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Application of Power System Reliability and Outage Cost Indices on 33/11 kV Distribution Injection Substation: A Case Study of Asaba Business District

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ABSTRACT

The energy satisfaction that consumers can obtain from a power service provider solely depends on how reliable the feeder to which such customers are connected guarantees adequate and secure energy delivery. This research work is, therefore, to assess the reliability indices and the cost of expected electricity not supplied to the Asaba metropolis through the Benin Electricity Distribution Company (BEDC) Asaba 33/11 kV distribution injection substation. The method used consists of computing the System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), and Expected Energy Not Supplied Index (EENS) of the four feeders emanating from the substation and radiating into the metropolis. This is achieved by first collecting the outage hour, frequency of outage, and expected energy at the point of outage from the station's hourly logbook. The input data is fed into a program written in a MATLAB/OCTAVE environment. The values of the most important reliability index, ASAI, or availability, computed on the SPC, Anwai, Express, and Asaba Commercial feeders are 0.24, 0.23, 0.23, and 0.76 p.u., respectively, in 2020, while in 2021, these values are 0.32, 0.31, 0.33, and 0.83 p.u., respectively. Using the ASAI standard value from IEEE Standard 1366-2003, which is 0.999 as a benchmark, shows that all the feeders can be categorized as less reliable in the years under study. The annual cost of expected energy not supplied during power interruptions to Asaba electricity consumers in 2020 is $2,426,187.046 and $2,214,669.91 in 2021, respectively.

Keywords: *Reliability, Feeders; Average service availability; Expected energy not supplied; Logbook*

1.0 INTRODUCTION

An electric power distribution system is expected to provide electricity to its customers at the lowest possible cost and within acceptable reliability levels. The availability of reliable power supply at a reasonable cost guarantees the economic growth and development of a country (Mgaya et al., 2022). However, power outages occur sometimes when least expected, thus calling into question the reliability of the power distribution system.

Power outages have engaged the minds of various scholars over the last three decades. Electricity energy utilized in Nigeria is generated from power plants powered by various sources, such as steam power plants, hydroelectric power plants, and gas power plants. Reliability in a distribution system is a measure of the availability or level of electricity supply service from the system to the user or customer. The size of reliability can be expressed as how often the system goes into an outage or blackout, how long the outage or blackout occurs, and how fast it takes to recover from the outage or blackout (Ali et al., 2017).

Reliability is a subset of power quality, and many reliability decisions affect other areas of power quality. Because of this, familiarity with basic power quality indices is desirable. Many new power quality indices are being proposed, but most are less appropriate for aggregate utility measures and are more appropriate for measuring power quality at specific customer locations. The most common among them are SAIDI, CAIFI, and ASAI (IEEE 1998).

A power outage is a crisis in any country, whether it occurs on a small or large scale, because it hinders social and economic activities in an area (Carreras et al., 2003). Also, it affects several sectors and may cause severe damages to entities and organizations such as hospitals, telecommunication facilities, and industrial installations.

Distribution systems account for up to 90% of all customer reliability problems; thus, improving distribution reliability is the key to improving customer reliability (Zhang et al., 2008), and therefore, distribution reliability is one of the most important in the electric power Industry due to its high impact on the cost of electricity and its high correlation with customer satisfaction.

Electric power interruptions occur when system capacity is insufficient to meet system load levels. During these periods of inadequacy, outage costs will be borne by the utility, its customers, and perhaps by the entire society. The utility outage costs include loss of revenue, loss of future sales, and increased repair expenditures and maintenance. These costs usually form only a small part of the total outages.

In addition to reliability indices, the cost of energy as it affects the utility will be computed using two notable indices: the expected energy not supplied index (EENS) and the average energy not supplied index (AENS). The main problem facing electric power utilities in developing countries today is that power demand is increasing rapidly and supply growth is constrained by scarce resources, environmental problems, and other societal concerns. This has resulted in a need for more extensive justifications of the new system facilities and improvements in the production and use of electricity. The analysis of the customer failure statistics reveals that the distribution system makes the highest individual contribution to the unavailability of supply to the customer. With the vision of electricity deregulation for all within this period, will the interruptions improve or may they further deteriorate due to the individual rapid expansion of the distribution systems? This is the question we should ask ourselves before embarking on deregulation.

We are optimistic that the entire Disco will have a high level of performance and deliver power quality to the customer because of the market competition involved and to attract investors. The reliability improvement should be based most probably on the consideration of reliability worth and, to find the reliability worth, formulation. Intelligent placement of protection devices such as sectionalizes and switches in the distribution feeders has a significant impact on reliability improvement, and this will be further assessed along with the outage mitigation techniques for the distribution system network.

2.0 MATERIALS AND METHOD

2.1 Reliability Indicators for Measuring Service Quality Performance

These are the five key reliability indicators recently introduced for the purpose of assessing distribution reliability performance (Okorie and Ezekiel, 2014).

2.1.1 System Average Interruption Frequency Index *(SAIFI)*:

This is the measurement of how many sustained interruptions an average consumer will experience during the course of a year. (Akpojedje et al., 2021)

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

2.1.2 System Average Interruption Duration Index (*SAIDI*)

This defines the measurement of how many interruption hours an average customer will experience during the course of a year. (Akpojedje et al., 2021)

$$\text{SAIDI} = \frac{Total\ Outage\ Duration\ in\ Hours}{Number\ of\ Custormer\ Served} \quad (2)$$

2.1.3 Average Service Availability Index (ASAI)

This defines the average availability of the distribution network's services to customers. (Akpojedje et al., 2021).

$$\text{ASAI} = \frac{\text{Customer Hours of Available Service}}{\text{Customer Hours Demanded}} \quad (3)$$

2.1.4 Average Service Unavailability Index (ASUI)

This defines the measure of the average unavailability of the distribution system services to customers. (Akpojedje et al., 2021)

$$\text{ASUI} = \frac{\text{Customer Hours of Unavailable Services}}{\text{Customer Hours Demanded}} = 1 - \text{ASAI} \quad (4)$$

2.1.5 Expected Energy Not Supplied Index (EENS)

This defines the energy that didn't reach the customers and can be expressed as

$$EENS = \sum \sqrt{3} \times V_L \times A_i \times OH_i \quad (5)$$

Where, V_L is the line or feeder voltage, A_i is the load current at the point of outage and OH_i the outage hour. (Igbogidi et al., 2023)

2.2 Data collection

A daily power failure data of the 11 kV feeder (line) of the Asaba 2x15 MVA, 33/11 kV injection substation was collected, including the outage hour (OH), the frequency of outage hour, and the average hourly Ampere (A) of electricity lost by the energy provider. These data were collated from the substation logbooks using analytical methods for the period under study. Tables 1 and 2 present the collated data taken from the logbooks in 2020 and 2021, respectively.

Table 1: Data obtained from Asaba 33/11 kV Feeders in the year 2020

Feeder	SPC			Anwai			Express			Commercial		
No of Cust.	5680			4382			5234			148		
Month	OH	FoO	Cum Amp	OH	FoO	Cum Amp	OH	FoO	Cum Amp	OH	FoO	Cum Amp
Jan	609	54	838	605	54	681	616	50	512	232	41	387
Feb	552	57	856	558	57	685	548	49	544	88	27	304
Mar	597	57	698	604	55	511	602	62	508	210	67	414
Apr	537	55	774	534	54	605	543	58	642	213	50	210
May	584	56	845	592	54	500	580	70	978	185	47	427
Jun	573	56	864	575	49	572	535	50	925	214	71	444
Jul	572	48	768	598	43	930	601	46	799	150	63	443
Aug	600	54	744	591	55	464	591	64	721	223	62	305
Sept	545	60	815	570	56	591	546	64	770	64	36	271
Oct	506	93	618	463	80	751	478	80	670	207	66	358
Nov	518	74	671	515	71	602	502	78	680	154	54	303
Dec	461	95	594	493	80	615	572	91	545	148	60	290
Total	6082	332	9148	6698	708	7517	6714	757	8278	2088	644	3713

- Cust = No of customers in feeder
- OH = No of outage hours
- FoO = frequency of outages
- Cum Amp = total feeder current at the point of outage

Table 2: Data obtained from Asaba 33/11 kV Feeders in the year 2021

Feeder	SPC			Anwai			Express			Commercial		
No of Cust	5740			4479			5261			151		
Month	OH	FoO	Cum Amp	OH	FoO	Cum Amp	OH	FoO	Cum Amp	OH	FoO	Cum Amp
Jan	437	95	944	498	77	680	499	65	584	125	27	345
Feb	432	64	744	447	64	751	460	71	840	79	27	302
Mar	467	87	647	544	63	680	491	95	1056	79	24	295
Apr	469	82	362	449	71	543	547	63	803	64	32	287
May	479	104	750	523	91	692	502	95	878	80	33	219
Jun	495	101	684	449	97	866	429	105	607	90	31	331
Jul	605	52	859	634	41	719	586	82	863	158	63	352
Aug	550	84	617	478	87	425	463	84	730	333	80	336
Sept	466	85	788	485	85	733	451	76	829	67	30	306
Oct	523	89	672	551	70	688	545	81	687	200	59	352
Nov	509	66	454	473	71	690	450	78	963	78	20	355
Dec	511	89	815	514	74	501	488	84	997	54	26	295
Total	5943	998	8331	6045	891	7968	5891	979	9837	1407	452	3775

- Cust = No of customers in feeder
- OH = No of outage hours
- FoO = frequency of outages
- Cum Amp = Total current at the point of outage

3.0 RESULTS AND DISCUSSIONS

3.1 Feeder Analysis for 2020

3.1.1 SPC 11 KV Feeders

Figure 1 shows the results of monthly reliability indices SAIFI, SAIDI, CAIDI, ASAI, analyses carried out with respect to electricity supplied to customers in the SPC 11 kV in 2020 while the monthly expected energy not supplied is shown in Figure 2.

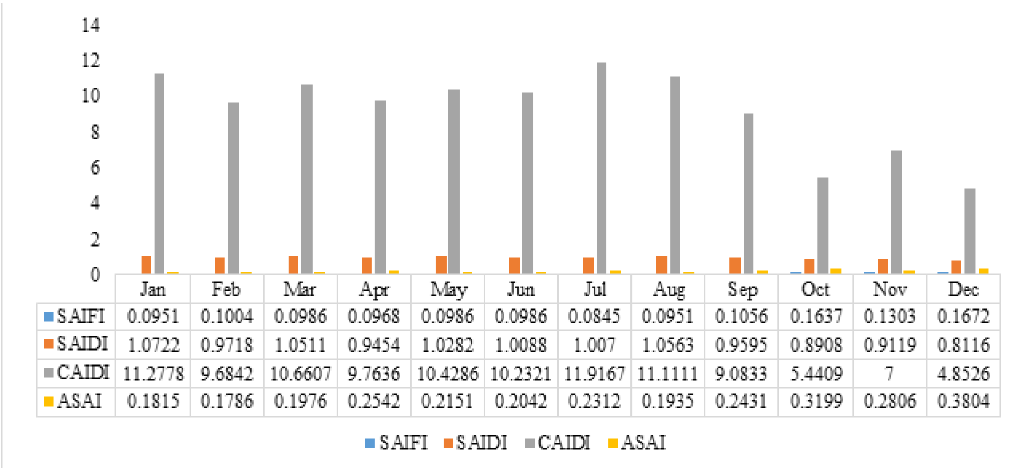


Figure 1: Monthly Reliability indices for SPC 11KV Feeder in 2020

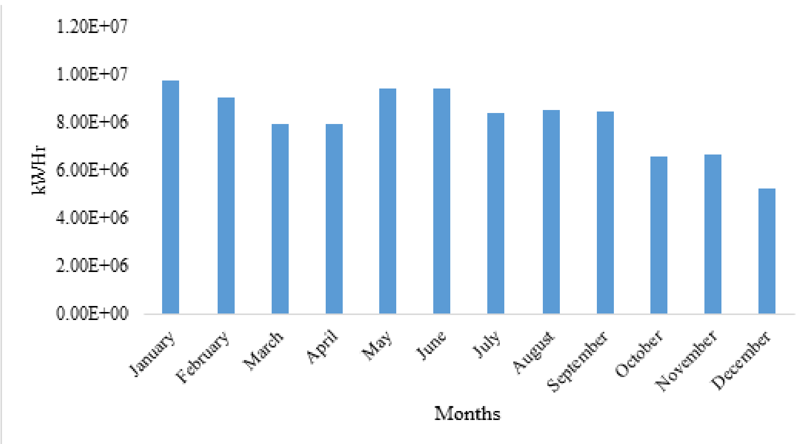
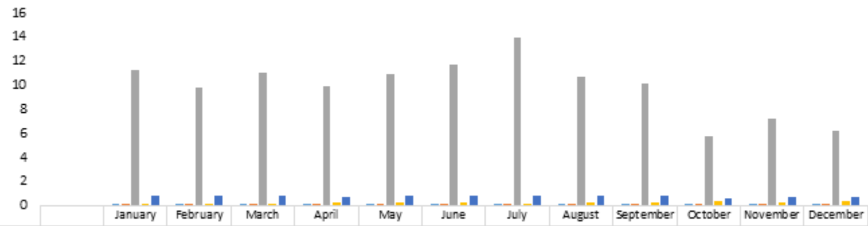


Figure 2: Monthly Expected Energy Not Supplied (SPC 11 kV Feeder) in 2020

As revealed in Figure 1, in February this feeder has low energy availability (ASAI) of 0.1786 or 18% and in the month of December, it has the highest energy availability (ASAI) of 0.3804 or 38.04 %. As shown in Figure 2, the monthly expected energy not supplied was however highest in January and lowest in December.

3.1.2 Anwai 11 KV Feeder

Figure 3 shows the results of monthly reliability indices SAIFI, SAIDI, CAIDI, ASAI, analyses carried out with respect to electricity supplied to customers in the Anwai 11 KV in 2020 while the monthly expected energy not supplied is shown in Figure 4.



	January	February	March	April	May	June	July	August	September	October	November	December
SAIFI	0.0123	0.013	0.0126	0.0123	0.0123	0.0112	0.0098	0.0126	0.0128	0.0183	0.0162	0.0183
SAIDI	0.1381	0.1273	0.1378	0.1219	0.1351	0.1312	0.1365	0.1349	0.1301	0.1057	0.1175	0.1125
CAIDI	11.2037	9.7895	10.982	9.8889	10.963	11.7347	13.9069	10.7455	10.1786	5.7875	7.2535	6.1625
ASAI	0.1868	0.1696	0.1882	0.2583	0.2043	0.2014	0.1962	0.2056	0.2083	0.3777	0.2847	0.3374
ASUI	0.8132	0.8304	0.8118	0.7417	0.7957	0.7986	0.8038	0.7944	0.7917	0.6223	0.7153	0.6626

SAIFI SAIDI CAIDI ASAI ASUI

Figure 3: Monthly Reliability Indices for ANWAI 11 kV Feeder in 2020

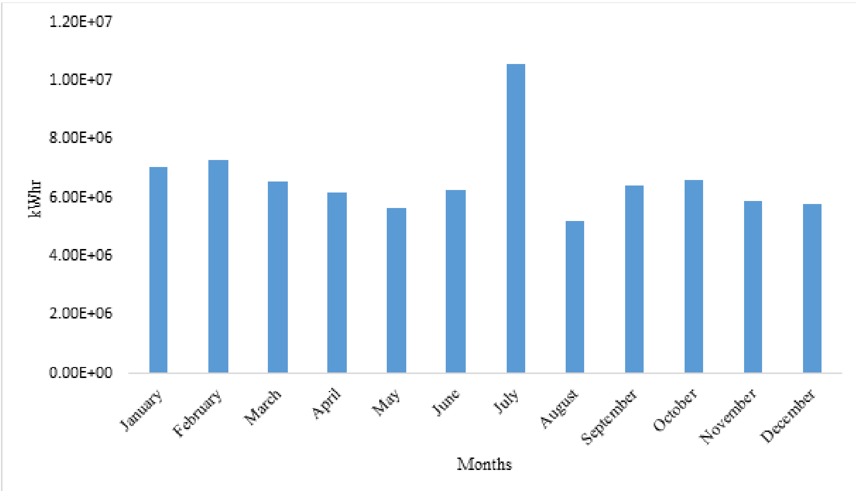
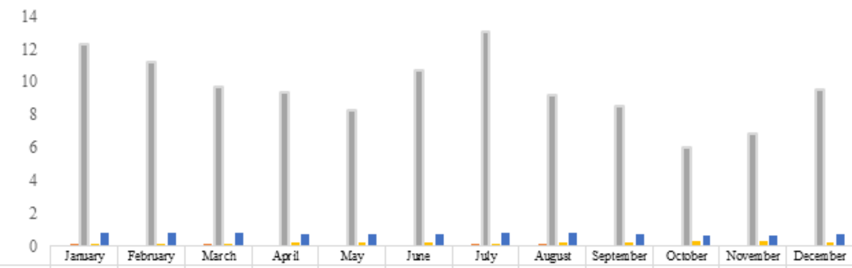


Figure 4: Monthly EENS in ANWAI 11 kV Feeder in 2020

From the Reliability indices shown in Figure 3, in February this feeder has a low energy availability (ASAI) of 0.1696 or 17% and in the month of October it has the highest energy availability (ASAI) of 0.3777 or 37.77 %. The monthly expected energy not supplied is shown in Figure 4 shows a high demand before the occurrence of an outage in the month of July.

3.1.3 Express 11 KV Feeder

Figure 5 shows the results of monthly reliability indices SAIFI, SAIDI, CAIDI, ASAI, analyses carried out with respect to electricity supplied to customers in the Express 11 KV in 2020 while the monthly expected energy not supplied is shown in Figure 6.



	January	February	March	April	May	June	July	August	September	October	November	December
SAIFI	0.0096	0.0094	0.0118	0.0111	0.0134	0.0096	0.0088	0.0122	0.0122	0.0153	0.0139	0.0115
SAIDI	0.1177	0.1047	0.115	0.1037	0.1108	0.1022	0.1148	0.1123	0.1043	0.0913	0.0959	0.1093
CAIDI	12.32	11.1836	9.7097	9.362	8.2857	10.7	13.0651	9.1875	8.5313	5.975	6.8767	9.5333
ASAI	0.172	0.1845	0.1909	0.2458	0.2204	0.2569	0.1922	0.2097	0.2417	0.3575	0.3028	0.2312
ASUI	0.8279	0.8155	0.8091	0.7542	0.7796	0.7431	0.8078	0.7903	0.7583	0.6424	0.6972	0.7688

SAIFI SAIDI CAIDI ASAI ASUI

Figure 5: Monthly Reliability Indices for Express 11 kV Feeder in 2020

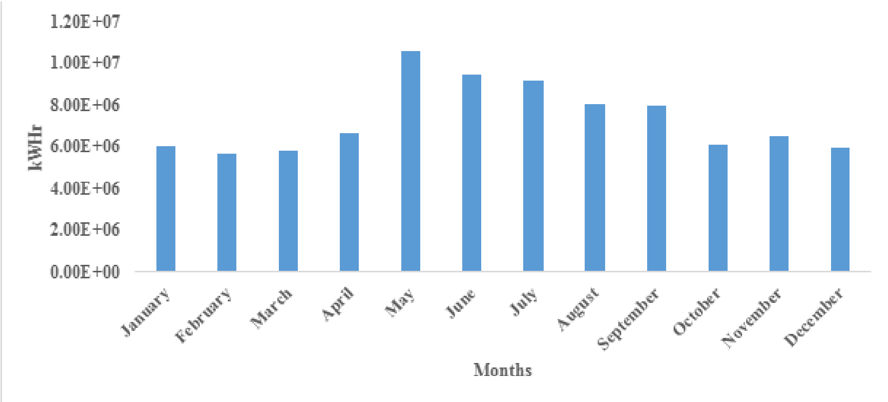
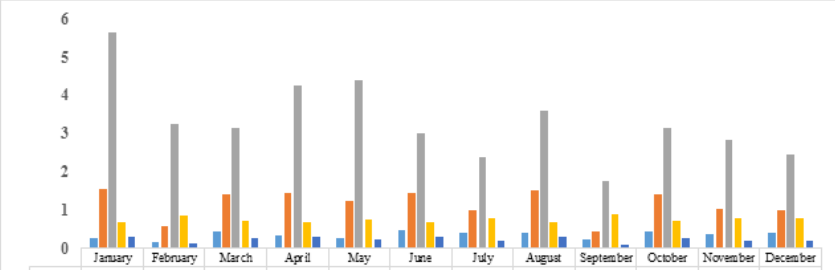


Figure 6: Monthly EENS in EXPRESS 11 kV Feeder in 2020

From the Feeder reliability indices shown in Figure 5, it could be seen that in January this feeder has a low energy availability (ASAI) of 0.1720 or 17% and in the month of October it has the highest energy availability (ASAI) of 0.3575 or 35.75 %.

3.1.4 Asaba Commercial 11 Kv Feeder
Figure 7 shows the results of monthly reliability indices SAIFI, SAIDI, CAIDI, ASAI, analyses carried out with respect to electricity supplied to customers in the Asaba Commercial 11 Kv in 2020 while the monthly expected energy not supplied is shown in Figure 8.



	January	February	March	April	May	June	July	August	September	October	November	December
SAIFI	0.277	0.1824	0.4527	0.3378	0.2838	0.4797	0.4257	0.4189	0.2432	0.4459	0.3649	0.4054
SAIDI	1.5676	0.5946	1.4189	1.4392	1.25	1.4459	1.0135	1.5068	0.4324	1.3986	1.0405	1
CAIDI	5.6585	3.2593	3.1343	4.26	4.4048	3.0141	2.3809	3.5968	1.7778	3.1364	2.8519	2.4667
ASAI	0.6882	0.869	0.7177	0.7042	0.7513	0.7028	0.7984	0.7003	0.9111	0.7218	0.7861	0.8011
ASUI	0.3118	0.1309	0.2823	0.2958	0.2487	0.2972	0.2016	0.2997	0.0889	0.2782	0.2139	0.1989

Figure 7: Monthly Reliability Indices for Asaba Commercial 11 kV Feeder (2020)

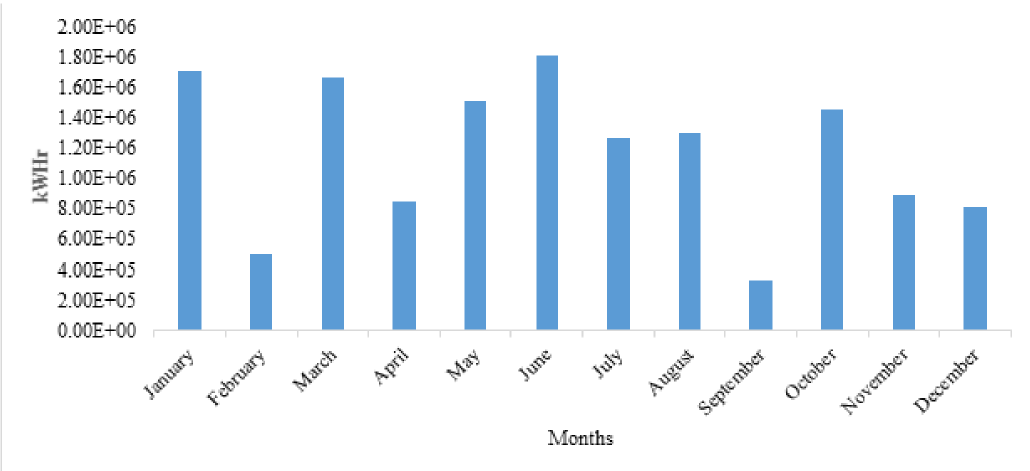


Figure 8: Monthly EENS In Asaba Commercial 11kv Feeder

From the Feeder reliability indices shown in Figure 7, it could be seen that in January this feeder has a low energy availability (ASAI) of 0.6882 or 69% and in the month of December it has the highest energy availability (ASAI) of 0.9111 or 91.11 %.

3.2 Comparative Analysis of the Four Feeders in 2020
Figure 9 shows the results of annual reliability parameters of SPC, ANWAI, EXPRESS, and ASABA COMMERCIAL 11 kV feeders during the year 2020 while Figure 10 shows the annual expected energy not supplied.

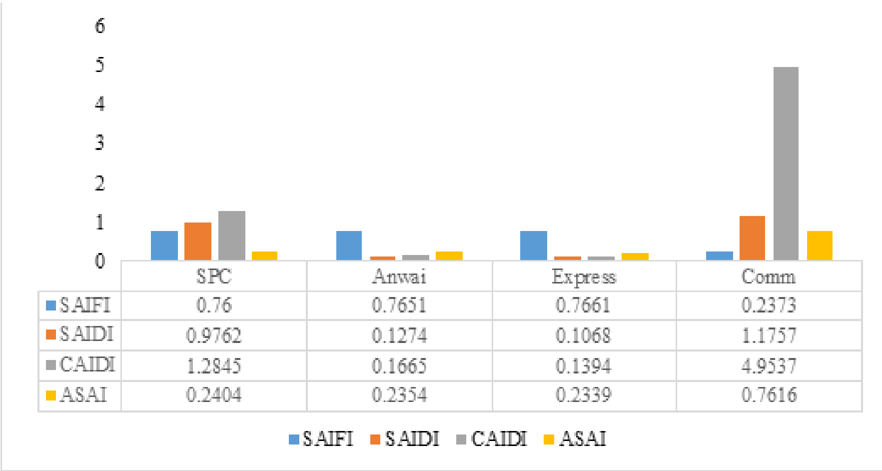


Figure 9: Comparative Reliability Indices Analysis of the Four Feeders (2020)

Figure 10: Comparative Analysis of EENS of the four 11 kV feeders (2020)

As revealed in Figure 9, Asaba Commercial feeder has the best performed reliability parameters, followed by SPC, ANWAI and EXPRESS respectively. The Availability (ASAI) for Asaba Commercial is 76%. The other three feeders experience load shedding and their MTTRs are almost the same. In the expected energy not supplied (Figure 10).

3.3 Comparative Reliability Analysis of the four Feeders (2021)

Figure 11 displays the annual reliability parameters of SPC, ANWAI, EXPRESS, and ASABA COMMERCIAL 11kV feeders for the year 2021. Meanwhile, Figure 12 illustrates the annual expected energy not supplied for the same period.

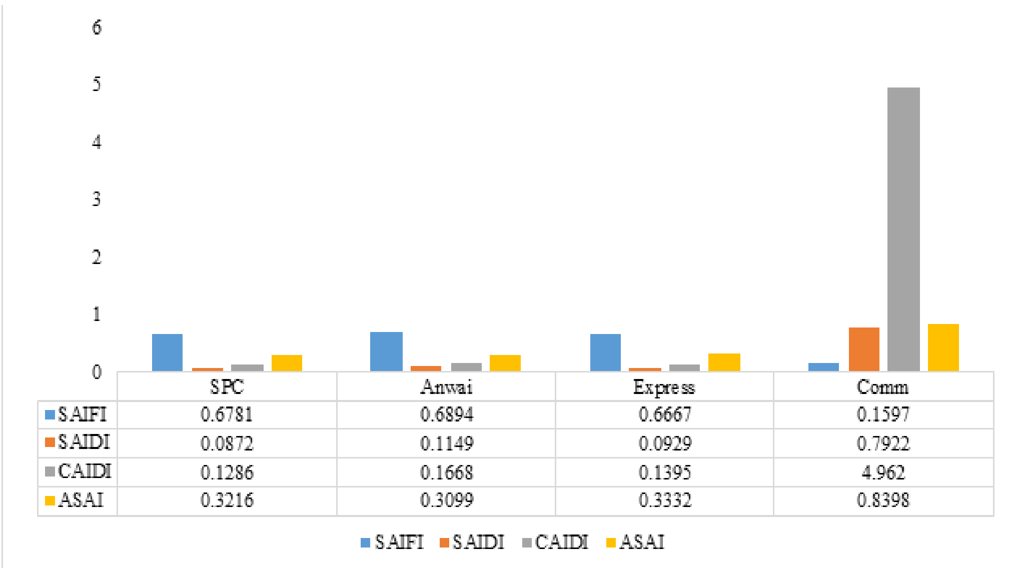


Figure 11: Comparative Reliability Analysis of the Four Feeders (2021)

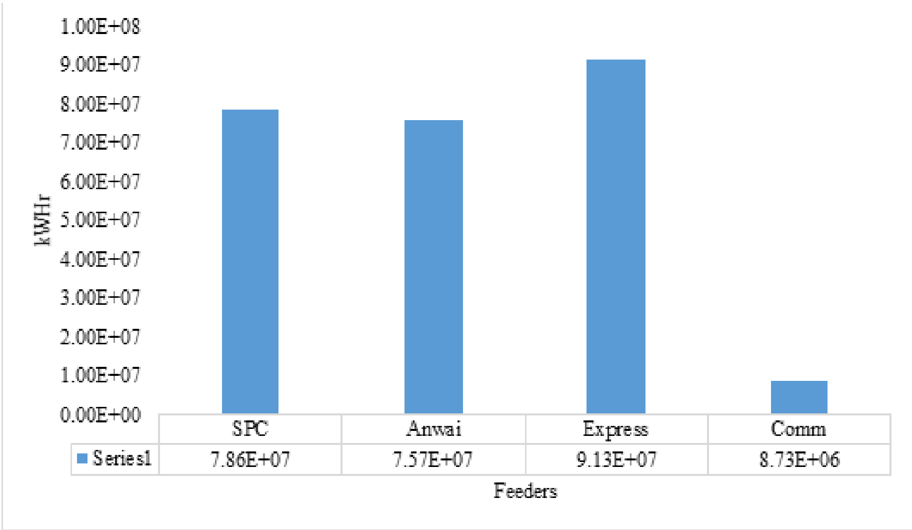


Figure 12: Comparative Analysis of Expected Energy Not Supplied (EENS) for the four 11kV Feeders in 2021

As depicted in Figure 11, the Asaba Commercial feeder exhibited the best-performing reliability parameters, boasting an Availability (ASAI) of 83%. This was closely followed by ANWAI, SPC, and EXPRESS, respectively.

3.4 Combined Comparative Analysis

3.4.1 Comparison of Yearly Reliability Indices for each Feeder in 2020 and 2021

The comparative study of the yearly reliability indices (2020 and 2021) for each feeder – SPC, ANWAI, EXPRESS, and COMMERCIAL – is presented in Figures 13, 14, 15, and 16, respectively.

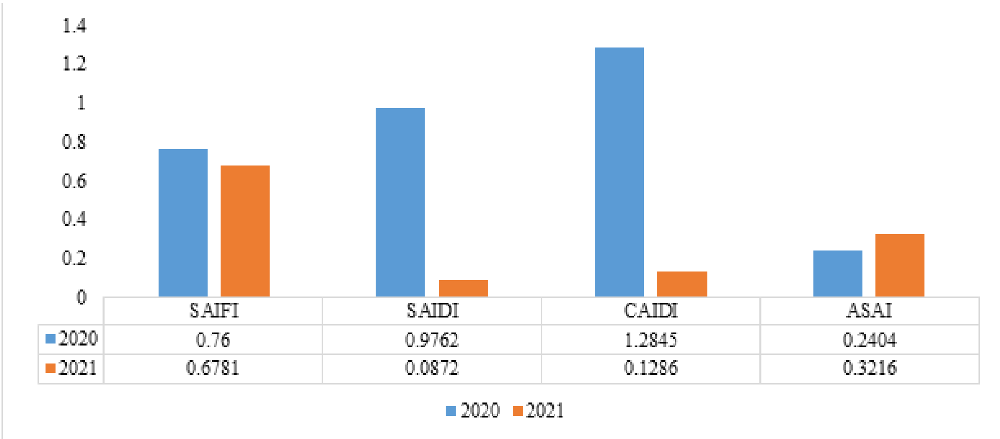


Figure 13: Comparison of Yearly Reliability Indices for the SPC feeder in 2020 and 2021

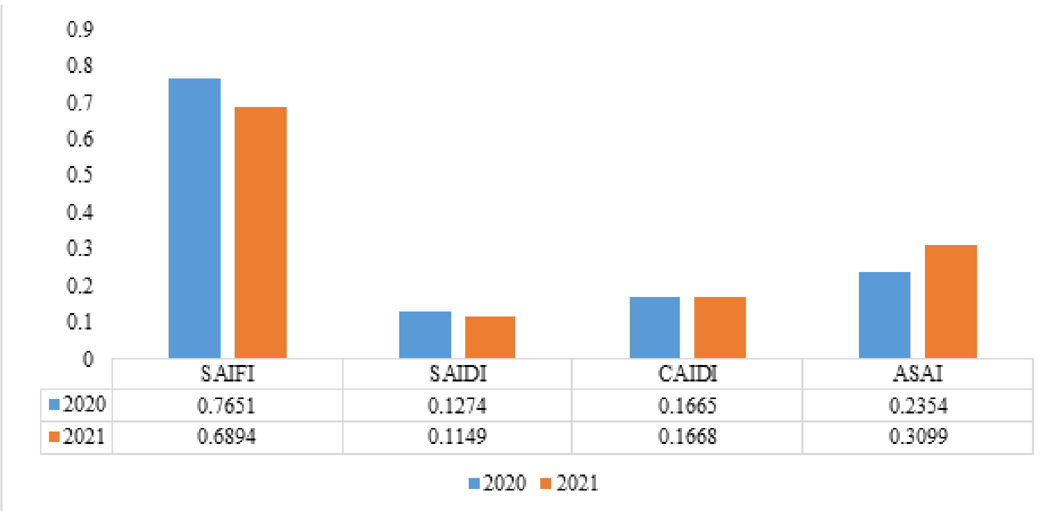


Figure 14: Comparison of Yearly Reliability Indices for the Anwai feeder in 2020 and 2021

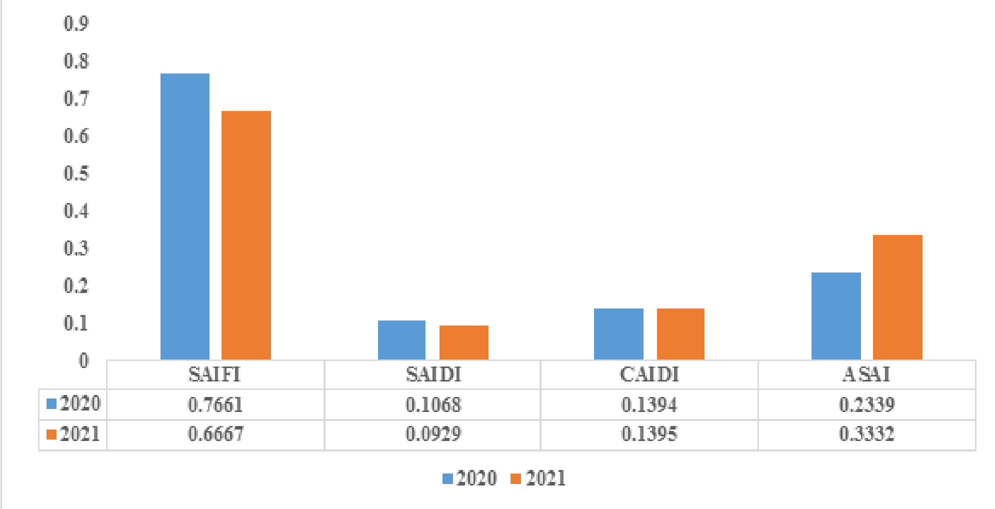


Figure 15: Comparison of Yearly Reliability Indices for the EXPRESS feeder in 2020 and 2021

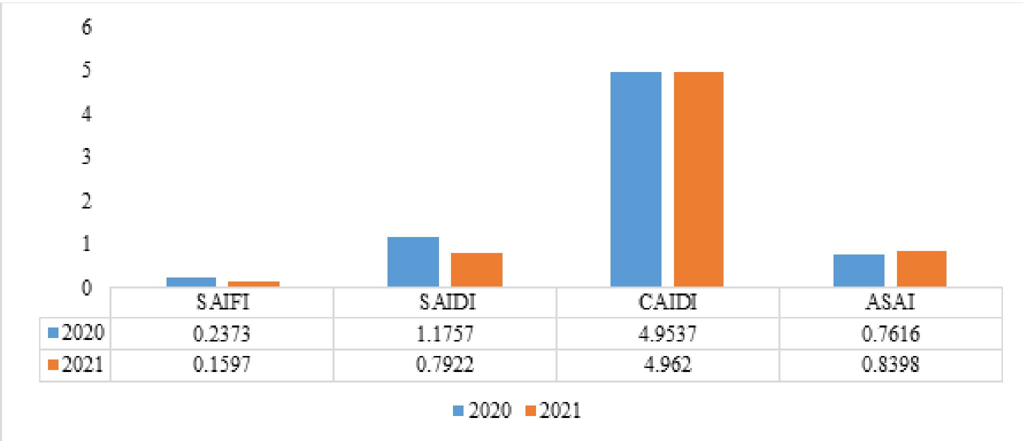


Figure 16: Comparison of Yearly Reliability Indices for the COMMERCIAL feeder in 2020 and 2021

As illustrated in Figure 13, the power availability (ASAI) in the SPC feeder improved from 24% in 2020 to 32% in 2021, indicating an increase in power supply of about 33.33%. The reliability indices for ANWAI 11kV feeder in 2020 and 2021 (Figure 14) demonstrate an improvement in power availability (ASAI) from 23% to 31%, representing an increase in power supply of about 43.78%. In the case of the EXPRESS 11kV feeder (Figure 15), power availability (ASAI) increased from 23% in 2020 to 33% in 2021, reflecting a 43.48% improvement in power supply. For the COMMERCIAL 11kV feeder (Figure 16), power availability (ASAI) rose from 76% in 2020 to 84% in 2021, indicating an increase in power supply of about 8%.

4.3.2 Cost of Expected Energy Not Supplied (CEENS)

The energy tariff in the Asaba Business Unit (ABU) charges customers on the SPC, ANWAI, and EXPRESS feeders at N69 ($0.166)/kWh, while those on the COMMERCIAL feeder are charged at N67.45 ($0.163)/kWh. The analysis of the Cost of Expected Energy Not Supplied in the four feeders (SPC, Anwai, EXPRESS, and COMMERCIAL) for 2020 and 2021 is presented in Figure 17.

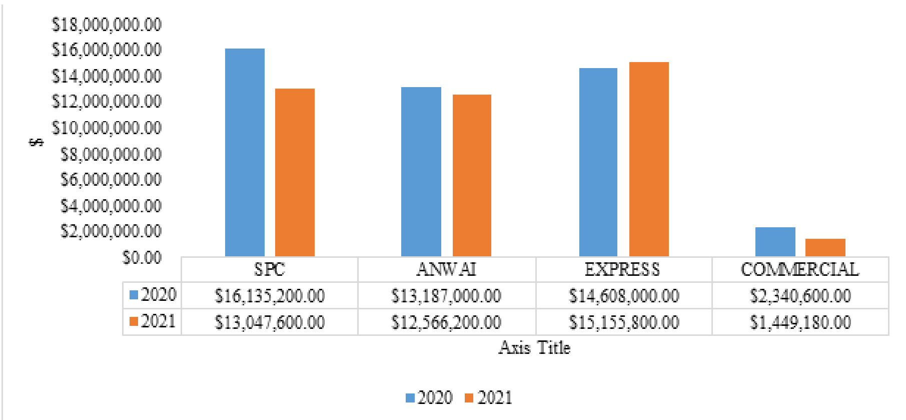


Figure 17: Cost of Expected Energy Not Supplied (2020 and 2021)

As depicted in Figure 17, the Total Cost of Expected Energy Not Supplied (CEENS) for the four feeders amounted to $46,270,800.00 in 2020, decreasing to $42,218,780.00 in 2021. Overall, there was a marginal improvement in power availability across all feeders, with the exception of Feeder Three (EXPRESS feeder) in the Asaba business unit.

4.0 CONCLUSION

In this study, the poor service of BEDC, the operators of the Asaba 33/11 kV injection substation, has been exposed, as evident from the reliability analysis conducted. The Asaba 33/11 kV distribution injection substation has four feeders: SPC, ANWAI, EXPRESS, and COMMERCIAL. The values of the most crucial reliability index, ASAI, computed on the SPC, ANWAI, EXPRESS, and Asaba COMMERCIAL feeders were 0.24, 0.23, 0.23, and 0.76, respectively, in 2020. In 2021, these values increased to 0.32, 0.31, 0.33, and 0.83. According to the IEEE standard 1366 (2003), which uses 0.999 as a benchmark, all the feeders can be classified as less reliable during the years under study. The annual cost of Expected Energy Not Supplied during power interruptions to Asaba electricity consumers was $2,426,187.046 in 2020 and $2,214,669.91 in 2021, indicating a cost reduction of 8.72%. The minimal drop is attributed to a slight improvement in the reduction of outage hours resulting from a decrease in activities leading to load shedding or equipment failures.

REFERENCES

Akpojedje, F.O., Abu, Y.O.A., Onowighose, O. (2021). Tripping Profile Analysis of the 33 kV Feeder of Ugbowo 2 X 15 MVA, 33/11 kV Injection Substation. Equity Journal of Science and Technology, 8(1), 19 – 26

Ali, K., Wiyagi, R.O., Syahputra, R. (2017). Reliability Analysis of Power Distribution System. ,Journal of Electrical Technology UMY (JET-UMY), 1(2), 67-74

Carreras, B.A., Lynch, V.E., Newman, D. E. & Dobson, I. (2003). Blackout mitigation assessment in power transmission systems, Proceedings of the 36th Annual Hawaii International Conference on System Sciences: 10. doi:10.1109/HICSS.2003.1173911.

IEEE (1998). Guide for Electric Power Distribution Reliability Indices: In IEEE Std 1366-1998, 1-21. doi: 10.1109/IEEESTD.1999.89432.

Mgaya, S., Maziku, H. (2022). Machine Learning Approach for Classifying Power Outage in Secondary Electric Distribution Network. Tanzania Journal of Engineering and Technology, 41(1), 1-9

Okorie, P.U., Ezekiel, D.M. (2014). Assessment of Reliability Indices of Abuja Distribution Network. International Journal of Engineering Research & Technology, 3(2), 415-419

Wang, R., Vanga, V.L., Zaiken, Z. B., Bennett, J. (2022). Analysis of the electric power outage data and prediction of electric power outage for major metropolitan areas in Texas using Machine Learning and Time Series Methods. *SMU Data Science Review*, 6(1), 1-39

Zhang, H., Bi, P., Zhong, X., Jin, Q. (2008). Development and Application of Reliability Analysis System for Medium and High Voltage Distribution Networks. Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, Nanjing, 2008. 937-940, doi: 10.1109/DRPT.2008.4523541.