Assessment of Secondary Feeders Reliability in Nigeria: A case of Ado-Ekiti Metropolis Distribution Network

Adewale Abe, Bankole Adebanji, and Taiwo Fasina

Abstract — **The major goal of power system is to ensure continuous supply of electricity at declared service quality to meet up with the demand of its customers. However, interruptions which sometimes may be unavoidable, tends to negate this trend. Identifying the problems will indeed enable the power utility companies to take the necessary steps in improving the reliability of the system. This paper used load point and customer-oriented reliability indices to evaluate the performance of the four distribution feeders within Ado-Ekiti metropolis, Nigeria, in order to identify the major causes of the frequent power supply outages and also suggested ways of improving its performance. Relevant outage data were collected from the supply utility-Benin Electricity Distribution Company of Nigeria (BEDC) daily operational logbooks from January 2021 to December 2021. Some of the data gathered were outage frequencies, fault durations, causes of outages, age of distribution transformers and number of customers on each of the feeders. Quantitative method of reliability indices was used to estimate and compare the performance of the feeders. The average availability (%) for the investigated period is 86.23%, 92.68%, 90.18% and 91.25% for Ajilosun, Basiri, Okesa and Adebayo feeders respectively. The results showed that almost all the feeders are not reliable. The study will enable the utility company in making informed decisions that will improve the reliability of the feeders and thereby facilitating effective monitoring to enhance optimum performance.**

Keywords — **Availability, distribution feeders, failure rate, feeder, forced outages, reliability indices.**

I. Introduction

Reliable electricity supply has become an important part of the electric power system along with the mutual benefits of power utility companies and the consumers [1]. A reliable and uninterrupted power supply at an optimum cost is a basic factor for industrial and socio-economic development for any place. As a matter of fact, the electricity consumption per capita of a nation is a measure of the standard of living of its citizens [2]. The inability of the power utility companies to effect positive change in ensuring continuous supply of electricity at a desired quality is not healthy for a developing nation like ours! The low level of availability of power supply has turned the country to a dumping ground to all kinds of generators. The generators operate virtually throughout the day constituting environmental pollution to the populace [3]. The impact of frequent power outages in the country has retarded her growth economically, socially, and economically.

The major goal of power system is to ensure continuous supply of electricity at declared service quality to meet up with the demand of its customers. However, interruptions which sometimes may be unavoidable, tends to negate this trend. Hence, the needs for reliability assessment of power system components in ensuring continuity of power supply to cope with the increasing teeming population and the need for rapid industrial growth [4], [5]. Identifying the problems will indeed enable the power utility companies to take the necessary steps in improving the reliability of the system. Reliability improvement methods in relation with protection are usage of sectionalizers, disconnectors, reclosers, fuses and relay fuses.

Electric power system is broadly divided into generation, transmission and distribution systems. Electricity is generated from the generating stations and subsequently stepped up for transmission at a very high voltage to the distribution substations [6]. The distribution systems serve as a link from the substations to the end-users. Analysis of the consumer failure statistics of most electricity companies show that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer (3). 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. No matter how efficient/reliable the generation and the transmission system may be, it will still be a failure if the distribution system (which is the final link to the consumers) is not reliable. This makes distribution system to be highly important. The distribution network is therefore expected to be highly reliable. However, this is not always the case, the distribution system is susceptible to frequent interruptions due to different types of faults (overcurrent, earth fault, single line to ground, transformer fuses) due to the radial configuration with several lateral branches and feeders for electric power supply to consumers [7]. The distribution feeders in Nigeria are not reliable at all.

The electricity utility industry is moving towards a deregulated, competitive environment where utilities must have accurate information about system performance to ensure that maintenance money are spent wisely and that customer expectations are met [8]. It is of utmost importance to assess the reliability of power system networks especially the distribution system, in order to be able to make informed decisions in planning and maintenance operations. Power system reliability can therefore be said to be the probability that power system will

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be able to perform its intended role of delivering continuous electrical energy at an acceptable service quality. As the major aim of power system is to ensure continuous supply of electricity at a declared service quality to its consumers, informed knowledge on reliability assessment will indeed improve the performance of the system components. The assessment of distribution feeders should be a routine exercise considering its major role in power system design, operation, control, and maintenance.

Some very useful techniques for reliability analysis were presented by Sonware and Kinshare [9]. An overview of distribution system reliability study was carried out, stating the need for accurate and consistent representation of models in system behaviour analysis. Available reliability indices for distribution system assessment for different substation configurations were discussed. Akinola and Awosope [10] used analytical and network reduction methods to determine the reliability indices of secondary distribution system using Ayetoro 1 substation in Lagos state, Nigeria as a case study. The outcome of the study showed that transformer and fuse failures are the most common faults affecting reliable power supply in the area. Akintola [10] analyzed the injection substation in Aguda, Nigeria using information gathered from the daily logbooks of the power utility in order to determine the substation's reliability. The major faults identified are the transformer and fuse failures.

Idoniboyeobu *et al*. [11] worked on the improvement of 33/11 kV distribution network in selected villages in Benue state, Nigeria. The study identified the problems of overloading of transformers, low voltage profile and single-phase faults. The line impedance and the fault current were determined using Newton-Raphson method while Electrical Transient Analyzer Program (ETAP) was used for the simulation. The research recommended the use of load tap changer as an optimization tool instead of capacitor bank placemen since it is cheaper. Several studies have been carried out regarding the reliability of electrical power system. Shonkora and Salau [12] performed a reliability analysis of Minch distribution feeders in Ethiopia and used smart reclosers to improve the unreliability of the system. ETAP software was used to verify the results of the analysis. The reliability indices showed great improvement in the test network. A critical analysis review of distribution system reliability and its possible mitigations were done by [13]. The review provided a clear/ detailed comparison of literature surveys of so many improvement methods, optimization techniques and reliability evaluation methods.

The two main approaches applied to reliability evaluation of distribution system are simulation method that is based on drawings from statistical distributions (Monte Carlo) and the analytical method based on solution of mathematical models. The Monte Carlo techniques are normally 'time' consuming due to large number of drawings necessary in order to obtain accurate results. This work used load point and customer-oriented reliability indices to evaluate the performance of the four distribution feeders within Ado-Ekiti metropolis, Nigeria, in order to identify the major causes of the frequent power supply outages and also suggested ways of improving its performance.

II. Methodology

Relevant outage data were collected from the supply utility-Benin Electricity Distribution Company of Nigeria (BEDC) daily operational logbooks from January 2021 to December, 2021. Some of the data gathered were outage frequencies, fault durations, causes of outages, age of distribution transformers and number of customers on each of the feeders. Quantitative method of reliability indices was used to estimate and compare the performance of the feeders. The reliability assessments of the feeders were done using both system oriented and customer-based reliability indices.

A. Distribution Feeder Description

The single line diagram of the 33/11 kV injection substation, Basiri-Ado-Ekiti is as shown in Fig. 1. The substation is fed from 132/33 kV substation, Omisanjana, Ado-Ekiti, Nigeria. It has 2×15 MVA power transformers with each having two feeders. The four outgoing feeders are Ajilosun, Basiri, Okesa and Adebayo feeders. The areas covered and the distance covered by each feeder is as shown in Table I.

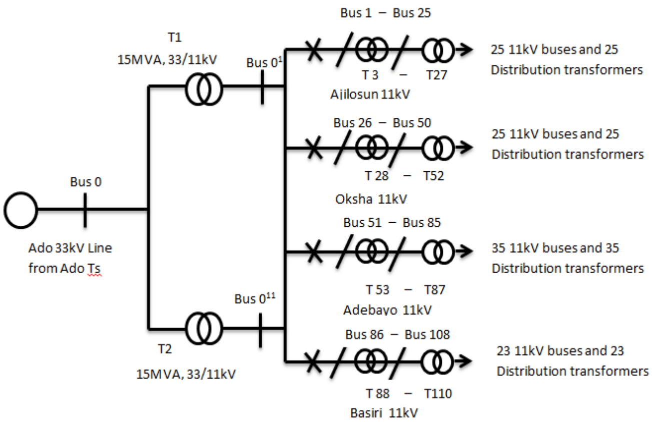

Fig. 1. Single line diagram of 2x15MVA, 33/11kV Ado main injection substation.

TABLE I: 33/11kV Injection Substation

Feeder	Area covered	Distance (km)
Ajilosun	Ajilosun/GRA	15.5
Basiri	Basiri/Iyin/Igede	16.0
Okesa	Okesa/Federal Housing	13.8
Adebayo	Adebayo/Opopogboro	28.7

B. Data Reliability Indices Analysis

The outage data collected from BEDC were used to compute the Load point reliability indices (Means Time Before Failure, (MTBF), Mean Time to Repair (MTTR), Failure Rate and Availability) and customer orientation indices (SAIFI, SAIDI and ASAI) using equations 1 to 8 [14]. The symbols and the meaning of the terms used for the analysis is as shown in Table II. The data collected are shown in Tables III, IV, V and VI.

$$\text{MTBF} = \frac{Total\ System\ operating\ hours}{Number\ of\ Failures} \quad (1)$$

$$\text{MTTR} = \frac{Total\ duration\ of\ outages}{Frequency\ of\ outage} \quad (2)$$

$$\text{Failure rate } (\lambda) = \frac{Number\ of\ times\ that\ failure\ occured}{Number\ of\ unit-hours\ of\ operation} \quad (3)$$

$$f(t) = \lambda e^{-\lambda t} \quad (4)$$

and the hazard rate is given by

$$\lambda(t) = \frac{f(t)}{1-f(t)} = \lambda \quad (5)$$

$$\text{Availability } (A) = \frac{MTBF-MTTR}{MTBF} \quad (6)$$

$$SAIDI = \frac{\sum N_i \times d}{N_t} \quad (7)$$

$$SAIFI = \frac{\sum N_i}{N_t} \quad (8)$$

$$ASAI = = 100\left(1 - \frac{\sum(N_i \times d)}{N_t \times T}\right) \quad (9)$$

TABLE II: SYMBOLS AND MEANINGS

Symbol	Meaning
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
λ	Failure rate
A	Availability
SAIFI	System Average Interruptions Frequency Index
SAIDI	System Average Interruptions Deviation Index
ASAI	Average System Availability Index
N_i	Customers affected by outage
N_t	All registered customers
d	Outage duration
T	Period under investigation

TABLE III: FREQUENCY AND OUTAGE DURATION OF AJILOSUN FEEDER

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Freq.	Duration (h)	Freq.	Duration (h)	Freq.	Duration (h)
January	107	170.04	45	103.07	152	273.11
February	98	190.05	36	80.00	134	270.05
March	75	160.12	46	88.21	121	248.33
April	76	165.09	45	82.27	121	247.36
May	91	155.15	56	91.10	147	246.25
June	33	120.40	55	181.13	88	301.53
July	53	260.19	60	90.12	90	296.48
August	62	179.10	52	90.18	114	269.28
Sept.	51	185.23	49	68.28	100	253.51
October	60	190.07	46	45.13	106	235.20
Nov.	51	240.19	28	51.15	87	291.34
Dec.	77	200.04	51	71.03	128	271.07
Total	834	2215.67	569	1041.67	1403	3251.34

TABLE IV: FREQUENCY AND OUTAGE DURATION OF BASIRI FEEDER

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Freq.	Duration (h)	Freq.	Duration (h)	Freq.	Duration (h)
January	91	168.10	33	40.12	124	208.22
February	78	179.06	31	35.09	109	214.15
March	62	149.04	29	39.04	91	188.08
April	64	138.05	36	42.18	100	180.23
May	52	129.05	39	62.12	91	191.17
June	42	100.20	40	40.14	82	140.34
July	42	179.60	38	93.16	80	272.26
August	50	256.10	34	36.03	84	292.13
Sept	42	167.10	38	48.21	80	215.31
October	49	152.14	23	40.26	72	192.40
Nov.	59	162.15	27	52.15	86	214.30
Dec.	61	154.12	31	45.16	92	199.28
Total	692	1795.59	399	712.28	1071	2507.87

TABLE V: FREQUENCY AND OUTAGE DURATION OF OKESA FEEDER

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Freq.	Duration (h)	Freq.	Duration (h)	Freq.	Duration (h)
January	98	169.40	39	65.06	137	234.46
February	82	182.19	32	48.09	114	230.28
March	73	153.40	50	61.18	123	214.58
April	78	146.16	43	53.20	121	199.36
May	80	142.09	40	75.18	120	217.27
June	38	112.04	50	96.12	88	208.16
July	42	249.16	31	56.10	73	305.26
August	50	163.12	47	53.14	97	216.26
Sept.	43	177.16	38	62.23	81	239.39
October	52	180.06	43	49.10	95	229.16
Nov.	49	160.15	29	71.14	78	231.29
December	68	208.05	48	54.04	116	262.09
Total	753	2042.98	482	844.28	1235	2887.26

TABLE VI: FREQUENCY AND OUTAGE DURATION OF ADEBAYO FEEDER

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Freq.	Duration (h)	Freq.	Duration (h)	Freq.	Duration (h)
January	88	159.13	46	111.06	134	270.19
February	76	181.08	40	45.15	116	226.23
March	65	146.05	36	49.04	101	195.10
April	59	129.08	47	59.06	106	188.14
May	54	126.04	50	69.18	104	195.22
June	45	97.19	47	53.17	92	150.36
July	40	168.20	51	58.14	91	226.34
August	48	249.16	49	47.26	97	296.42
Sept.	39	159.18	41	61.13	80	220.31
October	43	144.16	31	42.14	74	186.28
Nov.	63	154.17	34	64.11	97	218.28
Dec.	57	149.19	38	53.09	95	202.28
Total	677	1862.64	516	530.23	1193	2392.87

III. RESULTS AND DISCUSSIONS

The outage data collected as discussed in section 3 were analyzed using both load point and customer-oriented indices. The result of the analysis is presented and discussed in the following subsections

A. Load Point Reliability-based Indices

The computed Load point-oriented indices (MBBF, MTTR, Failure rate and Availability) for the four feeders are as shown in Fig. 2-7. The computation is based on the following assumptions:

1. The generation and the transmission stations are very reliable
2. Planned interruptions were not considered.

B. Mean Time Between Failures (MTBF)

The MTBF for each of the feeders on a monthly basis is shown in Fig. 2. The lowest MTBF for all the feeders (Ajilosun-10.58, Basiri-16.58, Okesa-12.60 and Adebayo-11.88) occurred between June and July except Adebayo feeder which occurred in February. The highest MTBF for the feeders (Ajilosun-22.50, Basiri-27.60, Okesa-21.72 and Adebayo-20.48) occurred between October and November 2021

C. Mean Time to Repair (MTTR)

The MTTR for each of the feeders on a monthly basis is shown in Fig. 3. The lowest MTTR for Ajilosun feeder

(0.6049) occurred in March, Basiri feeder (1.0035) in June, Okesa feeder (1.1307) in August, and Adebayo feeder (0.8592 in February. The highest MTTR for the feeders (Ajilosun-3.2933, Basiri-2.4516, Okesa-2.4537 and Adebayo-1.8856) occurred in June, July, and November 2021.

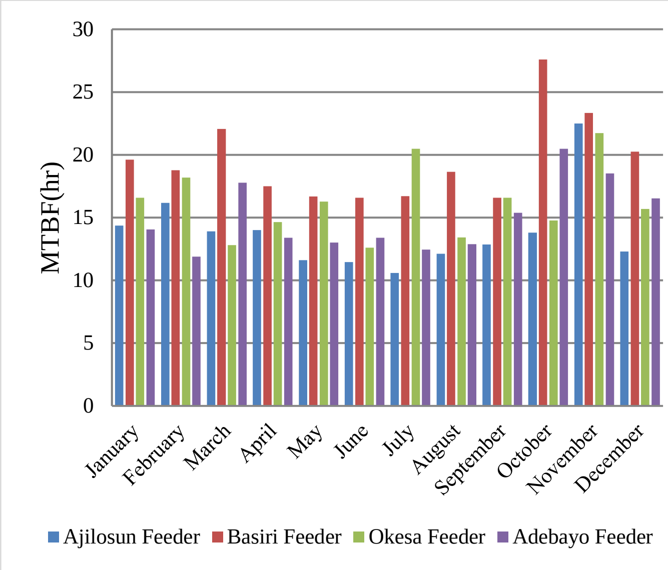

Fig. 2. MTBF (h) January to December 2021.

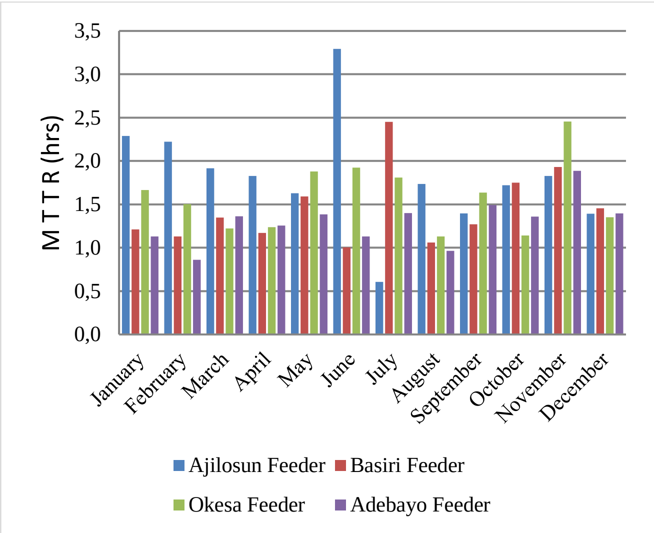

Fig. 3. MTTR (h) January to December 2021

D. Failure Rate

The failure rate for each of the feeders on a monthly basis is shown in Fig. 4. The lowest Failure rate for all the feeders (Ajilosun-0.0481, Basiri-0.0363, Okesa-0.0550 and Adebayo-0.0489) occurred between October and November except Okesa feeder which occurred in February. All the feeders have the highest failure rate (Ajilosun-0.0945, Basiri-0.0635, Okesa-0.0794 and Adebayo-0.0804) between June and July 2021. This may be due to the heavy rainfall accompanied by lightning strikes which caused system failures as a results of earth fault or over currents. The average failure rate for all the feeders is as shown in Fig. 5. Ajilosun feeder recorded the highest failure rate while Basiri recorded the lowest failure rate.

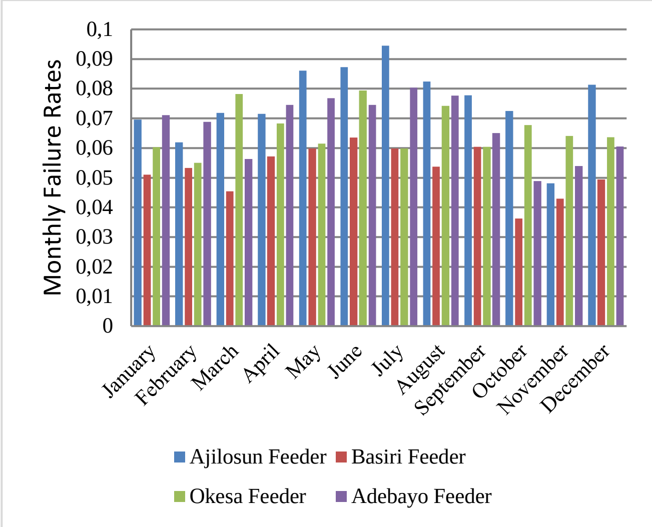

Fig. 4. Monthly failure Rate (events/h) January to December 2021.

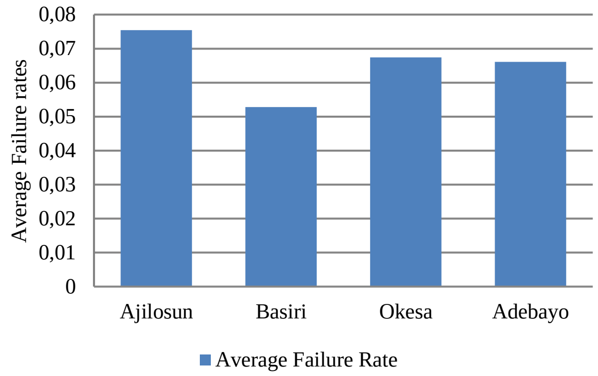

Fig. 5. Average Failure rate for the four feeders for the year 2021.

E. Availability (%)

The percentage availability for each of the feeders on a monthly basis is shown in Fig. 6. All the feeders recorded the lowest percentage availability (Ajilosun-71.24%, Basiri-85.33%, Okesa-84.75% and Adebayo-88.76%) between June and July. All the feeders have the highest percentage availability (Ajilosun-92.89%, Basiri-95.41%, Okesa-92.27% and Adebayo-93.37%) in the month of October 2021. The average percentage availability for all the feeders is as shown in Fig. 7. Basiri feeder recorded the availability while Ajilosun recorded the lowest percentage availability.

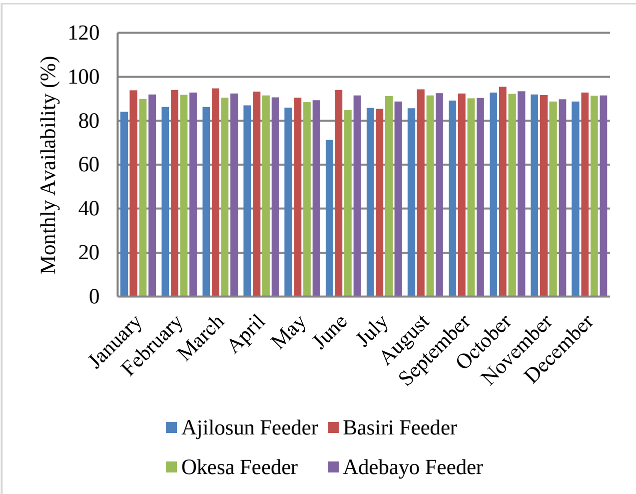

Fig. 6. Monthly Availability (%) for the feeders.

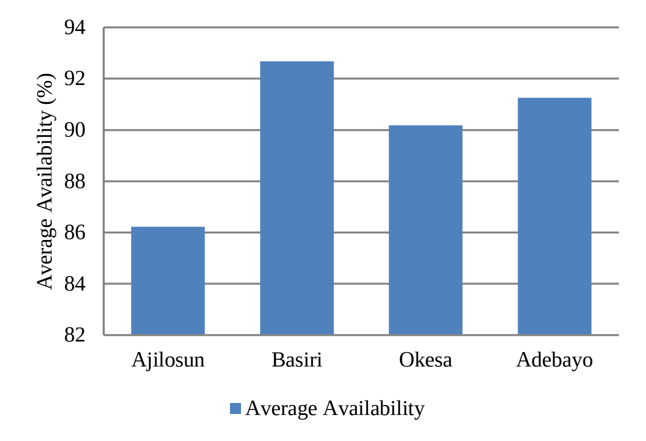

Fig. 7. Average Availability (%) for four feeders for the year, 2021

F. Customer Oriented Reliability Indices

The computed customer-oriented indices (SAIFI, SAIDI and ASAI) for the four feeders are as shown in Tables 7-10. The computation is based on the assumption that all the interruptions affected all the customers once whether the interruptions were on 1-phase 0r 3-phase along with other basic assumptions as in sub section 3.2. The average ASAI for all the feeders is 62.62%. The reliability is very low compared to the IEEE standard of 99.99%.

TABLE VII: CUSTOMER ORIENTED INDICES (JAN-DEC 2021) FOR AJILOSUN FEEDER

Month	Freq.	Outage (h)	Service hours	Monthly hours	SAIFI (int./Cst)	SAIDI (hrs/cust.)	ASAI (p.u)
Jan.	152	273.11	647	744	0.0145	0.0266	0.5778
Feb.	134	270.05	582	672	0.0128	0.0257	0.5360
March	121	248.33	640	744	0.0120	0.0236	0.6119
April	121	247.36	630	744	0.0115	0.0236	0.6073
May	147	246.25	651	720	0.0140	0.0234	0.6217
June	88	301.53	630	744	0.0084	0.0287	0.5213
July	113	350.19	635	744	0.0108	0.0333	0.4485
August	114	269.28	631	720	0.0109	0.0256	0.5732
Sept.	100	253.51	630	744	0.0095	0.0241	0.5976
Oct	106	235.20	635	720	0.0100	0.0224	0.6261
Nov.	79	291.34	630	720	0.0075	0.0277	0.3750
Dec	128	271.07	628	744	0.0122	0.0258	0.5683
Total	1403	3257.22	7569	8760	0.1341	0.3106	0.5554

TABLE VIII: CUSTOMER ORIENTED INDICES (JAN-DEC 2021) FOR BASIRI FEEDER

Month(s)	Freq.	Outage (h)	Service hours	Monthly hours	SAIFI (int./cust)	SAIDI (h/cust.)	ASAI (p.u)
Jan	124	208.22	645	744	0.0129	0.0216	0.6781
Feb.	109	214.15	574	672	0.0113	0.0222	0.6947
March	91	188.08	643	744	0.0092	0.0195	0.7061
April	100	180.23	632	744	0.0104	0.0187	0.7139
May	91	191.17	653	720	0.0094	0.0198	0.7063
June	82	140.34	627	744	0.0085	0.0146	0.7772
July	80	272.26	631	744	0.0082	0.0282	0.5712
Aug.	84	292.13	637	720	0.0087	0.0303	0.5370
Sept.	80	215.31	621	744	0.0087	0.0223	0.6582
Oct.	72	192.40	632	720	0.0075	0.0200	0.6970
Nov.	86	214.30	624	720	0.0089	0.0222	0.6598
Dec.	92	199.28	624	744	0.0095	0.0207	0.6826
Total	1091	2507.87	7543	8760	0.1132	0.2601	0.6773

TABLE IX: CUSTOMER ORIENTED INDICES (JAN-DEC 2021) FOR OKESA FEEDER

Month(s)	Freq.	Outage (h)	Service hours	Monthly hours	SAIFI (int./cust)	SAIDI (h/cust.)	ASAI (p.u)
Jan	137	234.46	643	744	0.0200	0.0344	0.6376
Feb	114	230.38	579	672	0.0166	0.0338	0.5360
March	123	314.58	638	744	0.0180	0.0461	0.5084
April	121	199.36	634	744	0.0177	0.0292	0.6835
May	120	217.27	658	720	0.0175	0.0318	0.6662
June	88	208.16	633	744	0.0129	0.0305	0.6695
July	73	305.26	632	744	0.0122	0.0447	0.5192
August	97	216.26	634	720	0.0142	0.0317	0.6572
Sept	81	239.39	628	744	0.0118	0.0351	0.6200
Oct	95	229.16	632	720	0.0139	0.0336	0.6391
Nov	78	231.29	626	720	0.0114	0.0339	0.6328
Dec	108	262.09	627	744	0.0158	0.0384	0.5826
Total	1235	2887.26	7564	8760	0.182	0.4232	0.6127

TABLE X: CUSTOMER ORIENTED INDICES (JAN-DEC 2021) FOR ADEBAYO FEEDER

Month (s)	Freq.	Outage (h)	Service hours	Monthly hours	SAIFI (int./cust)	SAIDI (h/cust.)	ASAI (p.u)
January	134	270.19	646	744	0.0104	0.0211	0.5824
February	116	226.23	581	672	0.0091	0.0176	0.6112
March	101	195.10	642	744	0.0078	0.0152	0.6951
April	106	188.14	634	744	0.0082	0.0147	0.7013
May	104	195.22	643	720	0.0080	0.0152	0.7001
June	92	150.36	632	744	0.0071	0.0117	0.7613
July	97	226.34	636	744	0.0076	0.0177	0.6435
August	97	296.42	637	720	0.0230	0.0231	0.5302
Sept	80	220.31	633	744	0.0063	0.0172	0.6503
October	74	186.28	646	720	0.0058	0.0145	0.7066
November	97	218.28	634	720	0.0076	0.0170	0.6535
December	95	202.28	645	744	0.0074	0.0158	0.6777
Total	1193	2392.8	7609	8760	0.1083	0.2008	0.6594

IV. CONCLUSION AND RECOMMENDATIONS

Reliability assessment of the four 11 kV secondary distribution feeders within Ado-Ekiti metropolis was carried out in this work. The outage data collected from BEDC were used to compute the Load point reliability indices (Means Time Before Failure, (MTBF), Mean Time to Repair (MTTR), Failure Rate and Availability) and customer orientation indices (SAIFI, SAIDI and ASAI). The results showed that Basiri feeder has the highest availability (92.68%) while Ajilosun feeder has the lowest availability (86.23%). It is noted that that the percentage of availability is still below the IEEE recommended standard for ASAI (0.99989). A critical analysis of the results showed that the non-availability of the feeders cannot be due to faults on the feeders alone but also on other factors such as the insufficient load allocation from the transmission station, the willingness of consumers to pay, load scheduling as a result of overloading on the transformers, long duration of fault clearing, vandalization of the substation equipment etc.

The distribution utility company, BEDC should pay more attention to the routine maintenance of the distribution network**.** Equipment and materials needed for repairs and maintenance should be readily available in store in order to reduce the long duration on clearing of faults. A situation where the community has to provide transformers for themselves when need arises is absolutely not acceptable. Prompt response to fault clearing by technical staff of power utility is highly recommended as this will considerably reduce down time.

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CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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