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RELIABILITY ASSESSMENT OF EKPOMA 33/11KV INJECTION SUBSTATION DISTRIBUTION NETWORK

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ABSTRACT

Power system reliability is the probability that an electric power system can perform required functions satisfactorily under given conditions for a given time interval. This study investigates the reliability assessment of Ekpoma 33/11kV Injection substation distribution network on Iruekpen, Irrua, and Express feeders. The reliability indices data were collected from the distribution network daily operational logbook from January to December, 2024; and used to analyzed the reliability indices including power interruptions and outage durations, and customers' reliability indices using statistical database and Microsoft Excel to plots the Pie charts. Results shown that, Irrua feeder has the least average annual failure rate of 0.1624 event/hr. followed by Express feeder with 0.1647 event/hr. while Iruekpen feeder has the highest recorded failure rate of 0.1716. Iruekpen, Irrua, and Express feeders has Availability values of 61.47%, 63.42%, and 63.71%. These values were considered relatively "fair and consistent" in performance, compared to 99.99% stipulated by IEEE 1366-2022 standard. Express feeder registered the highest SAIFI values of 1.2418, followed by Irrua feeder with values of 0.2868, and Iruekpen feeder with the least values of 0.1324. Meanwhile, MTBF, MDT, SAIDI, CAIDI, ASAI and ASUI were as well analyzed and results presented. Also, interrupted frequency and outage duration were 1503, 1423, 1443; and 3375, 3204 and 3179 in hours for Iruekpen, Irrua, and Express feeders respectively. Major causes of power interruption on these feeders was largely due to long circuits length, configurations, ageing equipment, complete system collapse as a result of under frequency operation, scheduled and forced outages.

Keywords: Outages durations, SAIDI, SAIFI, Availability, Failure rate, Reliability indices

INTRODUCTION

The primary goal of an electric power distribution network system is to efficiently provide uninterrupted electricity to customers while ensuring reliable service at an affordable cost. In recent years, power distribution networks have experienced significant growth in both size and technological advancements. Consequently, utility companies must prioritize meeting customer reliability needs through strategic planning while minimizing operational costs. Adetunmbi, A O., et al., (2024). The term reliability is a crucial factor in assessing the ability of the system to consistently provide an adequate supply of electrical energy. Reliability analysis of distribution networks has been a longstanding focus in the electric power industry. Extensive research and studies have been conducted, driven by the growing costs associated with blackouts and fault outages by researchers Cruz, L.M., et al., (2020). The economic advancement of any nation is anchored upon its readiness to generate adequate power supply to its citizenry (Nasir *et al*, 2023). Adequate power supply is a humongous ingredient to a nation's economic development and wellbeing, indeed, ensuring a more reliable electricity supply is crucial for fostering technological advancements and promoting the development of modern society, while inadequate power supply possess a detrimental effect on the social-economic growth of a nation. Reliability in power distribution underpins numerous aspects of our daily lives, from innovation in technology to the overall well-being of communities. Thus, reliability plays a crucial role in power systems as it directly impacts the productivity and efficiency of electricity generation and distribution (Ahumibe, *et al.* 2024). A reliable power system ensures consistent access to electricity, benefiting various sectors of the economy and contributing to overall productivity and development. The power system consists of three main subsystems: generation, transmission, and distribution. Electricity is generated in power plants, and then transmitted at high voltages through transmission lines to distribution network substations, where it is further distributed to homes, businesses, and other end-users at lower voltages. This division allows for efficient and effective delivery of electricity to consumers (Aibangbee, and Chukwuemeka, 2017). The distribution system substation serves as an intermediary point between the sub-transmission system, which carries electricity at higher voltages like 11 kV, and the final distribution to end-users, where voltages are reduced to the standard household levels of 415/240 V before reaching the consumer's meter according to (Roystone, A. (2014); IEEE Power Engineering Society (2014). In their studies, Adetunmbe, *et al*, (2024); and Olumuyiwa, A. A. *et, al*. (2020) carried out analysis on reliability indices which revealed that distribution systems were responsible for about 90% of all customer reliability issues, increasing distribution reliability has become critical to utility companies. As a result, distribution dependability is very critical to the electric power sector owning to its significant influence on electricity costs and strong association with customer satisfaction. Aibangbee, and Ckukwuemeka, (2017), carried out reliability assessment of APO 132/33 KV Electric Transmission Substation Abuja. In this research, outage duration, a measure using various metrics reliability indices such as system average interruption duration index (SAIDI) which represents the average outage time per customer, and system average interruption frequency index, (SAIFI) which is the average duration of a single sustained outage as well as the customer average interruption duration index (CAIDI), and average service availability index (ASAI) etc were deduced for the substation.

Distribution system reliability is not a new subject, but the deregulation of electricity is a new factor which changes the orientation of research on distribution system. Thus, distribution system can be discussed under two general aspects namely: system adequacy and system security. System adequacy relates to the system capacity in relation to energy demand while system security relates to the dynamic response of the system, such as fault. According to researchers (Roy B, and R.N. Allan, 2008); and Onime, and Adegboyega, 2014). According to Dorji, T. (2019); Perekebina, and Patrick, (2022) in their articles stipulated that with increasing demand for electricity supply, the necessity to achieve an acceptable level of reliability, quality and safety at an economic price, the utility company has to evolve and improve the system continuously depending upon the requirement of the customers. Ekpoma 33/11kV Injection substation distribution network usually experienced power supply failure resulting to unavailability of supply to numerous customers connected to the distribution feeders, and the Edo state power supply systems appears to be in a state of emergency in terms of adequate and regular power supply to consumers.

This paper study focuses on analyzing the reliability indices, of Ekpoma 33/11kV Injection substation distribution network on Iruekpen, Irrua, and Express feeders which include failure rate, Mean Time Between Failure, Mean Down Time, Availability and outage duration such as SAIDI, SAIFI, CAIDI, ASAI etc. using statistical database and Microsoft Excel Program.

MATERIALS AND METHODS

Ekpoma Substation is a 33/11kV injection substation distribution network comprising of three 11kV feeders namely Iruekpen, Irrua, and Express feeders. It is located in Ekpoma town in Esan West Local Government Area of Edo State, Nigeria. The aimed to assess the seriousness of disruptions was based on the loss of load during each interruption and involve weighted indices calculated for specific load points. Electric power outage durations data were collected from Ekpoma 33/11kV Injection substation distribution network (2024) Daily operational reports logbook comprising of information obtained on each of the three feeders' failure event during the period of one year (January to December, 2024) under review.

The Institute of Electrical and Electronics Engineers (IEEE) Std 1366-2022 is the standard for electric power distribution reliability that provide definitions, indices like SAIFI, SAIDI, CAIDI and methodologies for utilities to consistently measure and report the performance and outages of their distribution system. This section presents detailed reliability analysis of the studied distribution system which include reliability indices such as SAIFI, SAIDI, CAIDI which can be expressed mathematically as listed in equations (1) to (5).

System Average Interruption Duration Index, SAIDI =

$$\frac{\text{Total duration in hour}}{\text{Number of customers supplied}} \quad (1)$$

Is the total duration of all outages for the average customer in a year? Similarly, the average number of interruptions per customer per year is called SAIFI, which is expressed as

System Average Interruption Frequency Index, SAIFI =

$$\frac{\text{Frequency of outages}}{\text{Number of customers supplied}} \quad (2)$$

Customer Average Interruption Duration Index (CAIDI) is defined as the average time it takes to restore services for customers during a sustained outage. It is given as in (3)

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

Also, ASAI is defined as the percentage of time a customer has services available for a year. Thus, it is expressed as ASAI

$$= \frac{Consumer\ hours\ service\ availability}{consumer\ hours\ service\ demand} \quad (4)$$

Average Service Unavailability Index, ASUI =

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

In reliability analysis, the random variable is frequency time and so the standard function that best fit is the exponential function because it has only time as the independent variables, according to Aibangbee, and Chukwuemeka, (2017); Akhikpemelo, A., *et al.* (2016). Hence, the most important factor for this function to be used is that the hazard rate (λ) should be constant known as failure rate (λ). According to equation (1) gave the density function as follows

$$f(t) = \lambda e^{-\lambda t} \quad (6)$$

And the hazard rate is given by

$$\lambda(t) = \frac{f(t)}{1-f(t)} = \lambda \quad (7)$$

Failure rate is a measure of how frequently a component or systems fails. It is a key metric for reliability and is often expressed in failure/hour, or as a percentage.

$$\text{Failure rate } (\lambda) = \frac{\text{Number of times that failure occured}}{\text{Number of unit–hours of operation}} \quad (8)$$

Reliability is the probability that a component will perform properly for a specified period of time under a given set of operating condition. Mathematically, it is expressed as

$$R(t) = 1\text{-}f(t) = e^{\lambda t} \quad (9)$$

Mean Time Between Failure (MTBF) is the time that passes before a component, Assembly or system fails. It specifies the total amount of time the component is in use. Mathematically, MTBF is expressed as

$$\text{MTBF} = \frac{\text{Total system operating hours}}{\text{Number of Failures}} \quad (10)$$

Also, Mean Time to Repair (MTTR) or Mean Down Time (MDT) is the average time it takes to repair a failed component, hence, restoring the component back to normal operation. Mathematically, MTTR is expressed as

$$\text{MTTR} = \frac{\text{Total duration of outages}}{\text{Frequency of outage}} \quad (11)$$

Availability is the probability that a system will perform its intended function at a given time if operated and maintained as prescribed. Mathematically, it is expressed as:

$$\text{Availability (A)} = \frac{\text{MTBF}-\text{MTTR}}{\text{MTBF}} \quad (12)$$

The results obtained will be the outage rates of the feeders which include scheduled and forced outages, percentage of occurrences and availability of the feeders within the period of study.

Data Collection and Reliability Analysis

Outage frequency and duration data were collected from the three feeder's logbook over a period of twelve months between January and December, 2024 at the Ekpoma 33/11kV injection substation network. These data encompassed crucial information such as system downtime (failures), outages, number of customers, total hours, as well as the nature and types of faults that occurred during this period. Reliability analysis was performed using statistical data and Microsoft Excel software environment.

The information recorded in a narrative form were translated into a statistical database. The outages were classified as scheduled and forced outages. Hence, data on failure rates and repair times of component used in the distribution system were compiled for reliability evaluations. In addition, data on statistical information consisting of outages arising from system collapse, scheduled and unscheduled maintenance on each feeder were collected. These data were used to analyzed the reliability indices which include (MTBF, MDT, and Availability), total hours of outages and the number of interruptions (frequency) per day and Customer Reliability Indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) using equations (1) to (12).

RESULTS AND DISCUSSION

Detailed reliability analysis of the injection substation network was presented. Based on the statistical database computed from the substation, the collected data was used to evaluate the frequency and duration of outages, failure rate, MTBF, MDT, availability, reliability indices and customer reliability indices like the SAIFI, SAIDI, CAIDI, ASAI and ASUI index results were presented in Tables 1 to 10.

However, these Tables was divided into three sections. Tables 1, 2 and 3 shown summary of frequency and duration of outages, reliability indices, and customer reliability indices, like the SAIFI, SAIDI, CAIDI, ASAI and ASUI index affected by power interruption on IRUEKPEN feeder from January to December, 2024. Same procedure followed by Tables 4, 5, and 6 for IRRUA feeder while Tables 7, 8 and 9 for EXPRESS feeder respectively. Meanwhile, Table 10 depicts summary of scheduled and forced outages of frequency and duration in hours for Iruekpen, Irrua, and Express road feeders.

Table 1: Summary of Frequency and Duration of Outages On Iruekpen Feeder

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Freq.	Duration [hr]	Freq.	Duration [hr]	Freq	Duration [hr]
Jan	117	180.04	45	113.07	162	293.11
Feb	108	200.05	31	30.26	139	230.31
Mar	85	170.12	46	98.21	131	268.33
April	86	175.09	45	92.27	131	267.36
May	101	165.15	56	101.10	157	266.25
June	43	130.40	55	191.13	98	321.53
July	63	270.19	37	46.29	100	316.48
Aug	72	189.10	52	55.18	124	244.28
Sept	61	195.23	49	78.28	110	273.51
Oct	70	200.07	46	89.09	116	289.16
Nov	61	250.19	36	61.15	97	311.34
Dec	87	210.04	51	81.03	138	291.07
Total	954	2336.47	549	1038.26	1503	3375.13

Table 2: Reliability Indices On Iruekpen Feeder

Month(s)	Freq.	Outage[hr]	Total [hr]	Failure Rate[event/hr]	MTBF [hr]	MDT [hr]	Availability [p.u]
Jan	162	293.11	744	0.2177	4.5935	1.8093	0.6061
Feb	139	230.31	672	0.2068	4.8356	1.6569	0.6574
Mar	131	268.33	744	0.1760	5.6818	2.0483	0.6395
April	131	267.36	720	0.1819	5.4975	2.0409	0.6288
May	157	266.25	744	0.2110	4.7393	1.6959	0.6422
June	98	321.53	720	0.1361	7.3475	3.2809	0.5535
July	100	316.48	744	0.1344	7.4405	3.1648	0.5747
Aug	124	244.28	744	0.1667	5.9988	1.9700	0.6716
Sept	110	273.51	720	0.1528	6.5445	2.4865	0.6201
Oct	116	289.16	744	0.1559	6.4144	2.4928	0.6114
Nov	97	311.34	720	0.1347	7.4239	3.2097	0.5677
Dec	138	291.07	744	0.1855	5.3908	2.1092	0.6087
Total	1503	3375.13	8760	0.1716	5.8275	2.2456	0.6147

Table 3: Customer Reliability Indices On Iruekpen Feeder

Month(s)	Freq.	Outage[hr]	Hours	Customers.	SAIFI[int/cust]	SAIDI[hrs/cust]	CAIDI[hrs/cust]	ASAI[p.u]	ASUI [p.u]
Jan	162	293.11	744	11355	0.0143	0.0258	1.8093	0.6060	0.3940
Feb	139	230.31	672	11355	0.0122	0.0203	1.6569	0.6573	0.3427
Mar	131	268.33	744	11355	0.0115	0.0236	2.0483	0.6393	0.3607
April	131	267.36	720	11355	0.0115	0.0235	2.0409	0.6287	0.3713
May	157	266.25	744	11355	0.0138	0.0234	1.6959	0.6421	0.3579
June	98	321.53	720	11355	0.0086	0.0283	3.2809	0.5534	0.4466
July	100	316.48	744	11355	0.0088	0.0279	3.1648	0.5746	0.4254
Aug	124	244.28	744	11355	0.0109	0.0215	1.9700	0.6717	0.3283
Sept	110	273.51	720	11355	0.0097	0.0241	2.4865	0.6201	0.3799
Oct	116	289.16	744	11355	0.0102	0.0255	2.4928	0.6113	0.3887
Nov	97	311.34	720	11355	0.0085	0.0274	3.2097	0.5676	0.4324
Dec	138	291.07	744	11355	0.0122	0.0256	2.1092	0.6088	0.3912
Total	**1503**	**3375.13**	**8760**	**11355**	**0.1322**	**0.2972**	**2.2456**	**0.6147**	**0.3853**

Tables 4 to 6 shows summary of the number of outages, their duration, reliability indices as well as customer reliability indices such as SAIFI, SAIDI, CAIDI, ASAI and ASUI index over the period of study for Irrua feeder.

Table 4: Summary of Frequency and Duration of Outages on Irrua Feeders

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Frequency	Duration [hr]	Frequency	Duration [hr]	Frequency	Duration [hr]
Jan	120	160.10	38	100.11	158	260.21
Feb.	92	185.25	28	35.16	120	220.41
Mar.	75	175.20	60	63.10	135	238.30
April	90	145.15	20	55.18	110	200.33
May	105	159.23	35	71.22	140	230.45
June	53	250.10	27	90.05	80	340.15
July	75	220.16	27	95.15	102	315.31
Aug	60	168.19	55	100.04	115	268.33
Sept	55	195.15	70	90.10	125	285.25
Oct.	80	180.21	20	96.30	100	276.51
Nov.	58	210.28	40	106.20	98	316.48
Dec	93	153.15	47	97.05	140	250.20
Total	956	2203.37	467	1000.56	1423	3204.32

Table 5: Reliability Indices On Irrua Feeder

Months	Freq	Outage [hr]	Total [hr]	Failure Rate [event/hr]	MTBF[hr]	MDT[hr]	Availability[p.u]
Jan	158	260.21	744	0.2124	4.7081	1.6469	0.6502
Feb	120	220.41	672	0.1786	5.5991	1.8368	0.6719
March	135	238.30	744	0.1815	5.5096	1.7652	0.6796
April	110	200.33	720	0.1528	6.5445	1.8212	0.7217
May	140	230.45	744	0.1882	5.3135	1.6461	0.6902
June	80	340.15	720	0.1111	9.0009	4.2519	0.5276
July	102	315.31	744	0.1371	7.2939	3.0913	0.5762
Aug	115	268.33	744	0.1546	6.4683	2.3333	0.6393
Sept	125	285.25	720	0.1736	5.7604	2.2820	0.6038
Oct	100	276.51	744	0.1344	7.4405	2.7651	0.6284
Nov	98	316.48	720	0.1361	7.3475	3.2294	0.5605
Dec	140	250.20	744	0.1882	5.3135	1.7871	0.6637
Total	1423	3204.33	8760	0.1624	6.1576	2.2518	0.6343

Table 6: Customer Reliability Indices on Irrua Feeder

Months	Freq	Outages [hr]	Hours	Cust-omers	SAIFI [int/cust]	SAIDI [hrs/cust]	CAIDI [hrs/cust]	ASAI [p.u]	ASUI [p.u.]
Jan	158	260.21	744	4961	0.0318	0.0525	1.6469	0.6503	0.3497
Feb	120	220.41	672	4961	0.0242	0.0444	1.8368	0.6720	0.3280
Mar	135	238.30	744	4961	0.0272	0.0480	1.7652	0.6797	0.3203
Apri	110	200.33	720	4961	0.0222	0.0404	1.8212	0.7218	0.2782
May	140	230.45	744	4961	0.0282	0.0465	1.6461	0.6903	0.3697
June	80	340.15	720	4961	0.0161	0.0686	4.2519	0.5276	0.4724
July	102	315.31	744	4961	0.0206	0.0636	3.0913	0.5762	0.4238
Aug	115	268.33	744	4961	0.0232	0.0541	2.3333	0.6393	0.3607
Sept	125	285.25	720	4961	0.0252	0.0575	2.2820	0.6038	0.3962
Oct	100	276.51	744	4961	0.0202	0.0557	2.7651	0.6283	0.3717
Nov	98	316.48	720	4961	0.0198	0.0638	3.2294	0.5604	0.4396
Dec	140	250.20	744	4961	0.0282	0.0504	1.7871	0.6637	0.3363
Total	1423	3204.33	8760	4961	0.2869	0.6459	2.2518	0.6342	0.3658

Similarly, Tables 7, 8 and 9 depict summary of frequency and duration of outages, reliability indices, and customer orientation indices of SAIFI, SAIDI, CAIDI, ASAI and ASUI index on Express road feeder during the period under study.

Table 7: Frequency and Duration of Outages On Express Feeder

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Freq.	Duration [hr]	Freq.	Duration [hr]	Freq.	Duration [hr]
Jan	98	165.42	40	85.08	138	250.50
Feb	83	180.25	19	65.13	102	245.38
Mar	120	145.12	40	117.23	160	262.35
April	84	157.20	36	48.25	120	205.45
May	102	138.08	38	82.07	140	220.15
June	47	269.15	43	51.13	90	320.28
July	78	198.26	47	97.14	125	295. 40
Aug	72	122.14	63	156.06	135	278.20
Sept	62	153.48	38	139.06	100	292.54
Oct	70	160.32	28	90.16	98	250.48
Nov	68	204.15	37	111.17	105	315.32
Dec	97	120.05	33	120.13	130	240.18
Total	981	2015.22	462	1163.41	1443	3179.03

Table 8: Reliability Indices On Express Feeder

Month(s)	Freq.	Outage[hr]	Total[hr]	Failure Rate[event/hr]	MTBF[hr]	MDT[hr]	Availability[p.u]
Jan	138	250.50	744	0.1855	5.3908	1.8152	0.6633
Feb	102	245.38	672	0.1518	6.5876	2.4057	0.6348
March	160	262.35	744	0.2151	4.6490	1.6397	0.6473
April	120	205.45	720	0.1667	5.9988	1.7121	0.7146
May	140	220.15	744	0.1882	5.3135	1.5725	0.7041
June	90	320.28	720	0.1250	8.0000	3.5587	0.5552
July	125	295.40	744	0.1680	5.9524	2.3632	0.6030
Aug	135	278.20	744	0.1815	5.5096	2.0607	0.6260
Sept	100	292.54	720	0.1389	7.1994	2.9254	0.5937
Oct	98	250.48	744	0.1317	7.5930	2.5559	0.6634
Nov	105	315.32	720	0.1458	6.8587	3.0030	0.5622
Dec	130	240.18	744	0.1747	5.7241	1.8475	0.6772
Total	1443	3179.03	8760	0.1647	6.0716	2.2031	0.6371

Table 9: Customer Orientation Indices On Express Feeder

Months	Freq	Outage [hr]	Hours	Customer	SAIFI[int/cust]	SAIDI [hrs/cust]	CAIDI [hrs/cust]	ASAI [p.u]	ASUI [p.u]
Jan	138	250.50	744	1162	0.1188	0.2156	1.8152	0.6633	0.3367
Feb	102	245.38	672	1162	0.0878	0.2112	2.4057	0.6349	0.3651
Mar	160	262.35	744	1162	0.1377	0.2258	1.6397	0.6474	0.3526
April	120	205.45	720	1162	0.1033	0.1768	1.7121	0.7147	0.2853
May	140	220.15	744	1162	0.1205	0.1895	1.5725	0.7041	0.2959
June	90	320.28	720	1162	0.0775	0.2756	3.5587	0.5552	0.4448
July	125	295.40	744	1162	0.1076	0.2542	2.3632	0.6030	0.3970
Aug	135	278.20	744	1162	0.1162	0.1964	2.0607	0.6933	0.3067
Sept	100	292.54	720	1162	0.0861	0.2518	2.9254	0.5937	0.4063
Oct	98	250.48	744	1162	0.0843	0.2156	2.5559	0.6633	0.3367
Nov	105	315.32	720	1162	0.0904	0.2714	3.0030	0.5621	0.4379
Dec	130	240.18	744	1162	0.1119	0.2067	1.8475	0.6772	0.3228
Total	1443	3179.03	8760	1162	1.2418	2.7358	2.2031	0.6371	0.3629

Failure Rate: Irrua feeder has the least average annual failure rate corresponding to 0.1624 event/hr. The major causes of outage on this feeder was largely due to complete system collapse in the network as a result of under frequency operation and scheduled outages. Follow closely by Express feeder with 0.1647 event/hr; while Iruekpen feeder has the highest recorded average annual failure rate of 0.1716 within the studied period. The relatively moderate values of failure rate indicated low/less reliable system. The lower the failure rate of a system, the better.

Mean Time Between Failures (MTBF). Iruekpen feeder followed by Express feeder has the shortest MBTF values of 5.8275 hrs, and 6.0716 hrs. This explained that the feeder with short MTBF is more likely to fail often thereby reducing the overall system reliability. It is equally observed that Irrua feeder has the longest recorded MTBF values of 6.1576 hrs during the studied period. The longer the MTBF, the more reliable the system or component is.

Mean Down Times (MDT): It revealed that Irrua, Iruekpen, and Express feeder has the values of 2.2518, 2.2456, and 2.2031 MDT in ascending order listed. This mean that when these feeders failed it takes a longer time to be restored to service. It means that the higher the value of MDT, it's an indication of poor maintainability of the system.

Availability: Iruekpen feeder has the least average annual values of 61.47%, followed by Irrua feeder of 63.43% and Express feeder with 63.71% respectively. These values were considered relatively fair and consistent in performance over the period under reviewed compared to 99.99% stipulated by IEEE 1366-2022 standard. Tables 3, 6, and 9 presented summary of annual customer reliability indices for Iruekpen, Irrua, and Express feeder's outage durations in hours which include SAIDI, SAIFI, CAIDI, ASAI. The results analysis is presented as follows:

i. System Average Interruption Duration Index (SAIDI), represents the average outage duration per customer interrupted. Express feeder recorded the highest SAIDI values of 2.7358 in 2024 with 1162 customers interrupted, signifying longer interruptions. Followed by Irrua feeder which recorded values of 0.6459 with 4961 customers interrupted during the year. While, Iruekpen feeder exhibited the least values of 0.2972 with 11355 customers interrupted, indicating shortest interruptions.
ii. System Average Interruption Frequency Index (SAIFI) assesses the average frequency of interruptions. Express feeder registered the highest SAIFI values of 1.2418, followed by Irrua feeder which recorded values of 0.2868 in 2024, indicating an average frequency of interruptions and, Iruekpen feeder recorded the least values of 0.1324 during the year.
iii. Customer Average Interruption Duration Index (CAIDI) computes the average duration of interruptions per customer. Express feeder consistently demonstrated the lowest CAIDI values of 2.2031, indicating shorter interruptions per customer. Conversely, Iruekpen and Irrua feeders recorded the highest values of 2.2456 and 2.2518, respectively in 2024.
iv. Average Service Availability Index (ASAI), evaluate the percentage of time customers has service available for a given year. Express feeder registered the highest ASAI values of 63.71%, followed by Irrua feeder which recorded values of 63.42%, indicating average percentage of services availability and, Iruekpen feeder depicted the least values of 61.47% during the year.

Results have shown that there was strong relationship among the reliability indices based on the evaluations of failure rate, MTBF, MDT, Availability, SAIDI, SAIFI, CAIDI, and ASAI.

Table 10 presented summary of scheduled and forced outages of frequency and duration in hours for Iruekpen, Irrua, and Express feeders. The table also showed average annual interrupted frequency and outage durations of 1503, 1423, 1443; and 3375, 3204 and 3179 hours for Iruekpen, Irrua, and Express distribution feeders from January to December 2024. Assessment also shown that major causes of power interruption on these feeders was largely due to long circuits length, configurations, ageing equipment, complete system collapse in the network as a result of under frequency operation, scheduled and forced outages.

Table 10: Summary of Frequency and Outage Duration for The Corresponding Feeders

Outages	Iruekpen		Irrua		Express Road	
	Freq	Duration	Freq	Duration	Freq	Duration
Scheduled	954	2336.47	956	2203.37	981	2015.22
Forced	549	1038.26	467	1000.56	462	1163.41
Total	1503	3375.13	1423	3204.33	1443	3179.03

Figure 1 showed summary of pie charts of the monthly outages' duration in hour for Iruekpen, Irrua and Express feeders. Figure 2 depicted the chart of monthly failure rate for the corresponding three feeders, while Figure 3 indicated monthly availability on Iruekpen, Irrua and Express feeders respectively.

Figure 1: Monthly Outage Duration (hours) on Iruekpen, Irrua and Express Feeders

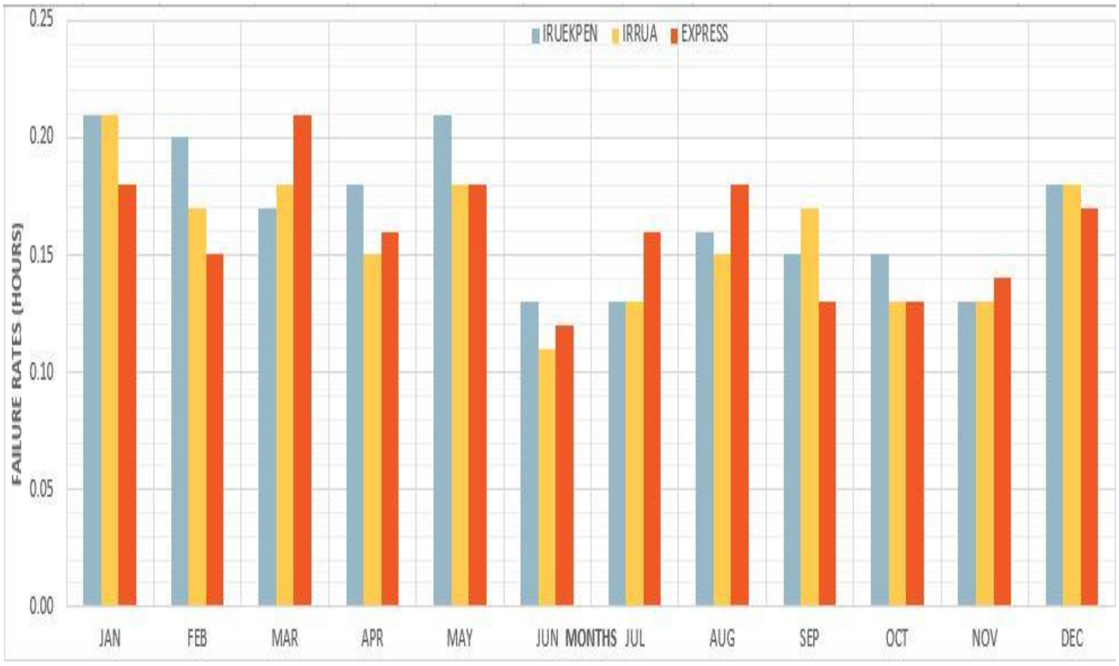

Figure 2: Monthly Failure Rate on Iruekpen, Irrua and Express Feeders

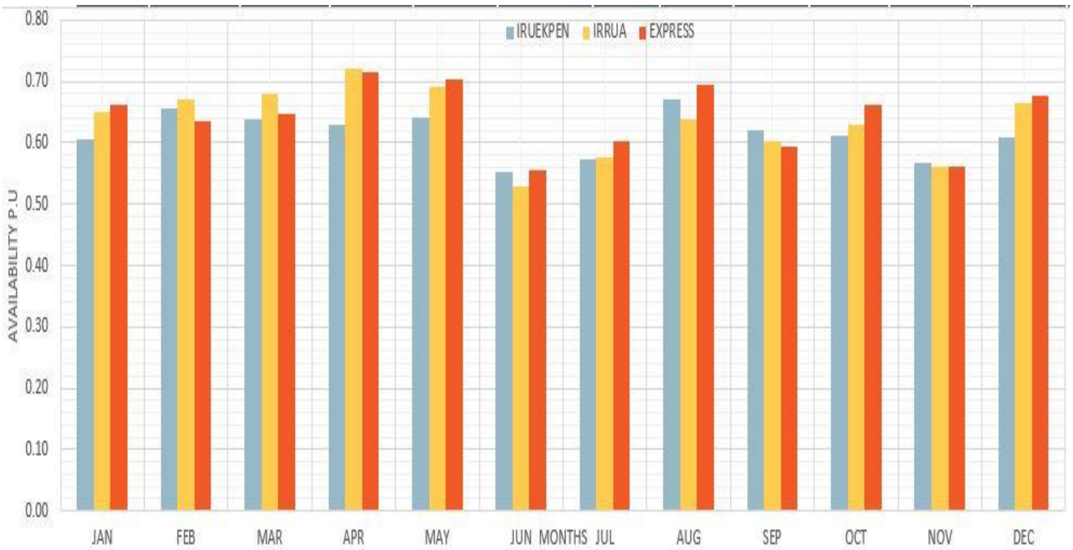

Figure 3: Monthly Availability on Iruekpen, Irrua and Express Feeders

CONCLUSION

This research paper studied Ekpoma 33/11kv injection substation distribution feeders' namely: Iruekpen, Irrua and Express feeder's reliability performances. The daily power outage frequency and interruption durations data of these feeders were obtained from the substation distribution network daily operational logbook for a period of 12 months between January and December,2024, and analyzed using statistical data methods and Microsoft Excel software environment. The reliability indices such as Failure Rate, MTBF, MDT, and Availability as well as Customer Reliability Indices including SAIFI, SAIDI, CAIDI, ASAI and ASUI were analyzed using relevant equations and results presented. Frequency of scheduled and forced outages and duration in hours for Iruekpen, Irrua, and Express feeders were also evaluated and results presented. The monthly outages' duration in hour, Failure rate and availability Pie charts for the above-mentioned feeders were also considered and presented. Studied shown that all the feeders Availability and ASAI values of 61.47%, 63.42%, and 63.71% respectively; these values were considered relatively fair and consistent in performance over the period under reviewed, compared to 99.99% stipulated by IEEE 1366-2022 standard. Assessment shown that major causes of power interruption on these feeders was largely due to long circuit length, configurations, ageing equipment, complete system collapse in the network as a result of under frequency operation, scheduled and forced outages.

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