Australian Journal of Science and Technology

ISSN Number (2208-6404)
Volume 9; Issue 1; March 2025

Original Article

Assessment of operational reliability and future performance of Kakuri distribution feeder Kaduna

Isaac I. Alabi, Abel E. Airoboman*, Matthew D. Nwachukwu

Department of Electrical/Electronic Engineering Nigerian Defence Academy, Kaduna, Nigeria

ABSTRACT

The reliability of a power system refers to the probability of its satisfactory operation on a long-term basis. It also denotes the ability of the system to supply adequate electric power on a continuous basis with limited interruptions over an extended time period. Reliability assessment plays an important role in the planning of the distribution system. It ensures that the system is operated in an economical manner where interruption at the customer load will be minimal. This research work is aimed at assessing and predicting the reliability of Kakuri 132/33 kV substation with emphasis on the Arewa, PAN, and Ugwan Boro 33kV feeders. The reliability of Kakuri 132/33 kV substation was assessed using electrical transient analyzer program reliability assessment module. The power network was modeled and the reliability assessed employing the reliability assessment module. The reliability prediction of Arewa, PAN, and Ugwan Boro feeders was achieved through the utilization of the curve fitting tool in MATLAB. Outage data for the years 2017–2022 were collated from the station which was used for the analysis. The failure rate (FR), mean down time (MDT), mean time between failure (MTBF), and mean time to failure (MTTF) of Arewa, PAN, and Ugwan Boro feeders were also computed. System average interruption duration index, customer average interruption duration index, average service availability index, expected energy not supplied and average energy not supplied of 1.1217f/customer, year, 15.7358 h/customary, 14.029 h/customer-interruption, 0.9982 pu, 2455.586 MWh/customary, and 223.2351 MWh/customary for the entire network were obtained, respectively. The average interruption rate, average outage duration, annual duration, and expected energy not supplied of 1.3922f/year, 15.53 h, 21.6221 h/year, and 326.2703MWh/year, respectively, were obtained for Arewa feeder. Furthermore, for the same Arewa feeder, the average values for the FR, MDT, MTBF, and MTTF of 0.015107/h, 1.493213h, 68.12776h, and 1.95462h, respectively, were obtained. Hence, the results obtained from the analysis revealed the status of the Kakuri 132/33kV substation and the Arewa, PAN, and Ugwan Boro feeders in particular.

Keywords: Distribution, feeder, network, reliability

Submitted: 20-01-2025, **Accepted:** 04-03-2025, **Published:** 30-03-2025

INTRODUCTION

Background of the Study

The significance and growing demand for electric power supply in contemporary society cannot be overstated, as it constitutes a fundamental component of daily human activities across domestic and commercial domains. The modern world is increasingly dependent on the continuous and high-quality supply of electricity. Empirical evidence underscores the critical role of electricity in sustaining essential applications such as computer systems, telecommunication networks, financial institutions, manufacturing industries, offices, educational institutions, healthcare facilities, residential homes, and life-support systems. Consequently, ensuring an uninterrupted and stable electricity supply remains paramount.[1] In Nigeria, the demand for a power system that guarantees adequate and reliable electricity supply has been a persistent concern. The attainment of national independence, coupled with economic growth and population expansion, has led to a significant rise in electricity demand. To assess system performance, electric utility companies have established various reliability metrics, including outage duration, frequency of outages, system availability, and response time.[2] The majority of reliability studies primarily focus on steady-state (static) conditions.[3] Power system reliability is defined as the probability of maintaining satisfactory operational performance over an extended period. It also encompasses the system's capacity to supply adequate electricity with

Address for correspondence: Abel E. Airoboman, Department of Electrical, Electronic Engineering Nigerian Defence Academy, Kaduna, Nigeria. E-mail: airobomanabel@nda.edu.ng

minimal interruptions over time.[4] Reliability assessment is an essential component of distribution system planning, ensuring economic operation while minimizing service interruptions to customers.[5]

Reliability in power systems is categorized into two key aspects: Security and adequacy. Security pertains to the ability of an electric power system to withstand sudden disturbances, such as short circuits and unforeseen failures of system components. It also refers to the degree of risk associated with the system's capability to endure contingencies without disrupting customer service. Adequacy, on the other hand, evaluates the system's ability to meet total consumer electricity demand, considering both scheduled and unscheduled outages.[6] Two primary approaches are employed in the reliability evaluation of distribution systems: Historical assessment and predictive assessment. Historical assessment involves the collection and analysis of system outage data and customer interruption records to measure past performance. This approach systematically logs the frequency, duration, and causes of system failures and customer interruptions.[5] Conversely, predictive assessment integrates historical outage data with mathematical models to estimate the performance of specific network configurations. This approach relies on component reliability parameters and network physical configurations to compute service reliability.[7] Predictive reliability estimation applies mathematical modeling techniques to assess system reliability before empirical data becomes available.[8] Power outages have remained a critical challenge in power distribution networks due to recurrent tripping incidents on distribution lines. Various methods have been employed to evaluate power system reliability, including artificial neural networks (ANN), Monte Carlo simulations, and analytical techniques.[5] ANN and Monte Carlo simulations are particularly effective for complex networks with multiple load buses, whereas the analytical method is more efficient for simpler networks due to its reduced computational requirements.[7] Given the structure of the Kakuri 132/33kV network, which consists of a single load bus with ten outgoing feeders, the analytical method was deemed the most suitable approach for reliability assessment. This study focuses on the reliability analysis and prediction of the Kakuri 132/33kV substation under steady-state conditions, with particular emphasis on the Arewa, PAN, and Ugwan Boro feeders. The prevalence of unreliable power supply within Nigeria's distribution network has significant economic implications. Successive governments have implemented various initiatives to address power supply challenges, leading to increased private sector participation in the energy sector through independent power projects and national integrated power projects. However, supply reliability remains a key concern for stakeholders, as the nation continues to experience power outages due to system tripping and collapses. Reliable electricity supply is a critical factor in investment decision-making, as prospective investors require prior knowledge of supply stability within their chosen business locations. Therefore, this study seeks to investigate the reliability indices of power supply within the Kakuri transmission network to facilitate informed decision-making regarding power facility utilization and its economic implications within the study area.

LITERATURE REVIEW

The paper in Adeoye and Okereke[3] investigated and analyzed the supply of energy to consumers in Ado-Ekiti metropolitan. Direct interviews, questionnaire distribution, the 9-S reliability method, and the reliability index were utilized as approaches. The work recommendations were as follows: Generation of the required MW by the city, enhanced service by the Power Company, proper sizing of conductors, correct capacity of transformers, and re-orientation of consumers on energy usage. The results demonstrate that the reliability of electricity supply to Ado-Ekiti metropolis is quite low when compared to the 9-S reliability level, except for locations such as Erinfun and Federal Polytechnic districts where the power supply in 1 year is fair with reduced power outages of 182.5 h/year.

This paper Okorie *et al*.[9] examines the dependability of the electric distribution network using the indicators of reliability analysis system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI), customer average interruption frequency index (CAIFI), momentary average interruption frequency index (MAIFI), average service availability index (ASAI), and it gave a very comprehensive reliability assessment of distribution infrastructure-based reliability measures to be computed based on field data collected throughout the study period. To provide strong operational philosophies focused at ensuring efficient, secure, reliable, and high-quality power delivery to consumers, both narrative and quantitative reliability characterizations of distribution infrastructure outlays should be used to proffer sound operational idea aimed at insuring efficient, secure, reliable, and high-quality electricity delivery to consumers. The work in Airoboman and Simon[10] showed the dependability forecasting of feeders in the Nigerian power industry (NPI) using ANN was reported in this article. Historical monthly reliability data for Guinness, GRA, Koko, Ikpoba-Dam, Etete, Nekpenekpen, and Switch station feeders from the Benin Utility Transmission Company in Edo State were acquired from literature for 5 years (2011–2015). The ANN model was created for each feeder in the network, trained using the back propagation forward feed supervised learning approach, and projected out to 2025. The network verified the use of ANN for this investigation with minimum and maximum errors of 0.0092 and 0.04. The findings of this study indicate that the feeders are reliable and the NPI is expected to fall in the near future, necessitating immediate action to address this issue. This study in Aibangbee and Chukwuemeka[4] looks into the reliability of the Apo 132/33kV Transmission substation in Abuja, Nigeria, to deliver adequate electrical power to its clients as affordably as feasible while maintaining a decent level of reliability. The system reliability impact statistics on statistical information were classed as unscheduled (forced) and scheduled (planned) maintenance outages on each feeder, as reported in the daily logbooks, from January to December 2015. The data were utilized to compute and assess the dependability indices with respect to the customer orientation indices SAIFI, SAIDI, CAIDI, and ASAI utilizing the Microsoft and Excel packages. The results show that the unscheduled (forced) outage reliability indices for H3, H13, and H15 feeders for ASAI were 0.9935, 0.9935, and 0.996, respectively, while the consumer average interruption length index was 0.9935, 0.9935, and 0.996. CAIDI was 3.48, 3.7, and 2.368, respectively. In the month of October, the largest CAIDI was reported on feeder H13, with an interruption length of 3 h and 42 min. The maximum SAIDI was 17.193, 13.49, and 9.875 in June, with the greatest on feeder H3 and 13 h 33 min. Furthermore, the highest SAIFI for the corresponding feeders was 7.6, 6.0, and 5.7. The results of scheduled outages on the same feeders were also studied and provided. The significance of distribution performance reliability for H3, H13, and H15 feeders was investigated in this paper. The study found that circuit configuration affects system reliability. Due to their geographical position, the reliability indices for the three feeders have a high level of reliability and esteem customers served by these feeders. The network systems offer higher levels of service reliability than any normal distribution arrangement in the region. This study in Al-Shaalan[11] discusses methodology and strategies for quantitatively assessing power system dependability and applying them to cost/benefit analysis in system generation expansion planning. A realistic way for estimating reliability worth is to evaluate the expected energy not served (EENS) to consumers as a result of power outages and service disruptions. The EENS cost is then compared to the system cost (fixed and variable) to determine the best appropriate dependability level that ensures both acceptable service quality and economical cost. The study demonstrates access to and evaluation of the perceived losses sustained by various customer categories within the Saudi Electric Company in the Kingdom of Saudi Arabia's central region as a result of significant power outages and energy curtailment. It has concentrated on the development and application of theoretical and mathematical tools for analyzing the basis for determining the most appropriate system dependability level of a power system while taking into account both company and customer outage costs. The primary contribution of this work is the development and application of a unified consumer losses function for a specific service region to define overall consumer losses as a function of outage length. Furthermore, the study reveals a compilation of major energy customers' outages data, which can be used as a crucial input to reliability-cost evaluation in power system planning. This study investigates the impact of interconnecting electric power systems on enhancing overall reliability and reducing both fixed and operational costs. A unified methodology for reliability evaluation was developed and applied to three distinct power systems before and after interconnection, utilizing efficient and practical techniques. Through these parameters, the study assesses the economic and technical benefits derived from the interconnectivity of the three electric utilities. Furthermore, this research explores and presents concepts, strategies, and criteria for reliability-cost tradeoffs in both isolated and interconnected power system planning scenarios. The analysis incorporates reliability standards and economic metrics to evaluate these tradeoffs comprehensively. The findings indicate that the reliability-cost tradeoff in power systems is a complex and sensitive issue that must be carefully considered in power system development and interconnectivity. The results demonstrate that interconnection enhances system dependability, mitigates power outage risks, prevents service interruptions, lowers overall system costs, and provides a buffer against potential energy curtailment. These findings offer valuable insights for engineers, utility executives, and stakeholders involved in power system management and planning. In prior research Conejoa *et al*.,[12] a simulation-based approach was proposed for reliability evaluation in power systems with significant renewable energy penetration. This study introduced reliability indices tailored to systems incorporating renewable power plants. The adopted methodology leveraged historical data on renewable energy sources, particularly wind and solar, to estimate power generation levels and compare them with demand to identify power mismatches. This approach facilitates the determination of optimal renewable energy penetration levels and aids system operators in deciding the proportion of generation that renewable energy power plants can reliably contribute. In addition, a statistical method was employed to quantify the availability of renewable energy sources in reliably meeting load demand over a given period. The study demonstrated that integrating multiple renewable energy sources, such as wind and solar, significantly improves system dependability. A key advantage of this strategy is its reliance on historical rather than projected data, enhancing the accuracy of reliability assessments. Furthermore, research Wang and Billinton[13] introduced a time-sequential simulation technique to evaluate the reliability cost/worth of distribution systems, incorporating the effects of meteorological conditions and restoration resources. Time-varying weight factors (TVWFs) were used to model the impact of weather conditions and available restoration resources on component failure rates (FR) and restoration times. The study developed time-varying FR (TVFRs) by combining average FR with TVWFs, while time-varying restoration times (TVRTs) were derived by integrating average restoration times with TVWFs. Findings from test distribution systems revealed that TVFRs significantly influence interruption costs for frequency-sensitive consumers, while TVRTs have a pronounced effect on all customer categories. The study highlights the necessity of considering TVRTs in reliability cost assessments and network reinforcement planning. The incorporation of TVFRs and restoration times in this analysis underscores the significance of accounting for weather-related uncertainties and resource availability in power system reliability evaluations. In another study Daramola and Olulope,[14] the operational and performance challenges of the Ota 132 kV injection substation were examined. Using numerical statistical methodologies, outage records, and key reliability indices - including mean time between failures (MTBF), mean downtime, outage rate, dependability, and supply availability - the substation's power supply issues were analyzed. Load flow analysis was performed using MATLAB's Newton-Raphson method to evaluate the efficiency of power delivery through the substation. The simulation results indicated efficiency levels ranging from 92.3% to 94.4% across different scenarios. The analysis identified load shedding as the primary cause of outages in the substation's incoming lines, with an availability rate of 0.47 and an outage rate of 0.065 outages/h. Based on load flow results, the study recommended replacing the existing 100 MVA transformer with a 200 MVA transformer to adequately meet.

METHODOLOGY

This section deals with the reliability assessment and prediction of Kakuri 132/33kV feeder to ascertain the reliability state and system performance. Reliability indices such as SAIFI, SAIDI, ASAI, average service unavailability index (ASUI), and CAIDI were obtained from simulation using electrical transient analyzer program (ETAP) software. These indices provide a relative measure for a group of load points or for the entire system. The Arewa, PAN, and Ugwan Boro feeder's reliability prediction was done employing MATLAB/SIMULINK software. This research was solely dependent on data obtained from the Transmission Company of Nigeria log book to calculate parameters needed for the reliability analysis. Operational data from 2017 to 2022 comprising forced outages, planned outages, supply availability, number of customers, and feeder route length were collated. Data collated are contained in appendix C. Kakuri 132/33kV feeder is one among the feeders emanating from the Kaduna Town1 station. It has 4 transformers each rated 60MVA, 132/33kV. The feeder gets its supply from the Mando 330/132kV sub-transmission station. The power network has 11 33kV feeders emanating from it, these include NOL feeder, KPC feeder, LAM feeder, Arewa feeder, Ugwan Boro feeder, UNTL feeder, IND Way feeder, PAN feeder, Narayi feeder, Gonin Gora feeder, and Mogadishu feeder.

Reliability Evaluation

Two key steps are essential for reliability evaluation[15] and these include: Data collection, and data analysis for creating statistical indices. The field data are first gotten by documenting the facts of failures occurrence and the different outage durations related to these failures. These field data are then analyzed to generate statistical indices. The quality of these data depends on two very important factors, which include: Confidence and relevance. According to Billinton *et al*.,[15] the data quality, and the confidence placed in it is obviously reliant on the precision of the gathered information. Statistical indices quality is reliant on: First, the processing method of the data, the amount of pooling carried out, as well as the age of currently stored data. These factors obviously affect the significance of indices in their future usage. The quantity and varieties of collected data are reliant on the indices that need to be computed. These sets of indices consider the number of customers involved. According to Okorie *et al*.,[9] the mathematical definition of these indices is shown as follows.

SAIDI

This is defined as the average interruption duration for customers served during a specified time period. This index helps the utility to report for how many minutes customers would have been out of service if all customers were out at one time. It is expressed as

$$SAIDI = \frac{\sum \lambda_i N_i}{N_T} = \frac{Total\ Duration\ in\ hours\ /\ month}{Number\ of\ customers\ supplied\ /\ feeder} \quad (1)$$

Where;

λ_i = Failure rate

N_i = number of customers

N_T = Total number of customers served

SAIFI

This is defined as the average number of times that a customer is interrupted during a specified time period. The resulting unit is "interruptions per customer." It is expressed as

$$SAIFI = \frac{\sum U_i N_i}{N_T} = \frac{Frequency\ of\ outage\ /\ month}{Number\ of\ customers\ supplied\ /\ month} \quad (2)$$

Where;

U_i = Annual outage time

CAIDI

This is defined as the average length of an interruption, weighted by the number of customers affected, for customers interrupted during a specific time period. The index enables utilities to report the average duration of a customer outage for those customers affected. It is expressed as

$$CAIDI = \frac{\sum U_1 N_1}{\sum \lambda_1 N}$$

$$= \frac{Total\ Duration\ in\ hours\ /\ month}{Number\ of\ customers\ affected\ /\ feeder} = \frac{SAIDI}{SAIFI} \quad (3)$$

ASAI

This is a measure of the average availability of the distribution system that serves customers. It is usually represented in percentages. It is expressed as

$$ASAI = \frac{\sum N_1 \times 8760 - \sum U_1 N_1}{\sum N_1 \times 8760}$$

$$= \frac{Customer\ hours\ service\ availability}{Customer\ hours\ service\ demand}$$

$$= \frac{outage\ /\ month}{total\ duration\ in\ hours\ /\ month} \quad (4)$$

ASUI

It provides the fraction of time customers which are without electricity throughout the predefined interval of time. It is expressed as

$$ASUI = \frac{\sum U_1 N_1}{\sum N_1 \times 8760}$$

$$= \frac{Duration\ of\ outage\ hours\ /\ month}{Total\ duration\ in\ hours\ /\ month} = 1 - ASAI \quad (5)$$

Other vital parameters necessary for the analysis of reliability are FR, MTBF, mean down time (MDT), and availability.

FR

FR is used to show the number of times failure occurred to the number of unit hour of operation. This would alert the engineer to ascertain the state of the system and easily proffer solution to it. The FR is mathematically represented by the equation below:

$$Failure\ Rate = \frac{Frequency\ of\ outage\ /\ month}{Total\ hours\ available\ /\ month} \quad (6)$$

MTBF

MTBF is like a forecasting tool that is used to predict when a system would fail during operation. It is advantageous in the sense that it is used to know when to carry out maintenance. It is mathematically represented as

$$MTBF = \frac{Total\ system\ operating\ hours}{Frequency\ of\ failure} \quad (7)$$

MDT

MDT is also known as mean time to failure (MTTF). The significance of this computation is to know when the system would be completely down beyond repair when failure occurs.

$$MDT = \frac{Total\ duration\ of\ outage}{Frequency\ of\ outage} \quad (8)$$

Model Simulation

The reliability assessment was performed by switching from the ETAP "Edit Mode" to the ETAP "Reliability Assessment Run Mode" that the interface of the "Run Mode" contains the necessary tools needed for performing reliability assessment. Before performing the reliability assessment, several input parameters which are needed for an effective simulation were inputted through the reliability assessment study case editor.

Reliability Prediction of Arewa, PAN, and Ugwan Boro Feeders

The prediction of the reliability was performed employing curve fitting tool implemented in MATLAB. The collated reliability data of the Arewa, PAN, and Ugwan Boro feeders were used to generate the mathematical models which were then used for prediction. The reliability of Arewa, PAN, and Ugwan Boro feeders was modeled as a polynomial function of degree five. This was achieved through the use curve fitting tool program in MATLAB as contained in appendix A. This was done to obtain a general expression that models the behavior of the feeder's reliability based on the collated data under review. The generated models for Arewa, PAN, and Ugwan Boro feeders are shown in equation 9, equation 10, and equation 11.

$$R_{(x)} = a_1x^5 + b_1x^4 + c_1x^3 + d_1x^2 + e_1x + f_1 \quad (9)$$

Where;
R = Reliability, x = Time in years, $a_1 = -0.00063$, $b_1 = 0.01232$, $c_1 = -0.09087$, $d_1 = 0.30942$, $e_1 = -0.46594$, $f_1 = 1.207$

$$R_{(x)} = a_1x^5 + b_1x^4 + c_1x^3 + d_1x^2 + e_1x + f_1 \quad (10)$$

Where;
R = Reliability, x = Time in years, $a_1 = -0.00030$, $b_1 = 0.00611$, $c_1 = -0.04574$, $d_1 = 0.15309$, $e_1 = -0.22716$, $f_1 = 0.83820$

$$R_{(x)} = a_1x^5 + b_1x^4 + c_1x^3 + d_1x^2 + e_1x + f_1 \quad (11)$$

Where;
R = Reliability, x = Time in years, $a_1 = -0.00128$, $b_1 = 0.02339$, $c_1 = -0.16167$, $d_1 = 0.51916$, $e_1 = -0.76010$, $f_1 = 0.57100$

To test the validity and accuracy of a given fitted model, the following was carried out to getting an estimate of the error of the fit.

Given a fitting function $f(x)$ to a set of collated data t_i. The sum of the squares of the residuals is shown in equation 12.

$$A = \sum_{i=1}^{N}\left[f\left(x_i\right) - t_i\right]^2 \quad (12)$$

Given that the mean or average value of the collated data is $\overline{t_i}$. The sum of the squares of the deviation of the collated data from the mean is shown in equation 13.

$$S = \sum_{i=1}^{N}\left(t_i - \overline{t_i}\right)^2 \quad (13)$$

The r-squared value is then computed using equation 14.

$$r^2 = 1 - \frac{A}{S} \quad (14)$$

If $r^2 = 1$, then the function would be a perfect fit to the collated data. Hence, the closer r^2 is to 1, the better the fit.

The above model validation computation was done through the use of MATLAB codes.

RESULTS AND DISCUSSION

Reliability assessment analysis of the network was performed and the results are presented in Tables 1 and 2, respectively. While the simulated models are shown in Figure 1 and Table 1 represents the computed and predicted reliability of the feeders while Table 2 shows the reliability indices as computed on the ETAP environment.

Table 1: Computed and Predicted Reliability Values of PAN, UNGWAN BORO AND AREWA Feeder

Time (Years)	PAN	
	Computed Values	Predicted Values
1	0.9522	0.9522
2	0.9579	0.9579
3	0.9547	0.9548
4	0.9672	0.9678
5	0.9811	0.9830
6	0.9791	0.9840
Time (Years)	**UNGWAN BORO FEEDER**	
	Computed Values	**Predicted Values**
1	0.9515	0.9515
2	0.9746	0.9746
3	0.9600	0.9604
4	0.9727	0.9746
5	0.9763	0.9825
6	0.9863	0.9865
Time (Years)	**AREWA FEEDER**	
	Computed Values	**Predicted Values**
1	0.9713	0.9713
2	0.9628	0.9628
3	0.9852	0.9853
4	0.9864	0.9871
5	0.9827	0.9853
6	0.9830	0.9904

Discussion of Results for Computed and Predicted Values of Arewa, PAN, and Unwan Boro Feeder

From Table 1, the reliability starts near 0.97 at year 1 for Arewa Feeder. It decreases to its lowest point of 0.965 around year 2. Following year 2, reliability improves significantly, reaching approximately 0.985 by year 3. After year 3, reliability stabilizes, fluctuating slightly but staying above 0.98 until year 6. There is a noticeable drop in reliability between year 1 and year 2. This could be due to increased FR or unexpected issues during this period; maintenance or operational challenges that were not effectively mitigated. There is a noticeable drop in reliability between year 1 and year 2. This could be due to increased FR or unexpected issues during this period. Maintenance or operational challenges that were not effectively mitigated. After year 2, reliability improves sharply and stabilizes by year 3. This improvement suggests: Implementation of corrective measures, such as maintenance or system upgrades. Enhanced operational strategies that address prior issues. The fitted graph aligns well with the initial graph, indicating that the model accurately represents the observed reliability data.

For the PAN Feeder, the reliability starts near 0.95 at year 1. It increases to a point close to 0.96 around year 2. Following year 2, reliability decreases significantly, reaching approximately 0.955 by year 3. After year 3, reliability increases steadily slightly above 0.98 at year 5 attaining a value close to 0.985 and dropped slightly below 0.98 at year 6. There is a noticeable drop in reliability between year 2 and year 3. This could be due to increased FR or unexpected issues during this period; maintenance or operational challenges that were not effectively mitigated.

For Ungwan Boro Feeder, the reliability begins at approximately 0.95 in year 1 and improves to nearly 0.97 by year 2. However, following year 2, it experiences a significant decline, dropping to around 0.96 by year 3. After this dip, reliability steadily increases, surpassing 0.985 by year 6. The sharp decline between year 2 and year 3 may be attributed to increased

Table 2: Reliability Indices for UNGWAN BORO, PAN AND AREWA FEEDERS

Year	No of outtages	Downtimes (h)	Downtime (Min)	Total available hours	No of customers population	Failure rate	MTBF	MTTR	MDT	Availability	MTTF
2017	151	251	15060	8509	4156	0.017746	56.35099	0.060395	1.662252	0.9713	2.047401
2018	114	326.17	19570.2	8433.83	4242	0.013517	73.98096	0.076891	2.86114	0.9628	1.988173
2019	94	129.88	7792.8	8630.12	4359	0.010892	91.80979	0.029796	1.381702	0.9852	1.979839
2020	154	119.04	7142.4	8640.96	4483	0.017822	56.11013	0.026554	0.772987	0.9864	1.927495
2021	135	151.77	9106.2	8608.23	4544	0.015683	63.76467	0.0334	1.124222	0.9827	1.894417
2022	129	149.25	8955	8610.75	4555	0.014981	66.75	0.032766	1.156977	0.9830	1.890395
Pan feeder reliability indices											
2017	188	418.81	25128.6	8341.19	1475	0.022539	44.36803	0.283939	2.227713	0.9522	5.655044
2018	183	369.11	22146.6	8390.89	1194	0.021809	45.85186	0.309137	2.016995	0.9579	7.027546
2019	267	396.96	23817.6	8363.04	1140	0.031926	31.32225	0.348211	1.486742	0.9547	7.336
2020	269	287.5	17250	8472.5	1561	0.03175	31.49628	0.184177	1.068773	0.9672	5.427611
2021	231	165.24	9914.4	8594.76	1689	0.026877	37.20675	0.097833	0.715325	0.9811	5.088668
2022	217	183.43	11005.8	8576.57	1654	0.025301	39.52336	0.110901	0.8453	0.9791	5.185351
UNGWAN BORO FEEDER RELIABILITY INDICES											
2017	249	424.63	25477.8	8335.37	7328	0.0298727	33.475382	0.0579462	1.7053414	0.9515	1.1374686
2018	180	222.55	13353	8537.45	6660	0.0210836	47.430278	0.0334159	1.2363889	0.9746	1.2818994
2019	234	350.77	21046.2	8409.23	6848	0.0278266	35.93688	0.0512223	1.4990171	0.9600	1.2279834
2020	204	239.58	14374.8	8520.42	6918	0.0239425	41.766765	0.0346314	1.1744118	0.9727	1.2316305
2021	219	207.77	12466.2	8552.23	8717	0.0256074	39.051279	0.023835	0.9487215	0.9763	0.9810979
2022	205	119.84	7190.4	8640.16	8641	0.0237264	42.147122	0.0138688	0.5845854	0.9863	0.9999028

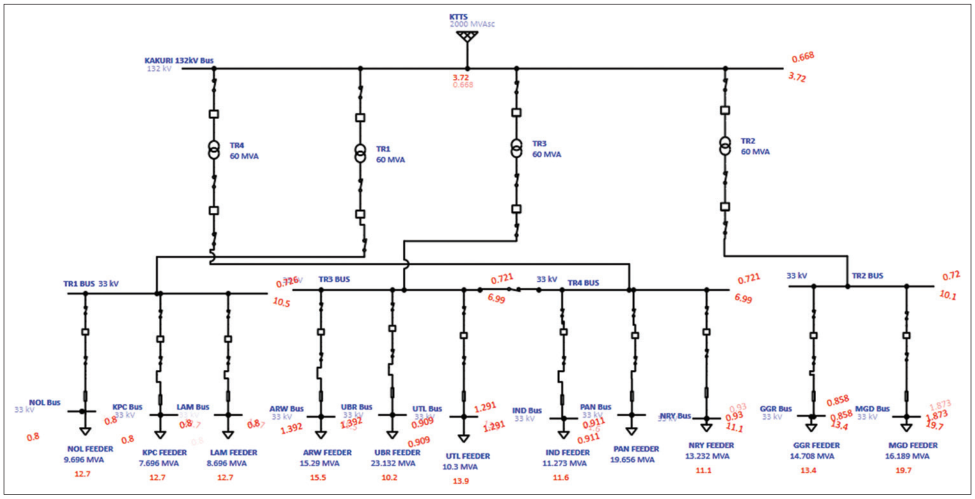

Figure 1: Simulated electrical transient analyzer program model of the network

FR, unexpected issues during that time, or maintenance and operational challenges that were not adequately addressed.

Discussion of Results for Arewa Feeder Computed Indices

Table 2 contained the computed FR, MDT, MTBF, and MTTF of Arewa, PAN, and Ungwan Boro feeder for the years 2017–2022. The Arewa Feeder has a FR of 0.017746/h, 0.013517/h, 0.010892/h, 0.017822/h, 0.015683/h, and 0.014981/h were obtained for the years 2017–2022, respectively. Similarly, MDT of 1.662252 h, 2.861140 h, 1.381702 h, 0.772987 h, 1.124222 h, and 1.156977 h were obtained for the years 2017–2022, respectively. Furthermore, MTBF of 56.35099 h, 73.98096 h, 91.80979 h, 56.11013 h, 63.76467 h, and 66.75 h were obtained for the years 2017–2022, respectively. MTTF of 2.047401 h, 1.988173 h, 1.979839 h, 1.927495 h, 1.894417 h, and 1.890395 h were obtained for the years 2017–2022, respectively. In addition, PAN Feeder has a FR of 0.022539/h, 0.021809/h, 0.031926/h, 0.03175/h, 0.026877/h, and 0.025301/h were obtained for the years 2017–2022, respectively. Similarly, MDT of 2.227713 h, 2.016995 h, 1.486742 h, 1.0687737 h, 0.715325 h, and 0.8453 h were obtained for the years 2017–2022, respectively. Furthermore, MTBF of 44.36803 h, 45.85416 h, 31.32225 h, 31.49628 h, 37.20675 h, and 39.52336 h were obtained for the years 2017–2022, respectively. MTTF of 5.655044 h, 7.027546 h, 7.336 h, 5.427611 h, 5.088668 h, and 5.185351 h were obtained for the years 2017–2022, respectively. Conclusively, Ungwan Boro Feeder contained a computed A FR of 0.0298727/h, 0.0210836/h, 0.0278266/h, 0.0239425/h, 0.0256074/h, and 0.0237264/h were obtained for the years 2017–2022, respectively. Similarly, MDT of 1.7053414 h, 1.2363889 h, 1.4990171 h, 1.1744118 h, 0.9487215 h, and 0.5845854 h were obtained for the years 2017–2022, respectively. Furthermore, MTBF of 33.475382 h, 47.430278 h, 35.93688 h, 41.766765 h, 39.051279 h, and 42.147122 h were obtained for the years 2017–2022, respectively. MTTF of 1.1374686 h, 1.2818994 h, 1.2279834 h, 1.2316305 h, 0.9810979 h, and 0.9999028 h were obtained for the years 2017–2022, respectively.

CONCLUSION

The reliability assessment of Kakuri 132/33kV feeder was carried out. The results obtained which reveals the status of the network and that of the Arewa feeder were presented accordingly. Furthermore, the reliability of the Arewa, PAN, and Ugwan Boro feeders was predicted accordingly. The FR, MDT, MTBF, and MTTF of Arewa, PAN, and Ugwan Boro feeders were also computed. This research revealed the reliability status of the network through the reliability indices. The prediction of AREWA, PAN, and Ugwan Boro feeders performed revealed the future status of the feeders, thereby providing adequate information for the purpose of future expansion.

REFERENCES

1. Gupta JB. A Course in Electrical Power. New Delhi: S. K. Kataria and Sons; 2013.
2. John JS, Suganthi ST. Enhancing reliability by reconfiguration of power distribution systems considering loss. Int Electr Eng J 2013;4:987-91.
3. Adeoye OS, Okereke CO. Investigation and analysis of reliability of power supply in Ado-Ekiti metropolis, Ekiti state, Nigeria. Res J Energy Power Eng 2008;1:1-3.
4. Aibangbee JO, Chukwuemeka IN. Reliability assessment of APO 132/33 kVA electric transmission substation Abuja. Am J Eng Res 2017;6:170-6.
5. Liu Y, Li Y, Sheng M, Wang S. Reliability prediction method and application in distribution system based on genetic algorithm-back-propagation neural network. Inst Eng Technol 2019;13:984-8.
6. Chen G, Zhang F, You D, Wang Y, Lu G, Zou Q, *et al.* Reliability

evaluation of distribution system with distributed generation. IOP Conf Ser Mater Sci Eng 2017;224:012035.
7. Ghiasi M, Ghadimi N, Ahmadinia E. An analytical methodology for reliability assessment and failure analysis in distributed power system. SN Appl Sci 2019;1:44.
8. Jan M, Janusz WB, Bumby J. Power System Dynamics and Stability. Chichester, New York: John Wiley and Sons; 2006.
9. Okorie PU, Aliyu UO, Jimoh B, Sani SM. Reliability indices of electric distribution network system assessment. J Electron Commun Eng Res 2015;3:1-6.
10. Airoboman AE, Simon IN. Reliability prediction in the Nigerian power industry using neural network. J Electr Electron Eng 2020;13:17-22.
11. Al-Shaalan AM. Reliability/cost tradeoff evaluation for interconnected electric power systems. Int J Comput Digit Syst 2017;6:371-4.
12. Conejoa AJ, Contrerasa J, Espinola R, Plazas M. Forecasting electricity prices for a day-ahead pool-based electric energy market. Int J Forecast 2005;21:435-62.
13. Wang P, Billinton R. Reliability cost/worth assessment of distribution systems incorporating time varying weather conditions and restoration resources. IEEE Power Eng Rev 2001;21:63.
14. Daramola DA, Olulope PK. Analysis of power supply operation in a typical Nigerian transmission substation: A case study of Ota 132/33 kV substation. Int J Sci Eng Res 2017;8:484-96.
15. Billinton R, Allan RN, Reliability RN. Evaluation of Power Systems. 2nd ed. New Delhi: Springer; 2008. p. 514.