Reliability Analysis of Power Distribution System in Nigeria: A Case Study of Ekpoma Network, Edo State

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***Abstract*—Reliability engineering with regard to distribution systems involves gathering outage data and evaluating system designs. The great majority of service interruptions that affect customers are caused by problems on the distribution system. Customer service interruptions in Ekpoma were also caused by failure in distribution substations. Time series load data on the feeders were collected from Power Holding Company of Nigeria (PHCN) daily operational log book from January to December 2012. Outages were classified into types, frequency and durations. The reliabilities of the feeders were evaluated on monthly basis for one year. The average availability of Iruekpen, Irrua, and Express feeders were 0.61, 0.63 and 0.64 respectively. The distribution feeders experience outages on a daily basis due to faults and suggestions were made to minimize system failure in order to improve the reliabilities of the network.**

***Index Terms*—distribution feeders, availability, reliability Indices and distribution networks**

I. Introduction

The purpose of an electrical power generation system is to distribute energy to a multiplicity of points for diverse applications. The system should be designed and managed to deliver this energy to the utilization points with high reliability and adequate economy. Reliability can be defined as the probability that a device or a system will perform a given task under specified environmental condition for a specific period of time, while availability is that, a system will be able to perform its required function over a specific period of time [1]. Reliability, availability together with maintainability is analysed to determine the ability of equipment to accomplish an intended task [2]. Reliability of an electric power system is defined as the probability that the power system will perform the function of delivering electric energy to customers on a continuous basis and with acceptable service quality [3]. Distribution system reliability is not a new subject, but the deregulation of electricity is new factor which changes the orientation of research on distribution system. Distribution system can be discussed under two general aspects namely: system adequacy and system security [4]. 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 [5]. When fault occurs, there may be three possible states in the distribution system in terms of the supply of power:

i. Permanent load shedding due to the loss of power supply.
ii. Momentary load shedding due to loss of supply but cleared by auto-protection operation.
iii. Voltage dips due to larger faults current.

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 have to evolve and improve the system continuously depending upon the requirement of the customers [5]. Since the primary purpose of electric power is to satisfy customer's requirements, power system basically consists of generation, transmission and distribution. Ekpoma power distribution network comprising of three 11kV feeders namely Iruekpen, Irrua, and Express in Esan West Local Government Area of Edo State, Nigeria could not meet the customers' energy demand. In view of reference [6] independent electric power producers and distribution companies were encouraged to take over the unbundling Power Holding Company of Nigeria (PHCN), in order to improve power supply in the country. The study and analysis of outages of the installations in Ekpoma power distribution systems is necessary for improved performance. It is also useful in planning, design operation and maintenance. According to [7] improving distribution system is the key to improving reliability of supply to customers.

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Reference [4] stated that the function of an electric power system is to satisfy the system load requirement with adequate assurance of continuity of high quality of electricity supply. Reference [4] gave the reliability indices which [8] also cited for general application as follows:

System Average Interruption Duration Index, SAIDI

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

System Average Interruption Frequency Index, SAIFI

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

Consumer Average Interruption Duration Index, CAIDI

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

Average Service Availability Index, ASAI

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

Average Service Unavailability Index, ASUI

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

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 [9], [10]. 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).

Reference [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 (λ)

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

And the reliability distribution function is given by

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

Further reliability parameters given by [8] are as follows:

Mean Time Between Failure (MTBF)

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

Also Mean Time To Repair (MTTR) or Mean Down Time (MDT)

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

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

The results obtained are 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.

II. Methodology

Reliability engineering with regard to distribution systems involves gathering outage data and evaluating system designs. The outage data collected from PHCN comprise of information on each failure event within the period of one year (January to December, 2012). The information recorded in a narrative form was translated into a statistical database. The outages were classified as forced and scheduled. Hence, data on failure rates and repair times of component used in the distribution system were compiled for reliability calculations. In addition, data on statistical information consisting of outages arising from the load shedding, system collapse, scheduled or unscheduled maintenance and hourly load shedding on each feeder were collected. These data were used to compute the reliability indices (MTBF, MDT, and Availability), total hours of outages and the number of interruptions (frequency) per day and Customer Orientation Indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) using equations 1 to 12. A low value of MDT indicates good maintainability. SAIFI indicates how often an average customer is subjected to sustained interruption over a predefine time interval whereas SAIDI indicates the total duration of interruption an average customer is subjected for a predefined time interval. CAIDI indicates the average time required to restore the service. ASAI specifies the fraction of the time that a customer has received power during the predefine interval of time and vice versa for ASUI. The results are shown in Tables I to XIII and analysed graphically in Fig. 1 to Fig. 9.

III. Results and Discussion

Tables I to IX shows the variation of the number of outages, their duration, basic reliability indices and Customer Orientation Indices over the period of study for each of the distribution feeders. Due to the computation which followed from the statistical database, the behaviour of the feeders in terms of the duration of outages, failure rate and availability are shown in Fig. 1 to Fig. 9. Specifically, the graphs of monthly outage, failure rate and availability on Iruekpen feeder is presented in Fig. 1, Fig. 2 and Fig. 3 respectively while the graphs of monthly outage, failure rate and availability on Irrua feeder is presented in Fig. 4, Fig. 5 and Fig. 6 respectively. Furthermore, the graphs of monthly outage, failure rate and availability on express feeder is presented in Fig. 7, Fig. 8 and Fig. 9 respectively.

TABLE I. 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 II. COMPUTED BASIC RELIABILITY INDICES, JANUARY TO DECEMBER 2012 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 III. COMPUTED CUSTOMER ORIENTATION INDICES, JANUARY TO DECEMBER 2012 ON IRUEKPEN FEEDER

Month(s)	Freq.	Outage[hr]	Hours	Cust.	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**	**0.1324**	**0.2972**	**2.2456**	**0.6147**	**0.3853**

TABLE IV. SUMMARY OF FREQUENCY AND DURATION OF OUTAGES ON IRRUA FEEDER

Month(s)	Scheduled Outage (SO)		Forced Outage (FO)		Total Outage (TO)	
	Freq.	Duration [hr]	Freq.	Duration [hr]	Freq.	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	3204.33

TABLE V. COMPUTED BASIC RELIABILITY INDICES, JANUARY TO DECEMBER 2012 ON IRRUA FEEDER

Month(s)	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
Mar	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 VI. COMPUTED CUSTOMER ORIENTATION INDICES, JANUARY TO DECEMBER 2012 ON IRRUA FEEDER

Month(s)	Freq.	Outage[hr]	Hours	Cust.	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
April	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	0.3097
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	**0.2868**	**0.6459**	**2.2518**	**0.6342**	**0.3658**

TABLE VII. SUMMARY OF 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 VIII. COMPUTED BASIC RELIABILITY INDICES, JANUARY TO DECEMBER 2012 ON EXPRESS FEEDER

Month(s)	Freq.	Outage[hr]	Total[hr]	Failure Rate[event/hr]	MTBF[hr] [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
Mar	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 IX. COMPUTED CUSTOMER ORIENTATION INDICES, JANUARY TO DECEMBER 2012 ON EXPRESS FEEDER

Month(s)	Freq.	Outage[hr]	Hours	Cust.	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**

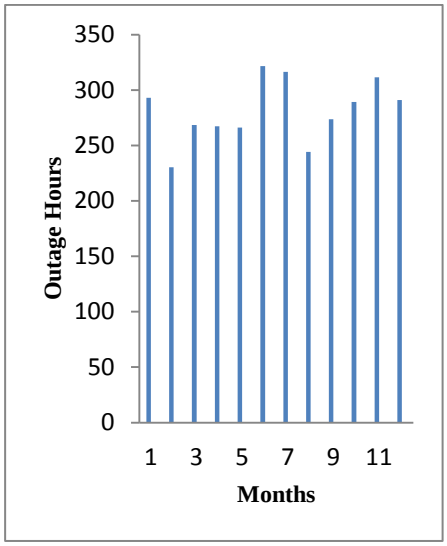

Figure 1. Bar chart of monthly outage duration (hours) demanded on Iruekpen feeder in the Year 2012

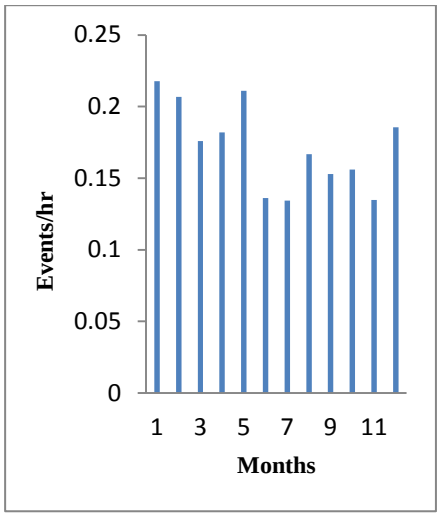

Figure 2. Bar chart of monthly failure rate on Iruekpen feeder in the Year 2012.

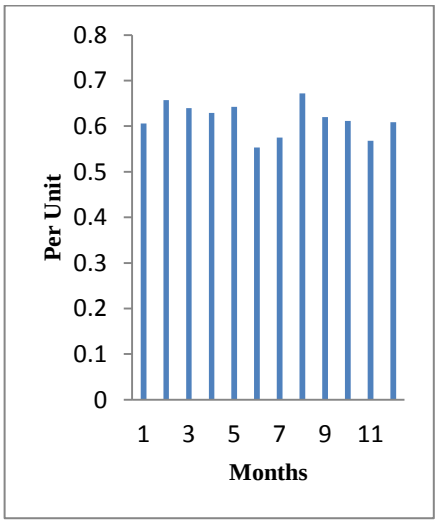

Figure 3. Bar chart of monthly availability of Iruekpen feeder the in Year 2012

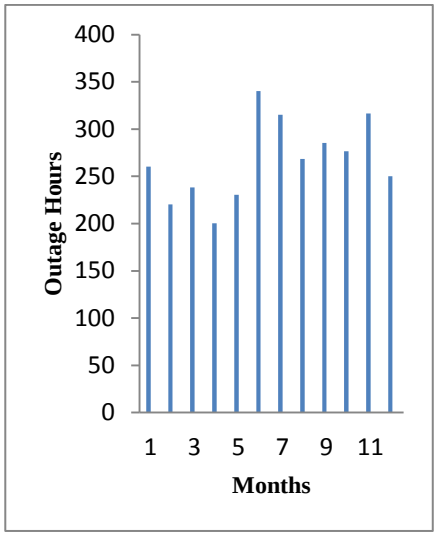

Figure 4. Bar chart of monthly outage duration (hours) on Irrua feeder in the Year 2012

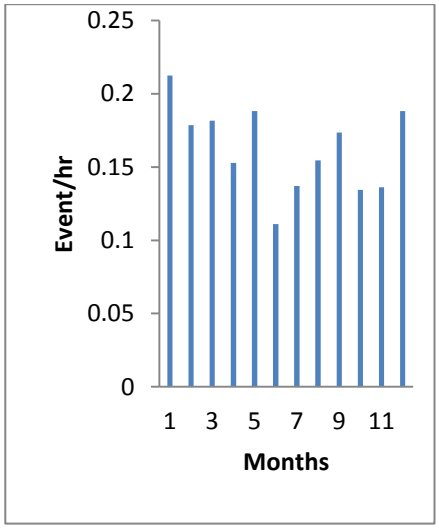

Figure 5. Bar chart of monthly failure rate on Irrua feeder in the Year 2012

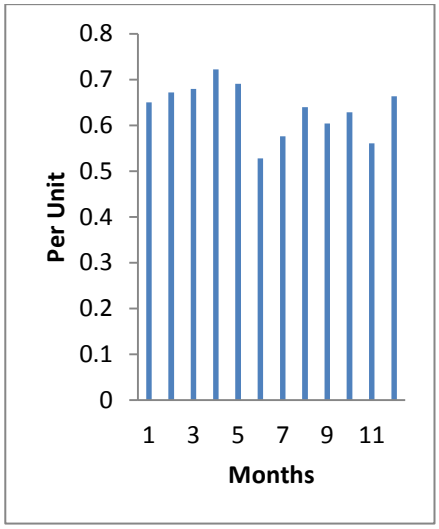

Figure 6. Bar chart of monthly availability of Irrua feeder in the Year 2012

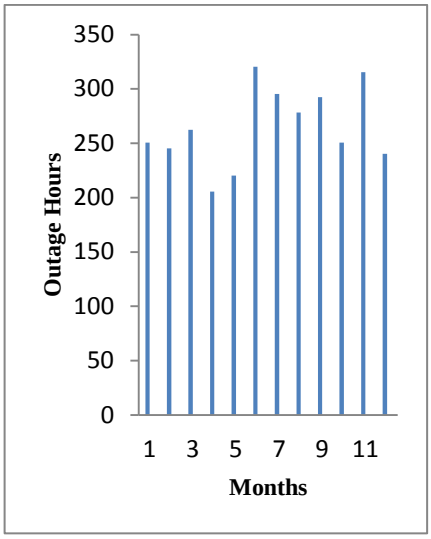

Figure 7. Bar chart of monthly outage duration (hours) on Express feeder in the Year 2012

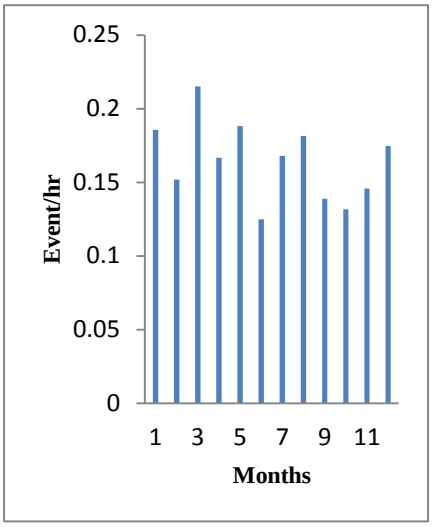

Figure 8. Bar chart of monthly failure rate on Express feeder in the Year 2012

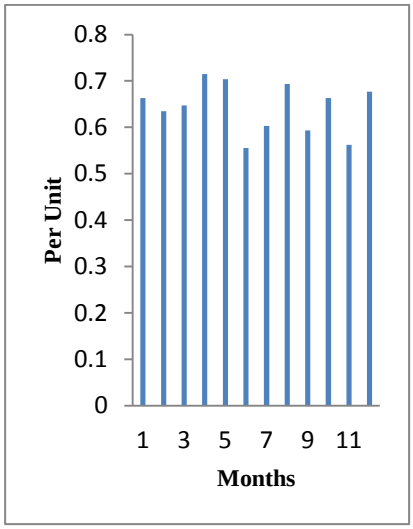

Figure 9. Bar chart of monthly availability of Express feeder in the Year 2012

The distribution feeders: Iruekpen, Irrua, and Express had 1503, 1423 and 1443 interruptions respectively from January to December (2012) as shown in Table X while duration of outages in hours was 3375, 3204 and 3179 as shown in Table XI.

TABLE X. SUMMARY OF OUTAGES FREQUENCY ON DISTRIBUTION FEEDERS IN THE YEAR 2012

Outages	Iruekpen	Irrua	Express
Scheduled	954	956	981
Forced	549	467	462
Total	1503	1423	1443

TABLE XI. SUMMARY OF DURATION OF OUTAGES ON DISTRIBUTION FEEDERS IN THE YEAR 2012

Outages [hr]	Iruekpen	Irrua	Express
Scheduled	2336.47	2203.37	2015.22
Forced	1038.26	1000.56	1163.41
Total	3375.13	3204.33	3179.03

The main cause of interruption on the feeders was load shedding (LS) (45.8%, 44.2% and 42.2% for Iruekpen, Irrua and Express feeders respectively) as shown in Table XII. Other causes of interruption on the distribution feeders were planned outage (PO) for maintenance, supply failure (SF) and earth fault (EF) as shown in Tables XII and XIII. Failure rate was high around January to May due to heat in the dry season and wind storm during the approach of the rainy season as shown in Fig. 2, 5 and 8.

TABLE XII. SUMMARY OF SCHEDULED OUTAGES ON DISTRIBUTION FEEDERS IN THE YEAR 2012

	Iruekpen		Irrua		Express	
	PO	LS	PO	LS	PO	LS
Number of Occurrence	265	689	326	630	372	609
% of Occurrence	17.6	45.8	22.9	44.2	25.8	42.2

TABLE XIII. SUMMARY OF FORCED OUTAGES ON DISTRIBUTION FEEDERS IN THE YEAR 2012

	Iruekpen		Irrua		Express	
	EF	SF	EF	SF	EF	SF
Number of Occurrence	496	53	414	53	409	53
% of Occurrence	33.0	3.5	29.0	3.7	28.3	3.7

IV. CONCLUSION

This study has shown that the basic reliability indices for Iruekpen feeder were as follows: failure rate of 0.1716, MBTF of 5.8275, MDT of 2.2456 and Availability of 0.6147. The Customer Orientation Indices were SAIFI of 0.1324, SAIDI of 0.2972, CAIDI of 2.2456, ASAI of 0.6147 and ASUI of 0.3853. The results for the other two feeders were as shown in the Tables IV to IX.

Due to constant power interruptions and voltage fluctuations occurrence, fire hazard was recorded. In fact, interruption of electricity occurred several times in a day which resulted in damage of production lines in factories. Hence, the reliability of the system should be improved in order to keep valued customers satisfied.

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REFERENCES

[1] K. Kolowrocki, "Limit reliability functions of some series-parallel and parallel series systems," *Journal of Applied Mathematics and Computation*, vol. 62, pp. 129-151, 1994.

[2] K. Kolowrocki, "Reliability analysis of large systems with degrading components," *International Journal of Reliability, Quality and Safety Engineering*, vol. 10, no. 3. Pp. 249-288, 2003.

[3] M. P. Bhavaraju, R. Billinton, R. E. Brown, J. Endrenyi, W. Li, A. P. Meliopoulos, and C. Singh, "IEEE tutorial on electric delivery system reliability evaluation," *IEEE Power Engineering Society (PES)*, 2005.

[4] B. Roy and R. N. Allan, *Reliability Evaluation of Power Systems*, 2 nd Ed. Springer, New Delhi, 2008, pp 220-221.

[5] T. Dorji, "Reliability assessment of distribution systems," M.Eng. Thesis, Norwegian University of Science and Technology, Bhutan, Norway, pp. 9-20, 2009.

[6] "The Obasanjo reforms electric power sector," in *The Federal Ministry of Information and National Orientation Production*, Abuja, Nigeria: Radio House, 2004

[7] R. E. Brown, *Electric Power Distribution*, New York, USA: Marcel Dekker Inc, 2002.

[8] A. S. Pabla, *Electric Power Distribution*, 5th Ed., New Delhi, India: Tata Mc Graw–Hill Publishing Company Limited, 2008.

[9] J. C. Nwachukwu, *Introduction to Maintenance and Reliability*, Benin City, Edo State, Nigeria: Ambik Press Limited, p 4, 1984.

[10] B. E. Okah-Avae, *Science of Industrial Machinery and System Maintenance*, Nigeria: Spectrum Books Limited, Ibadan, 1995.

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