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Fault analysis and prediction of power distribution networks on 11kV Feeders: A case study of Eleweeran and Poly Road 11kV Feeders, Abeokuta

Omowumi G. Olasunkanmı[1], Ajibola O. Oyedejı[2,*], Ayodeji A. Okubanjo[3]

[1]Department of Electrical and Electronics Engineering, Olabisi Onabanjo University, Ago-Iwoye, Nigeria.
grace.olasunkanmi@oouagoiwoye.edu.ng, ORCID: 0000-0002-4797-588X

[2]Department of Computer Engineering, Olabisi Onabanjo University, Ago-Iwoye, Nigeria.
oyedeji.ajibola@oouagoiwoye.edu.ng, ORCID: 0000-0002-0180-492X

[3]Department of Electrical and Electronics Engineering, Olabisi Onabanjo University, Ago-Iwoye, Nigeria.
okubanjo.ayodeji@oouagoiwoye.edu.ng, ORCID: 0000-0003-1908-0365

ABSTRACT

Distribution system, a vital link between the bulk power system and end users, accounts for 90% of power service interruptions. This study analyses faults occurring on power distribution network using Eleweeran and Poly Road 11 kV feeders in Abeokuta as case studies. Faults data, between 2014 and 2018, are collected for selected feeders using fault log books. Trend analysis of faults data is accomplished using MATLAB software with associated statistical measures (mean median mode, standard deviation, coefficient of correlation) determined. Reliability figure is thereafter computed for each of the two feeders. The mean and median of both actual and predicted fault values during the period under consideration are similar for the two feeders. The reliability index on Eleweeran 11 kV feeders showed that 2015 was the worst with failure rate of 1.55 and reliability figure of 0.21% while it was at its best in 2017 (failure rate of 1.07 and reliability of 0.34%). In the case of Poly Road 11 kV feeder, the highest failure rate of 0.62 with corresponding reliability of 0.54% was recorded in 2016 while in 2018 the failure rate was about 0.49 and reliability of 0.61%.

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**Corresponding author*

1. Introduction

Electric power systems are complex interconnected and most spatially extended technical systems, which are often prone to faults because of harsh environment they are exposed to. Power system or its sub-systems can be analysed through determination of the system voltages and currents under normal and abnormal conditions [1]. Generation, transmission and distribution are the three main stages involved in electric power system [2].

However, among these stages, the performance and maintenance of the distribution networks, which basically connect the generation centres to the end users, have received little attention in the field of power system [3]. The reasons for this are, the generating stations and the transmission systems are capital intensive and that the inadequacy of the generation and transmission are often associated with widespread catastrophic consequences for both the society and environment. A distribution system, however, is relatively cheaper compared to other two because its effects are localized. Therefore, less effort has been put to the evaluation and assessment of performance of this stage of electric power system [3]. The distribution system is the nearest stage to the customers and may be very prone to fault occurrence which may be human-induced or natural [4].

On the other hand, analysis of the customer failure statistics of most utilities shows that the distribution system contributes the most to the unavailability of supply to customers. Hence, the distribution systems account for about 90% of customers supply reliability problems [3]. Since the primary purpose of the system is to satisfy customer requirements and, proper functioning and longevity of the system are essential requisites for continued satisfaction, it is necessary that both demand and supply considerations are appropriately viewed and included in the systems. Therefore, improving the distribution system reliability through checkmating of the system against possible and frequent faults occurrence (supply interruptions) has become a topical issue in the electric power industry due to its high impact on the cost of electricity and its high correlation with customer satisfaction [5].

Electric power is a vital element in any modern economy. Availability of reliable power supply at a reasonable cost is crucial for economic growth and development of any country. Electric power utilities throughout the world therefore endeavour to meet customer demands as much as economically at reasonable service reliability. To meet customer demands, power utility company has to evolve with the distribution system upgraded periodically to meet operation and maintenance performance indicator [3].

A fault in power system is described as any failure that causes interruptions of power supply [6-7]. Generally, faults occurring in power systems are traceable to natural events or by accidents where a phase establishes a connection with another phase, the ground or both in some cases [1]. In some cases, faults may be as a result of deterioration in insulation, damages by wind or sabotage or vandalism by human [1].

Power system faults can be temporary or permanent. A temporary fault occurs when the actuation of protective systems allows the circuit to be re-energized (fault clearing) after a reclosing operation. Examples of temporary faults are the insulation breakdown by the interaction between components and external agents (lightning strikes, wind, transient tree contacts, etc.) during a short period of time. Permanent faults require repair or replacement of the damaged components. Examples of permanent faults include insulators damage by flashover, underground cable breakdown and surge arrester damage [4, 7]. The fault phenomenon can affect system's reliability, security, and energy quality [6]. Any reliable electric power system should serve consumers without awkward interruptions in power supply voltage, but in Nigeria today, consumers of the electric power supply are subjected to unplanned outages on a regular basis which influence customer satisfaction [8].

The study of the effect of active failure on the power system reliability is important [9-10]. A new method for power system reliability assessment by using the fault tree analysis (FTA) approach was designed and the results identify the reliability measures connected to particular loads and the reliability measures connected to the power system as a whole: the probability of failed power delivery to selected loads, the importance measures of components corresponding to selected loads and the importance measures of components corresponding to the whole power system [11].

In [12], the reliability assessment of power equipment on the 33/11kV Anglo-Jos distribution substation of the Jos Electricity Distribution company was studied using the FTA technique. The study showed that 11kV liberty dam feeder had the highest occurrence of failure with the 110V DC battery bank having the highest mean time to repair [12].

In this study, the main focus is on analysis of faults that are associated with Eleweeran and Poly Road 11kV distribution feeders controlled by Ibadan Electricity Distribution Company (IBEDC), Abeokuta Business Unit in Ogun State as well as determining the reliability of the feeders in order to make useful suggestions on how to improve the service level of these feeders.

2. Material and methods

It is well-known that distribution systems are affected by stochastic events such as faults on lines, sudden failures of power plants and random variations in demand. Probabilistic methods are therefore essential for a sound assessment of the reliability of power systems. To increase the reliability, it is necessary to understand the causes of outages and types of equipment failures. In order to evaluate reliability of a system, few parameters are required, which are;

1.1 Mean Failure Rate

The mean failure rate λ of a given set data is the number of failure occurring per unit time. Mathematically, it is expressed as

$$\lambda = \frac{\sum f}{\sum T} \qquad (1)$$

where $\sum f$ is the total number of failure and $\sum T$ is the cumulative operating period.

Since components of a failure could be more than one, for instance, in this study different types of faults occurring on a distribution feeder are considered, equation 1 is modified as

$$\lambda = \lambda_1 + \lambda_2 + \cdots \lambda_n \qquad (2)$$

where $\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n$ are failure rates due to different types of faults contributing to the overall failure rate λ.

1.2 Reliability

The reliability function $R(t)$ is the probability that no failures occur within time period 0 to time period t [13]. It is given by

$$R(t) = \exp(-\lambda t) \qquad (3)$$

where t is time period (in days, months or years) for which the reliability is desired and λ is the failure rate per time unit.

1.3 Statistical Analysis

Statistical analysis is needed in this study for the purpose of checking whether there is any correlation between predicted total fault values obtained from model (the trend equation) and actual total fault values for the data collected. In order to do this, linear correlation coefficient is used along with other measures of central tendency (mean, median and mode) and dispersion (standard deviation). Generally, for a pair of data set $X = x_1, x_2, \cdots x_n$ and $Y = y_1, y_2, \cdots y_n$, linear coefficient of correlation is given by

$$r = \frac{\sum xy}{\sqrt{(\sum x^2)(\sum y^2)}} \quad (4)$$

where x is the independent variable which representing the period of sixty (60 month) and y is dependent variable which stands for fault value of the period under consideration.

2.4 Regression Analysis

Regression or trend analysis is the study of the behaviour of a time series or a process in the past and its mathematical modelling so that future behaviour can be extrapolated from it. Two general approaches usually followed in trend analysis are [14]:

- The fitting of continuous mathematical functions through actual data to achieve the least overall error, known as regression analysis.
- The fitting of a sequence on discontinuous lines or curves to the data.

The second is usually employed for short-term forecasting. A time-varying event such as power system load can be broken down into the following four major components [14]:

- Basic trend.
- Seasonal variation (Monthly or yearly variation of load).
- Cyclic variation which influences of periods longer than the above and causes the load pattern to be repeated for two or three years (or even longer cycles).
- Random variations which occur on account of the day-to- day changes and in the case of power systems are usually dependent on the time of the week e.g. weekend, week day, weather etc.

The last three variations have a long-term mean of zero. Generally, in forecasting, either a continual variation process model or a model that is based only on certain points at regular intervals of the process is used. In either case, the process is modelled as time series [14].

The principle of regression theory is that any function $y = f(t)$ can be fitted to a set of points (x_1, y_1), (x_2, y_2) so as to minimize the sum of errors= squared at each point, that is:

$$\sum_{i}^{n} \{y_i - f(x_i)\}^2 = minimum \quad (5)$$

2.5 Collection of Fault Data

Monthly information and data on the various types of faults associated with the selected Eleweeran and Poly Road feeders are collected from IBEDC, Abeokuta Business Unit for period of five years (2014 – 2018) through personal contact with service personnel and maintenance staffs of the Business Unit.

Appendices I and II show monthly breakdown of faults recorded on Eleweeran 11 kV feeder and Poly Road feeder for the years 2014 – 2018 respectively. Tables 1 and 2, show the monthly total faults on Eleweeran and Poly Road 11 kV feeders, respectively for the five years period under consideration in this study. Table 3 shows the individual fault total over the five years period while Table 4 presents total yearly faults for the two feeders.

Table 1. *Monthly Total Faults on Eleweeran 11kV Feeder*

Month	2014	2015	2016	2017	2018
January	33	34	22	13	17
February	33	41	26	22	27
March	43	55	49	37	42
April	38	58	44	39	43
May	37	57	47	47	45
June	35	57	47	45	50
July	41	55	48	44	44
August	30	31	26	24	30
September	38	57	38	34	41
October	40	56	44	44	43
November	33	38	24	27	40
December	29	26	22	17	29
Total	**430**	**565**	**437**	**393**	**451**

Table 2. *Monthly Total Faults on Poly Road 11kV Feeder*

Month	2014	2015	2016	2017	2018
January	12	11	12	17	11
February	15	14	14	16	14
March	22	24	26	26	25
April	21	15	26	21	16
May	24	24	31	21	20
June	21	24	27	24	19
July	17	18	19	24	15
August	16	21	18	20	14
September	16	19	17	18	15
October	12	14	13	15	13

November	9	12	13	11	11
December	9	8	10	6	7
Total	**194**	**204**	**226**	**219**	**180**

Table 3. *Individual fault total for Eleweeran and Poly Road 11 kV Feeders from 2014 – 2018*

Fault Type	Eleweeran 11 kV feeder	Poly Road 11 kV feeder
Over-current	908	322
Earth	923	298
Instantaneous earth	115	178
Transient	335	225

Table 4. *Total yearly fault for Eleweeran and Poly Road 11 kV Feeders from 2014 – 2018*

Year	Eleweeran 11 kV feeder	Poly Road 11 kV feeder
2014	430	194
2015	565	204
2016	437	226
2017	393	219
2018	451	180

2.6. Trend Analysis of the Fault Data

In order to analyse the fault data to observe the trend and obtain predicted values, two approaches adopted are time series modellers and modelling of the pattern. The former gives the distribution of fault data against time (month) while the latter returns model equation to describe the data. MATLAB software is used to accomplish these tasks [5].

To aid further analysis of fault data on Eleweeran and Poly Road 11 kV feeders, trend curves generated from Tables 1 and 2, for Eleweeran and Poly Road 11 kV feeders, respectively are fitted with regression curves using MATLAB software built-in tool.

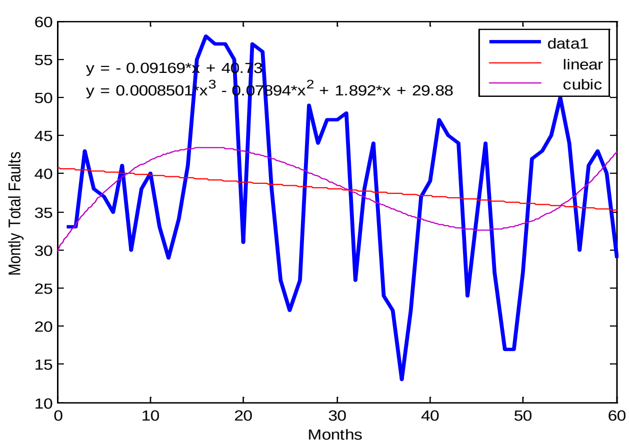

Figure 1. *Total fault from January 2014 to December 2018 (60 months) for Eleweeran 11 kV feeder with both Linear and Polynomial (Cubic) Curves fitting*

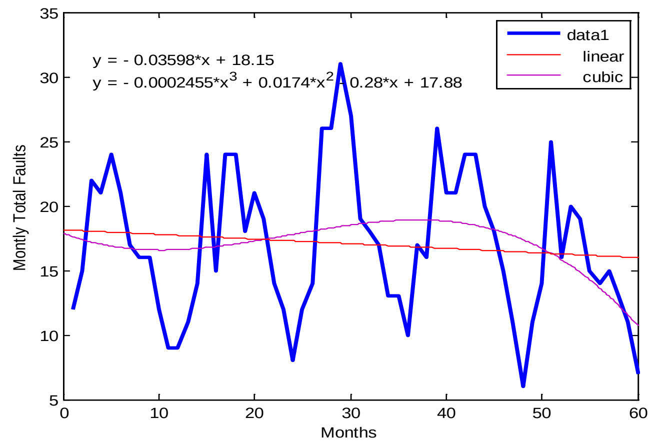

Figure 2. *Total fault from January 2014 to December 2018 (60 months) for Poly Road 11 kV feeder with both Linear and Polynomial (Cubic) Curves fitting*

Based on Figures 1 and 2, in terms of time period t (month), the following curve fits are obtained for Eleweeran 11 kV feeder, where LT is the linear predicted total fault and CT is the cubic predicted total fault.

$$LT_{eleweeran} = -0.09169t + 40.73 \quad (6)$$

$$CT_{eleweeran} = 0.0008501t^3 - 0.0789t^2 + 1.892t + 29.88 \quad (7)$$

$$LT_{polyroad} = -0.03598t + 18.15 \quad (8)$$

$$CT_{polyroad} = -0.0002455t^3 + 0.0174t^2 - 0.28t + 17.88 \quad (9)$$

3. Results and discussions

Having obtained trend equations for each of the two feeders under study, fault values are predicted from January 2014 to December 2018 from equations 6 - 9. The seasonal deviations (errors) between the predicted fault values and the actual fault values are calculated. These are presented in Tables 5 and 6, respectively, for Eleweeran and Poly Road 11 kV feeders.

Table 5. *Predicted Fault Values for Eleweeran 11 kV Feeder from January 2014 to December 2018 using trend equations*

Months (x)	Actual Total Monthly Faults (TT)	Linear Predicted Total Faults (LT)	LT-TT (nearest whole number)	Cubic Predicted Total Faults (CT)	CT-TT (nearest whole number)
1	33	40.6383	8	31.6939	-1
2	33	40.5466	8	33.355	0
3	43	40.4549	-3	34.8685	-8
4	38	40.3632	2	36.2394	-2
5	37	40.2715	3	37.4728	0
6	35	40.1799	5	38.5738	4
7	41	40.0882	-1	39.5475	-1
8	30	39.9965	10	40.3991	10
9	38	39.9048	2	41.1336	3
10	40	39.8131	0	41.7561	2
11	33	39.7214	7	42.2717	9
12	29	39.6297	11	42.6856	14
13	34	39.538	6	43.0028	9
14	41	39.4463	-2	43.2284	2
15	55	39.3546	-16	43.3676	-12
16	58	39.263	-19	43.4254	-15
17	57	39.1713	-18	43.4069	-14
18	57	39.0796	-18	43.3172	-14
19	55	38.9879	-16	43.1615	-12
20	31	38.8962	8	42.9448	12
21	57	38.8045	-18	42.6722	-14
22	56	38.7128	-17	42.3489	-14
23	38	38.6211	1	41.9799	4
24	26	38.5294	13	41.5703	16
25	22	38.4377	16	41.1253	19
26	26	38.3461	12	40.6499	15
27	49	38.2544	-11	40.1493	-9
28	44	38.1627	-6	39.6284	-4
29	47	38.071	-9	39.0925	-8
30	47	37.9793	-9	38.5467	-8
31	48	37.8876	-10	37.996	-10
32	26	37.7959	12	37.4455	11
33	38	37.7042	0	36.9004	-1
34	44	37.6125	-6	36.3657	-8
35	24	37.5208	14	35.8465	12
36	22	37.4292	15	35.348	13
37	13	37.3375	24	34.8753	22

38	22	37.2458	15	34.4333	12
39	37	37.1541	0	34.0273	-3
40	39	37.0624	-2	33.6624	-5
41	47	36.9707	-10	33.3436	-13
42	45	36.879	-8	33.076	-12
43	44	36.7873	-7	32.8648	-11
44	24	36.6956	13	32.7151	9
45	34	36.6039	3	32.6319	-1
46	44	36.5123	-7	32.6203	-11
47	27	36.4206	9	32.6855	6
48	17	36.3289	19	32.8325	16
49	17	36.2372	19	33.0665	16
50	27	36.1455	9	33.3925	6
51	42	36.0538	-6	33.8157	-8
52	43	35.9621	-7	34.3411	-9
53	45	35.8704	-9	34.9739	-10
54	50	35.7787	-14	35.7191	-14
55	44	35.687	-8	36.5819	-7
56	30	35.5954	6	37.5673	8
57	41	35.5037	-5	38.6805	-2
58	43	35.412	-8	39.9266	-3
59	40	35.3203	-5	41.3105	1
60	29	35.2286	6	42.8376	14

Table 6. *Poly Road: Predicted Fault Values for Poly Road 11 kV Feeder from January 2014 to December 2018 using trend equations*

Months (x)	**Actual Total Monthly Faults (TT)**	**Linear Predicted Total Faults (LT)**	**LT-TT (nearest whole number)**	**Cubic Predicted Total Faults (CT)**	**CT-TT (nearest whole number)**
1	12	18.114	6	17.6172	6
2	15	18.078	3	17.3876	2
3	22	18.0421	-4	17.19	-4
4	21	18.0061	-3	17.0227	-4
5	24	17.9701	-6	16.8843	-7
6	21	17.9341	-3	16.7734	-4
7	17	17.8981	1	16.6884	0
8	16	17.8622	2	16.6279	1
9	16	17.8262	2	16.5904	1
10	12	17.7902	6	16.5745	5
11	9	17.7542	9	16.5786	8
12	9	17.7182	9	16.6014	8

13	11	17.6823	7	16.6412	6
14	14	17.6463	4	16.6967	3
15	24	17.6103	-6	16.7664	-7
16	15	17.5743	3	16.8488	2
17	24	17.5383	-6	16.9425	-7
18	24	17.5024	-6	17.0458	-7
19	18	17.4664	-1	17.1575	-1
20	21	17.4304	-4	17.276	-4
21	19	17.3944	-2	17.3998	-2
22	14	17.3584	3	17.5275	4
23	12	17.3225	5	17.6576	4
24	8	17.2865	9	17.7886	10
25	12	17.2505	5	17.9191	6
26	14	17.2145	3	18.0475	4
27	26	17.1785	-9	18.1724	-8
28	26	17.1426	-9	18.2924	-8
29	31	17.1066	-14	18.4059	-13
30	27	17.0706	-10	18.5115	-8
31	19	17.0346	-2	18.6077	0
32	18	16.9986	-1	18.6931	1
33	17	16.9627	0	18.7661	2
34	13	16.9267	4	18.8253	6
35	13	16.8907	4	18.8692	6
36	10	16.8547	7	18.8964	9
37	17	16.8187	0	18.9053	2
38	16	16.7828	1	18.8945	3
39	26	16.7468	-9	18.8626	-7
40	21	16.7108	-4	18.808	-2
41	21	16.6748	-4	18.7293	-2
42	24	16.6388	-7	18.625	-5
43	24	16.6029	-7	18.4936	-6
44	20	16.5669	-3	18.3337	-2
45	18	16.5309	-1	18.1438	0
46	15	16.4949	1	17.9224	3
47	11	16.4589	5	17.6681	7
48	6	16.423	10	17.3793	11
49	11	16.387	5	17.0546	6
50	14	16.351	2	16.6925	3
51	25	16.315	-9	16.2916	-9
52	16	16.279	0	15.8503	0
53	20	16.2431	-4	15.3673	-5

54	19	16.2071	-3	14.841	-4
55	15	16.1711	1	14.2699	-1
56	14	16.1351	2	13.6527	0
57	15	16.0991	1	12.9877	-2
58	13	16.0632	3	12.2736	-1
59	11	16.0272	5	11.5089	1
60	7	15.9912	9	10.692	4

Consequently, the linear predictor models are used to generate predicted fault data on each of the two feeders under investigations. Presented in Table 7 are predicted total yearly faults on Eleweeran and Poly Road 11 kV feeders respectively using linear predictor model.

Table 7. *Total yearly predicted faults for Eleweeran and Poly Road 11 kV Feeders from 2014 – 2018 using Linear Predictors*

Year	Eleweeran 11 kV feeder	Poly Road 11 kV feeder
2014	482	215
2015	468	210
2016	455	205
2017	442	199
2018	429	194

It is clear from Table 7 above that predicted total yearly faults using linear predictor exhibit a downward linear trend for the two feeders under study, with the highest values recorded in 2014 for both feeders.

Next, monthly total faults are forecast for additional five years beginning from January 2019 to December 2023 (another 60 months) using linear predictor models for each of Eleweeran and Poly Road 11 kV feeders. Results are presented in Tables 8 and 9, for Eleweeran and Poly Road feeders, respectively. In addition, total yearly faults forecast for 2019 – 2023 are equally computed for the two feeders using linear predictor with results shown in Table 10.

Table 8. *Forecast fault values for Eleweeran 11 kV feeder from January 2019 to December 2023 (Nearest whole number) using Linear Predictor*

Month	Year				
	2019	**2020**	**2021**	**2022**	**2023**
January	35	34	33	32	31
February	35	34	33	32	31
March	35	34	33	32	31
April	35	34	33	32	30
May	35	34	33	31	30
June	35	34	32	31	30
July	35	33	32	31	30
August	34	33	32	31	30
September	34	33	32	31	30
October	34	33	32	31	30
November	34	33	32	31	30
December	34	33	32	31	30

Table 9. *Forecast fault values for Poly Road 11 kV feeder from January 2019 to December 2023 (Nearest whole number) using Linear Predictor*

Month	Year				
	2019	**2020**	**2021**	**2022**	**2023**
January	16	16	15	15	14
February	16	15	15	15	14
March	16	15	15	15	14
April	16	15	15	15	14
May	16	15	15	15	14
June	16	15	15	14	14
July	16	15	15	14	14
August	16	15	15	14	14
September	16	15	15	14	14
October	16	15	15	14	14
November	16	15	15	14	14
December	16	15	15	14	14

Just like what obtains in predicted total yearly faults via the use of linear predictor, values of forecast total monthly faults decrease marginally with increasing number of months. In fact, roughly a difference of a unit is noticed between forecast values of a particular year and preceding year for Eleweeran feeder while at Poly Road feeder, forecast values vary between 16 and 14 for the entire sixty months advance. Summation of entries in Tables 8 and 9 yield total yearly forecast data for the two feeders for year 2019 – 2023 as shown in Table10.

Table 10. *Total yearly forecast faults for Eleweeran and Poly Road 11 kV Feeders from 2019-2023*

Year	Eleweeran 11 kV feeder	Poly Road 11 kV feeder
2019	415	192
2020	402	181
2021	389	180
2022	376	173
2023	363	168

Again, there exists progressive decline in the number of total yearly forecast faults for the two feeders as shown in Table 10. Results of data statistics carried out on actual fault data as well as predicted faults using model equations for the two feeders is presented in Table 11. This is done to verify the statistical significance of the deviation (difference) in value between the actual monthly total faults and the predicted faults from January 2014 and December 2018 for Eleweeran 11 kV feeder and Poly Road 11 kV feeder.

Table 11. *Statistics of Faults Data from Eleweeran 11kV and Poly Road 11 kV Feeders*

Items	Poly Road Feeder		Eleweeran Feeder	
	Actual Fault Data	Predicted Fault Data (Linear Predictor)	Actual Fault Data	Predicted Fault Data (Linear Predictor)
Minimum	6	15.99	13	35.23
Maximum	31	18.11	58	40.64
Mean	17.05	17.05	37.93	37.93
Median	16	17.05	38.5	37.93
Mode	24	15.99	44	35.23
Standard Deviation	5.637	0.6284	11.05	1.601
Range	25	2.123	45	5.41
Linear Coefficient of Correlation	0.1115		0.1450	

In order to determine level of performance (reliability) of both Eleweeran and Poly Road 11 kV feeders, reliability index of each of the two feeders is computed using equation 2. The failure rate and reliability values for each year under consideration (2014 to 2018) for both feeders are evaluated. Also, the predicted failure rate and reliability values from 2014 to 2018 and the forecast failure rate and reliability values from 2019 to 2023 are determined.

Using values of total yearly fault data presented in Table 4 along with expressions stated in (1) – (4), the actual failure rate and reliability values for the two feeders readily emerge as presented in Tables 12, 13 and 14.

Table 12. *Failure rate and reliability figures for Eleweeran and Poly Road 11 kV Feeders from 2014-2018 based on actual fault data*

Parameters	Year 2014	2015	2016	2017	2018
	Eleweeran 11 kV Feeder				
Failure rate/day	1.1781	1.5479	1.1973	1.0767	1.2356
% Reliability/year	0.3079	0.2127	0.3020	0.3407	0.2907
	Poly Road 11 kV Feeder				
Failure rate/day	0.5315	0.5589	0.6192	0.6000	0.4932
% Reliability/year	0.5877	0.5718	0.5384	0.5488	0.6107

Table 13. *Failure rate and reliability figures for Eleweeran and Poly Road 11 kV Feeders from 2014-2018 based on predicted total yearly faults using linear predictor model*

Parameters	Year 2014	2015	2016	2017	2018
	Eleweeran 11 kV Feeder				
Failure rate/day	1.3205	1.2822	1.2466	1.2110	1.1753
% Reliability/year	0.2670	0.2774	0.2875	0.2979	0.3087
	Poly Road 11 kV Feeder				
Failure rate/day	0.5890	0.5753	0.5616	0.5452	0.5315
% Reliability/year	0.5549	0.5625	0.5703	0.5797	0.5877

Table 14. *Failure rate and reliability figures for Eleweeran and Poly Road 11 kV Feeders from 2019-2023 based on forecast total yearly faults using linear predictor model*

Parameters	Year 2019	2020	2021	2022	2023
	Eleweeran 11 kV Feeder				
Failure rate/day	1.1370	1.1014	1.0658	1.0301	0.9945
% Reliability/year	0.3208	0.3324	0.3445	0.3570	0.3699
	Poly Road 11 kV Feeder				
Failure rate/day	0.5260	0.4959	0.4932	0.4740	0.4603
% Reliability/year	0.5909	0.6090	0.6107	0.6225	0.6311

Result presented in Tables 12-14 revealed that for the actual fault data between years 2014 and 2018, Eleweeran feeder recorded its highest failure rate 0f 1.55 per day with corresponding reliability figure of 0.21% in 2015 while the highest reliability figure was obtained in 2017 as 0.34% with failure per day of 1.08. For Poly road feeder, 2018 was the best year with failure per day of 0.49, reliability figure of

0.61% while the worst year was 2016 having 0.62 failures per day and reliability figure of 0.54%.

For predicted fault data from Table 13, and forecast data from Table 14, both failure rate and reliability figure vary linearly with increasing year. For both feeders, the highest failure rate occurred in 2014 for predicted data while the best year in terms of reliability index was 2018. In the case of forecast data, low failure rate and best reliability figure will be recorded in 2023 while the year 2019 is least in terms of reliability index.

The study revealed that over-current fault, earth fault, transient fault and instantaneous fault were the most common faults associated with both feeders. While earth fault is the highest at Eleweeran feeder, over-current fault is the most common fault at Poly Road feeder. At both feeders, instantaneous earth fault is the least occurring fault. The trend plots using MATLAB software (version 2016) revealed that the individual faults and the monthly total faults trends for both feeders were non-linear.

In addition, with the trend equation, fault values were forecast for additional five years (additional 60 months) for both feeders with average values of 33 and 15 total faults per month respectively for Eleweeran and Poly Road feeders. The reliability analysis carried out revealed that for both feeders predicted total faults between 2014 and 2018 and forecast total faults from 2019 to 2023 followed the same trend with failure rate decreasing while reliability was increasing.

4. Conclusion

Results obtained from this study provide insight into patterns of faults occurring on Eleweeran and Poly Road 11 kV feeders in Abeokuta Business Unit of IBEDC. However, the followings are suggestions for future extensions of the investigation carried out in the present effort. Although, linear predictor is used to obtain forecast values in this study, it is recommended that other approaches such as Auto-Regressive Moving Average (ARMA) model can be used to enhance the accuracy of the model equation. In addition, the study can be further carried out to show the trend of individual fault occurrence which will help the distribution company to have a better plans towards mitigation the occurrence of faults and maintenance strategy so as to improve customer satisfaction.

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APPENDIX I: FAULT DATA FOR 11kV INJECTION SUB-STATION, POLICE HQ, ELEWEERAN

2014					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	20	10	1	2	33
Feb	21	10	1	1	33
Mar	15	18	4	6	43
Apr	10	18	3	8	38
May	10	17	2	8	37
Jun	9	18	1	7	35
Jul	15	18	2	6	41
Aug	8	19	1	2	30
Sept	10	22	2	4	38
Oct	15	18	2	5	40
Nov	22	8	1	2	33
Dec	20	8	0	1	29
Total	**175**	**184**	**20**	**52**	**430**

2015					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	22	5	2	5	34
Feb	20	10	1	10	41
Mar	18	20	5	12	55
Apr	18	18	7	15	58
May	17	20	5	15	57
Jun	17	20	6	14	57
Jul	15	22	4	14	55
Aug	5	18	1	7	31
Sept	20	20	6	11	57
Oct	18	18	5	15	56
Nov	14	15	1	8	38
Dec	10	11	1	4	26
Total	**194**	**197**	**44**	**130**	**565**

2016					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	10	8	2	2	22
Feb	12	12	1	1	26
Mar	21	18	4	6	49
Apr	22	16	2	4	44
May	22	18	2	5	47
Jun	20	20	1	6	47
Jul	18	20	3	7	48
Aug	6	17	1	2	26
Sept	15	18	2	3	38
Oct	18	20	2	4	44
Nov	10	12	1	1	24
Dec	8	11	1	2	22
Total	**182**	**190**	**22**	**43**	**437**

2017					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	4	5	2	2	13
Feb	8	8	1	5	22
Mar	15	14	2	6	37
Apr	15	18	0	6	39
May	18	18	1	10	47
Jun	17	20	0	8	45
Jul	17	20	1	6	44
Aug	9	13	0	2	24
Sept	15	15	2	2	34
Oct	18	20	2	4	44
Nov	12	13	1	1	27
Dec	9	7	0	1	17
Total	**157**	**171**	**12**	**53**	**393**

2018					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	10	5	0	2	17
Feb	12	10	0	5	27
Mar	17	18	1	6	42
Apr	20	18	2	3	43
May	20	20	1	4	45
Jun	19	20	4	7	50
Jul	20	17	1	6	44
Aug	13	11	3	3	30
Sept	18	15	2	6	41
Oct	18	18	2	5	43
Nov	17	19	1	3	40
Dec	16	10	0	3	29
Total	**200**	**181**	**17**	**57**	**451**

APPENDIX II: FAULT DATA FOR 11kV INJECTION SUB- STATION, POLY ROAD, ABEOKUTA

2014					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	10	1	0	1	12
Feb	10	3	1	1	15
Mar	6	11	2	3	22
Apr	6	8	3	4	21
May	5	8	6	5	24
Jun	4	7	4	6	21
Jul	3	5	3	6	17
Aug	1	6	3	6	16
Sept	2	6	6	2	16
Oct	5	3	1	3	12
Nov	9	0	0	0	9
Dec	7	1	1	0	9
Total	**68**	**59**	**30**	**37**	**194**

2015					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	8	2	1	0	11
Feb	9	2	1	2	14
Mar	7	9	3	5	24
Apr	4	7	1	3	15
May	4	7	7	6	24
Jun	5	6	5	8	24
Jul	1	5	5	7	18
Aug	3	5	6	7	21
Sept	4	6	7	2	19
Oct	4	2	4	4	14
Nov	8	2	2	0	12
Dec	6	1	1	0	8
Total	**63**	**54**	**43**	**44**	**204**

2016					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	7	3	2	0	12
Feb	10	3	0	1	14
Mar	6	12	3	5	26
Apr	6	12	4	4	26
May	3	10	6	12	31
Jun	3	10	2	12	27
Jul	2	5	5	7	19
Aug	1	4	5	8	18
Sept	3	5	7	2	17
Oct	6	2	3	2	13
Nov	11	1	1	0	13
Dec	7	1	1	1	10
Total	**65**	**68**	**39**	**54**	**226**

2017					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	12	4	0	1	17
Feb	11	3	0	2	16
Mar	8	10	3	5	26
Apr	4	8	4	5	21
May	3	6	4	8	21
Jun	3	7	4	10	24
Jul	1	8	5	10	24
Aug	1	8	5	6	20
Sept	2	6	7	3	18
Oct	4	5	3	3	15
Nov	9	1	1	0	11
Dec	5	0	1	0	6
Total	**63**	**66**	**37**	**53**	**219**

2018					
Month	**Over Current**	**Earth Fault**	**Instantaneous Fault**	**Transient Fault**	**Total Fault**
Jan	8	2	1	0	11
Feb	10	3	0	1	14
Mar	7	12	2	4	25
Apr	5	6	2	3	16
May	4	6	5	5	20
Jun	4	5	3	7	19
Jul	2	3	4	6	15
Aug	0	4	4	6	14
Sept	2	5	6	2	15
Oct	5	3	2	3	13
Nov	10	1	0	0	11
Dec	6	1	0	0	7
Total	**63**	**51**	**29**	**37**	**180**