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Reliability Assessment of a Nigerian Distribution Substation Using Component Reliability and Availability Modeling

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Abstract
Reliable electric power supply is essential for economic growth and sustainable development. However, the Nigerian power distribution sector continues to experience frequent outages and poor service reliability. This study evaluates the reliability performance of the Ikorodu Distribution Network under Ikeja Electricity Distribution Company (IKEDC), Nigeria. Twelve months of outage data were analyzed using standard reliability indices including System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), and Average Service Unavailability Index (ASUI). The reliability assessment identified the major causes of service interruptions and evaluated their impacts on customer service delivery. Results indicate that transformer failures, fuse operations, and feeder faults are the dominant contributors to customer interruptions and network unavailability. The findings provide a basis for improving maintenance planning and network reinforcement strategies. Recommendations include implementation of preventive maintenance programs, deployment of intelligent monitoring systems, and modernization of aging distribution assets.
Keywords: *Reliability assessment, Distribution network, SAIDI, SAIFI, Power system reliability, Nigeria.*

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I. Introduction

Electric power distribution systems represent the final stage of the electrical energy supply chain, providing the connection between distribution substations and end users. The reliability performance of distribution networks is critical because interruptions at this level directly affect residential, commercial, and industrial consumers. A reliable distribution system should be capable of supplying electricity continuously with minimum failures, reduced outage duration, and acceptable service availability (Brown, 2009; Gonen, 2014).

Distribution substations contain several interconnected components, including power transformers, switchgear, circuit breakers, feeders, protection devices, busbars, and auxiliary equipment. The failure of any of these components may result in power interruptions, equipment damage, increased operational costs, and reduced quality of electricity supply. Therefore, evaluating the reliability of individual components is essential for identifying weak points within the network and improving overall system performance (Billinton& Allan, 1996).Reliability assessment involves the application of mathematical and statistical techniques to determine the probability that electrical equipment performs its intended function under specified operating conditions. Component reliability modeling provides important information regarding equipment failure behaviour, maintainability, and operational availability. Common reliability parameters used in distribution system analysis include failure rate (λ), Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), availability, and unavailability (Ebeling, 2019).

Failure rate analysis provides an indication of how frequently a component experiences failure during operation, while MTBF measures the average operating period between successive failures. MTTR evaluates the effectiveness of maintenance activities by determining the average restoration time after equipment failure. Availability combines both reliability and maintainability characteristics to determine the probability that a component remains operational when required (Mobley, 2011). These indices provide valuable information for maintenance planning, equipment replacement decisions, and reliability improvement strategies.The reliability of distribution networks is influenced by several factors, including aging infrastructure, equipment overloading, inadequate maintenance, environmental conditions, protection system failures, and increasing electricity demand. In developing countries such as Nigeria, these challenges are more pronounced due to limited infrastructure investment, inadequate network expansion, and operational constraints within the electricity supply industry (Adewuyi et al., 2020).

The Nigerian electricity distribution sector continues to experience reliability challenges despite ongoing reforms aimed at improving power supply performance. Distribution substations frequently experience equipment failures associated with transformers, feeders, switchgear, and protection devices. These failures contribute to frequent outages, prolonged restoration times, and reduced customer satisfaction. Consequently, component-based reliability evaluation has become necessary for identifying critical equipment and developing effective maintenance strategies (Ajenikoko et al., 2021).

Modern reliability assessment approaches increasingly emphasize data-driven analysis and component-level modeling to improve asset management decisions. Reliability modeling using historical failure data enables utilities to predict equipment performance, prioritize maintenance activities, and optimize resource allocation. Recent studies have demonstrated the effectiveness of data-driven reliability assessment methods in improving the performance of modern distribution systems (Li et al., 2022).

Availability modeling has also gained importance in distribution system reliability studies because it considers both failure occurrence and repair characteristics. Unlike failure-rate analysis alone, availability assessment provides a more comprehensive evaluation of the actual operational readiness of electrical equipment. This approach is particularly useful for identifying components that may have low failure frequencies but significant impacts due to long repair durations (Saha et al., 2021).The application of reliability and availability modeling is essential for Nigerian distribution utilities because it provides quantitative evidence for improving equipment performance and reducing service interruptions. By evaluating individual component reliability characteristics, utilities can develop targeted maintenance programs, improve asset management practices, and enhance network availability.

This study presents a component reliability and availability assessment of a Nigerian distribution substation using historical outage data. The study evaluates major substation components by determining their failure rates, MTBF, MTTR, availability, and outage contributions. The results provide insight into the most critical components affecting system reliability and offer recommendations for improving distribution network performance.

II. Literature Review

2.1 Concept of Power System Reliability

Power system reliability refers to the ability of an electrical system to continuously supply electricity to consumers within acceptable standards and operating conditions. Reliability is generally divided into adequacy and security.

Adequacy concerns the existence of sufficient facilities to meet customer demand, while security concerns the ability of the system to withstand disturbances.

2.2 Importance of Reliability Assessment in Distribution Substations

Distribution substations are critical components of electric power systems because they facilitate the transfer and distribution of electrical energy from transmission networks to end users. The performance of these substations directly affects the continuity, quality, and availability of power supply delivered to customers. Reliability assessment provides a systematic approach for evaluating the operational performance of substation equipment and identifying components that significantly contribute to system interruptions.

Reliability assessment enables utility operators to quantify system performance using indices such as failure rate, Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), availability, and unavailability. These parameters assist utilities in identifying weak points within the network, optimizing maintenance schedules, prioritizing equipment replacement, and improving overall service quality. Furthermore, reliability studies support effective asset management, reduce operational costs, minimize customer outages, and enhance decision-making regarding network expansion and modernization. Consequently, reliability assessment has become an essential tool for improving power system performance and ensuring customer satisfaction.

2.3 Reliability Assessment of Distribution Systems

Distribution systems are the final stage in electric power delivery and are responsible for the majority of customer interruptions. Reliability assessment methods include:

1. Analytical methods
2. Monte Carlo simulation methods
3. Markov modeling techniques
4. Failure Mode and Effect Analysis (FMEA)

Analytical methods are widely used due to their simplicity and computational efficiency.

2.4 Reliability Challenges Facing Nigerian Distribution Networks

The Nigerian power distribution sector faces numerous technical, operational, and economic challenges that adversely affect system reliability. One of the major challenges is the aging nature of distribution infrastructure, including transformers, switchgear, feeders, and protection devices that have exceeded their expected service life. Aging equipment is more susceptible to failures, resulting in frequent interruptions and increased maintenance requirements.

Another significant challenge is transformer overloading caused by rapid growth in electricity demand without corresponding expansion of network capacity. Overloaded transformers experience excessive heating, insulation deterioration, and eventual failure, leading to prolonged outages. Inadequate maintenance practices also contribute to poor reliability performance, as many distribution assets are not subjected to regular preventive maintenance.

Additional challenges include poor protection coordination, vandalism of electrical infrastructure, vegetation encroachment on overhead lines, adverse weather conditions, insufficient investment in network upgrades, and limited deployment of modern monitoring technologies. These factors collectively contribute to high outage frequencies, extended restoration times, and low customer satisfaction across many distribution networks in Nigeria.

2.5 Research Problem and Motivation

Despite various reforms introduced in the Nigerian electricity sector, consumers continue to experience frequent power interruptions and unreliable electricity supply. Distribution substations constitute a major source of these interruptions because failures of critical equipment such as transformers, feeders, switchgear, and protective devices directly affect the continuity of power delivery.

Although several studies have investigated power system reliability in Nigeria, limited attention has been given to component-level reliability evaluation and availability modeling of distribution substations. Consequently, utility operators often lack sufficient information regarding the performance characteristics of individual components and their contributions to system outages.

The motivation for this study arises from the need to identify the most critical components within the distribution substation, quantify their reliability characteristics, and develop data-driven recommendations for improving system performance. By analyzing actual outage records and evaluating reliability indices, the study provides valuable insights that can support maintenance planning, asset management, and investment decisions within the distribution sector.

2.6 Study Objectives and Contributions

The primary objective of this study is to evaluate the reliability performance of major components within the Ikorodu Distribution Network under Ikeja Electric Distribution Company using historical outage data and reliability assessment techniques.

The specific objectives are to:

1. Determine the failure rates of major distribution substation components.
2. Evaluate the Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) of each component.
3. Assess the availability and unavailability of substation equipment.
4. Identify the components contributing most significantly to service interruptions.
5. Rank components according to their reliability performance.
6. Recommend maintenance and operational strategies for improving distribution system reliability.

2.7 Contributions of the Study

This study contributes to knowledge and practice in the following ways:

1. Provides a comprehensive component-level reliability assessment of a Nigerian distribution substation.
2. Quantifies the failure characteristics of critical distribution assets using actual outage data.
3. Identifies transformers, fuses, and feeders as key contributors to system unavailability.
4. Establishes a framework for reliability-based maintenance planning and asset management.
5. Supplies valuable information for utility operators, regulators, and policymakers seeking to improve electricity service reliability in Nigeria.
6. Serves as a reference for future reliability studies involving distribution networks and smart-grid applications.

2.8 Research Gap

Most previous studies focused on feeder reliability assessment without detailed analysis of customer-oriented reliability indices and substation component contributions. This study addresses this gap by investigating the reliability characteristics of the Ikorodu distribution network and evaluating customer interruption indices.

III. Methodology

3.1 Research Design

This study adopted a quantitative reliability assessment approach to evaluate the performance of major distribution substation components within the Ikorodu Distribution Network. Historical outage and maintenance records were analyzed to determine the reliability characteristics of various equipment and assess their contributions to system performance. The methodology involved the collection, classification, and analysis of operational data to compute reliability indices commonly used in power system engineering.

The study focused on evaluating component failure behavior, repair characteristics, and operational availability using established reliability models. The results obtained provide a basis for identifying weak components, assessing maintenance effectiveness, and recommending strategies for improving system reliability.

3.2 Study Area

The study was conducted on the Ikorodu Distribution Network operated by Ikeja Electric Distribution Company in Lagos State, Nigeria. The network supplies electricity to residential, commercial, and industrial consumers through a distribution substation equipped with transformers, switchgear, protection devices, feeders, and associated control equipment.

The substation serves as a critical interface between the transmission system and end-users. Consequently, the reliability of its components significantly influences the quality and continuity of electricity supply within the service area.

3.3 Data Collection

The reliability assessment was based on historical outage records and maintenance reports obtained from the distribution substation over the study period.

The collected data included:

1. Number of failures recorded for each component.
2. Duration of each outage event.
3. Repair and restoration times.
4. Equipment maintenance records.
5. Operational logs.
6. Fault reports.

The major components investigated were:

1. Power Transformer, 2. Switchgear, 3. Supply Line, 4. Busbar, 5. Circuit Breaker, 6. Fuse, 7. Switch, 8. Outgoing Feeder, 9. Overcurrent Relay, 10. Earth-Fault Relay and 11. Surge Arrester’

3.4 Reliability Theory and Modeling

Reliability modeling provides mathematical tools for evaluating equipment performance and determining the probability that a component performs its intended function without failure for a specified period.

The reliability indices used in this study include failure rate, Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), availability, and unavailability.

3.4.1 Failure Rate (λ)

Failure rate represents the frequency of occurrence of component failures within a specified operating period.

The failure rate is given by:

$\lambda = N / T$

Where:

- λ = Failure rate (failures/year)
- N = Number of failures
- T = Total operating period

A higher failure rate indicates lower reliability.

3.4.2 Mean Time Between Failures (MTBF)

MTBF represents the average operating time between successive failures of a component.

$MTBF = 1 / \lambda$

Where:

- MTBF = Mean Time Between Failures
- λ = Failure rate

Higher MTBF values indicate better reliability performance.

3.4.3 Mean Time To Repair (MTTR)
MTTR measures the average duration required to repair and restore a failed component to normal operation.
MTTR = Total Repair Time / Number of Failures
Where:

- MTTR = Mean Time To Repair
- Total Repair Time = Sum of outage durations
- Number of Failures = Total recorded failures

Lower MTTR values indicate improved maintainability.

3.4.4 Availability Analysis
Availability is defined as the probability that a component is operational when required for service.
A = MTBF / (MTBF + MTTR)
Where:

- A = Availability
- MTBF = Mean Time Between Failures
- MTTR = Mean Time To Repair

Availability values range between 0 and 1.

3.4.5 Unavailability Analysis
Unavailability represents the probability that a component is not available for operation.
$U = 1 - A$
Where:

- U = Unavailability
- A = Availability

Components with high unavailability contribute significantly to system outages.

3.4.6 Annual Outage Time
Annual outage time was calculated to evaluate the contribution of each component to system interruptions.
Annual Outage Time = $\lambda \times$ MTTR
This index combines failure frequency and repair duration, providing an overall measure of outage impact.

3.5 Data Analysis Procedure
The collected outage data were organized according to component categories. Reliability indices were computed for each component using the mathematical models presented above.
The analysis was performed in the following stages:

1. Determination of component failure frequencies.
2. Calculation of failure rates.
3. Computation of MTBF values.
4. Computation of MTTR values.
5. Estimation of component availability and unavailability.
6. Determination of annual outage contributions.
7. Comparative evaluation of component performance.

The results were subsequently presented using tables, bar charts, and comparative graphs to facilitate interpretation and identify components that significantly influence overall system reliability.

3.6 Assumptions of the Study
The following assumptions were adopted during the reliability analysis:

- Failure events were assumed to occur independently.
- Operating conditions remained relatively constant throughout the study period.
- Recorded outage data accurately represented component performance.
- Maintenance records were complete and reliable.
- All repair activities restored components to their original operating condition.

These assumptions are consistent with conventional reliability assessment methodologies used in power system studies.

IV. Results and Discussion

Table 4.12: Basic Reliability Indices on Each Component

Component	Failure Rate (f/yr) λ	Average Outage Time (Hours)	Annual Outage Time (Hours)
Transformer	0.0031	38.1667	0.1181
Switch gear	0.0044	6.4167	0.0280
Supply line (Incoming)	0.0022	5.8333	0.0126
Bus bars	0.00046322	1.6667	0.00077203
Circuit Breakers	0.00068324	2.0833	0.0014
Fuses	0.0061	15.1667	0.0927
Switches	0.00045923	1.3333	0.00061231
Outgoing feeder	0.0045	13.2500	0.0593
Overcurrent relay	0.00023547	0.2083	0.000049057
Earth fault relay	0.00011201	0.1667	0.000018668
Surge Arrester	0	0	0

Table 4.13: Additional Basic Reliability Indices

Component	No. of Failures	Outage(hours)	Total (hours)	Failure rate (f/yr)	MTBF	MTTR	Availability
Transformer	27	458	8784	0.0031	325.3333	16.9630	0.9504
Switch gear	38	77	8784	0.0044	231.1579	2.0263	0.9913
Supply line (incoming)	19	70	8784	0.0022	462.3158	3.6842	0.9921
Bus bar	4	20	8784	0.00046322	2196	5.0000	0.9977
Circuit Breaker	6	25	8784	0.00068324	1464	4.1667	0.9972
Fuses	54	182	8784	0.0061	162.6667	3.3704	0.9797
Switches	4	16	8784	0.00045923	2196	4.0000	0.9982
Outgoing feeder	39	159	8784	0.0045	225.2308	4.0769	0.9822
Overcurrent Relay	2	2.5	8784	0.2083	4392	1.2500	0.9997
Earth Fault Relay	1	2	8784	0.1667	8784	2.0000	0.9998
Surge Arrester	0	0	8784	0	-	-	-
Total	194	1011.5	8784		45.2784	5.2139	0.8967

4.1 Failure Rate Evaluation

The reliability performance of the distribution substation components was first evaluated using the failure rate index. Failure rate provides a quantitative measure of the frequency with which a component experiences failure during operation and is widely used as an indicator of equipment reliability.

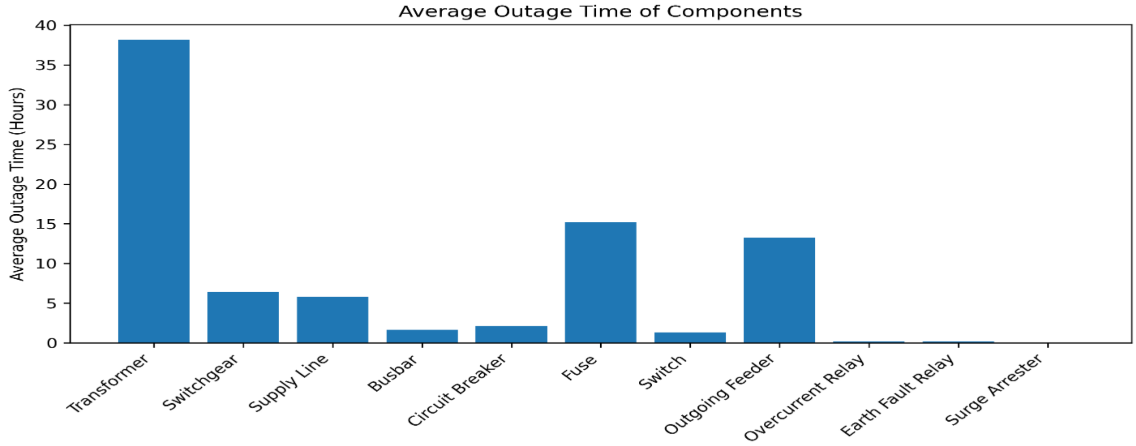
The results obtained show that the failure rates of the studied components varied significantly. The fuse recorded the highest failure rate of 0.0061 failures/year, indicating that it was the most frequently affected component during the study period. This high failure frequency may be attributed to recurrent feeder faults, overload conditions, and short-circuit disturbances within the distribution network.

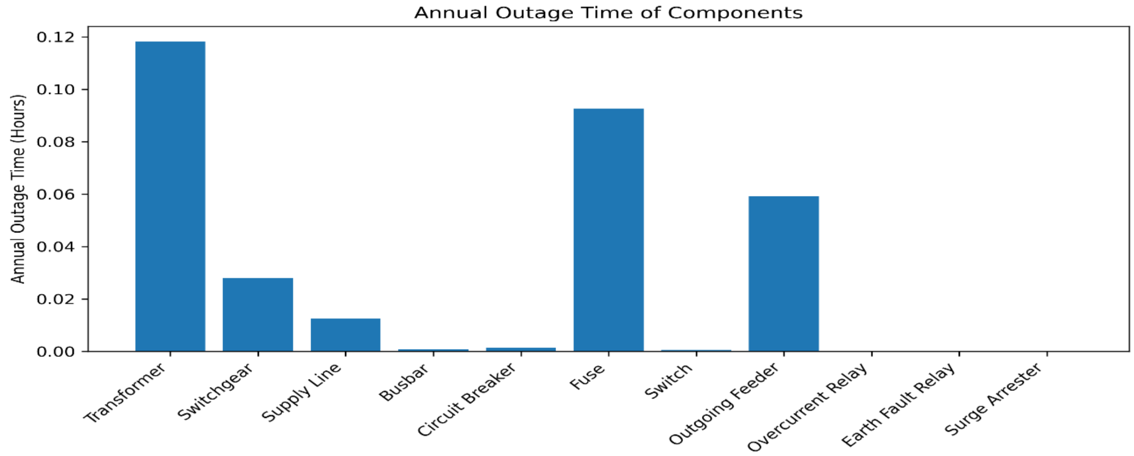
The outgoing feeder and switchgear recorded failure rates of 0.0045 failures/year and 0.0044 failures/year, respectively. These relatively high values suggest that feeder circuits and switching equipment are exposed to operational stresses, environmental conditions, and frequent switching operations that increase their susceptibility to failure.

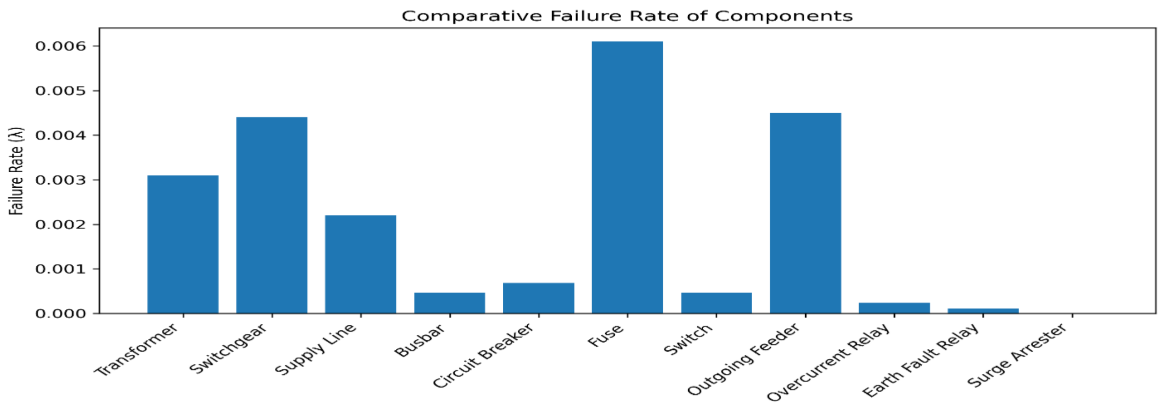
The transformer exhibited a failure rate of 0.0031 failures/year, while the supply line recorded 0.0022 failures/year. Although transformer failures occurred less frequently than fuse failures, their impact on service continuity was considerably greater due to longer repair durations and the larger number of customers affected.

Busbars, circuit breakers, switches, overcurrent relays, and earth-fault relays recorded comparatively lower failure rates, indicating satisfactory reliability performance. No failure was recorded for the surge arrester during the study period, demonstrating excellent operational reliability.

The results indicate that fuses, outgoing feeders, switchgear, and transformers constitute the most vulnerable components within the substation and should receive priority attention in maintenance planning.







4.2 Mean Time Between Failures (MTBF) Analysis

The MTBF values were computed to evaluate the average operating period between successive failures of each component. MTBF is an important reliability indicator because higher values correspond to greater operational dependability.

The analysis revealed that components with lower failure rates exhibited higher MTBF values. Surge arresters recorded the highest MTBF because no failures occurred during the study period. Earth-fault relays, overcurrent relays, switches, and busbars also demonstrated relatively high MTBF values, indicating stable operational performance.

Conversely, fuses exhibited the lowest MTBF values due to their high failure frequency. Outgoing feeders and switchgear also recorded relatively low MTBF values, reflecting their greater susceptibility to faults and operational disturbances.

Transformers exhibited moderate MTBF values. While transformer failures occurred less frequently than fuse failures, the operational consequences associated with transformer outages were significantly greater.

The MTBF results suggest that components such as fuses, feeders, and switchgear require more intensive monitoring and preventive maintenance to improve reliability performance.

4.3 Mean Time To Repair (MTTR) Analysis

MTTR was used to evaluate the maintainability of the various substation components by determining the average time required to restore failed equipment to service.

The transformer recorded the highest MTTR value of approximately 38.17 hours, indicating that transformer failures require extensive diagnostic, repair, and restoration activities. The complexity of transformer maintenance and the need for specialized equipment contribute significantly to this prolonged restoration period.

Fuses recorded an average repair duration of approximately 15.17 hours, while outgoing feeders recorded approximately 13.25 hours. These values suggest that protection-related faults and feeder disturbances require considerable effort to identify and rectify.

Switchgear and supply lines recorded MTTR values of approximately 6.42 hours and 5.83 hours respectively, indicating moderate maintenance requirements.

Circuit breakers, busbars, switches, overcurrent relays, and earth-fault relays exhibited comparatively lower MTTR values due to their simpler maintenance procedures and shorter restoration times.

The MTTR analysis demonstrates that transformer failures represent the greatest maintenance challenge within the distribution network and significantly influence overall service restoration performance.

4.4 Availability Analysis

Availability was calculated to determine the probability that each component remains operational and capable of performing its intended function when required.

The results showed generally high availability values for all components because the number of failures recorded during the study period was relatively low. However, differences were observed in the outage contributions of individual components.

Transformers recorded the highest annual outage contribution of approximately 0.1181 hours/year. Fuses followed with approximately 0.0927 hours/year, while outgoing feeders contributed approximately 0.0593 hours/year.

Switchgear and supply lines contributed approximately 0.0280 hours/year and 0.0126 hours/year respectively.

Other components exhibited relatively insignificant outage contributions due to their low failure frequencies and shorter repair durations.

The findings indicate that although many components exhibit satisfactory availability, transformers, fuses, and feeders continue to exert substantial influence on overall system reliability.

4.5 Unavailability Analysis

Unavailability was evaluated as the proportion of time during which a component was unable to perform its intended function.

The results indicate that transformers exhibited the highest unavailability among all components due to their long repair durations and significant outage contributions. Fuses and outgoing feeders also recorded relatively high unavailability values because of their frequent failures and prolonged restoration times.

Components such as overcurrent relays, earth-fault relays, switches, and busbars exhibited very low unavailability levels, reflecting their high reliability and maintainability.

The surge arrester recorded negligible unavailability because no failures were observed during the study period.

The unavailability analysis confirms that transformer-related outages contribute most significantly to service interruptions and therefore require targeted maintenance interventions.

4.6 Comparative Reliability Performance of Components

A comparative assessment of all reliability indices indicates that transformers, fuses, outgoing feeders, and switchgear are the most influential components affecting overall substation reliability.

The fuse exhibited the highest failure rate and lowest MTBF, indicating poor reliability performance. However, the transformer emerged as the most critical component because of its exceptionally high MTTR and annual outage contribution.

Outgoing feeders also demonstrated substantial contributions to both outage frequency and outage duration. These components therefore represent major sources of service interruptions experienced by consumers.

On the other hand, surge arresters, protection relays, switches, and busbars demonstrated superior reliability performance characterized by low failure frequencies, high MTBF values, low MTTR values, and high availability.

4.7 Discussion

The results obtained in this study highlight the importance of evaluating both reliability and maintainability parameters when assessing distribution substation performance. Components with high failure frequencies do not necessarily contribute the greatest outage impact; similarly, components with low failure frequencies may significantly affect service continuity if their repair durations are extensive.

The findings reveal that transformers represent the most critical assets within the distribution network due to their substantial outage contributions and prolonged restoration periods. Consequently, transformer condition monitoring, preventive maintenance, and timely replacement strategies are essential for improving overall network reliability.

The high failure rates observed for fuses and outgoing feeders suggest the need for enhanced protection coordination, feeder inspection programs, vegetation management, and fault detection systems. Improving these areas would significantly reduce outage frequency and improve customer service reliability.

Overall, the study demonstrates that reliability assessment based on failure rate, MTBF, MTTR, availability, and unavailability provides valuable information for maintenance planning, asset management, and reliability improvement initiatives. The results provide a strong basis for prioritizing maintenance activities and optimizing resource allocation within distribution substations.

V. Recommendations

Based on the findings obtained from the failure rate analysis, MTBF evaluation, MTTR assessment, availability modeling, and overall reliability assessment of the distribution substation components, the following recommendations are proposed to improve equipment performance, reduce outages, and enhance the reliability of the distribution network.

5.1 Strengthening Preventive Maintenance Programs

A comprehensive preventive maintenance program should be implemented for all critical substation equipment, particularly transformers, switchgear, fuses, and outgoing feeders. Regular inspections, testing, servicing, and replacement of worn-out parts should be conducted to reduce failure frequency and improve equipment reliability.

Preventive maintenance schedules should be based on equipment operating conditions, historical failure records, and manufacturer recommendations to ensure maximum effectiveness.

5.2 Improved Transformer Condition Monitoring

Since transformers recorded the highest outage duration and annual outage contribution, enhanced transformer monitoring techniques should be adopted. Recommended activities include:

1. Dissolved Gas Analysis (DGA).
2. Insulation resistance testing.
3. Transformer oil quality analysis.
4. Thermographic inspection.
5. Load monitoring and balancing.
6. Periodic maintenance of cooling systems.

The adoption of these measures will facilitate early fault detection and minimize transformer-related outages.

5.3 Feeder Reliability Improvement

Outgoing feeders were identified as major contributors to service interruptions. Therefore, utilities should implement feeder reliability improvement programs through:

1. Routine line inspections.
2. Vegetation control and right-of-way management.
3. Replacement of deteriorated conductors.
4. Installation of fault indicators.
5. Feeder sectionalization.
6. Automated fault isolation systems.

These measures will reduce fault occurrence and improve service restoration time.

5.4 Protection System Enhancement

The high failure rate observed in fuses indicates the need for improved protection system performance. Distribution utilities should:

1. Review protection coordination settings regularly.
2. Replace aged protective devices.

3. Upgrade conventional relays to digital relays where necessary.
4. Conduct routine testing and calibration of protection equipment.
5. Investigate recurring protection-related faults.

Proper protection coordination will reduce unnecessary outages and improve network stability.

5.5 Adoption of Condition-Based Maintenance (CBM)

Utilities should complement preventive maintenance with condition-based maintenance techniques. CBM involves monitoring the actual condition of equipment and carrying out maintenance only when required.
Key parameters that should be monitored include:

1. Temperature.
2. Vibration.
3. Insulation condition.
4. Oil quality.
5. Contact resistance.
6. Partial discharge levels.

Condition-based maintenance reduces maintenance costs while improving equipment reliability and availability.

5.6 Reduction of Mean Time To Repair (MTTR)

Since prolonged repair durations contribute significantly to system unavailability, efforts should be made to reduce MTTR through:

1. Availability of spare parts.
2. Improved fault diagnosis procedures.
3. Enhanced maintenance logistics.
4. Adequate maintenance staffing.
5. Specialized technical training.

Reducing MTTR will improve equipment availability and reduce customer outage durations.

5.7 Equipment Rehabilitation and Replacement

Components exhibiting persistent reliability issues should be prioritized for rehabilitation or replacement. Particular attention should be given to:

1. Aging transformers.
2. Obsolete switchgear.
3. Frequently failing fuses.
4. Deteriorated feeder equipment.

Timely replacement of deteriorated assets will reduce failure rates and improve long-term network performance.

5.8 Deployment of Smart Monitoring Technologies

The integration of modern monitoring and control technologies can significantly improve reliability performance. Recommended technologies include:

1. Supervisory Control and Data Acquisition (SCADA).
2. Intelligent Electronic Devices (IEDs).
3. Remote fault monitoring systems.
4. Smart sensors.
5. Automated switching systems.

These technologies facilitate real-time monitoring, faster fault detection, and quicker restoration of service.

5.9 Continuous Reliability Assessment

Distribution utilities should establish a reliability monitoring framework that continuously tracks key reliability indices such as:

1. Failure Rate (λ).
2. Mean Time Between Failures (MTBF).
3. Mean Time To Repair (MTTR).
4. Availability.
5. Unavailability.
6. Annual Outage Time.

Periodic assessment of these indices will support informed maintenance planning and performance improvement initiatives.

5.10 Capacity Building and Technical Training

Regular training should be provided for maintenance personnel, engineers, and system operators on modern reliability analysis techniques, predictive maintenance methods, and advanced diagnostic technologies.
Enhanced technical competence will improve maintenance quality, fault management, and overall system reliability.

5.11 Investment in Distribution Infrastructure

Adequate investment should be made in upgrading and expanding distribution infrastructure to accommodate increasing electricity demand and improve service reliability.
Investments should focus on:

1. Modern transformers.
2. Advanced protection systems.
3. Automated feeder systems.
4. Reliable communication infrastructure.
5. Smart-grid technologies.

Such investments will improve network resilience and reduce the occurrence of equipment failures.

VI. Conclusion

This study presented a comprehensive reliability evaluation of major distribution substation components within the Ikorodu Distribution Network using failure rate, Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), availability, and unavailability indices. The assessment was conducted using historical outage and maintenance records to determine the reliability characteristics and operational performance of critical substation equipment.

The results revealed considerable variations in the reliability performance of the investigated components. Fuses recorded the highest failure rate, indicating their susceptibility to frequent operational disturbances and protection-related faults. Outgoing feeders and switchgear also exhibited relatively high failure frequencies, demonstrating their significant influence on system reliability. Although transformer failures occurred less frequently, transformers recorded the highest repair durations and annual outage contributions, making them the most critical components affecting service continuity.

The MTBF analysis showed that components with lower failure rates generally exhibited longer operating periods between failures, indicating better reliability performance. Surge arresters, protection relays, switches, and busbars demonstrated high reliability characteristics, while fuses and outgoing feeders exhibited lower MTBF values due to frequent failures. Similarly, the MTTR analysis identified transformers as the most maintenance-intensive assets because of the time required for fault diagnosis, repair, and restoration activities.

Availability modeling indicated that most components maintained relatively high operational availability throughout the study period. However, transformers, fuses, and outgoing feeders contributed significantly to overall system unavailability due to their combined failure frequencies and repair durations. These findings demonstrate that both reliability and maintainability characteristics must be considered when evaluating component performance and determining maintenance priorities.

The study further established that failure rate, MTBF, MTTR, availability, and unavailability indices provide valuable tools for assessing equipment performance and identifying weak points within distribution substations. The results clearly indicate that transformers, outgoing feeders, switchgear, and fuses require priority attention in maintenance planning and asset management programs due to their substantial impact on system reliability.

Overall, the study confirms that effective reliability assessment can support informed decision-making, optimize maintenance resource allocation, and enhance electricity service delivery. The implementation of preventive maintenance programs, condition-based monitoring techniques, improved protection coordination, and timely asset replacement strategies will significantly improve equipment performance and reduce service interruptions.

The findings of this research provide useful information for distribution utility operators, maintenance engineers, asset managers, and policymakers seeking to improve the reliability and availability of electricity distribution systems in Nigeria. By adopting the recommended reliability improvement measures, utilities can achieve reduced outage frequency, shorter restoration times, increased equipment availability, and improved customer satisfaction.

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