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Statistical Analysis of Feeders' Reliability Metrics of the Ugbowo 2x15 MVA, 33/11 kV Electric Power Distribution System

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Abstract: *This paper evaluates the reliability metrics of the feeders of Ugbowo 2x15 MVA, 33/11 kV distribution network. Annual data of the daily power interruption from August 2019 to July 2020 of the feeders were collected from the network and the daily outages were computed for the monthly and yearly reliability of the feeders. The network modeled in ETAP software with the outdoor substations in composite form and the annual data collected were analyzed using the LPI technique to estimate the reliability indices of the network and also, simulations were run to assess the SPI of the network for an in-depth assessment. The annual and monthly failure rates, MTTR, MTBF, SAIFI, SAIDI, ASAI, etc. were evaluated. The results obtained from the analyses of the 11 kV feeders of the substation interpreted in Microsoft Excel showed that the availability is very poor for the period under investigation with Uselu feeder having 33.22% of power availability, FGGC feeder 30.69%, Eguaedaiken feeder 26.79% and Ugbowo feeder 23.69% in the network. The failure rate results also revealed that Ugbowo 11 kV feeder had the highest failure rate of 45.99%, followed by Eguaedaiken feeder 44.39%, FGGC feeder 43.88% and Uselu feeder 41.26%. Furthermore, the SPI of the system revealed that the yearly total outage duration (SAIDI), outage frequency (SAIFI) and percentage availability (ASAI) were 175.7504 hours, 3.3780 f/cu.yr and 97.99% which is a far cry from the international acceptable standard value (IASV) of 2.5 hours, 0.01 f/cu.yr and 99.99% respectively which showed that the power supply in the network is unreliable and unpredictable.*

Keywords: *Availability, Failure rate, Frequency of outage, Feeder, Reliability indices.*

1. INTRODUCTION

The satisfaction and importance of availability of electricity supply to consumers at the time of usage cannot be overemphasized. A reliable electricity supplies enhances productivity and minimizes waste in any system, thereby improving the standard of living and socioeconomic wellbeing of the citizens.

The power supply in the Nigerian power system has been epileptic for the past decades, before the power reform embarked upon by the Nigerian government which aimed at improving the total megawatts of electricity generated, transmitted and distributed to Nigerians [1]. But after the power reform, the electricity is still in a state of epilepsy. One of the reasons the power reform was embarked upon by the Nigeria government was to restructure the power sector for a reliable electricity supply. This is one of the most vital factors for the nation's economy growth and development. A reliable electricity supply is a foundation for ubiquitous use of electricity by the consumers [2]. The Nigerian citizens have been in a state of blackout and all efforts of the stakeholder in the power sector have not yield any meaningful fruit in the positive direction. Every part or section of the country is currently facing epileptic nature of electricity supply from the Nigerian power sector, especially the distribution system.

The regimented load shedding currently practiced has taken over the distribution network today. A situation where electricity is supplied for a given period to a given area and being in blackout for a scheduled time is not healthy for the economy, health sector and the security system of the country. According to [3] reliability is not new in the electrical power industry but has become a matter of serious concern to scientists and engineers in the past decades and even now due to impact of blackout and downtime, thus making the Nigerian market a suitable domain for generator dealers around the world. The reasons for frequent power interruptions are not far from scheduled and unscheduled (forced) outages [4]. According to [4] these unscheduled interruptions are commonly predominant with conventional electric power distribution network. Consequently, reliability of a system is defined as the probability of a system or any of its components to perform its function adequately [5]. Since frequent power outage (cut) is one of the major causes of poor performances of the distribution network, then its reliability assessment cannot be overemphasized.

Reliability assessment is an important tool for determining the performance of the power utility industry [6]. Reliability assessment is carried out by making use of reliability metrics or indices to evaluate the historical data collected from the utility station(s) or its component. Therefore, reliability metrics or indices are statistical data that help in computing and investigating the reliability characteristics for an entire system, operating section, substation service zone, feeders, substation components, etc. [7]. The System Performance Indices (SPI) are statistical tools that are very useful for assessing the severity of system failures in the past, present and even in future reliability prediction analysis.

Reliability estimation of power systems especially the distribution network reveals the System Performance Indices (SPI) in regards to the system operating state, customers' satisfaction and quality of the electricity supply at load points. Being able to proactively predict failure [8] of a system or its component will help to create preventive or routine maintenance method to forestall total breakdown and prolong downtime in the system. Therefore, accurately estimating the reliability of a system or its component will determine the failure of a system or when a system will fail or its component depending on it usage. Distribution network outages have localized effects compared to generating station and transmission network outages that are system wide. Hence, less attention has been given to the distribution reliability modeling and estimation. But over time, it has been observed that the analysis of customers' failure statistics of most utilities showed that the distribution system makes the greatest individual contribution to the unavailability of electricity supplied to consumers [9]. Consequently, this research work attempts to measure the system performance and reliability indices of the 11 kV feeders of Ugbowo 2x15 MVA, 33/11 kV electric distribution system using defined statistical reliability metrics.

2. MATERIALS AND METHODS

The materials and methods adopted in this research work are highlighted in the following subsections.

2.1 MATERIALS

The research investigation carried out involves personal consultation and interview of electric energy consumers of the network and the staff of Benin Electricity Distribution Company (BEDC) domiciled in the Ugbowo 2x15 MVA, 33/11 kV injection substation. Data was collected for the period of twelve (12) months (August 2019 to July 2020) from the following materials of the injection substation:

i. Daily hourly load scheduled logbook kept in the Ugbowo 2x15 MVA, 33/11 kV injection substation, Ugbowo, Nigeria;
ii. Daily shift report logbook kept in the Ugbowo 2x15 MVA, 33/11 kV injection substation;
iii. Daily report logbook of faults recorded in the distribution network ;
iv. Personal interaction with the competent distribution system operators (DSOs) for technical guidance and information;
v. Physical inspection of the recording meters of the panels of the Ugbowo 2x15 MVA, 33/11 kV injection substation;
vi. Software.

2.2 METHODS

The daily outage data of the unscheduled and scheduled outages of the Ugbowo 2x15 MVA, 33/11 kV injection substation were obtained from the substation logbooks for the period under investigation for the 11 kV feeders connected to 33/11 kV, 2x15 MVA Power Transformers. The data collected from the injection substation logbooks were analyzed using Load Point Indices (LPI) and System Performance Indices (SPI) to calculate the failure rate, mean time to repair, mean time to failure, mean time between failure, availability, SAIFI, SAIDI, ASAI, etc and the results were deduced using Microsoft Excel.

2.3 SINGLE LINE DIAGRAM OF UGBOWO 2X15 MVA, 33/11 KV INJECTION SUBSTATION IN ETAP MODEL

The single line diagram (SLD) of the Ugbowo 2x15 MVA, 33/11 kV distribution network modeled in Electrical Transient and Analysis Program (ETAP) with all the four (4) 11 kV feeders and their associated outdoor substations in composite form is as shown in Figure 1. The Ugbowo injection substation gets it electricity supply from the Oluku 33 kV feeder. The Oluku indoor 33 kV feeder control panels have two Incomers called Incomer 1 and Incomer 2 which control and distribute electricity to the Ugbowo 2x15 MVA, 33/11 kV distribution network. The Ugbowo 2x15 MVA, 33/11 kV distribution network in turn have four (4) 11 kV feeders; two (2) each connected to Incomer 1 and Incomer 2 with 15 MVA, 33/11 kV power transformer each. Incomer 1 has two (2) 11 kV feeders which are FGGC 11 kV feeder and Uselu 11 kV feeder; while Incomer 2 has two (2) 11 kV feeders which are Eguaedaiken 11 kV feeder and Ugbowo 11 kV feeder. The

Oluku 33 kV feeder which feeds the Ugbowo 2x15 MVA, 33/11 kV electric power distribution network gets it electricity supply from Ihovbor Power Station, Ihovbor, Benin City, Nigeria. The Ihovbor Power Station is a National Integrated Power Project (NIPP) built to cater for insufficient power in the country.

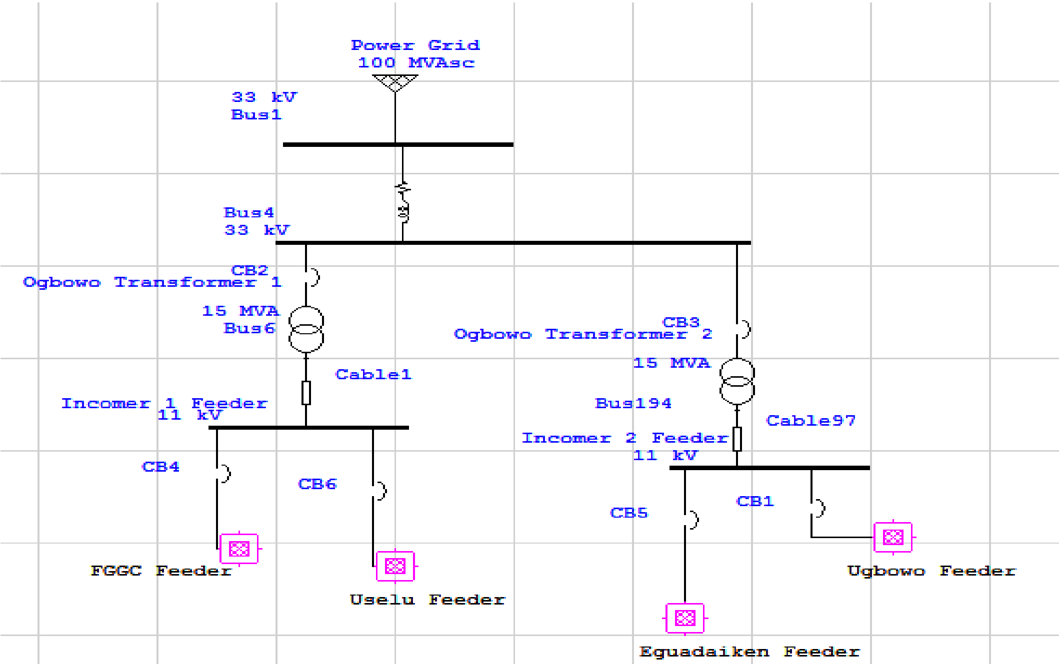

Figure 1: Single Line Diagram of Ugbowo 2x15 MVA, 33/11 kV Electric Power Distribution Network Model in ETAP

2.4 RELIABILITY INDICES

Reliability indices (RI) are essential metrics for evaluating the distribution network performance. The reliability metrics are statistical tool used to analyze data of a well-designed set of loads, component or customers' satisfaction. Most reliability characteristics of the component, feeder or entire system are evaluated by the statistical tool. Power companies commonly use two reliability indices which are frequency and duration, to assess the performance of their system or component. The following are brief description of reliability and customer oriented indices:

2.4.1 Failure Rate (λ): is defined as the basic index of reliability which measure the frequency at which faults occur in the system.

$$Failure\ Rate\ (\lambda) = \frac{Frequency\ of\ Outage/year\ or\ month}{Total\ Hours\ of\ Availability/year\ or\ month} \quad (1)$$

2.4.2 Mean Time to Failure ($MTTF$): is a reliability metrics that defined the function of non-repairable equipment in a given system.

$$Mean\ Time\ to\ Failure\ (MTTF) = \frac{1}{\lambda} \quad (2)$$

2.4.3 Mean Time to Repair ($MTTR$): it is the average time needed to repair a faulty system or component and bring it back to its full operating state.

$$MTTR = \frac{Total\ System\ Downtime}{Number\ of\ Outage} = \frac{1}{\mu} \quad (3)$$

2.4.4 Mean Time between Failure ($MTBF$): it is the average time interval between consecutive failures of a repairable system or component.

$$MTBF = \frac{Total\ System\ Operating\ Hours}{Number\ of\ Outage} = MTTF + MTTR \quad (4)$$

2.4.5 Availability (A): is the probability that an equipment or system will be available to perform the desired function.

$$Availability\ (A) = \frac{Uptime}{Expected\ Uptime} = \frac{\mu}{\lambda+\mu} = \frac{MTBF-MTTR}{MTBF} = \frac{MTTF}{MTTF+MTTR} \quad (5)$$

2.4.6 Unavailability (U): it is the average time interval in which a system or component is not available to perform the required function.

$$Unavailability\ (U) = \frac{MTTR}{MTTF+MTTR} = 1 - \frac{MTTF}{MTTF+MTTR} = 1 - A \quad (6)$$

2.4.7 Reliability (R): it is the probability that a system or device will perform a function correctly when required to do so.

$$R = e^{-\lambda t} \quad (7)$$

$Where\ \lambda = failure\ rate, t = time\ of\ outage$

2.4.8 System Average Interruption Frequency Index ($SAIFI$): it is the measure of how many sustained interruptions for a consumer will experience during the period of a year.

$$SAIFI = \frac{Frequency\ of\ Outage}{Number\ of\ Customer\ Served} = \frac{\sum \lambda iNi}{INi} \quad (8)$$

2.4.9 System Average Interruption Duration Index ($SAIDI$): it is defined as the measure of how many interruption hours an average customer will experience during the period of one year.

$$SAIDI = \frac{Total\ Outage\ Duration\ in\ Hours}{Number\ of\ Customer\ Served} = \frac{\sum UiNi}{\varepsilon Ni} \quad (9)$$

2.4.10 Customer Average Interruption Duration Index (CAIDI): it is define as the average length of an interruption as regard the number of customers affected for a specific period of time.

$$CAIDI = \frac{Sum\ of\ Customer\ Interruption\ Duration}{Total\ Number\ of\ Customer\ Interruption} = \frac{SAIDI}{SAIFI} = \frac{\sum UiNi}{\epsilon\lambda iNi} \quad (10)$$

2.4.11 Average Service Availability Index ($ASAI$): it is define as the measure of the average availability of the distribution network services to customers.

$$ASAI = \frac{Customer\ Hours\ of\ Available\ Service}{Customer\ Hours\ Demanded} = \frac{INix8760 - \epsilon UiNi}{INix8760} \quad (11)$$

2.4.12 Average Service Unavailability Index ($ASUI$): it is define as the measure of the average unavailability of the distribution system services to customers.

$$ASUI = \frac{Customer\ Hours\ of\ Unavailable\ Service}{Customer\ Hours\ Demanded} = 1 - ASAI = \frac{\sum UiNi}{INix8760} \quad (12)$$

3 RESULTS AND DISCUSSIONS

The following section presented the results and discussion of the research work.

3.1 RESULTS

This subsection presents the results obtained from the Ugbowo 2x15 MVA, 33/11 kV injection substation reliability assessment of the network. The results involved customers oriented, load point reliability and system performance indices and, the discussion is carried out in the subsequent subsection of this research work.

Table 1: Failure Rate of each Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation

Months / Feeder	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
FGGC	0.437	0.571	0.404	0.406	0.395	0.425	0.372	0.520	0.682	0.436	0.449	0.371
Uselu	0.307	0.382	0.404	0.371	0.483	0.405	0.351	0.544	0.402	0.522	0.505	0.430
Eguaed.	0.461	0.495	0.515	0.605	0.295	0.513	0.497	0.398	0.367	0.416	0.578	0.416
Ugbowo	0.495	0.457	0.429	0.434	0.412	0.558	0.497	0.480	0.396	0.512	0.514	0.392

Table 2: Reliability Indices from August 2019 to July 2020

AUGUST 2019 TO JULY 2020							
Description / Feeders	**Frequency of Outages**	**Outage Duration (Hrs)**	**Failure Rate (λ)**	**MTBF**	**MTTF**	**MTTR**	**Availability (A)**
FGGC	1183	6088	0.4388	7.4251	2.2789	5.1462	0.3069
Uselu	1204	5866	0.4126	7.2957	2.4236	4.8721	0.3322
Eguaedaiken	1044	6431	0.4437	8.4138	2.2538	6.1600	0.2679
Ugbowo	957	6703	0.4599	9.1786	2.1744	7.0042	0.2369

Table 3: Customer Oriented Indices from August 2019 to July 2020

AUGUST 2019 TO JULY 2020								
Description / Feeders	**Frequency of Outages**	**Outage Duration (Hrs)**	**Number of Customer**	**SAIFI**	**SAIDI (HRS)**	**CAIDI (HRS)**	**ASAI (PU)**	**ASUI (PU)**
FGGC	1183	6088	538	2.1989	11.3160	5.1462	0.3069	0.6931
Uselu	1204	5866	2137	0.5634	2.7450	4.8722	0.3322	0.6678
Eguaedaiken	1044	6431	2618	0.3988	2.4565	6.1597	0.2679	0.7321
Ugbowo	957	6703	2968	0.3224	2.2584	7.0050	0.2369	0.7631

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Table 4: System Performance Indices

Index	**Value**
SAIFI	3.3780 f / customer.yr
SAIDI	175.7564 hr / customer.yr
CAIDI	62.184 hr / customer interruption
ASAI	0.9799 pu
ASUI	0.02006 pu
EENS (Expected Energy Not Served)	3178.680 MW hr / yr
ECOST (Expected Customer Interruption Cost)	7,716,760.00 $ / yr
AENS (Average Energy Not Supplied)	22.3851 MW hr / customer.yr
IEAR (Interrupted Energy Assessment Rate)	8.0203 $ / kW hr

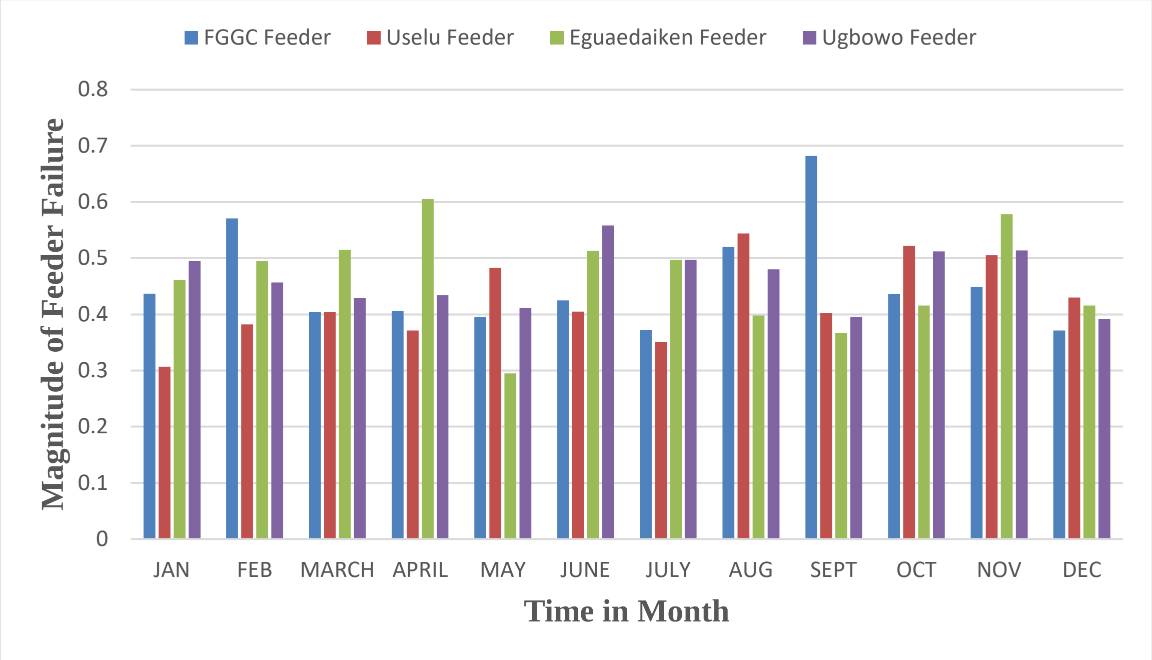

Figure 2: Failure Rate of each Feeder of Ugbowo 2x15 MVA, 33/11 kV Injection Substation

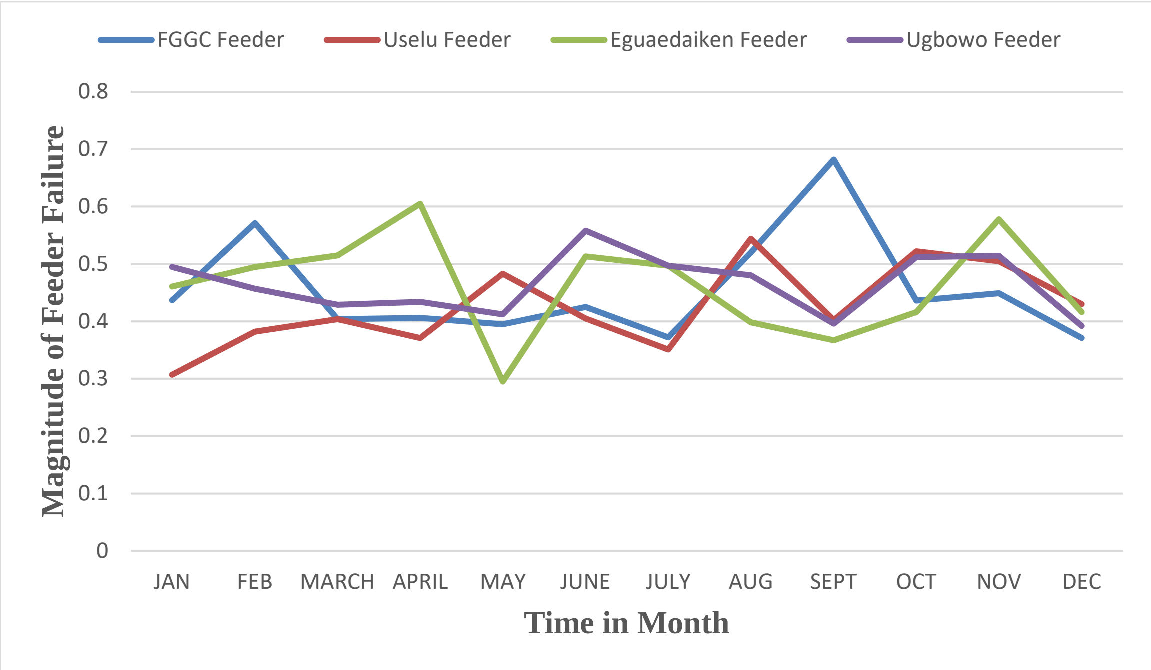

Figure 3: Failure Rate of the Four Feeders of Ugbowo 2x15 MVA, 33/11 kV Injection Substation

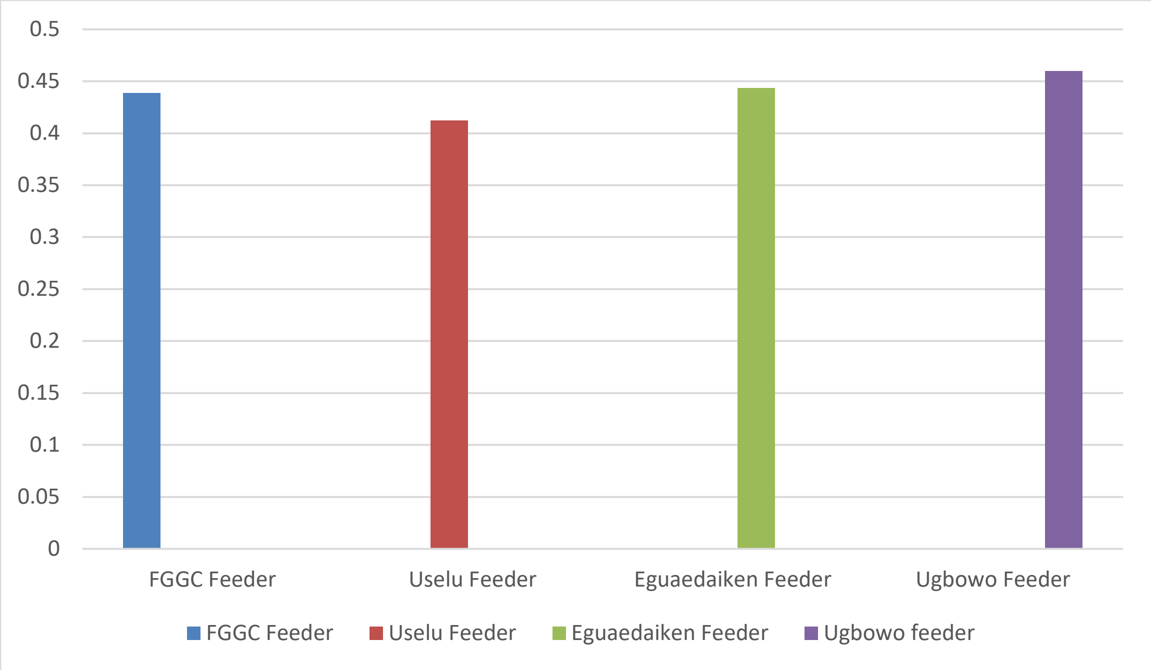

Figure 4: Failure Rate of the Four Feeders of Ugbowo 2x15 MVA, 33/11 kV Injection Substation

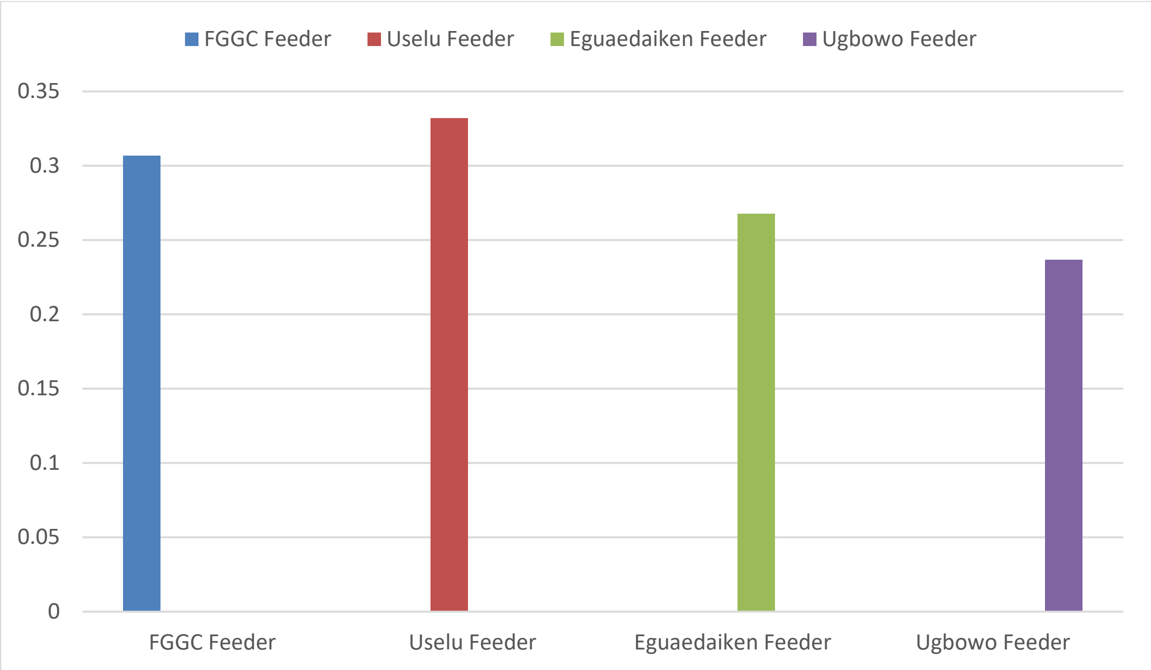

Figure 5: Availability of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

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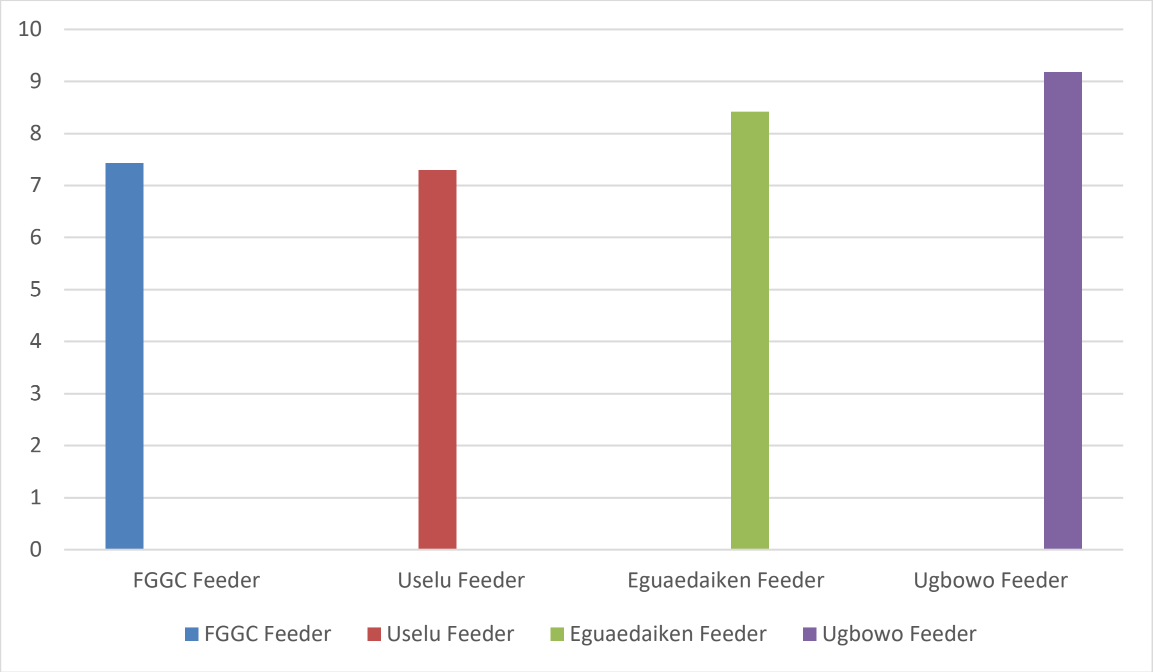

Figure 6: Mean Time between Failure of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

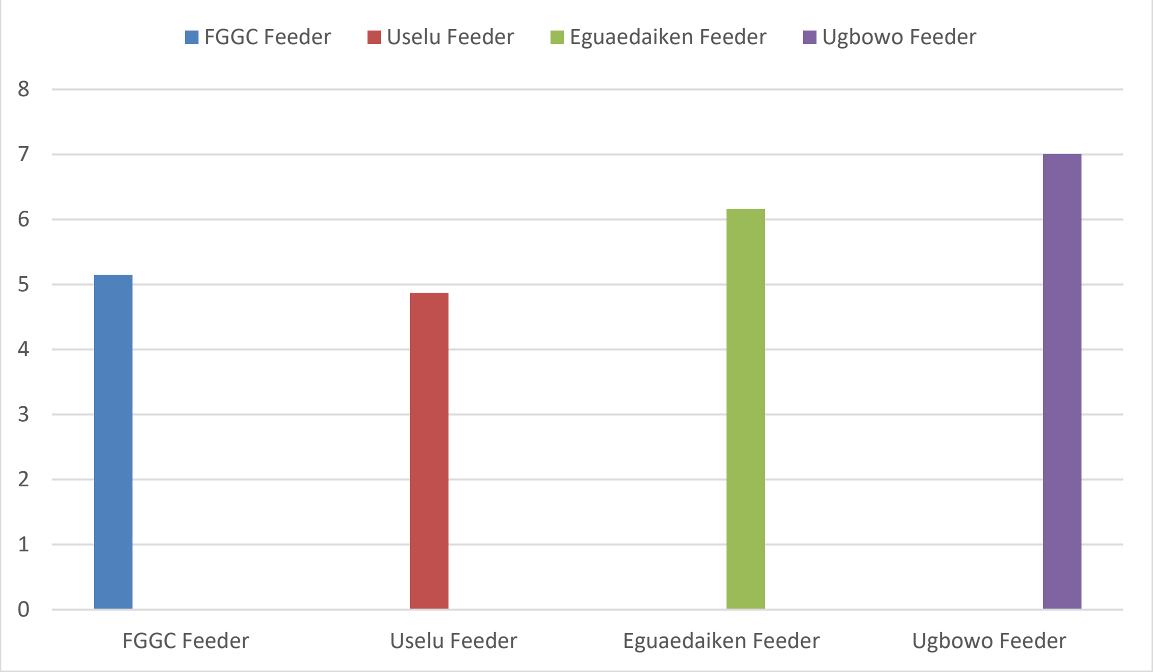

Figure 7: Mean Time to Repair of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

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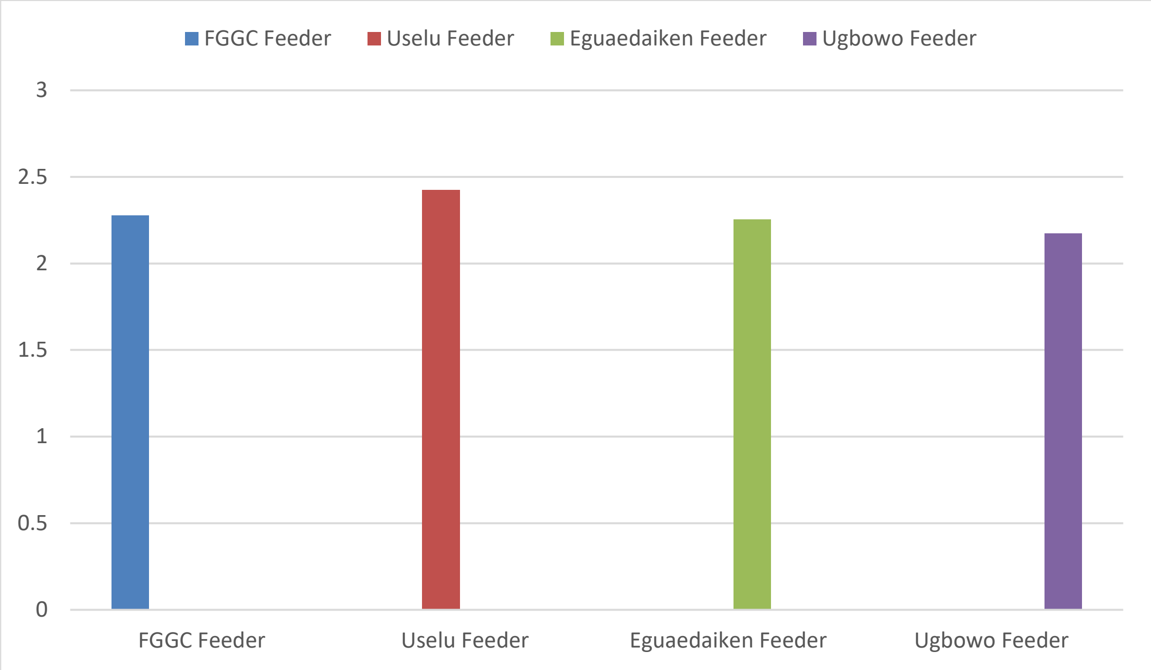

Figure 8: Mean Time to Failure of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

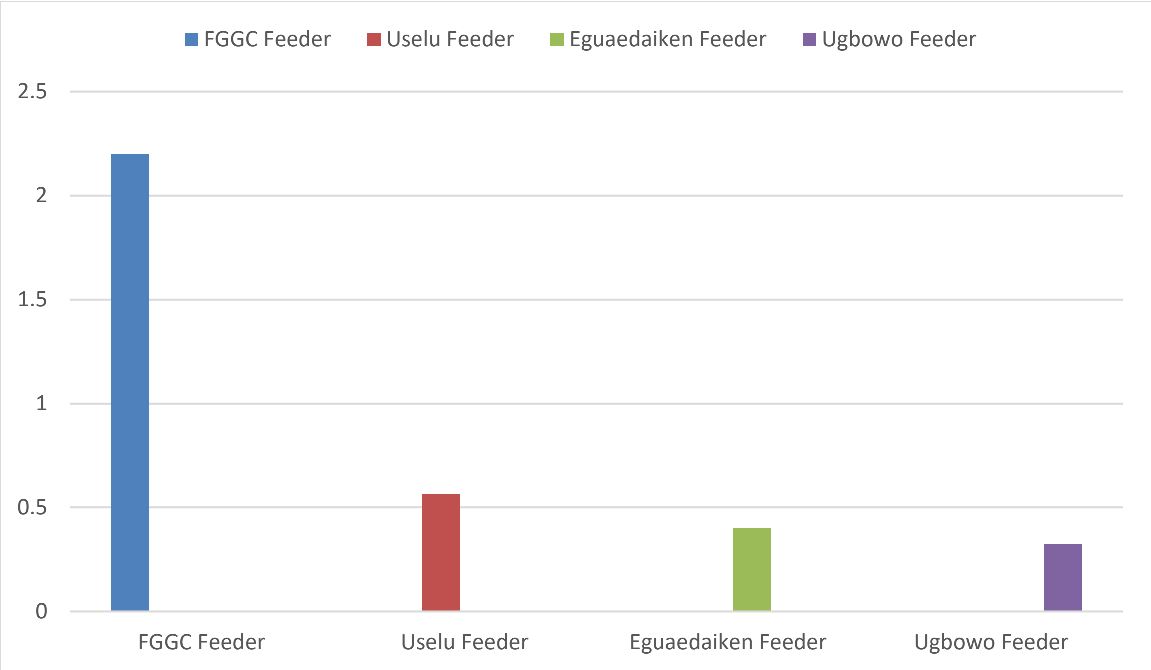

Figure 9: System Average Interruption Frequency Index of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

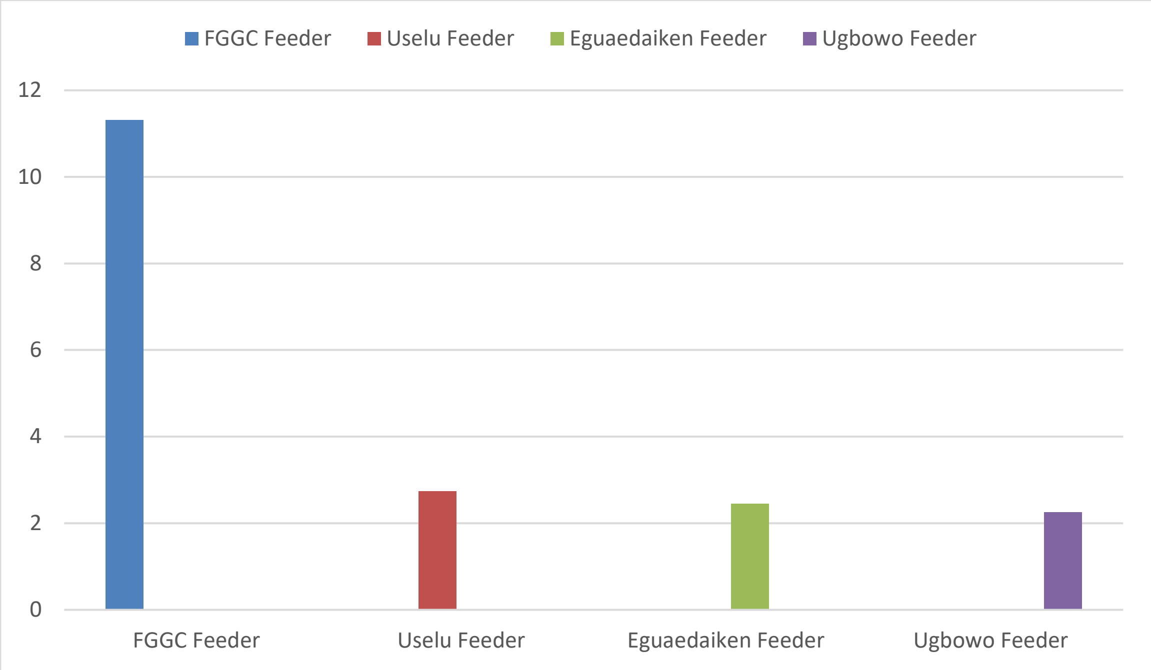

Figure 10: System Average Interruption Duration Index of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

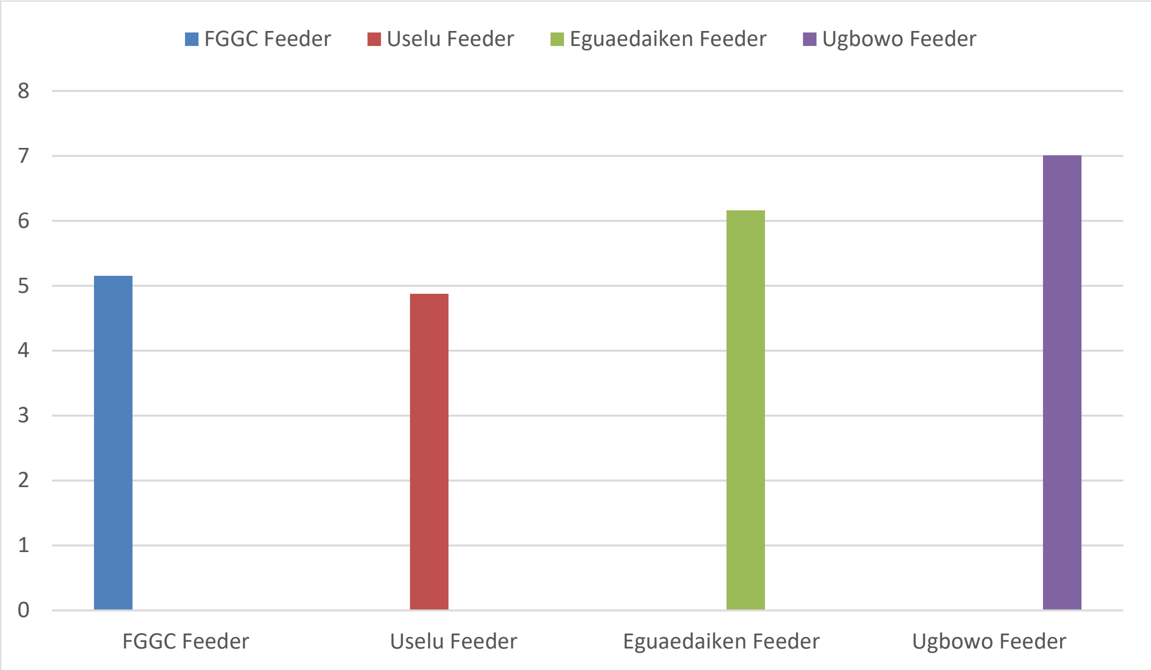

Figure 11: Customer Average Interruption Duration Index of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

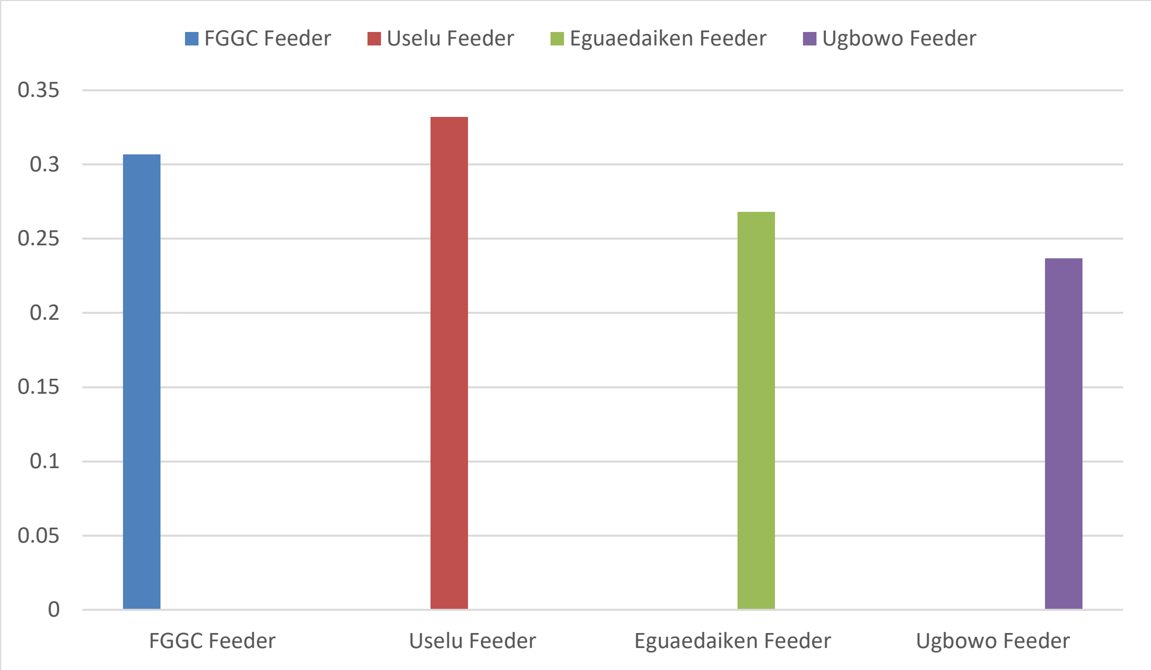

Figure 12: Average Service Availability Index of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

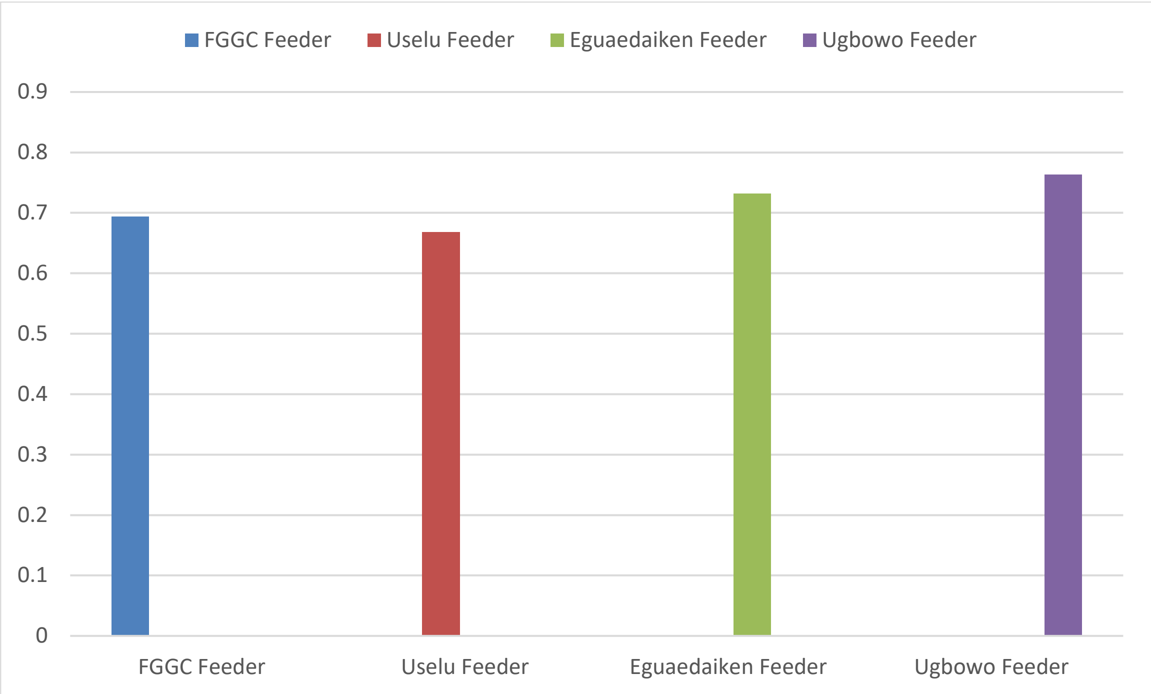

Figure 13: Average Service Unavailability Index of each 11 kV Feeder of the Ugbowo 2x15 MVA, 33/11 kV Injection Substation

3.2 DISCUSSION OF RESULTS

The reliability indices of the Ugbowo 2x15 MVA, 33/11 kV electric power distribution network has been determined and the outcomes interpreted graphically using the spreadsheet and SLD model in ETAP software. From the results shown in Table 1 and 2, the monthly failure rate and the annual reliability indices of the four (4) 11 kV feeders of the distribution network were analyzed and evaluated for an in-depth assessment. It was observed that the Ugbowo 11 kV feeder has the highest failure rate of 45.99%, followed by Eguaedaiken 11 kV feeder 44.37%, FGGC 11 kV feeder 43.88% and Uselu 11 kV feeder 41.26%. This high values of failure rates were due to the frequent power outages resulting from regimented load shedding (scheduled outages) being practiced in the network as a way to manage equipment limitations, poor power generation, poor energy management and forced (unscheduled) outages due to faults in the system. Figure 2, 3 and 4 showed the graphical representation of the monthly and yearly failure rate of the four (4) 11 kV feeders of the Ugbowo 2x15 MVA, 33/11 kV distribution network. Also, Table 2 showed the availability of electric power in the four (4) 11 kV feeders to consumers, while Figure 5 represented the graphical analysis and feeders' power availability in comparison. Figure 3 shows clearly the zigzag nature of electricity supply services to consumers in the network, which is a true reflection of the reality on ground. It was also observed that the power availability is very poor in the network with FGGC 11 kV feeder having 30.69%, Uselu 11 kV feeder 33.22%, Eguaedaiken 11 kV feeder 26.79% and Ugbowo 11 kV feeder 23.69% respectively. The very poor availability of electricity supply to consumers in the distribution network is occasioned by frequent power outages resulting from regimented load shedding (scheduled) and unscheduled outages that are predominant in the traditional distribution network.

Figure 6 shows the mean time between failure (MTBF) of the four (4) 11 kV feeders of the Ugbowo 2x15 MVA, 33/11 kV distribution network with Ugbowo 11 kV feeder having the highest mean time between failure, followed by Equaedaiken 11 kV feeder, Uselu 11 kV feeder and FGGC 11 kV feeder having the least MTBF. Additionally, Figure 7 show the mean time to repair of the four (4) 11 kV feeders of the Ugbowo 2x15 MVA, 33/11 kV distribution network with Ugbowo 11 kV feeder having the highest mean time to repair, followed by Equaedaiken 11 kV feeder, Uselu 11 kV feeder and FGGC 11 kV feeder having the least MTTR, while Figure 8 shows the mean time to failure of the four (4) 11 kV feeder of the network with Uselu 11 kV feeder having the highest mean time to failure, followed by FGGC 11 kV feeder, Equaedaiken 11 kV feeder and Ugbowo 11 kV feeder having the least MTTF. The aforementioned Figures shows how the four (4) 11 kV feeders functions in the distribution network and responded to failures and repairs with the average time span indicated for the period under investigation.

Table 3 showed the annual customer oriented indices for the 11 kV feeders of the Ugbowo 2x15 MVA, 33/11 kV electric power distribution network and the impact on customers' satisfaction for the period under review; while Figure 9, 10, 11, 12 and 13 showed the graphical interpretation in a comparative analysis of the customer oriented indices of the four (4) 11 kV feeders of the distribution network for the system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), average service availability index (ASAI), and average service unavailability index (ASUI) respectively. From Figure 9 and 10 it was observed that the FGGC 11 kV feeder have the highest system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI) respectively, followed by the Uselu 11 kV feeder, Equaedaiken 11 kV feeder and Ugbowo 11 kV feeder having the least SAIFI and SAIDI respectively. Figure 11 shows the customer average interruption duration index (CAIDI) of the four (4) 11 kV feeders of the network with Ugbowo 11 kV feeder having the highest customer interruption duration, followed by Equaedaiken 11 kV feeder, FGGC 11 kV feeder and Uselu 11 kV feeder having the lowest CAIDI. Figure 12 and 13 shows the average service availability index (ASAI) and average service unavailability index (ASUI) of the distribution network with Uselu 11 kV feeder having the highest availability and the lowest unavailability respectively, followed by FGGC 11 kV feeder, Equaedaiken 11 kV feeder and Ugbowo 11 kV feeder having the lowest availability and highest unavailability respectively in the network.

Furthermore, Table 4 showed the System Performance Indices (SPI) of the injection substation which shown that the yearly total outage duration (SAIDI), outage frequency (SAIFI) and percentage availability (ASAI) were 175.7504 hours, 3.3780 f/cu.yr and 97.99% respectively which is a far cry from the international acceptable standard value (IASV) of 2.5 hours, 0.01 f/cu.yr and 99.99% respectively and this clearly show that the electric power supply services in the network is unreliable and unpredictable with customers at disadvantage. The poor availability of electric power supply in the network calls for serious concern and intervention of both government and stakeholder.

4. CONCLUSION

Having x-rayed the effect of frequent power outages on the reliability of the feeders of Ugbowo 2x15 MVA, 33/11 kV electric power distribution network vis-à-vis customer oriented and system performance indices, it is obvious that the electric power supply availability in the Ugbowo distribution network is very poor for the period under investigation. It is imperative to note that the 11 kV feeders tripping profile have been interpreted both in tabular and graphical forms showing that there was a poor electricity supply in the network for the period under study. The system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and average service availability index (ASAI) values of the Ugbowo 2x15 MVA, 33/11 kV electric power distribution network is a far cry from the international acceptable standard value (IASV) as highlighted in the results analysis. Hence, conscious effort should be made to decrease wholly the values of SAIFI, SAIDI and ASUI for the enhancement of the values of the indices of the distribution network to the recommended values of IASV. The issue of regimented load shedding occurring in the network has contributed to the high frequent outages which need to be addressed.

It is pertinent to say here that the Ugbowo 2x15 MVA, 33/11 kV electric power distribution network need urgent upgrading of equipment to forestall frequent outages in the 11 kV feeders of the network. Hence, to achieve a better electric power supply availability and reliability in the network, it is recommended that: automated feeder switching technique be deployed to enhance quick restoration of electric power supply during fault; optimal feeder configuration is required for quick isolation of faulty section and restoration of electricity supply to healthy section of the network; upgrading of substation equipment to eliminate equipment limitation such as transformers limitation in the network; the present energy management system should be rejigged in order to improve it by adopting novel methods; customers' satisfaction should be the utility priority instead of profit driven orientation without achieving customer satisfaction.

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