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Comparative analysis of the reliability assessment of commercial and residential feeders in the power distribution utility of Nigeria

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ABSTRACT

Reliability studies serve as valuable tools for assessing and optimizing system performance. Utilities with higher reliability indices are more likely to achieve break-even points due to significantly reduced downtime. This paper explores a comparative assessment of two 11 kV feeders supplying electricity to residential and commercial customers, addressing concerns about distribution system reliability in Nigeria and its impact on the country's GDP. The study involves a comprehensive reliability analysis, utilizing a flowchart to outline procedural steps and employing the ETAP Software program for data analysis collected over a one-month period from a power utility company. The data encompass operational parameters such as day-hourly consumption, outage records, and network equipment data. Results indicate higher reliability indices in the commercial feeder compared to the residential feeder, with the Customer Average Interruption Duration Index (CAIDI) being lower in the commercial feeder. The research underscores the significance of reliability assessment in improving operational efficiency, facilitating maintenance planning, and enhancing customer satisfaction.

1. Introduction

A power system network encompasses various components crucial for electric power operations, including generation, transmission, and distribution. Energy-generating stations, such as hydro-power, coal, and thermal facilities, are typically located in remote areas, away from populated or consumer environments. The generated power from these stations is then transmitted to distribution stations through transmission networks for consumer use. In Nigeria, the distribution system is composed of both medium voltage (MV) and low voltage (LV) networks [1–6].

The nation power utility companies had undergone electricity deregulation and thus faced with competition such that power utilities now struggle to perform and ensure that financial allocation meant for network maintenance are judiciously spent, and customer targets are achieved. Performance metrics of the power utility have been developed to measure such utility performance reliability [7–13].

Furthermore, distribution network operation is the most difficult one when compared to operations in generation and transmission systems because of its wide range and complex structure which has an impact on reliability. Consequently, it becomes necessary to embark on studies that is related to distribution's network reliability analysis. However, the type of analysis that may be carried out include; analytic reliability, simulation approach, and artificial intelligence techniques [3,14–18].

Reliable supply of electricity is an important requirement to building a modern society. The components of a distribution network include, Injection substation, power transformers, distribution transformers, panels, circuit breaker, feeders, protection systems that covers earth fault relay, overcurrent relay etc., direct current (dc) unit, gang isolator, line isolator, lines, and so on. Importantly, a feeder serves as component that facilitate transfer of electric power from an injection substation to the consumers via distribution transformers. The reliability operation of these feeders is essential to ensure a stable and dependable supply to customers [4,19–22].

Generally, studies on distribution system reliability in most cases aimed at achieving the following:

- Understand the model of reliability calculation of components and the reliability parameters of the components and carry out a quantitative reliability level evaluation of the system;
- Sort out the weak links in the distribution system and develop ways of improving the system reliability.

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Table 1
Review of related past work done.

Name(s) of Authors	Research Title	Methodology	Strengths	Weaknesses
Shafik, et al. [7]	Distribution networks reliability assessment considering distributed automation system with penetration of DG units and SOP devices	A number of performance measures of reliability were developed. Made an arrangement of distribution automation system for reliability assessment. Distributed generation (DG) was linked up to the system. Reliability analysis module by NEPLAN Simulator was used to evaluate the reliability indices in different scenario using Reliability Cantered Maintenance (RCM) strategy which drastically reduced the maintenance expenses. This analysis also included the added distributed generation (DG) unit and an 'open point' that enables quality power reliability assessment.	Methodology is based on cost-benefit analysis for distribution networks which described the most appropriate location of distributed generator unit and the opening point device leading to best reliability network. The result obtained from the simulation indicates that system reliability cost has reduced drastically by 65.8 percent and while the reliability parameters have also been relatively enhanced. Also, at each load point, customer average interruption duration index (CAIDI) has improved. The unsupplied energy has reduced by about fifty percent. The involvement of DG or OP devices delivered good results most especially when both equipment is appropriately combined.	No data was used for the research described in the article. Thus, the results obtained has limited application. Also, NEPLAN Software has limited documentation. Thus, where the research project iteration convergence is higher than the design system (NEPLAN) iteration convergence, the research results will not converge and therefore, the results may not be reliable.
Adesina, et al. [14]	Evaluating Reliability Compliance of the Power Utility Distribution Network	The authors carried out research on reliability evaluation compliance on real-life network consideration. The paper considered the reliability assessment of distribution system. About Fifteen 11 kV radial feeders were used as case study and the necessary data were sourced from the selected power utility organization in Nigeria. A power system software known as Electric Transient Analyzer Program (ETAP) was applied in computing the parameter indices. The reliability indices of the selected power network were computed and the results are presented.	The reliability indices results shows that the 11 kV feeders' performance are classified as good, average and poor. Thus, the critically ill feeders requiring improvement were identified.	The researchers focused on too many 11 kV feeders and as results, all required reliability indices were not evaluated. As Nigerian feeders at that time mostly mixed all categories of loads i.e., residential, commercial and industrial loads unlike nowadays that investors are trying in most power utility companies to create feeders on the basis of load consumption customers. Furthermore, there was no basis to compare the reliability results of the 11 kV feeders considered in this study.
Xiangyu, et al. [19]	Power Supply Reliability Evaluation Based on Big Data Analysis for Distribution Networks Considering Uncertain Factors,	The research examines how safe and reliable power supply to urban areas is a critical requirement and the possible ways of sustaining the trend to the cities and society needs to be looked on to. Using big data analysis approach, a reliability evaluation approach for urban distribution systems via consideration of 'uncertain factors'. Investigation of history data on distribution system topology and parameters shows that by investigating historical data on distribution network topology and parameters, the major influencing factors affecting the reliability of electricity supply plus the uncertainties of such factors are eliminated. The methodology involved the application of Elman neural network (IENN) to achieve reliability evaluation of the target urban distribution system. The method made easy the calculations and accommodate all uncertain factors. The authors used urban distribution system data as case study and examine the effectiveness and feasibility of the said approach.	The achievements of this study include; • he factors affecting the reliability of distribution systems are analysed from network reliability index and structure and the method of screening the parameter of reliability is developed using historical data; with reliability parameters of the components, the distribution network structure, status of real time operation and the schedule are analysed; the reliability evaluation approach for distribution systems based on IENN is achieved, and finally the distribution systems reliability is analysed via data and charts to achieve factors having great influence on power supply reliability. • The authors also identified the system's weak portions and developed schemes for future reliability improvement. • Reliability analysis of cost benefit.	Attempt should have been made to evaluate the reliability parameters of the distribution networks based on the IENN without inputting variables of a neural network for a pre-processing using correlation analysis to make easier the calculations and to check the evaluation accuracy of the neural network.
Xu, et al. [23]	Reliability of Active Distribution Network Considering Uncertainty of Distribution Generation and Load.	The author presented the reliability study approach of the active distribution network (ADN) by applying the combination of the roulette wheel selection and the sequential Monte Carlo algorithm. In this approach, the uncertainty of DG and load was considered via power probability distribution (PPD) and the working state in the presented model. Findings however showed that the	Results validation was done using IEEE-RBTS Bus 6 which verifies the potential and validity of the model used. In this study, voltage control of ADN to maintain a stable distributed voltage is paramount. The multi-voltage level ADN model is presented based on real network data. By this ADN, modern communication technologies such as traffic control and differentiation, embedded networking, etc. are enabled.	The author used only one ADN as case study. However, it is generally known that the reliability of an ADN is not negligible due to the uninterruptible power supply. To add value to the work done, efforts should have been made to have a list of outages data from the source of supply other than the network outages used in the research.

(*continued on next page*)

Table 1 (*continued*)

Name(s) of Authors	Research Title	Methodology	Strengths	Weaknesses
		electricity supply improves the reliability and availability of the case studied distribution system.	With this literature, the voltage control and communication technologies are mature in the ADN and this suggest that the uncertainty of the DG and the load plays an important role on reliability of the ADN.	
Mamo & Hizkiel [24]	Relaibility assesment and enhancement of Dangila distribution with distribution generation,	The authors embarked on reliability assessment of Dangila distribution network without DG unit added and with the DG unit added using MATLAB software. The resulted reliability metrics falls below the benchmark of case study country power utility standard (Ethiopia) by 20 SAIFI and 25 SAIDI. Consequently, to improve the reliability standard, the authors then place a DG unit at different distances from the station (supply point) and took the reliability metrics.	The research carried out presents the base case results for customer average interruption duration index (CAIDI), system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), average service unavailability index (ASUI) and average service availability index (ASAI) were 1.589, 1231.48, 774.93, 14.04% and 85.96 % respectively. Final results shows that the more the distance of DG placement from the station, the better Athe reliability metrics and its closeness to standard. Its further shows that one of the feeders in the system had power outages in base case than case when a DG was added.	Based on this research methodology, all necessary thing has been done.
Alaska & Alkuhayli [25]	Reliability Evaluation of Active Distribution Systems with Distributed Generations.	The research has presented a reliability assessment of an active distribution network with DGs. A technique containing stochastic resources like photovoltaic to evaluate distribution networks was proposed. The method adopted Monte Carlo simulation with stochastic model to assess the distribution network's reliability.	Findings showed that the system as well as the load point reliability indices, for example, repeated power outage and the corresponding power not to have supplied will be computed in the method. More so, the connection of distribution networks to enhance system's reliability to improve system restoration mechanism after pre-fault conditions was assessed.	Determining the operation speed of power system reliability assessment using Monte Carlo simulation method was mixing. All other things are perfected.
Alkuhayl [26]	Reliability Evaluation of Distribution Systems Containing Renewable Distributed Generations	The author worked on reliability assessment of distribution networks with a Microgrid. Monte Carlo simulation algorithm was employed to test the network. The network includes three types of distributed energy resources solar photovoltaic (PV), wind turbine (WT) and gas turbine (GT). These distributed generators contribute to supply part of the load during grid-connected mode, but supply the entire load during islanded microgrid operation. PV and WT stochastic models have been used to simulate the randomness of these resources.	The study only shows that the implementation of distributed generations can improve the reliability of the distribution networks.	The power loss on each bus of the distribution system with and without DG were not estimated
Sangeetha & Sowjanya [27]	Reliability Assessment of Radial Distribution System	The research evaluated the reliability indices of radial distribution network by placing isolators. Isolators were placed at near the T-section of the main radial distribution network. These isolators were used as protection for the load points under abnormal conditions. A seven-load point distribution radial network was used to study without isolators and with isolators.	The reliability indices evaluated for the radial network with isolators was compared with those obtained without isolators. An improved reliability was noted in radial distribution network with T-section incorporation.	Based on the scope of work, the authors have done all that is expected.
Pani, et al. [28]	Reliability Assessment of Distribution Power Network	The research presents an analytical method of analysing the reliability of distribution networks which can be used in network planning. The IEEE 33-bus radial distribution system's reliability was used as base to test method without DG and later with DG connections at strategic load points. The significant of DG connections at various locations and availability on reliability indices were investigated. Varying Load effects on network reliability were also investigated.	The obtained results shows that every DG location had different reliability indices. However, the location with the lowest value becomes the most reliable portion of the system.	The power loss on each bus of the distribution system with and without DG were not estimated

(*continued on next page*)

Table 1 (*continued*)

Name(s) of Authors	Research Title	Methodology	Strengths	Weaknesses
Guru Prasad, et al.[29]	Reliability Analysis of Radial Distribution Networks with Cost Considerations	The authors developed a multi objective optimizing method called Weighted Mixed Integer Non-Linear Programming based on Pareto front technique. The method is applied in optimal placement of ties in a radial network. The network performance is later measured. The work also considered an IEEE 33 bus system in MATLAB Software environment for results validation.	The results obtained in the two scenarios on SAIFI, SAIDI, CAIDI, ASAI, ASUI and AENS both before and after network reconfiguration were compared for future investment to enhanced improved reliability. Validated results are also presented.	Cases such when customers are isolated through protective device like fuse or breaker without necessarily affecting the whole feeder. These authors couldn't touch on how this phenomenon affect computation of CAIDI (i.e., how the affected customers are considered in CAIDI computation).

- Obtain network reliability cost–benefit analysis of the system.

This research is aimed at comparing the reliability of two 11 kV feeders which are differentiated by the types of customers they feed electricity supply. Research carried out on both feeders employ data analysis tools. Microsoft Excel was used for commercial while Excel spreadsheet software was used for residential in parameters evaluation and graphical analysis of reliability indices. Several studies on reliability analysis of electrical power systems have been carried out in the past. However, some of these reliability evaluation studies and discussions were from a 'Regulatory Angle', while several others based their research on state estimation (operations condition) point of view. Some of the previous work done in a related field are briefly summarized in Table 1.

With all aforementioned contributions and the published literature on network reliability, none out of this literature has ever carried out reliability comparison assessment of two or more networks of medium level voltage. A comparative analysis of the reliability assessment of commercial and residential feeders in the power distribution utility of Nigeria is therefore proposed. The reliability results obtained is targeted to improve the network of the case studied (IBEDC Ilorin Network) and help the management in decision making about creation of new feeders as research assist in determining which feeder contribute maximally to revenue generation of the power utility company.

2. Materials and method

The two 11kVfeeders tagged residential and commercial and classified in marketing/sales section of the utility as commercial and industrial feeders of Ibadan Electricity Distribution Company (IBEDC), Nigeria, were used as case study. The reliability assessments cover a period of one month (June 2023) and the daily reading data for the two feeders were obtained from Ilorin Business District, a branch of IBEDC. The data collected include:

1. Copy of June 2023 injection substation monitoring record sheet. On this sheet, the following can be sighted on daily basis.
   - Faults record of the selected feeder.
   - Causes of this fault and duration of outages.
   - Feeder load loss immediately after outage and the corresponding system downtime before the feeder is restored.
   - Frequency of faults.
2. Collected the following information from the management of the selected power utility company.
   - Inventory of distribution transformers on each of the feeder.
   - Feeder length.
   - Transformer capacity.
   - Load demand of customers
   - Total number of customers on each distribution transformer

Based on the above data, the reliability analyzes of the two feeders were checked. The two feeders radiated from a 2 × 15MVA, 33/11 kV Agba Water Work injection substation as shown in Fig. 1.

Fig. 1 Key:

S_1: 33 kV Line isolator
CB_{T1} and CB_{T2}: Transmission line Circuit Breakers
T_1 and T_2: 15 MVA Transformer T_1 and T_2

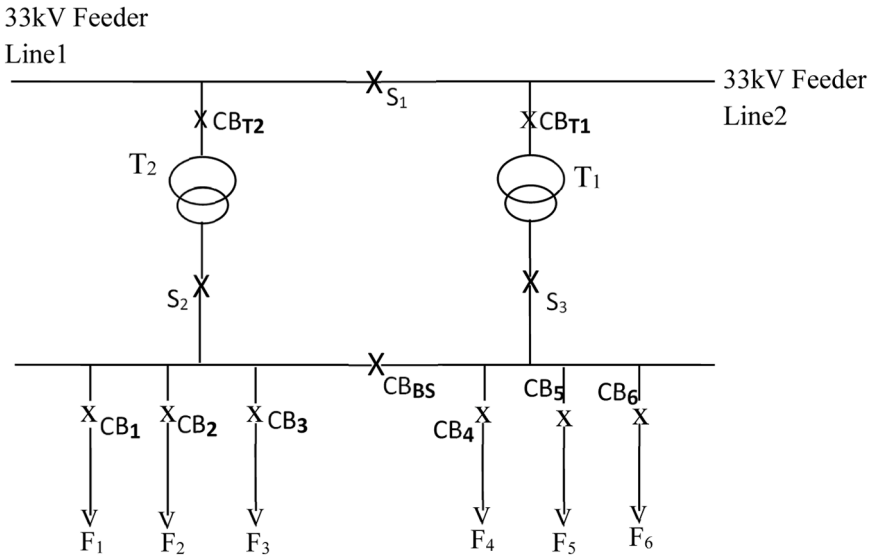


Fig. 1. Agba water work 2 × 15 MVA, 33/11 kV power injection substation.

S_2 and S_3: 11 kV Line Isolators
CB_{BS}: Bus Section Breaker
F_2: 11 kV Residential Feeder
F_5: 11 kV Commercial Feeder
F_1, F_3, F_4, and F_6
CB_1 to CB_6: Circuit Breakers of each 11 kV feeder respectively.

2.1. Reliability terminologies and their mathematical equations

Reliability studies are known for its terminologies inclusive. Readers need to understand the various terminologies used in this study for proper dealings. Most important among these terminologies used in this research work are presented on Table 2.

Failure Rate: Refer to as the frequency at which a substation feeder fails over a specified period of time. Mathematically expressed as in Eq. (1)

$$\lambda = \frac{\text{Outages on each feeder within a specified interval of time}}{\text{Number of time the feeder operates}} \quad (1)$$

Repair Rate: Refer to rate at which repairs is carried out. Mathematically expressed as the ratio of number of faults to service hours as in Eq. (2a).

$$\textit{Repair rate}\ (\mu) = \frac{\text{Number of Faults}}{\text{Total Forced outage Hours}} \quad (2a)$$

Alternatively, λ is defined as in Eq. (2b)

$$\textit{Repair rate}\ (\mu) = \frac{1}{\text{MTTR}} \quad (2b)$$

Mean time to repair (MTTR): Refer to the ratio of total forced outage hours to the number of faults that have occurred within the specified period of time. It is expressed as presented in Eq. (3). Thus, the unit of this parameter is in hours.

$$MTTR = \frac{Total\ Forced\ outage\ Hours}{Number\ of\ Faults\ that\ occured\ within\ the\ specified\ time} \quad (3)$$

Mean time to failure (MTTF): Refer to a maintenance metric that measures the average amount of time a non-repairable asset operates before it fails. Alternatively explained as the ratio of service Hour to the number of faults that have occurred within the specified period of time. Therefore, it is regarded as the average lifespan of an asset and the unit is also in hours. It is mathematically represented as in Eq. (4).

$$MTTF = \frac{Total\ service\ hour}{Frequency\ of\ outage\ (or\ Number\ of\ Faults)} \quad (4)$$

Mean time between failures (MTBF): It is referred to the algebraic sum of the mean time to repair (MTTR) and mean time to repair (MTTR). It measures the time that an asset or equipment or component is operating between breakdowns. MTBF therefore gives the time a component is in operation. It assists the businesses to understand the availability of their equipment. It is also measured in hours and mathematically expressed as in Eq. (5a & b).

Table 2
Reliability study terminologies.

Symbol	Interpretation
1. MTTR	mean time to failure
2. MTTR	mean time to repair
3. MTBF	mean time between failure
4. SAIDI	system average interruption duration index
5. SAIFI	system average interruption frequency index
6. CAIDI	customer average interruption duration index
7. λ	failure rate
8. μ	repair rate
9. A	availability

$$MTBF = MTTR + MTTF \quad (5a)$$

$$MTBF = \frac{total\ operating\ hours}{number\ of\ failures} \quad (5b)$$

Availability: Refer to measure of length of time for which an equipment or asset or component is in operation at any time. There are three types of availability with each applicable under certain conditions. These include; Inherent Availability, achieved availability and operational availability. Their mathematical representation is presented in Eqs. (6a), (6b) and (6c) respectively.

$$Availability\ (Ai) = \frac{MTBF}{MTBF + MTTR} \quad (6a)$$

$$Availability\ (Aa) = \frac{MTBM}{MTBM + r} \quad (6b)$$

where,

$$MTBF = \frac{System\ life\ units}{Maintenance\ actions\ During\ a\ stated\ Period\ of\ Time}$$

r = Active downtime which includes active preventive and corrective maintenance downtime, but excludes logistics time and administrative downtime.

$$Availability\ (Ao) = \frac{MTBM + Ready\ time}{(MTBM + Ready\ time) + MDT} \quad (6c)$$

Where,

MDT = Mean downtime which includes delays due to ready time, logistics and administrative downtime.

System average interruption duration index (SAIDI), System average interruption frequency index (SAIFI) and System average interruption frequency index (SAIFI) are mathematically defined and represented as presented in (7), (8) and (9) respectively:

$$SAIDI = \frac{Total\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customers\ Served} \quad (7)$$

$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} \quad (8)$$

$$CAIDI = \frac{Total\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customer\ Interruptions} \quad (9a)$$

Alternatively,

$$CAIDI = \frac{SAIDI}{SAIFI} \quad (9b)$$

2.2. Components on the feeder

Based on experience acquired while working with power utility company, the components on the two feeders that are prone to faults are too numerous to be mentioned and their repair or replace time varies and dependent on the ruggedness of the component and its availability in company stores for immediate replacement. Such components include;

1. Distribution Transformers: Faults on a transformer may be Low oil level, Cracked Bushings, Oil seal problem, Cable termination failure, Burnt J & P Fuses, Winding failure and Earthing Problems. All the listed faults here deserved seeking for at least two - hours power outage before such faults can be cleared except Winding failure that may require lifting the transformer out of the station for repairs.
2. Feeder Pillar: Common faults include; Upriser cable termination failure, burnt feeder pillar and Burnt feeder pillar unit. All the listed faults here deserved seeking for at least one - hours power outage

before such faults can be cleared except the replacement of burnt high rupturing capacity fuses which does not require any power outage. This fault can be cleared within 15 min.

3. Bank of Ring Main Unit (RMU): There are mainly two categories. The RMU component (J-RMU) is used for network flexibility and gives electricity supply to more than one transformer. while the GF3 RMU is used as a protective guide to supply power to one transformer. There are two types depending on the arc extinction medium i.e., Oil filled RMU and SF6 Gas RMU. Very common faults include; need to refill the gas or oil, burnt RMU fuses, mechanical faults and high voltage cable termination. All possible faults here required seeking for at least one - hours power outage before such faults can be cleared.
4. High Tension (HT) Overhead Lines: Common faults include; Snapping of Aluminum Conductor, Cracking of Pin insulator, Cracking of Disc insulator, Broken Wooden or Fiber cross arm and HT pole broken. All these faults here required seeking for at least one - hours power outage before such faults can be cleared.
5. Low Tension (LT) Overhead Lines: Common faults include; Snapping of Aluminum Conductor, Cracking of Shackle insulator, Cracking of d-Iron insulator, LT pole broken, Line Sagging, However, all these faults did not call for any HT power outage from the control room and has a negligible reliability effect on the overall system. Meanwhile, such repair of component doesn't take more than one hour.
6. 11KV Breakers in Injection substation: This is an equipment that is commonly used in the control room for controlling each feeder. Most often in Nigeria, the breakers are either oil filled or SF6 Gas filled. Again, common fault in this regard may be low dielectric strength of the oil in the breaker which would be seen fully carbonized and must be replaced to save lives and properties. In the same way, the SF6 gas must be refilled when exhausted for the same reason as above.
7. Outdoor 33 kV breaker: This is an equipment that serves as opening and closing mechanism for the incoming supply to the 15 MVA 33/11 kV injection station from transmission station. This equipment rarely has fault, but when it does so, it takes time to be cleared because transmission group will have to come down for the repair or replacement.
8. DC Unit: This is the source of supply to Auxiliary equipment in the station, such as relays used in protective system. Usually, when 33 kV line goes off perhaps due to Load shedding or system collapse, the battery charger stops working and as a result, the battery level might go down. Therefore, hours later when supply is restored, no feeder can be pick – ON unless the DC unit has built up to the required level. This often contribute highly to low reliability of feeders.

2.3. System algorithms

The various steps involved in getting the results of this research analysis follows:

1. Begin
2. Making contact with power utility company to obtain necessary operational data for June 2023 and Non-operational data.
3. Consider the reliability assessment of the of the two feeders one after the other Using ETAP Software. Algorithms 4 to 10 are covered by this ETAP Software.
4. Counter C = 1; Feeder in consideration
5. Input all necessary parameter data required for feeder 1.

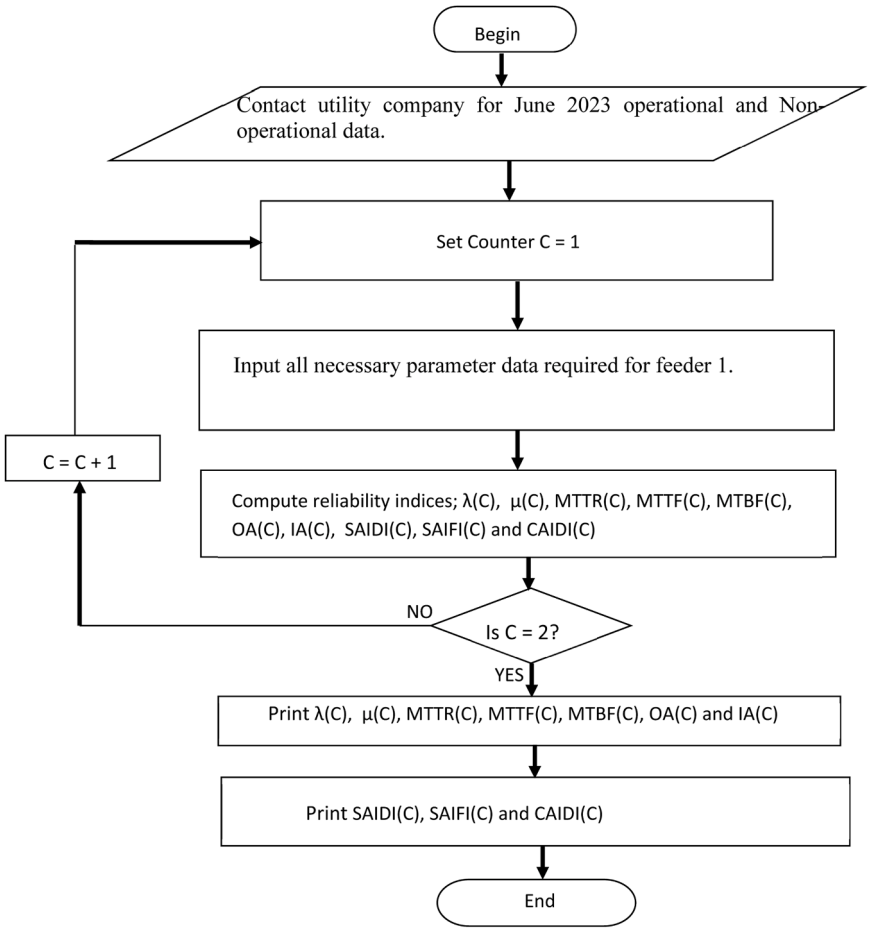


Fig. 2. Flow chart showing the Procedural steps in reliability analysis.

6. Calculate reliability metrics i.e., Failure rate λ(C), Repair rate μ(C), MTTR(C), MTTF(C), MTBF(C), Inherent Availability IA(C) and Operational Availability OA(C) using Eqs. (1), (2), (3), (4), (5), (6a) and (6c) respectively.
7. Calculate reliability indices i.e., SAIDI (C), SAIFI (C) and CAIDI (C) using Eqs. (7), (8) and (9) respectively.
8. Is C = 2, If No GOTO step 4: C = C + 1
9. Print λ(C), μ(C), MTTR (C), MTTF (C), MTBF (C), IA(C), OA (C)
10. Print SAIDI (C), SAIFI (C), CAIDI (C)
11. With the results steps 9 and 10, plot all charts using Microsoft excel application automation for the two feeders.
12. End.

2.4. Network case study and data collection

This study involved collating and evaluating the collected data over a period of a month. This monthly data was further subdivided into four weeks for easy analysis. This makes the analysis to be first carried out weekly before the four weeks are finally considered. The accuracy and comprehensiveness of this data were deemed crucial as it formed the empirical basis for performance assessment. Mathematical equations were employed to analyze the data using ETAP Software Program. This tool enormously assisted in evaluating the various reliability metrics and indices. With this tool application on the collected data and relevant mathematical equations, parameters such as failure rate (λ), repair rate, mean time to repair, mean time to failure, mean time between failures (MTBF), Availability, SAIDI, SAIFI and CAIDI were evaluated.

The flowchart in Fig. 2 and algorithms displayed in subSection 2.3 assisted in carrying out the analysis one feeder after the other. The results of the analysis for the two feeders i.e., the reliability indices obtained are presented and discussed in section 3.0. Table 3, Table 4a, Table 4b, Table 4c, Table 4d, Table 5, Table 6a, Table 6b, Table 6c, Table 6d, Table 6e

Table 4a
Week 1 summary.

Days	Planned outage	Forced outage	Load shelding	Service hours	Number of faults	Tripping Freq
1	0	2	1	21	0	1
2	0	0	0	24	0	0
3	0	4	0	19	1	1
4	0	1	0	23	2	1
5	0	5	0	17	0	2
6	0	0	0	24	0	1
7	0	5	1	18	0	1
8	0	0	0	24	0	0
TOTAL	**0**	**17**	**2**	**170**	**3**	**7**

Table 4b
Week 2 summary.

Days	Planned outage	Forced outage	Load shellding	Service hours	Number of faults	Tripping Freq
1	0	1	0	23	0	1
2	0	0	0	24	0	0
3	0	2	0	22	0	2
4	0	1	0	23	0	1
5	0	5	0	19	0	1
6	0	0	0	24	0	0
7	0	7	0	15	2	1
8	0	0	0	24	0	0
TOTAL	**0**	**16**	**0**	**174**	**2**	**6**

2.5. Tariff bands

In response to a directive from the Nigeria Electricity Regulatory Commission (NERC), adjustments have been made to the distribution of electricity feeders. This measure has been implemented to accommodate customers who face challenges in affording the higher costs associated with the electricity distribution companies (Disco). NERC has mandated that all Disco adhere to a feeder categorization system that takes into

Table 3
Monthly Reliability Data for the commercial Feeder.

Days	Planned outage	Forced outage	Load shellding	Service hours	Number of faults	Frequency of tripping
1	0	2	1	21	0	1
2	0	0	0	24	0	0
3	0	4	0	19	1	1
4	0	1	0	23	2	1
5	0	5	0	17	0	2
6	0	0	0	24	0	1
7	0	5	1	18	0	1
8	0	0	0	24	0	0
9	0	1	0	23	0	1
10	0	0	0	24	0	0
11	0	2	0	22	0	2
12	0	1	0	23	0	1
13	0	5	0	19	0	1
14	0	0	0	24	0	0
15	0	7	0	15	2	1
16	0	0	0	24	0	0
17	0	4	2	18	0	2
18	0	1	0	23	0	2
19	0	5	0	17	2	1
20	0	4	0	20	0	3
21	0	1	0	23	0	1
22	0	3	0	21	0	1
23	0	0	12	12	0	2
24	0	4	4	16	0	2
25	0	0	14	10	0	3
26	0	0	10	9	5	2
27	0	1	9	15	0	2
28	0	0	1	23	0	1
29	0	0	0	24	0	0
30	0	0	4	20	0	1
TOTAL	**0**	**56**	**58**	**595**	**12**	**36**

Table 4c
Week 3 summary.

Days	Planned outage	Forced outage	Load shellding	Service hours	Number of faults	Tripping Freq
1	0	4	2	18	0	2
2	0	1	0	23	0	2
3	0	5	0	17	2	1
4	0	4	0	20	0	3
5	0	1	0	23	0	1
6	0	3	0	21	0	1
7	0	0	12	12	0	2
TOTAL	**0**	**18**	**14**	**134**	**2**	**12**

account the specific needs of customers utilizing these feeders describes the feeder categorization system bands, each offering a different duration of electricity supply based on the customer's consumption level.

Furthermore, the feeder supplying electricity to commercial customers are categorized under Band A, ensuring that these facilities receive a minimum of 20 h and a maximum of 24 h of electricity supply daily. Distinct tariff rates have been established for each feeder category based on their respective bands. Notably, Band A's tariff rate exceeds that of Band B, signifying a differing cost structure. Consequently, customers are required to make payments in accordance with the specific band to which their feeder belongs.

Table 6a
Data for week 1.

Days	Planned outage	Forced outage	Load shellding	Service hours	Number of faults
1	0	2	0	12	10
2	0	0	8	16	0
3	0	5	2	17	0
4	0	1	8	15	0
5	0	7	3	14	0
6	0	2	6	16	0
7	0	5	5	14	0
8	0	0	8	16	0
TOTAL	**0**	**22**	**40**	**120**	**10**

3. Results and discussion

The reliability assessment results for commercial and Residential 11 kV feeders considered for comparative studies are presented in section. Table 7, Table 8, Table 9, Table 10, Table 11, Table 12, Table 13, Table 14 as well as Fig. 3 to 9 are clearly presented as follows. While, each table/figure are analyzed and extensively discussed one after the other.

The result presents detailed reliability analysis of the studied residential 11 kV and commercial 11 kV feeders of the distribution systems.

Table 4d
Week 4 summary.

Days	Planned outage	Forced outage	Loadshellding	Service hours	Number of faults	Tripping Freq
1	0	4	4	16	0	2
2	0	0	14	10	0	3
3	0	0	10	9	5	2
4	0	1	9	15	0	2
5	0	0	1	23	0	1
6	0	0	0	24	0	0
7	0	0	4	20	0	1
TOTAL	**0**	**5**	**42**	**117**	**5**	**11**

Table 5
Monthly reliability data for the residential feeder.

Days	Planned outage	Forced outage	Load shellding	Service hours	Number of faults	Frequency of tripping
1	0	2	0	12	10	2
2	0	0	8	16	0	2
3	0	5	2	17	0	2
4	0	1	8	15	0	4
5	0	7	3	14	0	3
6	0	2	6	16	0	2
7	0	5	5	14	0	2
8	0	0	8	16	0	3
9	0	1	2	21	0	2
10	0	0	2	22	0	1
11	0	2	3	19	0	2
12	0	1	4	16	3	3
13	0	5	0	19	0	1
14	0	0	4	20	0	2
15	0	9	3	12	0	3
16	0	0	15	9	0	2
17	0	4	3	17	0	3
18	0	2	8	14	0	2
19	0	8	3	13	0	2
20	0	4	4	16	0	4
21	0	1	3	20	0	2
22	0	3	3	17	1	4
23	0	0	17	7	0	3
24	0	4	7	13	0	3
25	0	0	18	6	0	2
26	0	0	15	9	0	1
27	0	0	12	12	0	2
28	0	0	1	16	7	2
29	0	0	5	16	3	3
30	0	0	6	18	0	1
TOTAL	**0**	**66**	**178**	**452**	**24**	**70**

Table 6b
Data for week 2.

Days	Planned outage	Forced outage	Load shellding	Service hours	Number of faults
9	0	1	2	21	0
10	0	0	2	22	0
11	0	2	3	19	0
12	0	1	4	16	3
13	0	5	0	19	0
14	0	0	4	20	0
15	0	9	3	12	0
16	0	0	15	9	0
TOTAL	**0**	**18**	**33**	**138**	**3**

Table 6c
Data for week 3.

Days	Planned outage	Forced outage	Loadshellding	Service hours	Number of faults
17	0	4	3	17	0
18	0	2	8	14	0
19	0	8	3	13	0
20	0	4	4	16	0
21	0	1	3	20	0
22	0	3	3	17	1
23	0	0	17	7	0
TOTAL	**0**	**22**	**41**	**104**	**1**

Table 6d
Data for week 4.

Days	Planned outage	Forced outage	Loadshellding	Service hours	Number of faults
24	0	4	7	13	0
25	0	0	18	6	0
26	0	0	15	9	0
27	0	0	12	12	0
28	0	0	1	16	7
29	0	0	5	16	3
30	0	0	6	18	0
TOTAL	**0**	**4**	**64**	**90**	**10**

Table 6e
Tariff bands.

SN	Band (Code)	Minimum daily supply	Maximum daily supply
1	Band A (A20H)	20hrs	24hrs
2	Band B (B16H)	16hrs	20hrs
3	Band C (C12H)	12hrs	16hrs
4	Band D (D8H)	8hrs	12hrs
5	Band E (E4H)	4hrs	8hrs

Table 7
Summary of collated data.

Name of feeders	Number of planned outages	Number of forced outages	Number of load-shedding	Number of service hours	Number of faults
Residential	0	66	178	452	24
Commercial	0	56	58	595	12

Obtain data from power utility company was used to calculate the feeder's reliability metrics as well as customers reliability indices of the two feeders since customers' patronage is one of the factors that determine level of revenue generation of the company. Thus, for any utility company to break-even, its reliability index must be relatively high.

Fig. 4 clearly shows that failure rate of Residential is high compared to commercial feeder. The major contribution to this is that Residential feeder has many customers on it and the route length of the feeder is longer than that of Commercial feeder which leads to load shedding during peak period and transformer limitation due to overloading of the transformer.

Table 8
Failure rate on residential and commercial feeders.

Names of feeders	Failure rate
Residential	0.053
Commercial	0.020

Table 9
Repair Rate on Residential and Commercial Feeders.

Names of feeders	Repair rate
Residential	0.364
Commercial	0.215

Table 10
Availability on Residential and commercial.

Names of feeders	Availability (Ao)
Residential	0.886
Commercial	0.921

Table 11
MTTF, MTTR and MTBF on Residential and Commercial Feeders.

Name of feeders	MTTF	MTTR	MTBF
Residential	18.8	2.75	21.55
Commercial	49.58	4.67	54.24

Table 12
SAIDI on residential and commercial feeders.

Names of feeders	SAIDI
Residential	0.293
Commercial	4.5

Table 13
SAIFI on residential and commercial feeders.

Names of feeders	SAIFI
Residential	0.076
Commercial	1.285

Table 14
CAIDI on residential and commercial feeders.

Names of feeders	CAIDI
Residential	3.829
Commercial	4.500

From Fig. 5, the availability on Commercial is high compared to that of the Residential 11 kV feeders due to limited fault that happened on the feeder and which is not also affected by transformer limitation and load shedding.

From Fig. 6, it is clear that MTTF of Commercial feeder is higher than that of the Residential feeder which implies that it takes commercial feeder less than before it can fail compare to Residential feeder which it takes less than 19 h before it can fail. It is also understood that MTBF of Commercial feeder is high compare to that of Residential feeder which means that commercial can operate for 54.24 h without being disrupted and Residential can operate 22 h before it can be disrupted. The MTTR of Commercial feeder is high compares to Residential feeder which implies that response to maintenance on Commercial feeder is higher compare to the Residential feeder. This means they have to improve on how to fix failure or fault on Commercial feeder than Residential feeder. This practically brought out delay in clearing commercial faults perhaps the

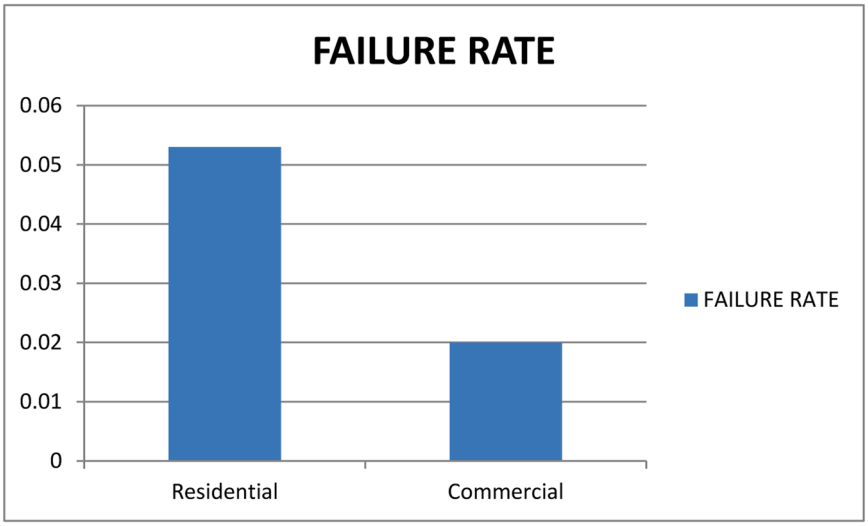


Fig. 3. Failure rate on Residential and Commercial Feeders.

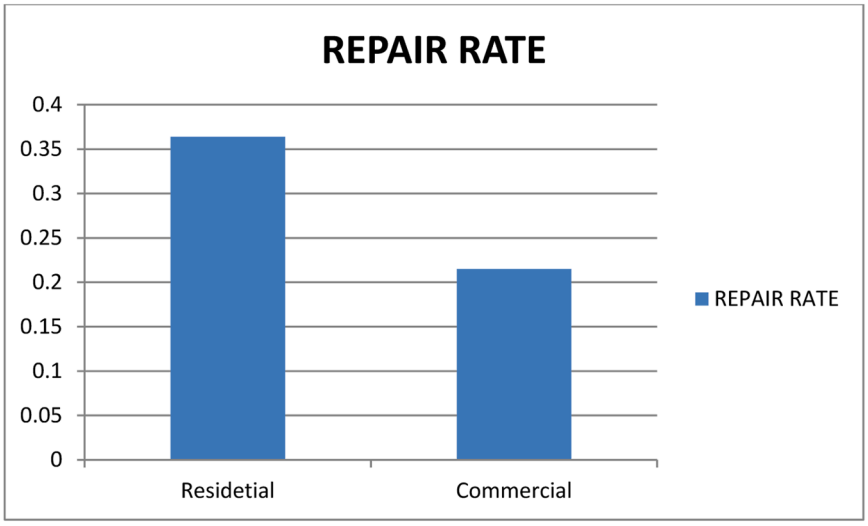


Fig. 4. Repair rate on Residential and commercial feeders.

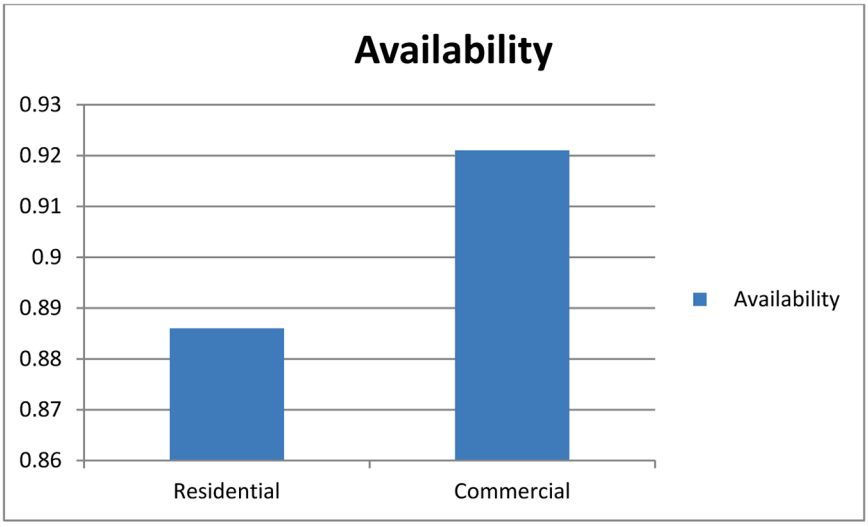


Fig. 5. Availability on residential and commercial feeders.

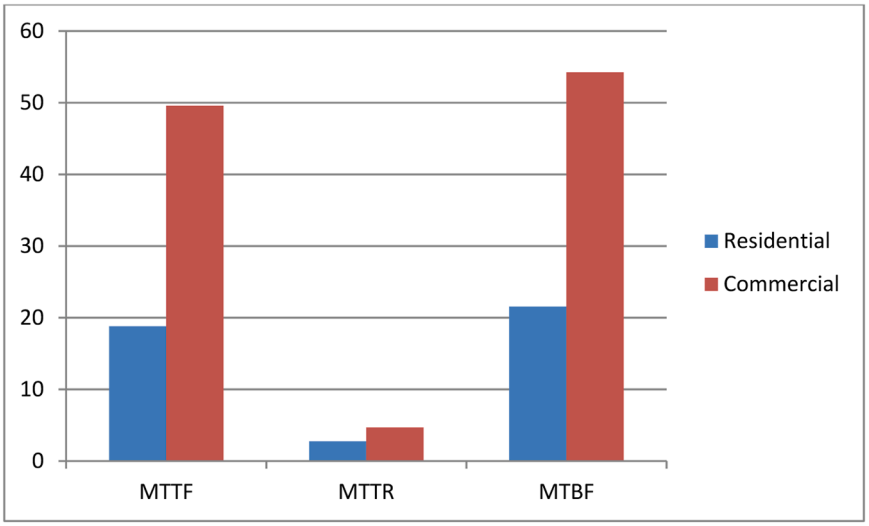


Fig. 6. MTTF, MTTR and MTBF on residential and commercial.

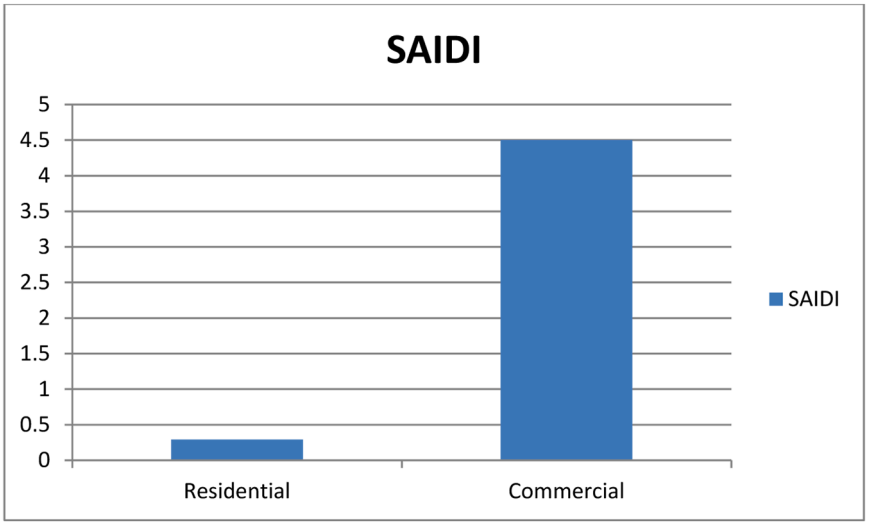


Fig. 7. SAIDI on residential and commercial feeders.

staffs of power utility are waiting for them to be tipped/bribed before clearing faults and this will definitely affect the monthly revenue collection. On the other hand, if the clearing of faults is been handle by individual organization like University, Polytechnic, Mini-Industry etc., the staff of that organizations are the one sabotaging their employer, and adding to unreliability of the power utility.

From Fig. 7, it could be observed that Commercial feeder has highest value of SAIDI compare to residential feeder which is an indication that the cause of feeder interruptions was not diagnosed on time. But, on Residential feeder, the faults were quickly identified and cleared. It is important to recall that SAIDI reliability parameter provides information about downtime of the customers. Based on IEEE standard 1366–2003 which gives a value of 1.5 hrs for North American Utility as standard. Since the SAIDI value of Residential feeder is less than 1.5 h and that of Commercial feeder is far greater than 1.5 h. Then, for this parameter, Residential feeder is considered to be more reliable than commercial feeder.

From Fig. 8, commercial is far greater than residential 11 kV feeders in terms of the value of SAIFI, this is an indication that feeder interruptions spread through the month is very high compare to residential 11 kV feeders. Based on IEEE Standard 1366–1998 the median value is approximately 1.10. What is our view then?

CAIDI is seen as the average restoration time and average outage duration that any given customer would experience. From Fig. 9, it could be seen that it takes 4.5 h/day to receive back electricity supply each time an interruption occurred on commercial feeder while it takes 3.8 h to receive back electricity supply each time an interruption occurred on residential feeder. Based on IEEE standard 1366–1998 median value for North American utilities is approximately 1.36 h. Based on this standard, it could be concluded that both 11 kV feeders are less reliable.

From the discussion of results above, Residential feeder 11 kV feeder has been identified as feeder that its reliability needs to improve and thus need the utility urgent attention. Presented below are recommendations to improve feeder performance and consequently makes the reliability indices better.

1. Reduce the number of affected customers by quickly isolating the faulty areas.
2. Quickly trace the fault on residential feeder to reduce the downtime.
3. Evaluate redundancy in both feeders and suggest recommendations for improving redundancy to enhance reliability.
4. Ensure components of the system are perfectly manufactured and maintained periodically.

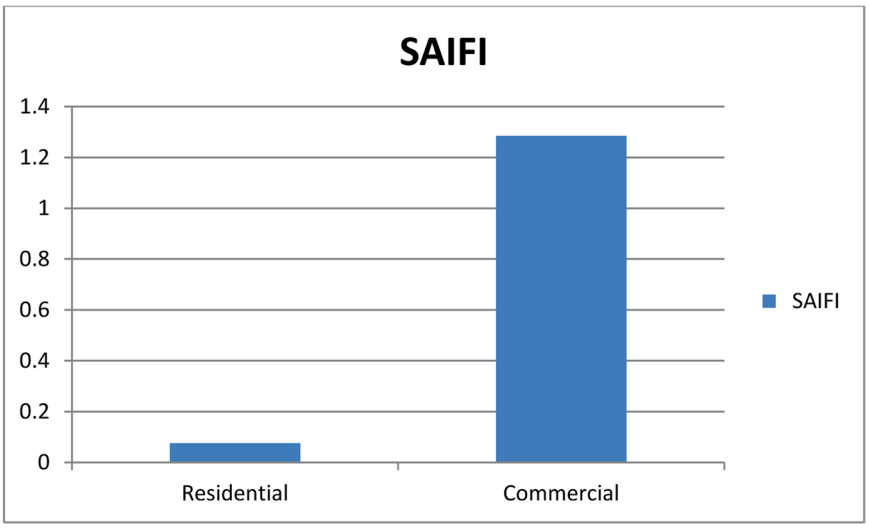


Fig. 8. SAIFI on residential and commercial feeders.

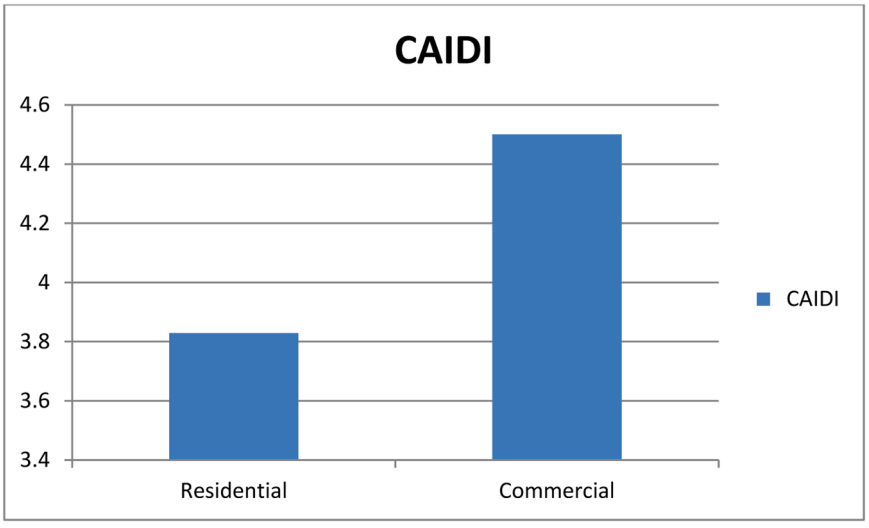


Fig. 9. CAIDI on residential and commercial feeders.

5. Operational guidelines should be strictly followed.
6. Routine check of the system components to minimized failure

4. Conclusion

In conclusion, this research project aimed to compare the reliability of two medium-level voltage feeders operating at 11 kV namely the commercial and residential 11 kV feeders, under a leading power utility company in Nigeria. The analysis of historical data, fault records, and maintenance records, along with mathematical equations, enabled a comprehensive assessment of their performance. The findings indicate a clear distinction in the reliability of the two feeders, with one exhibiting a significantly higher level of reliability than the other. This discrepancy can be attributed to various factors, including maintenance practices, equipment condition, and network topology. More importantly, lack of T-off branches, a smaller number of distribution transformers (DT), minima number of ring main units (RMU), absence of overhead lines as well as maturity behavior of customers at the various distribution transformers on commercial feeder contributed to the excellent reliability of this feeder than residential feeder. The results underscore the importance of regular maintenance, infrastructure upgrades, and strategic planning to enhance the reliability of power distribution systems. Moreover, the research highlights the significance of investing in technology and monitoring systems to minimize interruptions in the supply of electricity, thereby improving overall service quality and customer satisfaction.

CRediT authorship contribution statement

Lambe Mutalub Adesina: Writing – review & editing, Writing – original draft, Validation, Methodology, Funding acquisition, Data curation, Conceptualization. **Olalekan Ogunbiyi:** Writing – review & editing, Validation, Supervision, Software, Methodology, Funding acquisition. **Bilkisu Jimada-Ojuolape:** Writing – review & editing, Validation, Software, Methodology, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare there is no conflict of interests.

Data availability

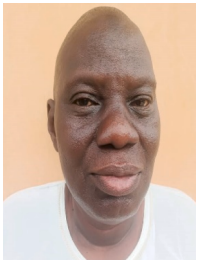
This is because all data used are already presented in the manuscript.

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