

## Reliability Assessment of some Selected 11 kV Feeders within Ibadan Distribution Network

<sup>1</sup>Abraham O. Amole, <sup>2</sup>Muniru O. Okelola, <sup>3</sup>Gabriel O. Amole

<sup>1</sup>Department of Electrical, Electronic and Computer Engineering, Bells University of Technology, P.M.B. 1015, Ota, Ogun State, Nigeria.

<sup>2</sup>Department of Electronic and Electrical Engineering, Ladoko Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria.

<sup>3</sup>Department of Mechanical Engineering, University of Lagos, P.M.B. 1005, Akoka, Lagos.

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### ABSTRACT

The energy satisfaction that consumers can obtain from the central grid solely depends on how reliable the feeder to which such customers are connected, simply because the reliability of both generation and transmission is not enough to guarantee adequate and secure energy delivery. It is on this premise that this paper employed load point reliability indices to assess selected feeders within the Ibadan electricity distribution network. The required data for this analysis was collected from the Ibadan Electricity Distribution Company, at Ring Road, Ibadan, the collected data captured the total number of faults, total fault duration, and total operating time from 2016 to 2019. The load point reliability indices used as performance metrics include Failure Rate (FR), Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), Availability Factor (AVF), and Maintainability (M). An adequate comparison of each of these indices on each feeder was made for the period of investigation. It was discovered that many of these feeders were not reliable. Therefore, the need to carry out extensive maintenance on these feeders is non-negotiable. Also, the result of this analysis will help the Distribution Company (DisCo) to make informed decisions that will accelerate the reliability of these 11kV feeders across the investigated region.

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### Amole Abraham O

Department of Electrical, Electronic and Computer Engineering,  
Bells University of Technology,  
P.M.B. 1015, Ota, Ogun State, Nigeria.  
Email: [latidassah@gmail.com](mailto:latidassah@gmail.com)

## 1. INTRODUCTION

The concept of reliability is a fundamental term in the fields of engineering that defines the ability of a system to satisfactorily perform its specified function within the stated lifespan [1]. Hence, reliability studies are a constant subject of discussion that cuts across a wide range of fields like power systems, telecommunications, computer, mechanical, and chemical engineering [1]–[5]. Reliability analysis of power systems has received more attention due to its complex nature.

Modern power systems are a critical setup consisting of several large-scaled interrelated systems like generators, power transformers, switches, and cables [6][7] that are interconnected for performing the responsibility of generating, transmitting, and distributing safe and usable energy to the electricity consumers to enable them to perform many of their day to day activities satisfactorily [8][9]. Several of man's activities in this recent time largely depends on the energy supply from the national grid, hence for maximum satisfaction, it is expected that these interrelated components that are adeptly interconnected should have the highest level of reliability and adequate economy [10][11][12]. Also, the link between the supply source and customer load

points is the distribution network, it is, therefore, expected that the distribution network should have adequate reliability [13]. However, the reverse is the case, research findings have shown that distribution systems are highly susceptible to interruptions in power supply to customers as a result of the frequent occurrence of several types of faults [13][14]. Several researchers reported that these vulnerabilities are a result of the radial nature of distribution systems having multiple lateral branches and several feeders for supplying electrical energy to consumers [15][16].

The likelihood that the power systems will accomplish its intended role of delivering electrical energy to end-users load point terminals continuously at an acceptable service quality is defined as power system reliability [17]. The assessment of distribution feeders should be a major concern of distribution power system planners for the fact its place in power systems planning, design, operation, and maintenance cannot be overemphasized [18][19]. The reliability of distribution feeders in Nigeria is far behind what is expected of the distribution system, looking at the roles of distribution systems in the hierarchical structure of the power system. It has been established that about 40% of total investment cost on the entire grid goes on distribution systems and about 80% interruption to power supply occurred at the distribution network [20][21]. The devastating state of Nigerian distribution feeder has been the main force encouraging competitive marketing of generators in many parts of the country, and as a matter of concern, these generators are sold extensively and operated virtually throughout the day thereby encouraging an increased level of gaseous pollution and increased noise level [18][20].

At the moment of writing this report, several Nigerian citizens rely on their standby generator more than that from the national grid for performing many of their essential duties, this is as well peculiar to many processing industries and health sector who predominantly runs generators to evade unprecedented downtime from the national grid purposely to ensure prevention of a huge financial loss in addition to the loss of life [22][23]. Several indices can be used to measure the reliability at both the equipment and consumers level. At equipment level (load point) indices such as failure rate ( $\lambda$ ), Mean time between failure (MTBF), Mean time to repair (MTTR), Availability factor (AVF), maintainability among others are employed, while indices such as System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI) determined the level of satisfaction that customers derived from the feeders supplying them with electricity [24][25].

Several authors have attempted the reliability evaluation of both the transmission and distribution feeders across the Nigerian network. Authors in [26] assessed the reliability of 11kV feeder in the Kano distribution network, customer-oriented indices such as SAIDI, CAIFI, CAIDI were employed as the performance metrics. The authors concluded that the environmental factor is the major factor responsible for the disruption of service to the consumer as it accounts for over 50% of the outages. The reliability evaluation of 33kV feeders in Ganmo Ilorin was evaluated using indices such as failure rate, availability, and maintainability as performance indices, the work concluded that feeders that exhibited low reliability and availability relative to others with higher reliability and available should be given frequent attention regarding maintenance so as is to cut down the rate of failure in the feeders [26][27].

Authors in [28] investigated occurrence and causes of faults and outages using Ikorodu distribution feeders over 8 years, eight feeders were examined using performance metrics such as downtime, failure rate, and reliability index such as mean downtime, MTBF, Availability. The results findings showed that some of the distribution transformers are obsolete, there is a high rate of failure, and the load demand on the investigated feeders was observed to be comparatively higher consequently the power supply is inadequate. The customer-oriented reliability indices were employed to evaluate the reliability assessment of 33 and 11kV feeders within Ede town in Osun State Nigeria. The work showed that the true reliability performance of electrical power systems cannot be quantify using the single index [29][30]. The reliability evaluation of 33/11kV Idi-Araba Injection substation, Mushin, Lagos was examined by authors in [31], within the period investigated the fault occurrence was observed to be very low hence the analysis showed a higher value of the reliability of the 33kV. The author in [32] has successfully applied a modified heuristic technique to solve the multi-objective reconfiguration problem in balanced and unbalanced test distribution networks.

The recent upsurge in the integration of renewable energy sources like solar photovoltaic and wind turbines has also affected the reliability of power systems. As an example, optimal stochastic scheduling of renewable sources like a wind turbine, photovoltaic units, and hydrogen storage was considered for reliability enhancement of microgrids by [33]. a scenario-based method was adopted to model the uncertainties of variables like an electrical market price, wind speed, and solar irradiance while the objective functions used were the market profit, total emission production, and average energy not supplied (AENS). A multi-objective firefly algorithm was consequently used to solve the stochastic mixed-integer nonlinear programming problem from this scenario. The proposed method was simulated using a modified 33-bus distributed network as a microgrid and its results were compared with those of mixed-integer nonlinear programming (MINLP),

combined genetic algorithm (GA), and power system computer-aided design (PSCAD). It found that the proposed method gave a better performance due to its low cost and total power loss. It was, therefore, concluded from the work that while optimal and coordinated scheduling of renewable energy resources and thermal units in micro-grids enhances objective functions, improvement in objective functions of the electricity market price, wind speed, and solar irradiance results in an increase in the operational reliability.

The results obtained on IEEE 34-bus distribution systems have shown the capability of transforming an existing distribution network into sets of microgrids to enhance the reliability and sustainability of the distribution system [34]. The existing distribution systems were cluster into a set of MGs based on the weighted graph partitioning technique taking the apparent power of the lines as the weights. Consequently, a multi-objective optimization algorithm based on the interactive fuzzy method was adopted to solve the optimization problem arising from this conversion. It was finally concluded from the work based on the tested scenarios that the proposed transformation technique is more reliable and cost-efficient.

This present works assessed the reliability of ten 11kV feeders within the Ibadan distribution network. The investigated 11kV feeders are Challenge, Ososami, Ring-Road, Oke-Ado, Cocoa-House, Railway, Industrial, Crin, Lagos By-pass, and Seven-up for 4 years. The rest of this paper is organized as follows; section 2 discussed the mathematical modeling of reliability indices, section 3 presented the results and discussion while the last section discussed the conclusion.

## 2. MATHEMATICAL MODELING OF RELIABILITY INDICES

Equipment/component-oriented reliability indices such as failure rate (FR), Mean time between failures (MTBF), Mean time to repair (MTTR), Availability factor (AVF), and Maintainability (M) are of interest in this work.

Failure rate ( $\lambda$ ): The feeder failure rate is the probability per unit time that the feeder experiences failure at the time (t), it is expressed as;

$$\lambda = \frac{\text{Number of time that failure occurred}}{\text{Number of unit-hours of operation}} \quad (1)$$

Mean time between failures (MTBF) is described as the time average intervals between successive failures in a system. It is expressed as;

$$MTBF = \frac{\text{Total system operation hours}}{\text{Number of failure}} \quad (2)$$

Mean time to repair (MTTR) describes is the average time interval before the first failure in the system is observed. It can be viewed as the function of the non-repairable equipment in the system.

$$MTTR = \frac{\text{Total duration of outage}}{\text{Frequency of outage}} \quad (3)$$

Availability factor (AVF) describes the ratio of the mean time between failures to the sum of the mean time between failures and mean time to repair.

$$AVF = \frac{MTBF}{MTBF+MTTR} \quad (4)$$

Maintainability (M) gives an indication of the probability of time for an already failed system to effectively return to the operation. It is expressed as;

$$M = \frac{MTTR}{MTTR+MTBF} \quad (5)$$

## 3. DATA COLLECTION

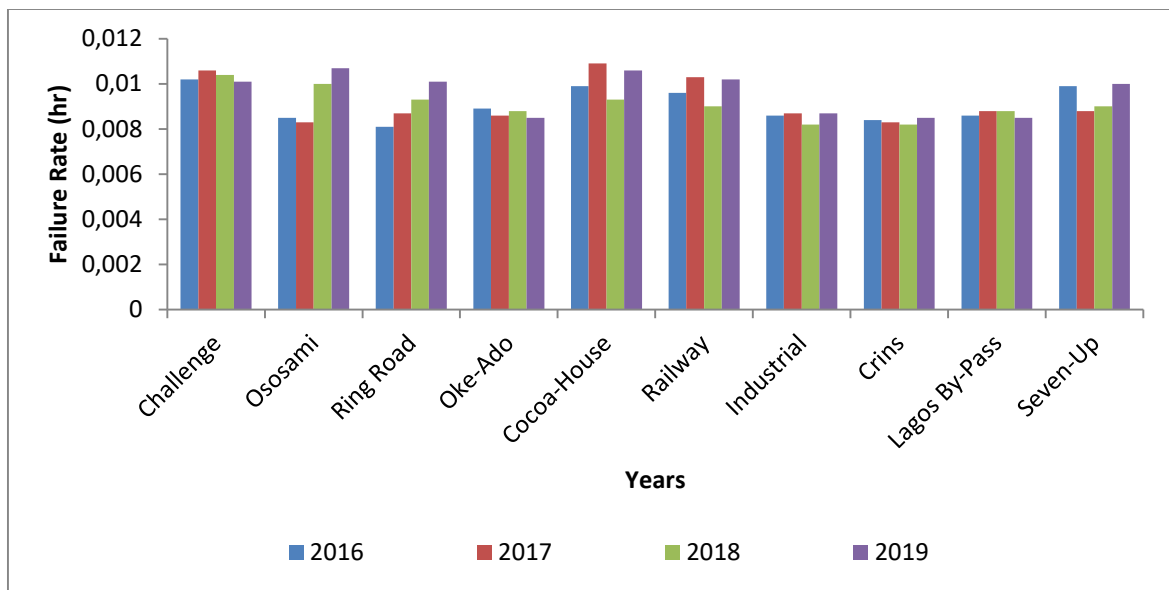
Equipment/component-oriented reliability indices such as failure rate ( $\lambda$ ), The 11kV feeders investigated are as shown in Table 1. The data collected on the feeders Challenge, Ososami, Ring-Road, Oke-Ado, Cocoa-House, Railway, Industrial, Crins, Lagos By-pass, and Seven-up comprises of the total number of faults, the total fault duration, and the total operating, these data were analyzed using Microsoft Excel software. The total fault duration and the total operating were evaluated by summing the outages duration and the active duration in hours over a year. The period of duration span from 2016 to 2019.

**Table 1.** Selected 11kV Feeders and the Data of Interest

Name of 11kV Feeder	Parameter of interest	Years			
		2016	2017	2018	2019
Challenge	Total number of faults	89.00	92.00	90.00	88.00
	Total fault duration (Hrs)	63.90	61.62	65.40	59.12
	Total operating time (Hrs)	8696.10	8698.38	8694.60	8700.88
Ososami	Total number of faults	74.00	72.00	87.00	93.00
	Total fault duration (Hrs)	50.20	54.13	60.87	62.97
	Total operating time (Hrs)	8709.80	8705.87	8699.13	8696.03
Ring-Road	Total number of faults	71.00	76.00	81.00	88.00
	Total fault duration (Hrs)	49.90	58.50	57.88	57.23
	Total operating time (Hrs)	8710.10	8701.50	8702.12	8702.77
Oke-Ado	Total number of faults	78.00	75.00	77.00	74.00
	Total fault duration (Hrs)	48.53	48.77	52.87	49.42
	Total operating time (Hrs)	8710.10	8711.23	8705.13	8710.58
Cocoa-House	Total number of faults	86.00	95.00	81.00	92.00
	Total fault duration (Hrs)	63.15	65.67	60.75	63.73
	Total operating time (Hrs)	8696.85	8694.33	8699.25	8696.27
Railway	Total number of faults	84.00	90.00	78.00	89.00
	Total fault duration (Hrs)	60.42	63.47	54.37	61.02
	Total operating time (Hrs)	8699.58	8696.53	8705.63	8698.98
Industrial	Total number of faults	75.00	76.00	71.00	76.00
	Total fault duration (Hrs)	51.38	50.52	51.75	53.20
	Total operating time (Hrs)	8708.62	8709.48	8708.25	8706.80
Crins	Total number of faults	73.00	72.00	71.00	74.00
	Total fault duration (Hrs)	50.85	51.78	51.65	50.73
	Total operating time (Hrs)	8709.15	8708.22	8708.35	8702.27
Lagos By-pass	Total number of faults	75.00	77.00	77.00	74.00
	Total fault duration (Hrs)	53.58	53.85	52.87	48.43
	Total operating time (Hrs)	8706.42	8706.15	8707.13	8711.57
Seven-up	Total number of faults	86.00	77.00	78.00	87.00
	Total fault duration (Hrs)	57.37	55.87	49.78	75.75
	Total operating time (Hrs)	8702.63	8704.13	8710.12	8702.25

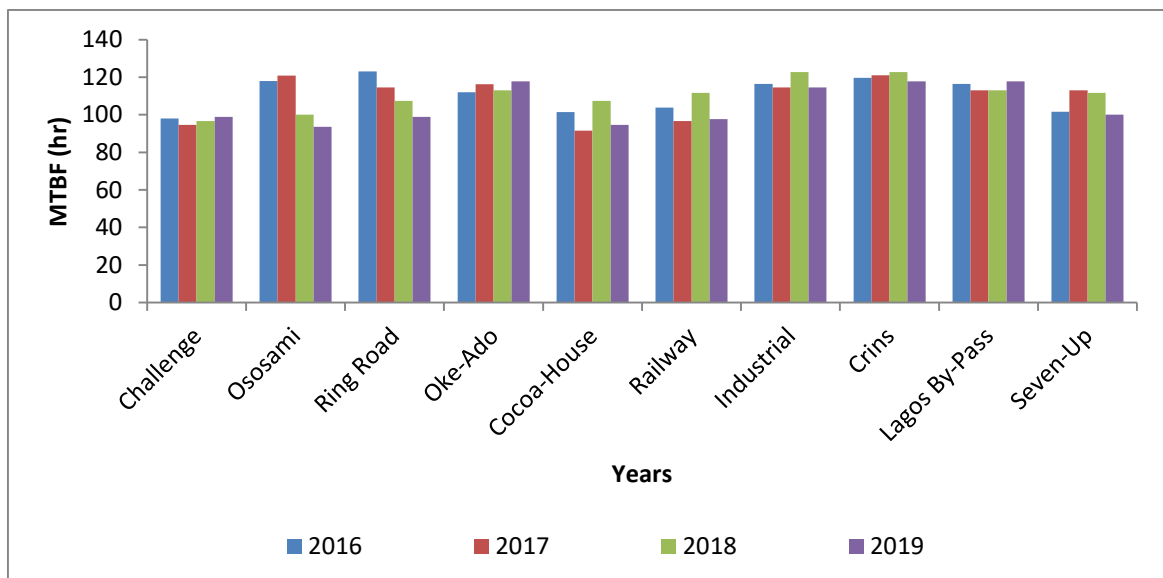
#### 4. RESULTS AND DISCUSSION

The analysis of the selected ten feeders within the Ibadan distribution network was as discussed in this section. Figure 1 presented the summary of the failure rate for all the ten feeders investigated for the year 2016 to 2019, it was observed that the failure rate per feeder on yearly basis was observed to be fluctuating, Challenge feeder has its failure rate to be fairly constant, for Ososami feeder, the failure rate of the feeder was found to be higher in 2018 and 2019 compared to what was observed in 2016 and 2017 respectively. It can as well be seen that the failure rate in the Ring-road feeder was found to increase progressively from 2016 to 2019. Oke-Ado feeder experienced a fairly constant rate of failure for the period investigated. A close examination of Cocoa-House feeders showed that the failure rate was comparatively high relative to other feeders while the trend of failure rate on Industrial, Crins, and Lagos-by-pass feeders appeared to be fairly constant. However, for the Seven-up feeder, the failure rate was high in 2016 and 2019 while it appears to be fairly constant in 2017 and 2018 respectively. Feeders such as Ososami, Ring-road, Cocoa-house, and Seven-up required constant maintenance and possibly replacement of aging distribution station equipment with a view of reducing the number of times that failure occurs.



**Fig. 1.** The Failure Rate of the selected 11kV Feeders

The mean time before failure (MTBF) for all the investigated feeders was as shown in Figure 2. A close examination of Figure 2 revealed that Challenge feeder recorded a higher value for MTBF for the year 2016 while the trend was found to increase progressively for 2017, 2018, and 2019 respectively. Also, MTBF was found to be higher in 2016 and 2017 respectively for Ososami feeder while it decreases progressively for the remaining years. Similarly, a closer look showed that a reverse trend for MTBF for Ososami occurred in the Ring-Road feeder. A similar trend for MTBF was observed for Oke-Ado, Cocoa-House, Railway, Industrial feeder, and Crins, however, a reverse trend for MTBF was recorded for Lagos-By-pass and Seven-up. General observation of Figure 2 showed that the successful average failure interval with the investigated feeders is higher, therefore there is a need for a specially designed scheme for restoring the feeder back into service after a failure has occurred so as to reduce the average interval at which failure occur.



**Fig. 2.** MTBF of the Selected 11kV Feeders

Figure 3 shows the availability factor of each of the investigated feeders over four years, over these years Challenge, Cocoa-House and Railway feeders are the least available feeders, while feeders Industrial, Crin, and Lagos-Bye pass were observed to be fairly available. A closer examination of Figure 3 showed that the availability factor of Ososami feeder decreased drastically over the year investigated. The least available feeder of the feeders investigated throughout the investigation is the Cocoa-House feeder. The availability factor of

Industrial feeder was also observed to decrease progressively throughout the investigation. The availability factor for the Seven-up feeder was observed to be fluctuating throughout the investigation.

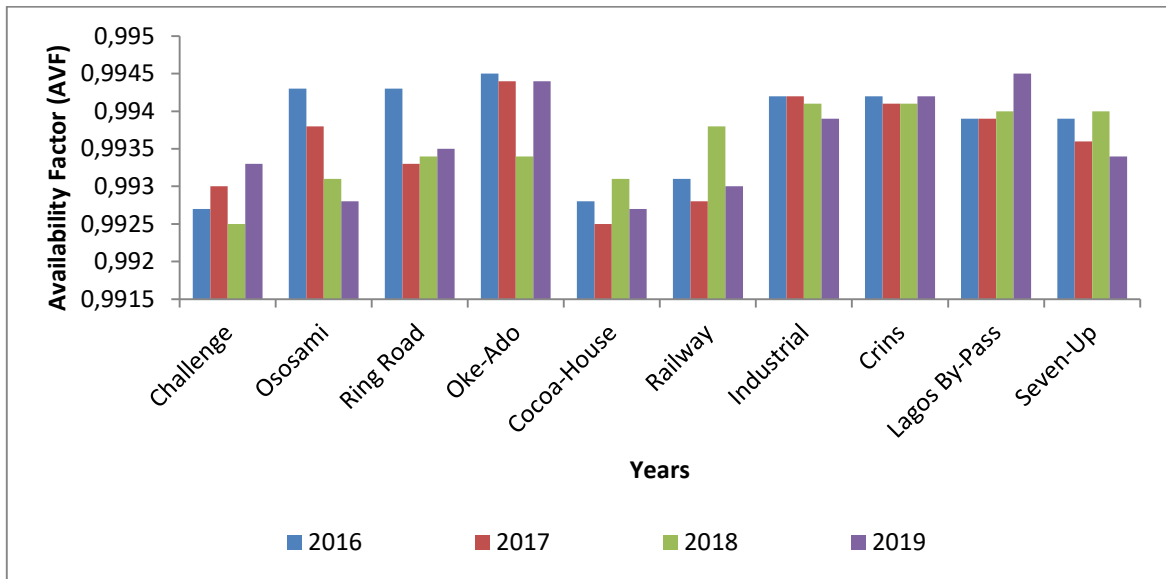
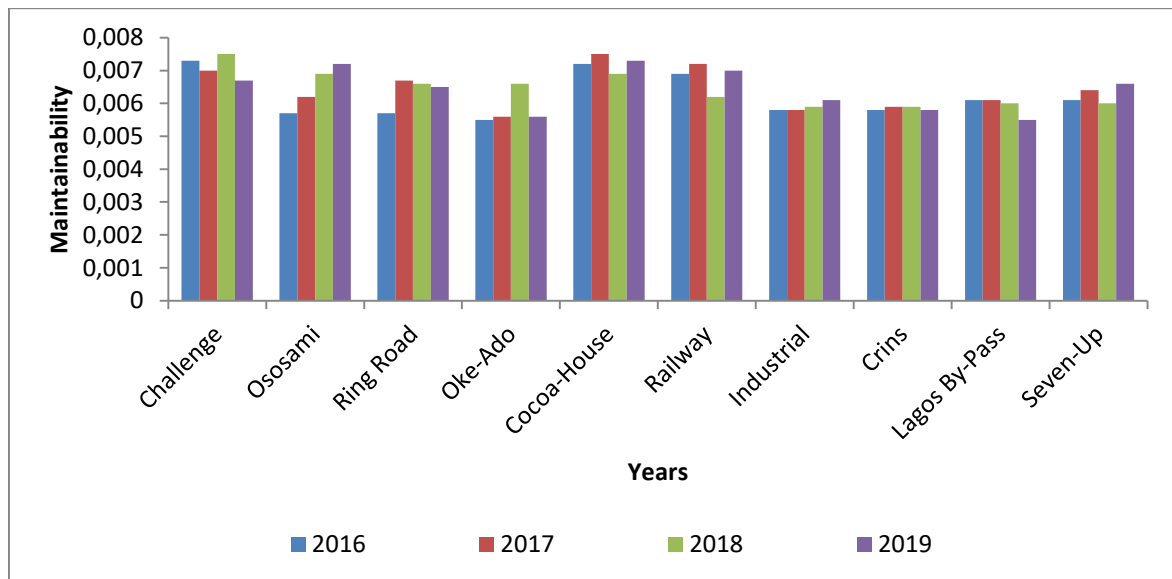


Fig. 3. AVF of the Selected 11kV Feeders

Figure 4 shows the maintainability of all the investigated feeders over four years. The maintainability of Ososami and Industrial feeder increased progressively while that of Challenge, Cocoa-House, Railway, and Seven-up feeders fluctuated for the period of investigation. Of all feeders investigated, the maintainability of the Oke-ado feeder was found to be relatively poor compared to other feeders.

From a general perspective, assessing each feeder yearly using the above-stated performance metrics gives insight into the technical actions that may be necessary to further improve the reliability indices of the feeders. The ring-Road feeder was found to be the most reliable feeder of the ten feeders investigated in 2016, it has the lowest value of failure rate and highest MTBF which are 0.0081 and 123.0155 hrs respectively. Another significant observation was that of Lagos-Bye pass and Industrial feeders that showed the same reliability indices. Similarly, for 2016, Challenge Feeder was found to be the least reliable of the feeders examined, its failure rate and MTBF was found to be 0.0102 and 97.9787 hrs respectively. With reference to 2017, the Crin feeder was found to be the most reliable of all with a failure rate and MTBF to be 0.0083 and 120.9475 hr respectively. However, the Challenge feeder remains the least reliable feeder with a failure rate and MTBF of 0.0106 and 94.6683 hr respectively.





**Fig. 4.** Maintainability of the Selected 11kV Feeders

Also, Lagos- Bye pass and seven-up was observed to have the same value for failure rate and the approximately same value of MTBF. Also, in 2018, Industrial and Crins feeders were found to have the same reliability indices and are adjured as the most reliable feeders with a failure rate and MTBF of 0.0082 and 122.65 hrs respectively. We equally observed that the Challenge feeder has the least reliability with a failure rate and MTBF of 0.00104 and 96.6067 hrs, respectively. In 2019, Lagos by-pass, Crins, and Oke-Ado were the most reliable feeders of all, with a failure rate and MTBF of 0.0085 and 117.72 respectively. However, the Ososami feeder was observed to be the least reliable feeder with a failure rate and MTBF of 0.0107 and 93.5165 hr respectively.

## 5. CONCLUSION

This paper presented the reliability analysis of ten different 11kV feeders within the Ibadan distribution network. The point load reliability indices such as failure rate, mean time between failure, mean time to repair, availability factor, and maintainability were employed to measure the extent of energy supply from these investigated feeders. Based on the result of the study for the period under investigation, the Challenge feeder was found to be the least reliable of all the feeders. The feeder needs total overhauling, replacement of aging substation equipment, and efficient management of fault reporting system between the end-user and the maintenance team.

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