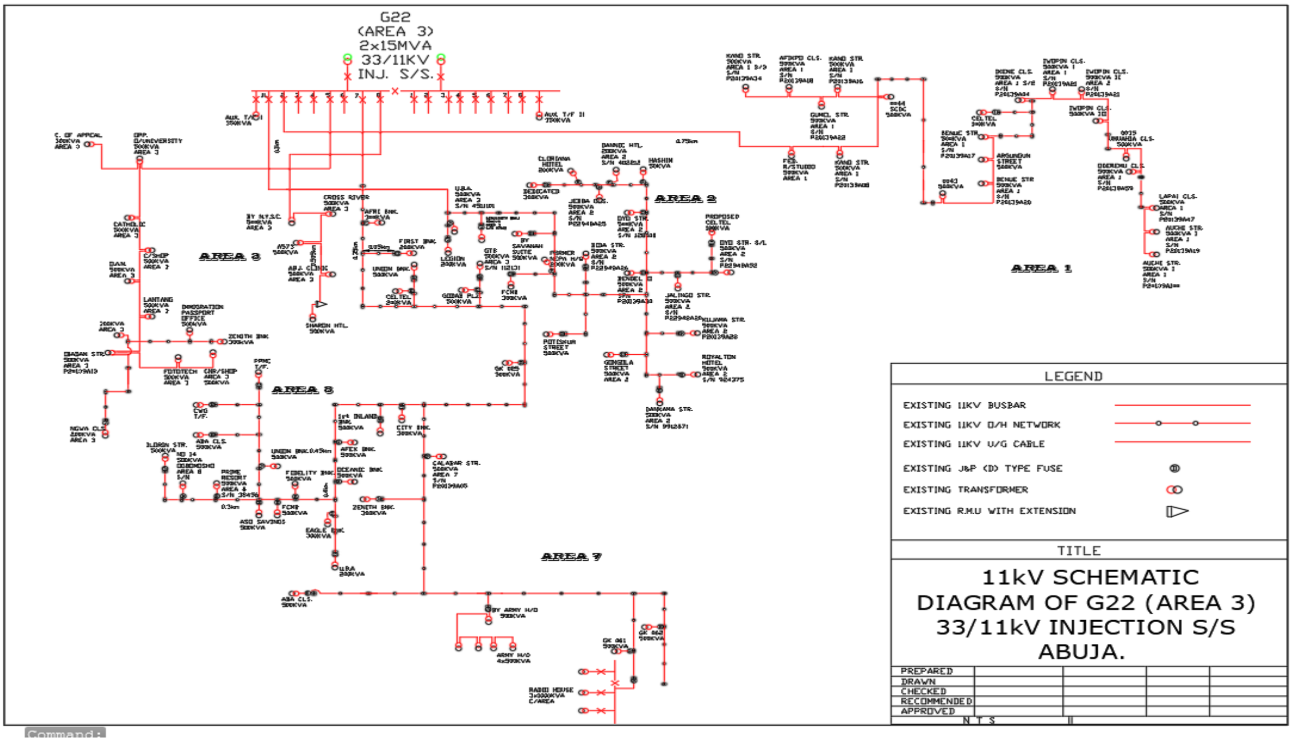

Figure 1: Schematic Diagram of Garki, Area 3 Substation Power System Network

The station is an injection substation originally design with 2x 15MVA transformer with five outgoing feeders and 99 numbers of distribution (11/0.415kKVA) transformer inclusive of two sub-service transformers (11/0.415 kV). The two-subservice transformer which serves as the domestic transformer of the substation receives supply even before switching ON the substation incoming feeder. This is to ensure that the substation auxiliaries which includes the rectifier unit, the battery charging unit, the current control panel, lighting and ventilation as well as the power supply unit 1 & 2 are successfully powered immediately. The output voltage from the sub-service transformer is sent to the low voltage apparatus distribution cabinet.

However, within the period of this study, one of the 15MVA Transformer was out of service due to fault. In the cause of study, we discovered that the total load available to be served by this substation is about 60MVA. More so, the substation is an 11kV substation formerly designed to handle the power requirements of AEDC costumers (living around Area 1, 2, 3, 7 and Area 8 of Abuja). The total numbers of customer are 5,171 and the breakdown according to the outgoing feeders is shown in Table 1.

Table 1: The breakdown of numbers of customer served by the substation.

S/N	Feeder name	Numbers of costumer
1	Outgoing Feeder 1	892
2	Outgoing Feeder 2	698
3	Outgoing Feeder 5	887
4	Outgoing Feeder 7	1901
5	Outgoing Feeder 8	793
	Total	5,171

2.1 Fault Tree Diagram of the Substation

Figure 2 illustrates the fault tree diagram of the substation. In this diagram, failure of thetop event (unavailability of the substation) can only occur when failure of either the incoming feeder, outgoing feeder 1, Outgoing Feeder 2, Outgoing Feeder 5, Outgoing Feeder 7, and outgoing feeder 8 together, earth fault, over-current fault, current cut-off, OCB failure, single phasing, voltage transformer, sub-service transformer, current transformers, isolator failure, as well as battery failure and rectifier failure together. This implies that failure of rectifier alone cannot lead to substation unavailability. Likewise, failure of battery alone cannot lead to substation unavailability.

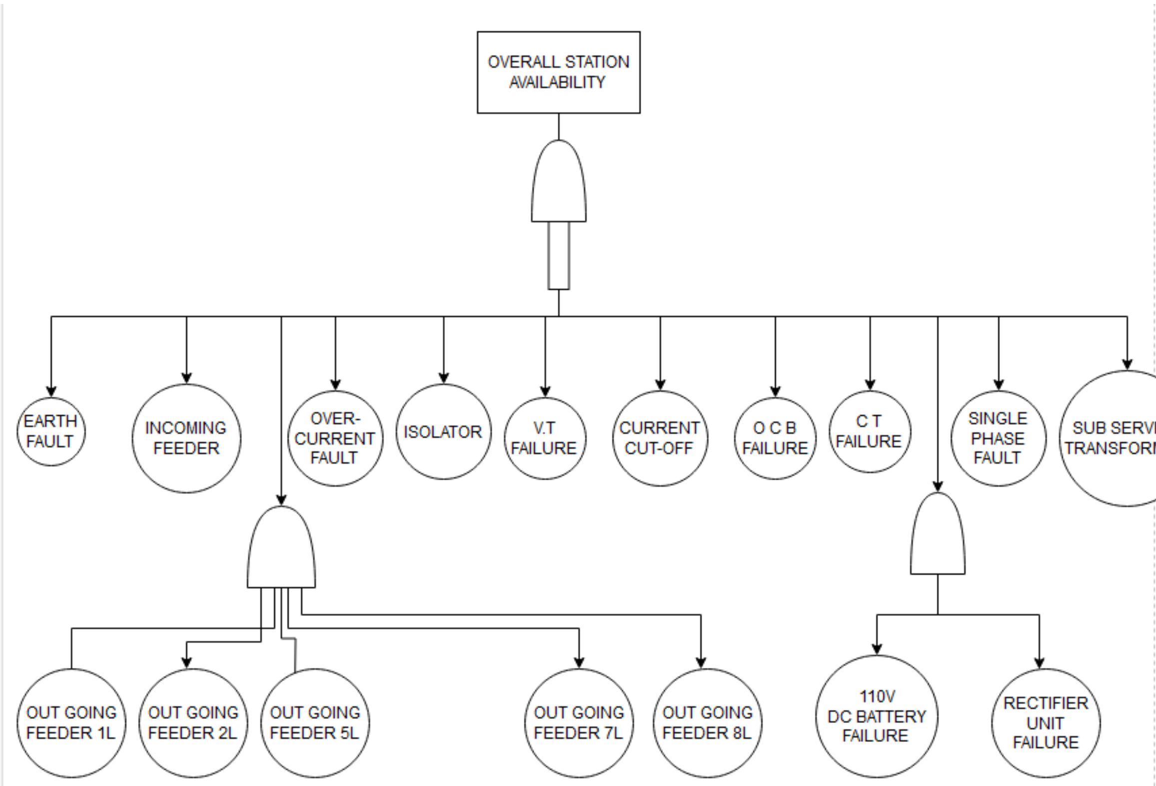

Figure 2: Fault Tree Diagram of G22 Injection Substation.

2.2 Reliability Block Diagram (RBD) of Garki – Area Three F.C.T, Abuja 33/11kv Distribution Substation Components.

The system consists of 17 blocks. The Incoming Feeder, Earth Fault Relay, Overcurrent Relay, Current Cut-off Relay, 11kV Oil Circuit Breaker, Pole Discrepancy Protection Relay (for Single Phasing Fault), Voltage Transformer, Sub Service Transformer, Current Transformers and Manual isolator on Outgoing Feeders can be considered to be connected in series because failure of one of these components results in the failure of the whole network Figure 3. However, the Outgoing Feeder 1, Outgoing Feeder 2, Outgoing Feeder 5, Outgoing Feeder 7 and Outgoing Feeder 8 are in parallel. Also, the 110V DC Battery Unit and Rectifier Unit can be considered to be connected in parallel because failure of the battery unit cannot result to failure of the system except when there isno power to the substation itself. Also, failure of the rectifier unit cannot result to failure of the system as the battery backup immediately comes into play. Therefore, both battery unit and rectifier unit must fail before the entire network fails.

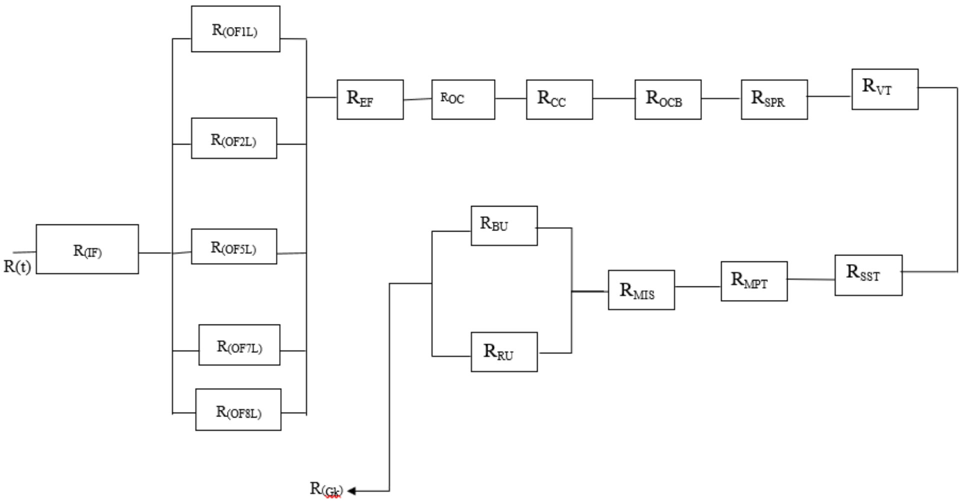

Figure 3: Reliability Block Diagram of Garki- Area Three F.C.T, Abuja 33/11kV Distribution Substation

The equivalent reliability block diagram of Garki – Area Three F.C.T, Abuja 33/11kV Distribution Substation is represented in figure 2 and the reliability of each component is represented as indicated in the block diagram.

2.3 *Development of Reliability Model of the Substation using RBD.*

The overall reliability of the substation from the block diagram can be expressed in (1)

$$R_{GK} = R_{IF} \times (R_{OF1L}//R_{OF2}//R_{OF5}//R_{OF7}//R_{OF8}) \times R_{EF} \times R_{CC} \times R_{OC} \times R_{OCB} \times R_{SPR} \times R_{VT} \times R_{SST} \times R_{CT} \times R_{MIS}\ X\ \ R_{BU}//R_{RU} \qquad (1)$$

Using series, parallel and redundancy reliability block diagram theorems, the reliabilitymodel of the substation can be presented in (2);

$$R_{GK} = R_{IF} \times (1 - (1 - R_{OF1L})(1 - R_{OF2})(1 - R_{OF5})(1 - R_{OF7})(1 - R_{OF8}) \times R_{EF} \times R_{CC} \times R_{OC} \times R_{OCB} \times R_{SPR} \times R_{VT} \times R_{SST} \times R_{CT} \times R_{MIS}[1 - (1 - R_{BU})(1 - R_{RU})] \qquad (2)$$

From the reliability expression given in (eqn 3), it is assumed that the failure rate follows exponential distribution,

$$R(t) = e^{-\lambda t} \qquad (3)$$

therefore; substituting the components failure rates in equation (2), the general reliability equation of the distribution substation can be generally expressed in (4);

$$R_{GK} = e^{-\lambda \mathrm{IFt}} \times (1\ \left(1 - e^{-\lambda OF1Lt}\right)\left(1 - e^{-\lambda OF2t}\right)\left(1 - e^{-\lambda OF5t}\right)\left(1 - e^{-\lambda OF7t}\right)\left(1 - e^{-\lambda OF8t}\right) \times e^{-\lambda EFt} \times e^{-\lambda OCt} \times e^{-\lambda CCt} \times e^{-\lambda CBt} \times e^{-\lambda SPt} \times e^{-\lambda VTt} \times e^{-\lambda SSTt} \times e^{-\lambda CTt} \times e^{-\lambda ISt}\left[1\left(1 - e^{-\lambda BUt}\right)\left(1e^{-\lambda RUt}\right)\right] \qquad (4)$$

2.4 Mathematical Expression o f the Reliability of the Entire Garki Substation.

The mathematical expression of the reliability of the entire power substation can be represented using exponential distribution model. With reference to equation (3); Where, ($e^{-\lambda t}$) = 0.773896146 and is the total failure rate of the entire power substation.

$$R_{GK} = e^{-0.773896146t} \quad (5)$$

$$Failure\ rate, \lambda = \frac{Number\ of\ times\ failure\ occurred}{Number\ of\ units - hours\ of\ operation} \quad (6)$$

3.0. Results and Discussion

The detailed reliability analysis of the studied carried out in Garki – Area three 33/11KV distribution Substation distribution substation is presented and discussed in this section. The data collected from the substation were used to estimate the reliability indices of the components in the substation. More so, the overall reliability of the substation and the customer reliability indices of the system were determined.

3.1 Failure Rate Evaluation of the Components

The monthly component failure rates for Garki – Area three 33/11KV distribution Substation were calculated using (6). The results of these analysis are shown in the Tables 1 to 2. Each of these tables contains the computed failure rates for the components highlighted earlier. In Table 2 the summary of outages on the incoming feeder from April, 2020 to march, 2021 was recorded. It shows the number or frequency of outages, outage time and total hours for 12 months duration and its monthly failure rate were also calculated and tabulated alongside. During the period covered, there was no outage on the incoming feeder for the months of December 2021. The highest frequency of outages was recorded in March, 2021 while the highest outage time was recorded in April, 2020 as shown in Table 2.

Table 2 Summary of Outages on Incoming Feeder.

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
April	6	188.5	720	0.008333333
May	10	14.35	744	0.013441
June	7	16.3	720	0.009722222
July	10	15.4	744	0.013441
August	5	4.3	744	0.00672043
September	3	3.5	720	0.004166666
October	9	48.2	744	0.0120968
November	6	27.3	720	0.008333333
December	0	26.3	744	0
January	12	48.5	744	0.016129032
February	12	47.75	696	0.0172414
March	17	51.3	744	0.02284947
Total				**0.132474687**

In Table 3 the summary of outages on the Outgoing Feeder 1, from April, 2020 to march, 2021 was recorded. It shows the number or frequency of outages, outage time and total hours for 12 months duration and its monthly failure rate were also calculated and tabulated alongside. During the period covered, there was no outage on the Outgoing Feeder 1 for the months of June 2020. The highest frequency of outages was recorded in May, 2020 while the highest outage time was recorded in July, 2020 as shown in Table 3

Table: 3 Summary of Outages on Outgoing Feeder 1.

Month	No. of Outages	Outage Time (Hrs)	Total Hours	Failure Rate (λ)
April	6	17.98	720	0.008333333
May	7	21.216	744	0.009408602
June	0	0	720	0
July	6	22.95	744	0.008064516
August	4	4.6833	744	0.005376344
September	5	21.35	720	0.006944444
October	1	0.4	744	0.001344086
November	4	19.4833	720	0.005555556
December	3	7.3	744	0.004032258
January	3	13.35	744	0.004032258
February	5	6.7166	696	0.007183908
March	11	36.95	744	0.014784946
Total				**0.075060252**

Table 4: Values of $e^{-\lambda t}$ from the above expression.

Component	**Failure Rate (λ)**	$e^{-\lambda t}$
Incoming Feeder (λ_{IF})	0.132474687	0.875925106
Outgoing Feeder 1 (λOF1L)	0.075060252	0.92768759
Outgoing Feeder 2 ($\lambda 0F2$)	0.09543628	0.90897628
Outgoing Feeder 5 ($\lambda\ OF5$)	0.168739958	0.84472854
Outgoing Feeder 7 ($\lambda 0F7$)	0.109952416	0.895876764
Outgoing Feeder 8 ($\lambda\ OF8$)	0.065056853	0.93701419
Earth Fault Relay (λEF)	0.081902731	0.921361574
Over-Current Relay ($\lambda\ OC$)	0.01374	0.986353963
Current Cut-off Relay (λCC)	0.002777778	0.997226076
11kV Oil Circuit Breaker (λCB)	0.016487455	0.983647719
Single Phasing Fault (λSP)	0.0026881	0.99731551
Voltage Transformer (1VT & 2VT) (λVT)	0.002777778	0.997226076
Sub-Service Transformer (1SST & 2SST) (λSST)	0.001388889	0.998612075
Rectifier unit Failure (λRU)	0.00138	0.998620952
Manual Isolator (λIS)	0.001388889	0.998612075
120V DC Battery (λBU)	0.0013	0.998700845
33/11KV mains power transformer (λMPT)	0.00134408	0.998656823

Therefore,

$R_{(Gk)}$ = (0.875925106) [1- (1-0.92768759) (1- 0.90897628) (1- 0.84472854) (1- 0.895876764) (1- 0.93701419)] (0.921361574) (0.986353963) (0.997226076) (0.983647719) (0.99731551) (0.997226076) (0.998612075) (0.998656823) (0.998612075) ([1- (1-0.998700845) (1-

0.998620952)]

$R_{(Gk)}$ = (0.875925106) (0.999993) (0.921361574) (0.986353963) (0.997226076) (0.983647719) (0.99731551) (0.997226076) (0.998612075) (0.998612075) (0.998612075) (0.000001792)

Hence,

$R_{(Gk)}$ = 0.461212611

3.2. Customer Reliability Indices Evaluation

The computed customer reliability indices (SAIFI, SAIDI, CAIDI. ASAI AND ASUI) were calculated using global indices equations respectively with the 5,171 total numbers of customer serviced by the substation. The results are computed and presented in Figures 4 to 8. The major assumption in computing the indices, in addition to the ones stated previously, is that the number of customers supplied from the substation was considered. The computed results of the global indices are presented in figures 4 to 8 respectively and as follow:
From Figure 5, it presents the total network characteristic performance of the system, the feeders and the components reliability. It can be deduced from the figure that the best feeder is the Feeder 8 and follow by Feeder 1, while the fairly performance feeder are Feeders 5 and 7 respectively. The reliability of components was all operating within an average except the earth fault relay which operate blow the average. Figure 6 present the substation SAIDI for the period of one year. The month of April has the highest interruption duration, follow by July, while February has the least follow by December. In figure 6 details the frequent interruption, May has the highest number of interruption, while the least is February follow by October. The total number of highest customers affected interruption duration occurred in the month of April as shown figure7. The unavailability of the network hint in the of April, while the most availability index was recorded against the month of October, November, December and February respectively as shown in figures 8 and 9.

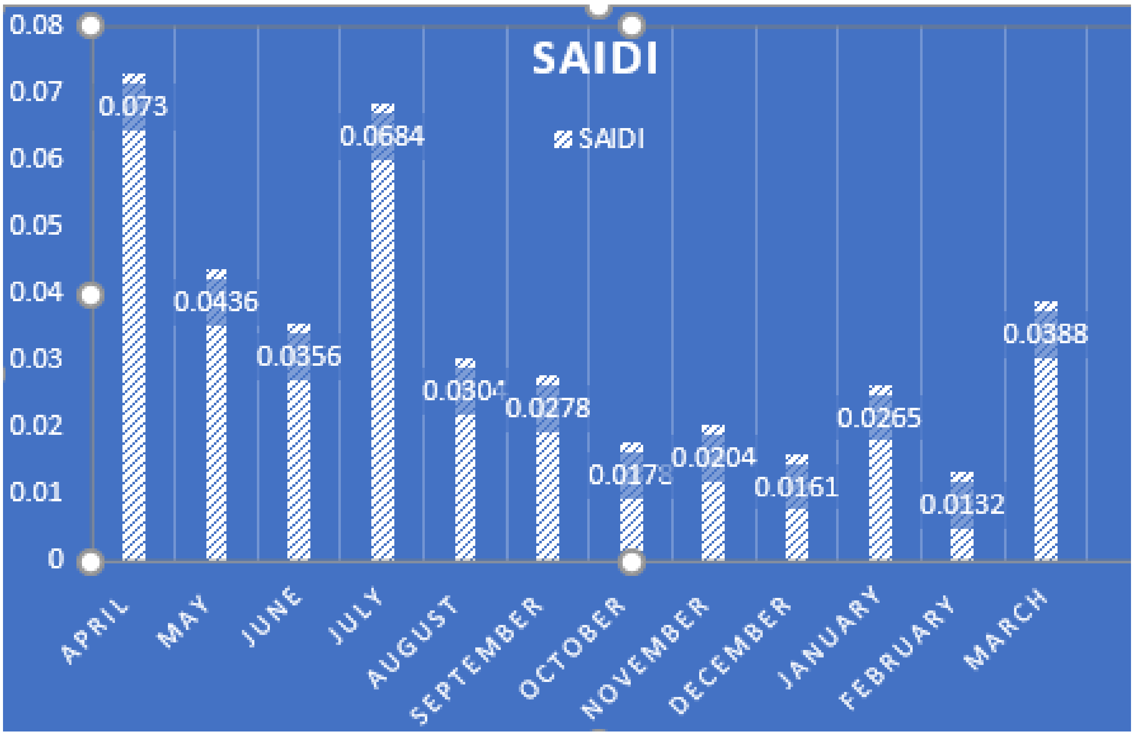

Figure 4: System Average Interruption Duration Index (SAIDI) for one year.

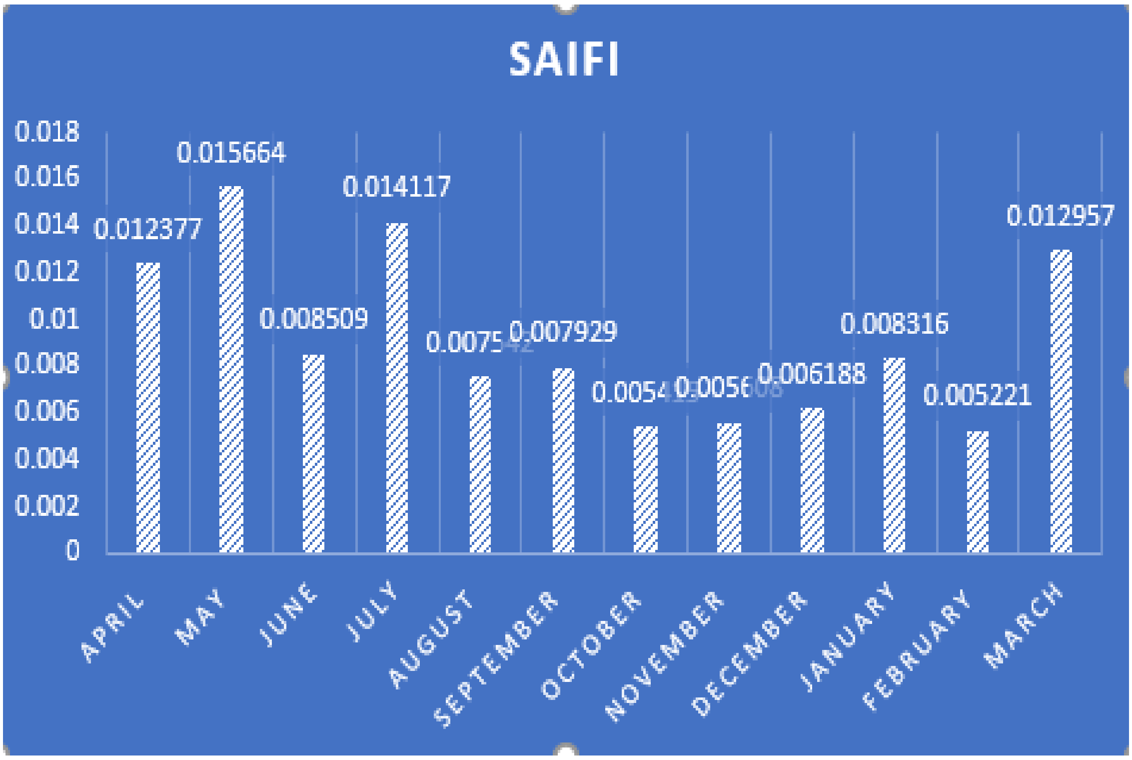

Figure 5: System Average Interruption Frequency Index (SAIFI) for one year.

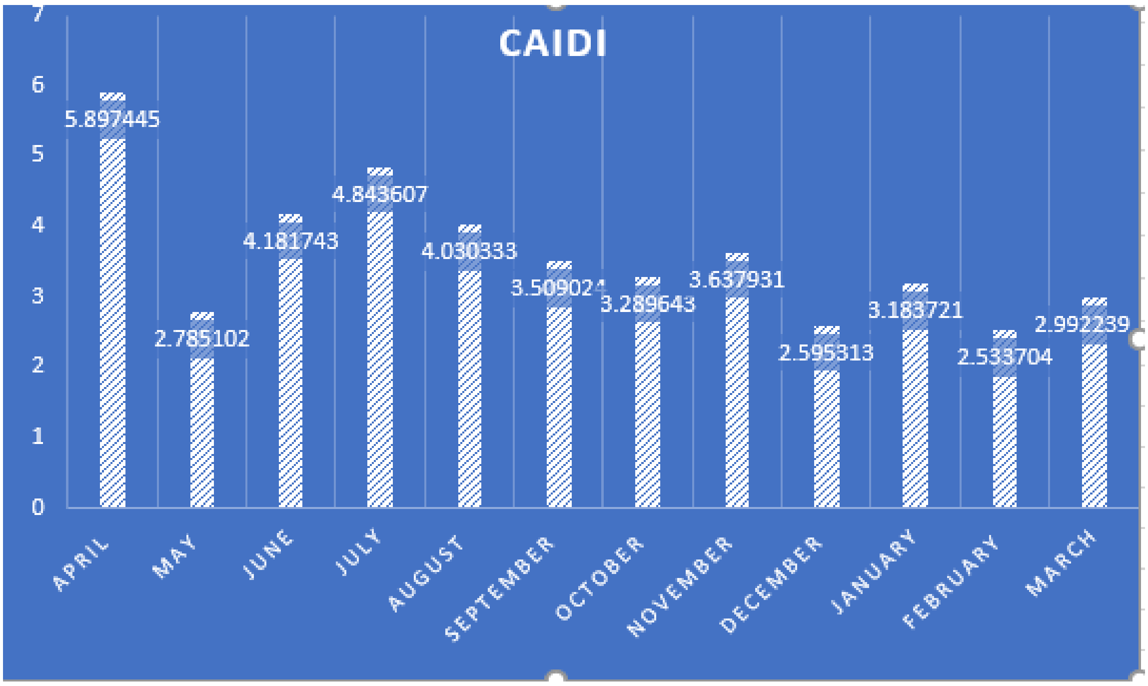

Figure 6: Customer Average Interruption Duration Index (CAIDI) for one year.

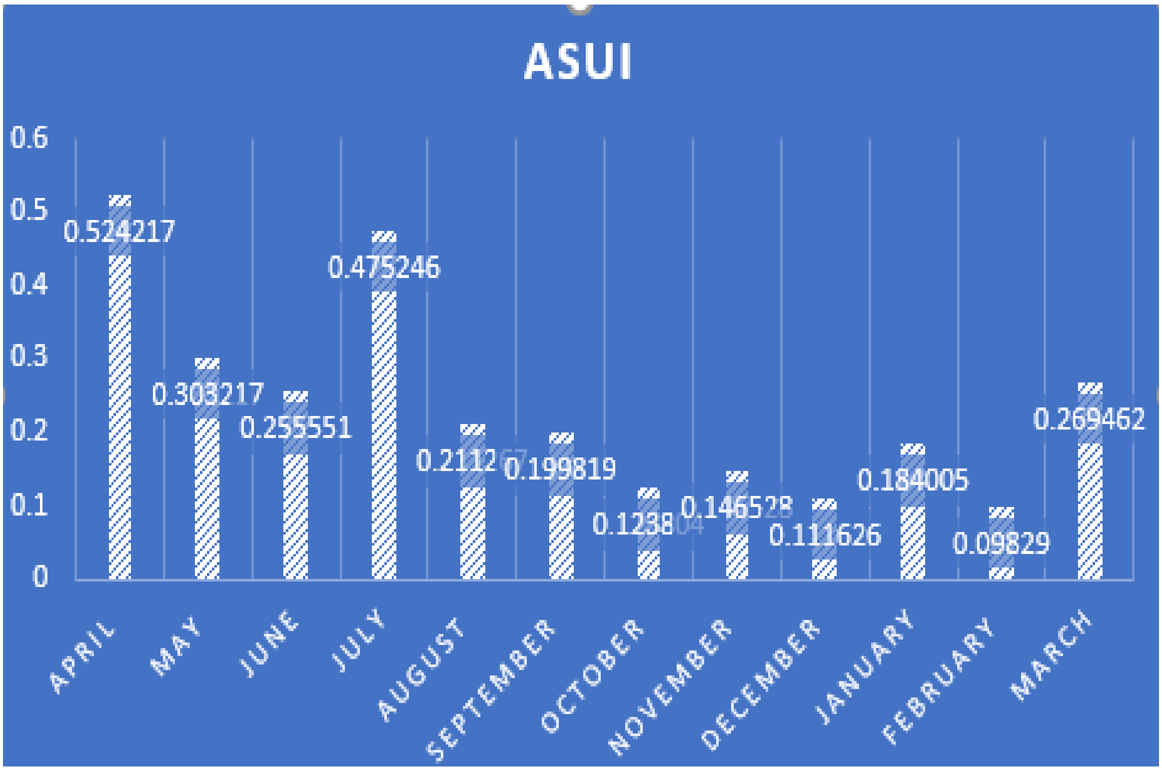

Figure 7: Average System Unavailability Index (ASUI) for one year.

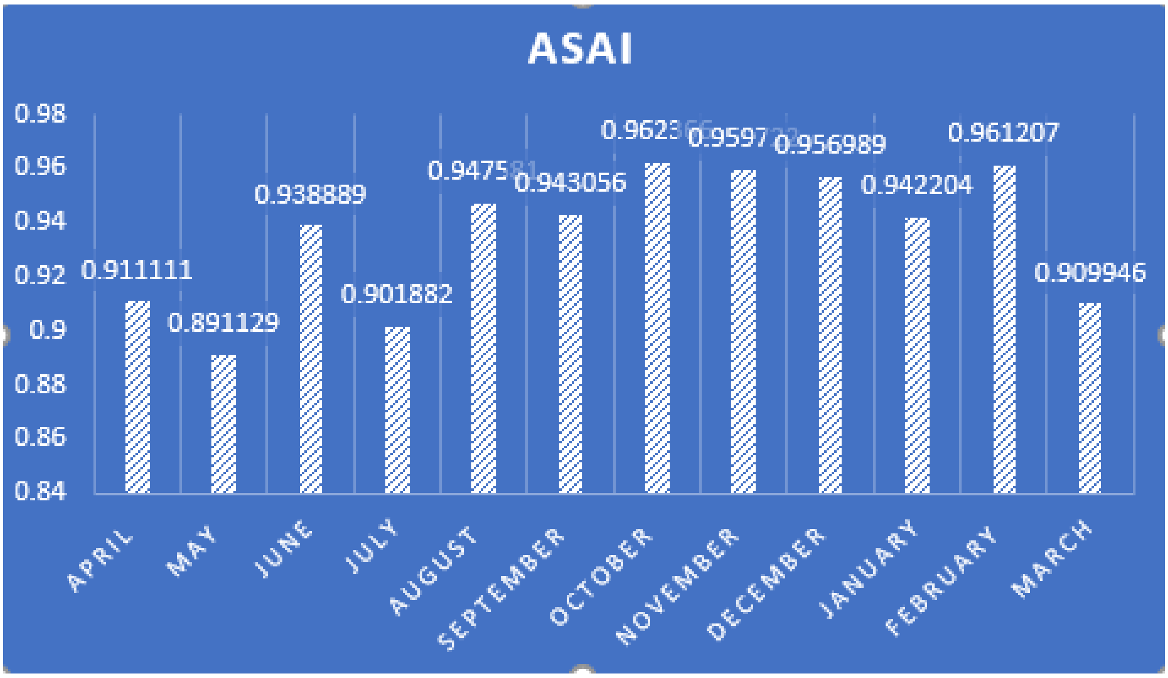

Figure 8: Average System Availability Index (ASAI) for one year.

4.0 Conclusions

The data and the information presented in this paper are the true reflection of the Abuja Distribution Network characteristics and activities as from April 2020 to March 2021 respectively. With this support, operational efficiencies and communications are improved; thereby helping to reduce dispatching bottlenecks that can occur during high-volume outage condition. This in turn improved the performances and reliability of the system. This study, evaluating reliability of power equipment in power system using Garki – Area three 33/11KV distribution Substation, Abuja F.C.T as a case study, is able to identify from the component reliability assessment, that the outgoing feeder 5 contributed most to the substation unavailability that resulted to loss of supply to the customers. More so, the overall reliability of the substation which was modelled and analysed by means of fault tree diagram and reliability block diagram stand at 0.461212611 equivalent to 46.12% of the system probability to failure. In addition, during the period of study, the worst availability is May 2020 owning to the fact the rain and wind storm was at its peak. The total interruption as at May 2020 was 225.60 hours which is approximately 9 days total black out for the period of the study. While the best month was October 2020 with 96% availability of 92.11hours approximately 3days black out within the period of study.

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