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RELIABILITY ASSESSMENT OF A POWER DISTRIBUTION NETWORK: A CASE STUDY

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Abstract

Every power consumer deserves a good and regular power supply from his service provider, and the quality of service depends on the degree of reliability of the power distribution system. The key factors that determine the reliability of the system are the frequency and duration of fault in the system. Therefore, this research seek to ascertain the level of reliability of electric power distribution network, using the GRA 33/11kVfeeder as case study for the year 2017. This research is unique because it took into consideration the estimated hours of scheduled load shedding in the distribution network. The feeder radiates Dumez, Ihama, Reservation, Oba Palace and GRA 11kV feeders in the network of Benin Electricity Distribution Company (BEDC). A monthly record of both scheduled (load shedding) and unscheduled frequency of interruption, duration of interruption and number of customers on each 11kV feeder were takenfrom the control room for the year under review. Using the basic mathematical tool, the customer service and basic reliability indices were studied for each month after which an average of each element was used for the analysis. Result showed that duration of interruption has a strong impact on the service customer reliability indices. The entire indices also show that Reservation 11kV feeder was worst hit as it had a failure rate of 0.2001 per hour in the year 2017, it also recorded the highest average fault frequency and duration of 145.83 and 469.47hrs respectively which consequently had direct impact on the entire indices. In comparison with international benchmark of 0.9998 for Average Service Availability Index (ASAI), it was observed that the 11kV feeders under study were grossly unreliable as Ihama feeder with the best reliability recorded 0.4634 as ASAI. With transient fault and failure of system components the major causes of failure, a massive overhaul of power system components and smart grid system should be implemented in the networks.

Keywords**:** Reliability, 11kV Feeders, SAIDI, SAIFI, Load Shedding, ASAI

1.0 INTRODUCTION

Reliability can be defined as the ability to provide uninterrupted power supply for customers, and any system's reliability is measured on the average customer interruption indices [1]. Devices and systems which are designed to carry out specific functions have the properties of reliability. Reliability of power systems can be reviewed from two perspectives, that is, as adequacy of system and security of system. From the former, adequate facilities are provided to meet customer demands and system requirements. Under this system adequacy, some facilities are required to generate adequate energy, while others are meant to wheel out or distribute the energy produced to customers. This system adequacy has to do with static conditions with no system disturbances. From the former, security of systems is the ability of the system to respond to possible changes or disturbances in the system. In order words, security has to do with the response of the system in time of disturbance. Under this sub-concept, there are general or locally centralized disturbances which lead to loss of energy generation and distribution system facilities [2, 3].

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Power system reliability is the probability that the power system will continually carry out its defined function of energy delivery to customers with expected quality of service. Power systems reliability evaluation has an effect on the management of asset of the system [4]. In years past, the distribution session of the power sector attracts less attention as regards reliability study and evaluation as compared to the generation and transmission sessions. This is as a result of the fact that generation and transmission possess more expensive and sensitive power systems and any shortfall can result in grave consequences [5]. The situation of electricity in Nigeria is presently erratic and has a direct consequence on industrial, commercial and residential class of the nation's economy [6]. A good number of the outages or downtime is due to damages caused by weather. Other causes can be accidents by vehicles, failure of equipment, animal contact and human error [7].

1.1 Reliability analyses:

Reliability indices are used to evaluate power outages and assess the performance of power systems. The power sector uses this index with an informed method for the collection data and analysis [8].There exist two approaches applied for the evaluation of reliability of power distribution. And they include simulation method which is based on statistical distributions and a good example is the Monte Carlo method and analytic methods which are based on mathematical models. Usually, reliability index evaluation has to do with an approach that is based on failure modes assessment together with the use of equations. The indices are evaluated by considering the rate of failure, the average outage time and the expected annual outage time [5] .

1.2 Reliability Indices:

Reliability evaluation of power systems measures the performance of the distribution system [9]. The indices statistically aggregate reliability data for a defined set of loads, customers or components. The indices are average values of a particular reliability characteristic for a complete system, substation territory of substation, operating feeder [5]. The indices of reliability frequently used for evaluation of power systems are: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), etc. Failure rate, annual unavailability, and average outage duration are indices which are affiliated with load points of systems.

System Average Interruption Frequency Index (SAIFI): this index has to do with the number of times the customer experiences interruption within a period of time in an area. It is the ratio of the total number of interruptions to the total number of customers served.

$$\text{SAIFI} = \frac{Frequency\ of\ outages}{Number\ of\ Customers\ served} \quad (1)$$

System Average Interruption Duration Index (SAIDI): this index is associated with the interruption of average service in the system. It serves the purpose of indicating the duration of an outage when thereis continuous interruption which lead to power loss. It is the ratio of the total duration of interruption to the total number of customers served.

$$\text{SAIDI} = \frac{Total\ duration\ in\ hours}{Number\ of\ customers\ served} \quad (2)$$

Customer Average Interruption Duration Index (CAIDI): this index determines the average duration for the restoration of service to customers. To improve CAIDI, reducing the duration of interruption and increasing restoration time can be done. CAIDI is the ratio of the sum of customer interruption duration to that of customer interruptions. It is also the ratio of SAIDI to SAIFI.

$$\text{CAIDI} = \frac{Total\ duration\ in\ hours}{Number\ of\ affected\ customers} \quad (3)$$

Average Service Availability Index (ASAI): shows the fraction of time (usually in percentage) in which a customer receives power during the defined reporting period.

$$\text{ASAI} = \frac{Customer\ hours\ availability}{Consumer\ hours\ service\ demand} \quad (4)$$

Average Service Unavailability Index (ASUI): this is the opposite of ASAI, it shows the fraction of time in percentage in which a customer experiences power interruption during the reviewed period.

$$\text{ASUI} = \frac{Duration\ of\ outages\ in\ hours}{Total\ hours\ demanded} \quad (5)$$

Frequency time is said to be the random variable in reliability, thus, the exponential function is said to be the most appropriate because the only independent variable it possesses is time. Therefore, an important factor to use this function is that the failure rate (λ) should be constant.

Reliability indices can be categorized as the load point indices of the failure rates mean value. Therefore, the density function is as shown below;

$$f(t) = \lambda e^{-\lambda t}$$

Hence, the failure rate (λ) is given as;

$$\lambda(t) = \frac{f(t)}{1-f(t)} = \frac{frequency\ of\ failure}{number\ of\ unit{-}hours\ of\ operation} \qquad (6)$$

Failure rate (λ) is regarded as the time rate of change of the probability of failure. It is dependent on time and it varies over the life cycle of power system and it is the number of failure per unit time [13].
Furthermore, the following can be calculated from the highlighted parameters above,

$$\text{Mean Time Between Failure (MTBF)} = \frac{Total\ hours\ of\ system\ operation}{Frequency\ of\ failure} \qquad (7)$$

$$\text{Mean Time To Repair (MTTR)} = \frac{Total\ duration\ of\ outage}{Frequency\ of\ outage} \qquad (8)$$

From the above, the system availability can be calculated as;

$$\text{Availability} = \frac{MTBF-MTTR}{MTBF} \qquad (9)$$

The Mean Time between Failures (MTBF) defines the average time which terminates between successive failures of repairable system. The longer this parameter, the more the system is said to be reliable.
Mean Time to Repair (MTTR) is the average time needed to restore a system to its operational state after failure. As a maintainability index, the lower its value the more the system is defined to have a good maintainability [11].
Availability (A) is the probability that the system will be in a good state to perform its required function within a given period.
The indices highlighted above are studied to determine the impact faults or breakdown has on the reliability and efficiency of the Benin Electricity Distribution network under study.

2.0 METHOD

This research appraises the level of reliability of a section of the Benin Electricity Distribution Company (BEDC) network. It takes into consideration fault and scheduled data for twelve months for the year 2017. Due to insufficient power generation and massive energy demand in Nigeria, majority of power distribution companies have put in place rationing modalities to enhance energy management among customers on various feeders. Thus, a daily schedule doutage (popularly known as load shedding) of "3hrs on and 3hrs off" which was largely the practice of the utility company managing the feeder under study was considered for the year 2017. This was considered together with unscheduled outage (fault) in the various 11kV feeders under study. The following steps were taken in carrying out this research.

i) Data containing the major causes of the fault recorded were collected, it is as shown in Table 1
ii) Data containing number of customers affected, frequency of interruptions and duration of interruptions record per month for Dumez, GRA, Oba Palace, Reservation and Ihama 11kV feeders were collected as shown in Tables 2, 3, 4, 5 and 6 respectively.
iii) The customer service reliability indices such as SAIFI, SAIDI, CAIDI, ASAI and ASUI were carried out using Eq.(1), Eq.(2), Eq.(3), Eq.(4) and Eq.(5) respectively.
iv) Basic reliability indices such as failure rate (λ), MTBF, MTTR and Availability was calculated by applying Eq.(6), Eq.(7), Eq.(8) and Eq.(9) respectively.
v) Calculated results for both the customer service and basic reliability indices were tabulated as shown in Table 7 through Table 12 for the various feeders. The calculated average of each element customer service reliability indices for the year 2017 were presented in charts as shown in Figure 2 to Figure 6, while the result for basic reliability indices were presented in charts as shown in Figure 7 to Figure 10. vi) Analysis of result and recommendation.

2.1 Description of case study feeders and associated data collected

These 11kV feeders are tied to GRA injection substation and Etete injection substation. These two substations are fed from GRA 33kV feeders. From the Etete injection substation of 2X15MVA transformers radiate Ihama 11kV feeder and Dumez 11kV feeder.
From GRA injection substation of 2X15MVA which is also from GRA 33kV feeds the following11kV feeders; Reservation, GRA and Oba Place 11kV feeders.
The Dumez 11kV feeder and Ihama 11kV feeder have total lengths of 8.6km and 16.2km respectively. While Reservation, GRA and Oba Place 11kV feeders have 18.3km, 11.9km and 7.2km respectively.

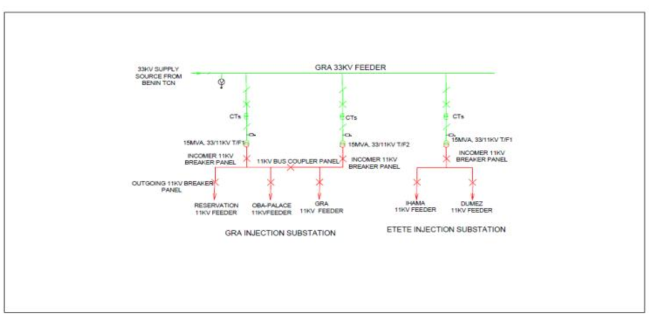

Figure 1: Single Line Diagram showing GRA 33kV Feeder and Associated Injection Substation and 11kV feeder [10]

The tables shown below contain the data collected from BEDC.

Table 1 Recorded causes of fault tripping in the 11kV feeders [10]

Major reasons recorded for 11KV feeders fault tripping in 2017	GRA 11KV feeder	Oba Palace 11kV feeder	Reservation 11kV feeder	Ihama 11kV feeder	Dumez 11kV feeder
Transient	49	30	207	82	80
Animal Bridges		2	1		1
Falling tree/Vegetation Interference	7	2	4	4	3
Jumper/Upriser Cut	7	8	26	3	6
Others (Broken Poles, Wire cut, Vehicular Collision, etc.)	37	28	52	20	22

Table 2: Data collected for Dumez 11kV feeder for the year 2017 [10].

		Fault Outage		Scheduled Outage		Total Outage		Total Duration (Hr)
Month	No of Customers	Freq	Duration (Hr)	Freq	Duration (Hr)	Freq	Duration (Hr)	
Jan	1207	3	18.2	124	372	127	390.2	744
Feb	1207	7	19.2	112	336	119	355.2	672
Mar	1207	7	2.15	124	342	131	344.15	744
April	1207	8	24.3	120	360	128	384.3	720
May	1207	5	13.8	124	372	129	385.8	744
June	1207	8	41.25	120	360	128	401.25	720
July	1207	12	98.1	124	372	136	470.1	744
Aug	1207	14	82.5	124	372	138	454.5	744
Sept	1207	9	60.9	120	360	129	420.9	720
Oct	1207	27	143.3	124	372	151	515.3	744
Nov	1207	8	165.3	120	360	128	525.3	720
Dec	1207	4	28.13	124	372	128	400.13	744
Total	**1207**	**112**	**697.13**	**1460**	**4350**	**1572**	**5047.13**	**8760**
Average	**1207**	**9.33**	**58.09**	**121.67**	**362.5**	**131**	**420.59**	**730**

Table 3:Data collected for GRA 11kV feeder for the year 2017 [10].

		Fault Outage		Scheduled Outage		Total Outage		Total Duration (Hr)
Month	No of Customers	Freq	Duration (Hr)	Freq	Duration (Hr)	Freq	Duration (Hr)	
Jan	1082	4	2.84	124	372	128	374.84	744
Feb	1082	12	16.75	112	336	124	352.75	672
Mar	1082	5	40.27	124	342	129	382.27	744
April	1082	13	61.18	120	360	133	421.18	720
May	1082	8	20.47	124	372	132	392.47	744
June	1082	7	85.93	120	360	127	445.93	720
July	1082	7	65.9	124	372	131	437.9	744
Aug	1082	12	62.42	124	372	136	434.42	744
Sept	1082	5	12.98	120	360	125	372.98	720
Oct	1082	11	55.3	124	372	135	427.3	744
Nov	1082	8	56	120	360	128	416	720
Dec	1082	8	59.82	124	372	132	431.82	744
Total	**1207**	**100**	**539.86**	**1460**	**4350**	**1560**	**4889.86**	**8760**
Average	**1082**	**8.33**	**44.99**	**121.67**	**362.5**	**130**	**407.49**	**730**

Table 4:Data collected for Oba Palace 11kV feeder for the year 2017[10].

		Fault Outage		Scheduled Outage		Total Outage		Total Duration (Hr)
Month	No of Customers	Freq	Duration (Hr)	Freq	Duration (Hr)	Freq	Duration (Hr)	
Jan	1872	7	35.28	124	372	131	407.28	744
Feb	1872	12	82.48	112	336	124	418.48	672
Mar	1872	9	31.08	124	342	133	373.08	744
April	1872	5	6.98	120	360	125	366.98	720
May	1872	4	39.12	124	372	128	411.12	744
June	1872	4	12.6	120	360	124	372.6	720
July	1872	7	72.67	124	372	131	444.67	744
Aug	1872	3	20.6	124	372	127	392.6	744
Sept	1872	6	21	120	360	126	381	720
Oct	1872	5	46.23	124	372	129	418.23	744
Nov	1872	5	42.37	120	360	125	402.37	720
Dec	1872	3	35.12	124	372	127	407.12	744
Total	**1872**	**70**	**445.53**	**1460**	**4350**	**1530**	**4795.53**	**8760**
Average	**1872**	**5.83**	**37.13**	**121.67**	**362.5**	**127.5**	**399.63**	**730**

Table 5: Data collected for Reservation 11kV feeder for the year 2017[10].

Month	No of Customers	Fault Outage		Scheduled Outage		Total Outage		Total Duration (Hr)
		Freq	Duration (Hr)	Freq	Duration (Hr)	Freq	Duration (Hr)	
Jan	4330	26	67.62	124	372	150	439.62	744
Feb	4330	47	163.58	112	336	159	499.58	672
Mar	4330	34	152.88	124	342	158	494.88	744
April	4330	26	91.47	120	360	146	451.47	720
May	4330	17	29.18	124	372	141	401.18	744
June	4330	25	143.98	120	360	145	503.98	720
July	4330	16	96.72	124	372	140	468.72	744
Aug	4330	18	75.07	124	372	142	447.07	744
Sept	4330	24	110.08	120	360	144	470.08	720
Oct	4330	16	102.38	124	372	140	474.38	744
Nov	4330	26	167.75	120	360	146	527.75	720
Dec	4330	15	82.9	124	372	139	454.9	744
Total	**4330**	**290**	**1283.61**	**1460**	**4350**	**1750**	**5633.61**	**8760**
Average	**4330**	**24.17**	**106.97**	**121.67**	**362.5**	**145.83**	**469.47**	**730**

Table 6:Data collected for Ihama 11kV feeder for the year 2017[10].

Month	No of Customers	Fault Outage		Scheduled Outage		Total Outage		Total Duration (Hr)
		Freq	Duration (Hr)	Freq	Duration (Hr)	Freq	Duration (Hr)	
Jan	1603	8	9.08	124	372	132	381.08	744
Feb	1603	8	42.02	112	336	120	378.02	672
Mar	1603	8	55.68	124	342	132	397.68	744
April	1603	8	44.38	120	360	128	404.38	720
May	1603	6	11.38	124	372	130	383.38	744
June	1603	11	56.2	120	360	131	416.2	720
July	1603	11	20.68	124	372	135	392.68	744
Aug	1603	19	56	124	372	143	428	744
Sept	1603	7	2.88	120	360	127	362.88	720
Oct	1603	13	26.38	124	372	137	398.38	744
Nov	1603	6	19.23	120	360	126	379.23	720
Dec	1603	4	4.13	124	372	128	376.13	744
Total	**1603**	**109**	**348.04**	**1460**	**4350**	**1569**	**4698.04**	**8760**
Average	**1603**	**9.08**	**29.00**	**121.67**	**362.5**	**130.75**	**391.50**	**730**

3.0 RESULTS AND ANALYSIS

3.1 Results

The following were the results obtained;

Table 7: Calculated reliability indices for Dumez 11kV feeder for the year 2017.

Month	Customer Service Reliability Indices					Basic Reliability Indices			
	SAIDI (Hr)	SAIFI	CAIDI (Hr)	ASAI (p.u.)	ASUI (p.u.)	Failure rate (λ)	MTBF (Hr)	MTTF (Hr)	Availability
Jan	0.3233	0.1052	3.0724	0.4755	0.5245	0.1707	5.8583	3.0724	0.4755
Feb	0.2943	0.0986	2.9849	0.4714	0.5286	0.1771	5.6471	2.9849	0.4714
Mar	0.2851	0.1085	2.6271	0.5374	0.4626	0.1761	5.6794	2.6271	0.5374
Apr	0.3184	0.1060	3.0023	0.4663	0.5338	0.1778	5.6250	3.0023	0.4663
May	0.3196	0.1069	2.9907	0.4815	0.5185	0.1734	5.7674	2.9907	0.4815
June	0.3324	0.1060	3.1348	0.4427	0.5573	0.1778	5.6250	3.1348	0.4427
July	0.3895	0.1127	3.4566	0.3681	0.6319	0.1828	5.4706	3.4566	0.3681
Aug	0.3766	0.1143	3.2935	0.3891	0.6109	0.1855	5.3913	3.2935	0.3891
Sep	0.3487	0.1069	3.2628	0.4154	0.5846	0.1792	5.5814	3.2628	0.4154
Oct	0.4269	0.1251	3.4126	0.3074	0.6926	0.2030	4.9272	3.4126	0.3074
Nov	0.4352	0.1060	4.1039	0.2704	0.7296	0.1778	5.6250	4.1039	0.2704
Dec	0.3315	0.1060	3.1260	0.4622	0.5378	0.1720	5.8125	3.1260	0.4622
Total	**4.1815**	**1.3024**	**38.4676**	**5.0875**	**6.9125**	**2.1530**	**67.0101**	**38.4676**	**5.0875**
Average	**0.3485**	**0.1085**	**3.2056**	**0.4240**	**0.5760**	**0.1794**	**5.5842**	**3.2056**	**0.4240**

Table 8:Calculated reliability indices for GRA 11kV feeder for the year 2017.

	Customer Service Reliability Index					Basic Reliability Index			
Month	SAIDI (Hr)	SAIFI	CAIDI (Hr)	ASAI (p.u.)	ASUI (p.u.)	Failure rate (λ)	MTBF (Hr)	MTTF (Hr)	Availability
Jan	0.3464	0.1183	2.9284	0.4962	0.5038	0.1720	5.8125	2.9284	0.4962
Feb	0.3260	0.1146	2.8448	0.4751	0.5249	0.1845	5.4194	2.8448	0.4751
Mar	0.3533	0.1192	2.9633	0.4862	0.5138	0.1734	5.7674	2.9633	0.4862
Apr	0.3893	0.1229	3.1668	0.4150	0.5850	0.1847	5.4135	3.1668	0.4150
May	0.3627	0.1220	2.9733	0.4725	0.5275	0.1774	5.6364	2.9733	0.4725
June	0.4121	0.1174	3.5113	0.3807	0.6193	0.1764	5.6693	3.5113	0.3807
July	0.4047	0.1211	3.3427	0.4114	0.5886	0.1761	5.6794	3.3427	0.4114
Aug	0.4015	0.1257	3.1943	0.4161	0.5839	0.1828	5.4706	3.1943	0.4161
Sep	0.3447	0.1155	2.9838	0.4820	0.5180	0.1736	5.7600	2.9838	0.4820
Oct	0.3949	0.1248	3.1652	0.4257	0.5743	0.1815	5.5111	3.1652	0.4257
Nov	0.3845	0.1183	3.2500	0.4222	0.5778	0.1778	5.6250	3.2500	0.4222
Dec	0.3991	0.1220	3.2714	0.4196	0.5804	0.1774	5.6364	3.2714	0.4196
Total	**4.5193**	**1.4418**	**37.5952**	**5.3026**	**6.6974**	**2.1376**	**67.4009**	**37.5952**	**5.3026**
Average	**0.3766**	**0.1201**	**3.1329**	**0.4419**	**0.5581**	**0.1781**	**5.6167**	**3.1329**	**0.4419**

Table 9:Calculated reliability indices for Oba Palace 11kV feeder for the year 2017.

	Customer Service Reliability Index					Basic Reliability Index			
Month	SAIDI (Hr)	SAIFI	CAIDI (Hr)	ASAI (p.u.)	ASUI (p.u.)	Failure rate (λ)	MTBF (Hr)	MTTF (Hr)	Availability
Jan	0.2176	0.0700	3.1090	0.4526	0.5474	0.1761	5.6794	3.1090	0.4526
Feb	0.2235	0.0662	3.3748	0.3773	0.6227	0.1845	5.4194	3.3748	0.3773
Mar	0.1993	0.0710	2.8051	0.4985	0.5015	0.1788	5.5940	2.8051	0.4985
Apr	0.1960	0.0668	2.9358	0.4903	0.5097	0.1736	5.7600	2.9358	0.4903
May	0.2196	0.0684	3.2119	0.4474	0.5526	0.1720	5.8125	3.2119	0.4474
June	0.1990	0.0662	3.0048	0.4825	0.5175	0.1722	5.8065	3.0048	0.4825
July	0.2375	0.0700	3.3944	0.4023	0.5977	0.1761	5.6794	3.3944	0.4023
Aug	0.2097	0.0678	3.0913	0.4723	0.5277	0.1707	5.8583	3.0913	0.4723
Sep	0.2035	0.0673	3.0238	0.4708	0.5292	0.1750	5.7143	3.0238	0.4708
Oct	0.2234	0.0689	3.2421	0.4379	0.5621	0.1734	5.7674	3.2421	0.4379
Nov	0.2149	0.0668	3.2190	0.4412	0.5588	0.1736	5.7600	3.2190	0.4412
Dec	0.2175	0.0678	3.2057	0.4528	0.5472	0.1707	5.8583	3.2057	0.4528
Total	**2.5617**	**0.8173**	**37.6178**	**5.4259**	**6.5741**	**2.0967**	**68.7093**	**37.6178**	**5.4259**
Average	**0.2135**	**0.0681**	**3.1348**	**0.4522**	**0.5478**	**0.1747**	**5.7258**	**3.1348**	**0.4522**

Table 10:Calculated reliability indices for Reservation feeder 11kV feeder for the year 2017.

	Customer Service Reliability Index					Basic Reliability Index			
Month	SAIDI (Hr)	SAIFI	CAIDI (Hr)	ASAI (p.u.)	ASUI (p.u.)	Failure rate (λ)	MTBF (Hr)	MTTF (Hr)	Availability
Jan	0.1015	0.0346	2.9308	0.4091	0.5909	0.2016	4.9600	2.9308	0.4091
Feb	0.1154	0.0367	3.1420	0.2566	0.7434	0.2366	4.2264	3.1420	0.2566
Mar	0.1143	0.0365	3.1322	0.3348	0.6652	0.2124	4.7089	3.1322	0.3348
Apr	0.1043	0.0337	3.0923	0.3730	0.6270	0.2028	4.9315	3.0923	0.3730
May	0.0927	0.0326	2.8452	0.4608	0.5392	0.1895	5.2766	2.8452	0.4608
June	0.1164	0.0335	3.4757	0.3000	0.7000	0.2014	4.9655	3.4757	0.3000
July	0.1082	0.0323	3.3480	0.3700	0.6300	0.1882	5.3143	3.3480	0.3700
Aug	0.1032	0.0328	3.1484	0.3991	0.6009	0.1909	5.2394	3.1484	0.3991
Sep	0.1086	0.0333	3.2644	0.3471	0.6529	0.2000	5.0000	3.2644	0.3471
Oct	0.1096	0.0323	3.3884	0.3624	0.6376	0.1882	5.3143	3.3884	0.3624
Nov	0.1219	0.0337	3.6147	0.2670	0.7330	0.2028	4.9315	3.6147	0.2670
Dec	0.1051	0.0321	3.2727	0.3886	0.6114	0.1868	5.3525	3.2727	0.3886
Total	**1.3011**	**0.4042**	**38.6548**	**4.2685**	**7.7315**	**2.4011**	**60.2209**	**38.6548**	**4.2685**
Average	**0.1084**	**0.0337**	**3.2212**	**0.3557**	**0.6443**	**0.2001**	**5.0184**	**3.2212**	**0.3557**

Table 11:Calculated reliability indices for Ihama 11kV feeder for the year 2017.

	Customer Service Reliability Index					Basic Reliability Index			
Month	**SAIDI (Hr)**	**SAIFI**	**CAIDI (Hr)**	**ASAI (p.u.)**	**ASUI (p.u.)**	**Failure rate (λ)**	**MTBF (Hr)**	**MTTF (Hr)**	**Availability**
Jan	0.2377	0.0823	2.8870	0.4878	0.5122	0.1774	5.6364	2.8870	0.4878
Feb	0.2358	0.0749	3.1502	0.4375	0.5625	0.1786	5.6000	3.1502	0.4375
Mar	0.2481	0.0823	3.0127	0.4655	0.5345	0.1774	5.6364	3.0127	0.4655
Apr	0.2523	0.0799	3.1592	0.4384	0.5616	0.1778	5.6250	3.1592	0.4384
May	0.2392	0.0811	2.9491	0.4847	0.5153	0.1747	5.7231	2.9491	0.4847
June	0.2596	0.0817	3.1771	0.4219	0.5781	0.1819	5.4962	3.1771	0.4219
July	0.2450	0.0842	2.9087	0.4722	0.5278	0.1815	5.5111	2.9087	0.4722
Aug	0.2670	0.0892	2.9930	0.4247	0.5753	0.1922	5.2028	2.9930	0.4247
Sep	0.2264	0.0792	2.8573	0.4960	0.5040	0.1764	5.6693	2.8573	0.4960
Oct	0.2485	0.0855	2.9079	0.4645	0.5355	0.1841	5.4307	2.9079	0.4645
Nov	0.2366	0.0786	3.0098	0.4733	0.5267	0.1750	5.7143	3.0098	0.4733
Dec	0.2346	0.0799	2.9385	0.4944	0.5056	0.1720	5.8125	2.9385	0.4944
Total	**2.9308**	**0.9788**	**35.9505**	**5.5610**	**6.4390**	**2.1491**	**67.0576**	**35.9505**	**5.5610**
Average	**0.2442**	**0.0816**	**2.9959**	**0.4634**	**0.5366**	**0.1791**	**5.5881**	**2.9959**	**0.4634**

Table 12: Average reliability indices for the 11kV feeders for the year 2017.

	Customer Service Reliability Index					Basic Reliability Index			
11kV Feeders	**SAIDI (Hr)**	**SAIFI**	**CAIDI (Hr)**	**ASAI (p.u.)**	**ASUI (p.u.)**	**Failure rate (λ)**	**MTBF (Hr)**	**MTTF (Hr)**	**Availability**
Dumez	0.3485	0.1085	3.2056	0.424	0.576	0.1794	5.5842	3.2056	0.424
GRA	0.3766	0.1201	3.1329	0.4419	0.5581	0.1781	5.6167	3.1329	0.4419
Oba Palace	0.2135	0.0681	3.1348	0.4522	0.5478	0.1747	5.7258	3.1348	0.4522
Reservation	0.1084	0.0337	3.2212	0.3557	0.6443	0.2001	5.0184	3.2212	0.3557
Ihama	0.2442	0.0816	2.9959	0.4634	0.5366	0.1791	5.5881	2.9959	0.4634

The calculated average customer service reliability indices in table 11 above are as presented in the following bar charts.

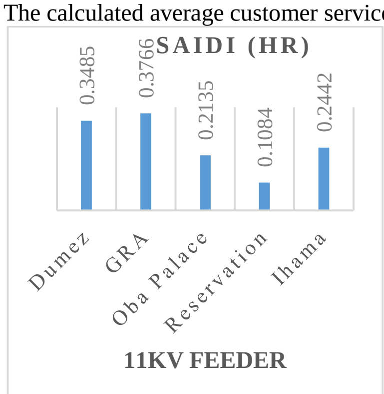

Figure 2: System Average Interruption Duration Index per month for the year 2017.

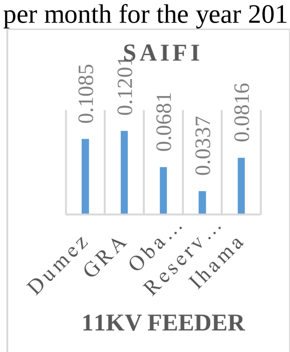

Figure 3: System Average Interruption Frequency Index per month for the year 2017.

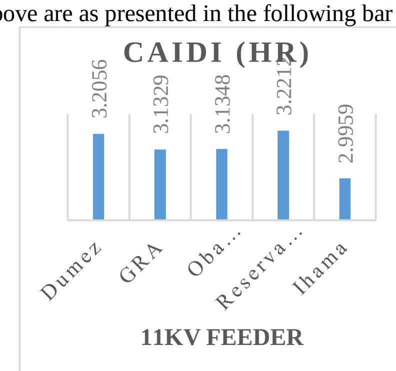

Figure 4: Customer Average Interruption Duration Index (Hr) per month for the year 2017.

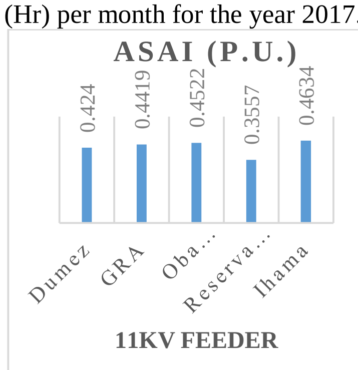

Figure 5: Average Service Availability Index per month for the year 2017.

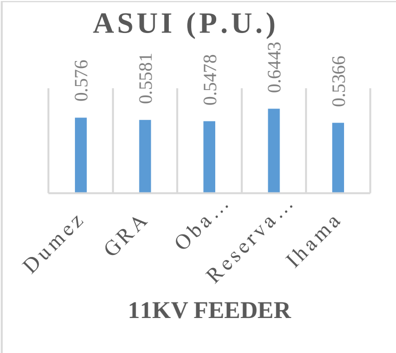

Figure 6: Average Service Unavailability Index per month for the year 2017.

The chartsbelow were gotten from table 12. The values in the table were gotten by taking the average of the total value gotten as the Basic reliability indices for the year 2017.

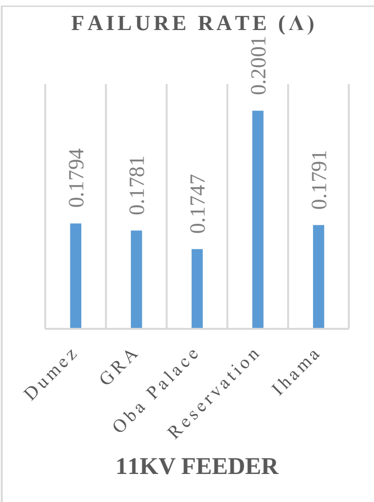

Figure 7: Average Failure rate (λ) per month for the year 2017.

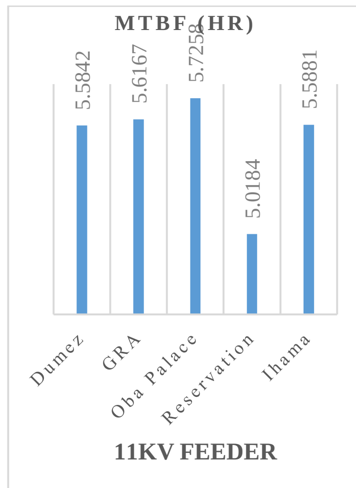

Figure 8: Average Mean Time Between Failure per month for the year 2017.

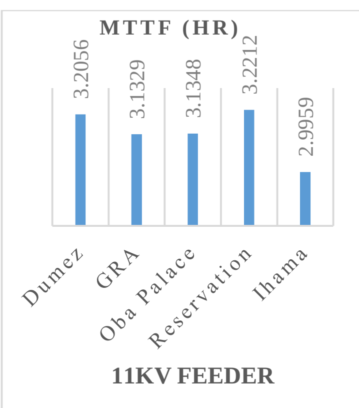

Figure 9: Average Mean Time To Failure (Hr) for the year 2017.

Figure 10: Average Availability for the year 2017

3.2 Discussions

From Table 7 through Table 11 above display the customer service reliability and basic reliability indices of the various 11kV feeders (Dumez, GRA, Oba Palace, Reservation and Ihama) for each month. An average of the total values for each measuring components of each feeder was taken for the year under study, it is as shown in Table 12. From the data for Reservation 11kV feeder table 5 above, it can be seen that Reservation 11kV feeder experienced largest frequency of interruptions with an average value of 145.83 in 2017, and this led to failure rate of 0.2001 per of the same feeder in table 12. While Oba Palace experienced the least number of interruptions and failure rates 127.5 and 0.1747 per hour in table 4 and table 12 respectively.

Figure 2 through figure 6 are the bar charts representing the averages of the various measuring components for the customer service reliability indices for 2017. The charts were produced using the figures in table 12 for the average customer service reliability indices for the various feeders for the year under study. As shown in Figure 2, GRA feeder recorded the highest value of 0.0.3766Hr as the SAIDI, with 0.1084Hr for Reservation which was the least. This is because the SAIDI index considers the duration of interruption as a ratio with the customer population. Relatively, SAIFI was also gotten by considering the customers' population and frequency of interruption and the chart is as shown in Figure 3 with GRA having same value of 0.1201 and Reservation 0.0337. Figure and Figure 6 shows the chart for CAIDI and ASUI where Reservation recorded the highest values of 3.2212 and 0.6443p.u. respectively as expected. In Figure 5, it recorded a corresponding value of 0.3557p.u. as least value for ASAI, indicating the feeder's level of availability.

The bar charts in figure 7, figure 8, figure 9 and figure 10 show the variations of the basic reliability indices. Figure 7 showed that Oba Palace had the least failure rate of 0.1747 while reservation had the most failure rate of 0.2001. Figure 8 shows that the Oba Palace feeder is more reliable as it recorded an average of 5.7258Hr as its MTBF for the year 2017, and again, the Reservation feeder is said to be least reliable with a figure of 5.0184Hr as its average MTBF in 2017. However, Ihama 11kV feeder has best maintainability with a figure of 2.9959Hr as the average MTTR in 2017 as shown in Figure 9. With the failure data the major tool for consideration, Ihama 11kV had the highest value of availability while Reservation 11kV feeder had the least value with values of 0.4634 and 0.3557 respectively. These values of availability appear grossly unimpressive as it implies that even the feeder with the highest availability did not supply power to customers for a cumulative duration of over six (6) months in 2017. This highest value of availability (also known as ASAI) for Ihama 11kV feeder is way below the international benchmark of 0.9998. This goes to show that a lot needs to be done to revamp the feeder under study and the entire distribution network at large.

From Table 1 above, majority of the unscheduled outage can be ascribed to transient fault and other technical fault such as Jumper/Upriser Cut and Others (Broken Poles, Wire cut, Vehicular Collision, etc.). This goes to show that the components of the power distribution network are obsolete and requires overhauling. There were other causes such as animal bridges and vegetation interference.

CONCLUSION

As indicated in this research, the data collected contains scheduled outages (excluding maintenance) due to load shedding and unscheduled outages due to faults and breakdown in the entire network under study. Following this appraisal on the GRA 33kV network, it can be observed that frequency of interruptions and duration of interruptions have great impact on the assessment. However, timely response to fault interruptions help to improve the system reliability. From the basic reliability and customer service reliability studies, it can be seen that Reservation 11kV feeder is most hit in terms of fault frequencies and duration of faults and the general assessment.

From the overall result on system availability (ASAI), there is great need to improve on the entire network as the achieved results are far below the global benchmark of 0.9998 for ASAI [12]. It is even worse considering the fact that this research only considered scheduled outages (excluding maintenance) due to load shedding and unscheduled.

RECOMMENDATIONS

There is great need to forestall the incessant tripping and downtime of the system and this will relatively improve on the system reliability. The entire system components should be placed on a regular checked for inherent failures and weakness. The minimum requirement for right of way of the power system utilities must be strictly observed by commuters and vehicles. This will reduce collision of vehicles cases. System hardware like wooden poles, crack concrete poles and undersized conductors that are prone to snapping and breakage should be changed from time to time. The entire feeders should be regularly patrolled to cut-off vegetation interfering with power conductors.

Appropriate mechanism of reading and recording fault current in BEDC injection substation should be put in place, as this will aid in network fault analysis and research into BEDC network. In the long term, the use of Supervisory Control and Data Acquisition (SCADA) systems should be integrated into BEDC distribution network operations to allow for real time network data collection. A smart grid system should be implemented.

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