Umahon Ovbiagele[1],

Odiase Friday[2],

H. E. Amhenrior[3]

Quantifying Seasonal Impacts on Distribution Network Reliability: A Statistical Analysis of Outage Frequency in the Auchi 11 kV Feeders, Nigeria

Journal of Electrical Systems

Abstract: - This study provides an empirical analysis of the impact of seasonal climate variability on power supply outage frequency within the Auchi distribution network, Edo State, Nigeria. Employing a quantitative research design, we analyzed historical outage data (2021-2023) for three key feeders—Auchi Town, Jattu, and Auchi GRA—sourced from the Benin Electricity Distribution Company (BEDC). Outages were classified by fault type and season (wet: April-October; dry: November-March). Descriptive statistics and a Chi-square test for independence were applied to the outage counts. The analysis reveals a statistically significant dominance of wet-season outages, with 63.8% of all outages occurring in this period, compared to 36.2% in the dry season ($\chi^2 = 81.0$, $p < .001$). Weather-sensitive faults exhibited dramatic seasonal variation; for instance, Earth Faults were 4.2 times more frequent network-wide during the wet season. Notably, Load Shedding, the most common fault type, also peaked in the wet season, suggesting indirect climate impacts on generation and transmission. The findings underscore the acute vulnerability of the network to wet-season conditions and highlight the imperative for pre-emptive, climate-resilient infrastructure upgrades and seasonally-targeted maintenance strategies to enhance reliability.

Keywords: Climate-resilient infrastructure upgrades; Distribution network reliability; Outage frequency analysis; Seasonal climate variability; Wet-season network vulnerability

1. Introduction

The reliability of electricity supply is a cornerstone of economic development and social well-being. In Nigeria, the power sector faces profound challenges, with frequent and prolonged outages significantly impeding national growth (Adewale et al., 2022). While the unreliability of the Nigerian grid is widely acknowledged, a critical gap exists in location-specific, quantitative analyses that statistically link seasonal climate variations to outage patterns at the distribution feeder level—the most direct point of contact with consumers.

The Auchi distribution network, operated by the Benin Electricity Distribution Company (BEDC) in Edo State, serves as a pertinent case study. The literature broadly identifies seasonal weather—including heavy rainfall, lightning, and high winds—as a primary stressor on distribution infrastructure (Omoroghomwan & Oyedoh, 2023). In Nigeria, these climatic effects are compounded by systemic vulnerabilities, notably an aging asset base, overloaded transformers, and inadequate vegetation management, which collectively degrade network resilience (Onime & Adegboyega, 2014; Onuoha, 2012). Globally, benchmarks such as the IEEE Standard 1366 provide frameworks for assessing reliability, against which the performance of networks like Auchi's is orders of magnitude worse. Although studies like Folarin et al. (2017) and Haroun et al. (2020) have established a general link between seasonality and outages in similar contexts, they often lack rigorous, feeder-level statistical validation and do not delve into the specific fault mechanisms driven by local climate and infrastructure conditions.

This study addresses this gap by conducting an empirical, data-driven analysis of outage frequency in the Auchi network. It moves beyond descriptive counts to statistically test the hypothesis that seasonal climate variability significantly influences outage occurrence. By analyzing three years of historical data from three distinct feeders, this research aims to:

- Quantify the disparity in outage frequency between wet and dry seasons.

[1] [1,3] Department of Electrical and Electronic Engineering, Edo University, Iyamho, Edo State, Nigeria.
[2] Department of Electrical and Electronic Engineering, University of Benin, Benin, Edo State, Nigeria.
Corresponding Author:
Umahon Ovbiagele
Email: ovbiagelehapiness@gmail.com

- Identify which fault types are most sensitive to seasonal changes.
- Provide statistically validated evidence to inform targeted, cost-effective maintenance and climate resilience strategies for utility managers.

2. Methodology

2.1 Research Design and Data Source

A quantitative research design was employed for this study. Historical outage records spanning January 2021 to December 2023 for three critical 11 kV feeders—Auchi Town, Jattu, and Auchi GRA—were obtained from the Auchi service station of the Benin Electricity Distribution Company (BEDC).

2.2 Data Collection and Processing

The raw data was extracted from BEDC's operational logbooks, which recorded the date, feeder name, and cause for each outage event. To ensure data integrity and consistency for analysis, a rigorous cleaning and validation process was implemented using Microsoft Excel. This process involved:

- Data Cleaning: Removing duplicate entries, correcting obvious typographical errors in fault descriptions, and standardizing feeder name spellings.
- Validation: Cross-referencing outage dates and durations with monthly operational reports to identify and rectify any major discrepancies or missing data points. Less than 2% of records were excluded due to irreconcilable inconsistencies.
- Structuring: The final, cleaned dataset consisted of outage frequency counts—specifically, the number of occurrences of each fault type per feeder per season.

2.3 Data Classification

The processed data underwent a two-stage classification:

- Fault Typology: Each outage was categorized into one of seven mutually exclusive fault types based on the standardized BEDC logs: (1) Load Shedding, (2) Earth Fault, (3) Overcurrent, (4) Ruptured Fuse Cut-Out, (5) Jumper/Wire Cut, (6) Broken Cross Arm, and (7) Maintenance/Repair.
- Seasonal Grouping: Outages were grouped into two climatic seasons defined for Edo State, Nigeria: The Wet Season (April to October) and the Dry Season (November to March). This aggregation resulted in seasonal fault frequency tables for each feeder.

2.4 Data Analysis Techniques

The analysis was conducted using MATLAB R2023a. The following techniques were employed:

- Descriptive Analysis: Frequencies and percentages were calculated to summarize the seasonal distribution of outages. Wet-to-dry season ratios were computed for key weather-sensitive fault types (e.g., Earth Faults) to quantify the magnitude of seasonal impact.
- Chi-square Test for Independence: A Chi-square test was performed to determine if a statistically significant association existed between the season (wet vs. dry) and the occurrence of outages. The test was applied to the aggregated contingency table of all feeders. The test statistic is given by Equation (1):

  $$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \qquad (1)$$

  where O_i is the observed frequency and E_i is the expected frequency under the null hypothesis of no seasonal association.

3. Results and Analysis

3.1 Descriptive Analysis of Outage Frequency

The seasonal outage frequency data for each feeder over the three-year study period is detailed in Tables 1, 2, and 3. A consistent and clear pattern emerges, showing a substantially higher number of outages during the wet season across all three feeders.

Table 1: Outage Frequency in Auchi Town Feeder (2021–2023)

Fault Type	Wet Season	Dry Season	3-Year Total
Load Shedding	1043	608	1651
Earth Fault	101	32	133
Overcurrent	98	39	137
Ruptured Fuse Cut-Out	70	58	128
Jumper/Wire Cut	2	5	7
Broken/Cross Arm	3	0	3
Maintenance/Repair	3	1	4
Grand Total	1320 (64.0%)	743 (36.0%)	2063

Note: This table presents summarized seasonal fault frequencies derived from raw BEDC outage logs.

Table 2: Outage Frequency in Jattu Feeder (2021–2023)

Fault Type	Wet Season	Dry Season	3-Year Total
Load Shedding	996	603	1599
Earth Fault	84	25	109
Overcurrent	83	39	122
Ruptured Fuse Cut-Out	74	55	129
Jumper/Wire Cut	2	2	4
Broken/Cross Arm	2	1	3
Maintenance/Repair	2	1	3
Grand Total	1243 (63.1%)	726 (36.9%)	1969

Note: This table presents summarized seasonal fault frequencies derived from raw BEDC outage logs

Table 3: Outage Frequency in Auchi GRA Feeder (2021–2023)

Fault Type	Wet Season	Dry Season	3-Year Total
Load Shedding	1266	749	2015
Earth Fault	119	16	135
Overcurrent	80	53	133
Ruptured Fuse Cut-Out	111	56	167
Jumper/Wire Cut	9	3	12
Broken/Cross Arm	0	4	4
Maintenance/Repair	2	1	3
Grand Total	1587 (64.3%)	882 (35.7%)	2469

Note: This table presents summarized seasonal fault frequencies derived from raw BEDC outage logs

A consistent and clear pattern emerges, showing a substantially higher number of outages during the wet season across all three feeders.

3.2 Network-Wide Seasonal Pattern and Statistical Significance

Aggregating data from all feeders yielded a total of 6,501 outages. Of these, 4,150 (63.8%) occurred in the wet season, compared to 2,351 (36.2%) in the dry season. A Chi-square test for independence was conducted to determine if this disparity was statistically significant. The test accounted for the different number of days in each season over the 1094-day study period (638 wet season days vs. 456 dry season days).

The expected frequencies, assuming no seasonal effect, were 3,792.2 for the wet season and 2,708.8 for the dry season. The comparison with observed frequencies (Wet: 4,150; Dry: 2,351) yielded a highly significant result, $\chi^2(1, N = 6501) = 81.0$, $p < .001$. This confirms a statistically significant association between the season and the occurrence of outages across the Auchi network.

3.3 Analysis of Weather-Sensitive and Prevalent Faults

The analysis revealed dramatic seasonal variation in specific fault types, particularly those sensitive to weather:

- Earth Faults: Exhibited the most pronounced seasonal effect. They were 3.2 times more frequent in the wet season on the Auchi Town feeder, 3.4 times on the Jattu feeder, and 7.4 times on the Auchi GRA feeder. Network-wide, Earth Faults occurred 4.2 times more often in the wet season (304 vs. 73).
- Load Shedding: This was the most prevalent fault category across all feeders. Crucially, it also demonstrated a strong seasonal pattern, consistently peaking during the wet season (see Tables 1-3).
- Other Faults: Faults such as Ruptured Fuse Cut-Out and Overcurrent also showed notable wet-season increases, suggesting they may be secondary consequences of weather-induced stress on the network.

4. Discussion

This study provides robust empirical evidence that the Auchi distribution network is significantly less reliable during the wet season, with outage frequency 1.76 times higher (63.8% vs. 36.2%) than in the dry season. This systematic pattern, confirmed by a highly significant Chi-square test ($p < .001$), underscores the profound impact of seasonal climate variability on power supply reliability. When viewed against international benchmarks like the IEEE 1366 standard, which assumes near-continuous availability, the network's performance highlights a critical infrastructure deficit.

The extreme wet-season sensitivity of Earth Faults (4.2 times higher network-wide) is a direct consequence of environmental conditions. As established in the literature, high humidity, persistent rainfall, and lightning strikes degrade insulation, increase tracking across polluted insulator surfaces, and cause flashovers (Haroun et al., 2020; Omoroghomwan & Oyedoh, 2023). These effects are severely exacerbated by the underlying systemic vulnerabilities of the Nigerian grid, including an aging asset base, inadequate corrosion protection, and overloaded components, which reduce the infrastructure's inherent resilience to weather stress (Onime & Adegboyega, 2014; Onuoha, 2012).

A pivotal finding is the seasonal peak of Load Shedding. Typically categorized as an operational or non-technical issue, its consistent increase during the wet season points to an indirect climate linkage. We posit that this is primarily due to faults on the upstream transmission network—which is equally, if not more, vulnerable to the same wet-season conditions—causing supply shortages that manifest as load shedding at the distribution level. This indicates that climate resilience efforts must extend beyond the distribution feeders to encompass the entire power supply chain.

5. Recommendations

Moving beyond generic maintenance advice, our findings dictate specific, actionable interventions:

- Pre-emptive, Season-Targeted Hardening: A rigorous pre-wet season program is essential. This should include aggressive vegetation management to prevent contact with lines, diagnostic testing of insulation resistance on feeders and transformers, and tightening of connections to prevent fuse ruptures from thermal cycling.
- Deployment of Adaptive Protection: Feeders with high fault frequencies, like Jattu, would benefit from installing auto-reclosers. These devices can automatically restore power after transient faults (e.g., momentary vegetation contact), drastically improving customer-level reliability indices like SAIFI and SAIDI.
- Strategic Infrastructure Modernization: Long-term planning must prioritize replacing aged and under-rated conductors, installing lightning arresters at critical points, and, where feasible, piloting underground cabling for the most sensitive sections of the network. This shifts the paradigm from reactive repair to proactive climate resilience.

6. Conclusion

This study has quantitatively established that seasonal climate variability is a primary determinant of power supply reliability in the Auchi distribution network. The analysis of three years of empirical data conclusively demonstrates a significant wet-season increase in outage frequency, with 63.8% of all outages occurring in this period ($\chi^2 = 81.0$, $p < .001$). The results pinpoint Earth Faults as the most climate-sensitive issue, being over four times more frequent network-wide during the wet season, directly implicating environmental moisture and lightning. Furthermore, the seasonal peak in Load Shedding reveals that climate impacts permeate the entire power value chain, from generation and transmission down to the distribution feeders.

The core conclusion is that the Auchi network's reliability is intrinsically linked to its climatic environment, a vulnerability amplified by underlying infrastructure weaknesses. Therefore, enhancing reliability is contingent upon building systemic climate resilience. This study underscores the necessity of moving beyond reactive repairs to a strategy of pre-emptive, data-driven intervention. The recommendations outlined—including season-targeted grid hardening, the use of auto-reclosers, and strategic modernization—provide a concrete roadmap for utility managers.

References

[1] Adewale, A., Bankole, A. B., & Fasina, T. (2022). Assessment of secondary feeders' reliability in Nigeria: A case of Ado-Ekiti metropolis distribution network. *European Journal of Electrical Engineering and Computer Science*, 6(4), 1–9.

[2] Folarin, D. A., Sakala, J. D., Matlotse, E., & Gasennelwe-Jeffrey, M. A. (2017). Appraisal of electric power distribution feeders' reliability in the region unit in Nigeria. *International Journal of Engineering Research & Technology (IJERT)*, 6(10), 1–8.

[3] Haroun, F. M. E., Deros, S. N. M., & Din, N. M. (2020). A review of vegetation encroachment detection in power transmission lines using optical sensing satellite imagery. *Journal of Engineering and Technological Sciences*, 52(5), 706–723.

[4] *IEEE Standard 1366-2022*. (2022). IEEE Standard for Distribution Reliability Indices. IEEE.

[5] Omoroghomwan, E. A., & Oyedoh, O. M. (2023). Modeling the impact of rainfall on power outages in Nigeria. *Journal of the Nigerian Association of Mathematical Physics*, 64, 289–296.

[6] Onime, F., & Adegboyega, G. A. (2014). Reliability analysis of power distribution system in Nigeria: A case study of Ekpoma network, Edo State. *International Journal of Electronics and Electrical Engineering*, 2(3), 227–231.

[7] Onuoha, K. C. (2012). The electricity industry in Nigeria: What are the challenges and options available to improve the sector? *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2157694