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Analysis of Oria Abraka 33/11 kV Power Sub-Station: A Case for Sustainable Power Supply

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Abstract

Frequent power outages in Nigeria's distribution network continue to hinder economic growth and industrial productivity. This study evaluates the reliability and performance of the Oria Abraka 33/11 kV substation in Delta State, Nigeria, to analyze power availability trends and propose improvement strategies. Daily power data, including power delivery, electric current, and outage hours, were obtained from the Benin Electricity Distribution Company (BEDC) for 2017–2022 and analyzed using Microsoft Excel for trend assessment and Python for power flow visualization. Findings reveal that power availability remains critically low, with January 2020 recording the highest monthly supply (207 hours, 6.68 hours per day), while 2022 had the highest annual power availability (1678 hours, 19.2%), reflecting persistent supply inadequacies. The total monthly available power peaked at 147.9 MW in December 2022, but yearly current delivery declined from 13,783 A in 2017 to 12,478 A in 2021, suggesting infrastructural constraints or load shedding. Fault Tree Analysis (FTA) identified key outage contributors, including transformer overloading, delayed switching, and high transmission losses, while power flow analysis highlighted voltage drops exceeding 43.3 V under peak loads. Unlike broader grid-wide studies, this research applies quantitative fault and power flow assessments at the substation level, revealing inefficiencies such as overloaded conductors, excessive power dissipation (0.5 MW loss at peak current), and prolonged restoration times (CAIDI: 28.31 hours). A comparative analysis with substations like Ugbowo 33/11 kV (Nigeria) and UK networks underscores the need for predictive maintenance, transformer capacity upgrades, and smart grid integration. These findings provide actionable insights for utilities, policymakers, and regulators to enhance power reliability across Nigeria and similar developing regions.

1. Introduction

Electricity supply is a basic necessity for the growth of the local economy, a good standard of living, and the social development of society. Issues surrounding electricity generation and distribution should be effectively tackled so that electricity can be supplied to consumers without fail. For electricity to reach the final consumer, it must be generated, transmitted, and distributed using an electric power system [1]. The disruptions encountered as the electrical system delivers electricity to consumers impact the reliability and availability of the system. Aside from interruptions in electricity supply, other concerns include the quality of electricity delivered, including the system's capacity to continuously deliver power at the expected quality to consumers. The goal is to ensure consumer satisfaction while enabling business owners to achieve a return on investment in the shortest possible time. This implies that irrespective of the power generated, without consumers, there is no business in the system, and investors would make no profit. However, care should be taken with regard to overloading an electrical power system, as it leads to disruption and failure of the system [2]. Generation, transmission, and distribution are the three major subsystems of an electrical power system. At the generation station, electricity is produced and stepped up to high voltage before being transmitted to various distribution stations [3, 4]. Thereafter, the distribution stations step down the electricity supply to lower voltage at the substations before distribution to consumers. In Nigeria, the transmission line transmits at **330/132 kV** to distribution stations. Distribution stations step down the received power to **33/11 kV** at substations before further reducing to **415 V** for end users. Figure 1 shows the network layout of the Oria Abraka 33/11 kV feeder**.** Substations are usually situated near consumers **to ensure** effective delivery, maintenance, and monitoring. Basically, substations act as secondary distribution systems, serving as the interface between distribution companies and end users**.** Safe and reliable power supply from these substations is crucial**, yet,** as population and demand increase, overloading becomes inevitable **[5, 6].** Overloading of substations results from increasing consumer demand, mostly due to urban migration and improved lifestyles**,** leading to higher energy consumption. For example, as rural areas transition into suburban regions, electricity demand rises, impacting distribution lines and causing insulation breakdown, voltage imbalance, and unplanned outages [7]. Apart from overloading, power reliability also depends on supply shocks, aging infrastructure, and inadequate capacity upgrades**.**

The Oria Abraka 33/11 kV power substation was selected for this study because it represents a critical distribution hub in Delta State, Nigeria, supplying power to residential, commercial, and industrial consumers. This substation has faced recurrent power outages and load management issues, making it a representative case for studying distribution network inefficiencies in Nigeria. While not the worst-performing substation in the country, its supply inadequacies and declining current capacity highlight common grid reliability challenges in semi-urban and urbanizing regions. Studying Oria Abraka provides valuable insights into localized power distribution constraints, making the findings applicable to other substations facing similar challenges. Nigeria's power sector is characterized by insufficient generation capacity, weak transmission infrastructure, and distribution inefficiencies, resulting in frequent blackouts and low power availability. The country generates approximately 4,000–5,000 MW for a population exceeding 200 million, leading to widespread load shedding, voltage fluctuations, and extended outages. While transmission constraints limit bulk power delivery, distribution substations play a crucial role in ensuring last-mile connectivity to consumers [8]. This study aligns with Nigeria's broader power distribution challenges by examining how substation-level inefficiencies contribute to unreliable electricity supply. The findings provide a micro-level perspective on load distribution, power availability, and outage management, offering data-driven recommendations that can be applied to other substations across Nigeria and similar developing regions. Addressing these inefficiencies is vital for improving energy reliability, supporting industrial productivity, and fostering economic growth [9]. This carries out a quantitative analysis of the available power, outage hours, and loading trends of the Oria Abraka 33/11 kV feeder substation. Using data from 2017 to 2022, the study evaluates power availability trends, highlights existing problems, and proposes improvement strategies. Figure 1 illustrates the layout of the substation, which serves as the focal point for assessing power distribution reliability in the region. Addressing these challenges is crucial, as serious load variations trigger over-voltage, leading to total shutdowns due to system protection failures in industries and other users [10].

2. Methodology

2.1 Data Collection and Processing

The dataset used in this study was obtained from the Benin Electricity Distribution Company (BEDC), which provided operational records of the Oria Abraka 33/11 kV feeder substation spanning six years, from 2017 to 2022. The collected data included records of power availability in hours, total outage durations, the supplied power in megawatts (MW), and the feeder current in amperes (A). These variables were crucial in assessing power reliability and supply trends. Data collection relied on BEDC's daily logs, which recorded feeder activity, enabling an in-depth analysis of power distribution patterns.

To ensure accuracy, data processing was carried out using Microsoft Excel, where the raw data was structured, missing values were identified, and anomalies were flagged for correction. Data inconsistencies, such as negative power availability values or sudden spikes in feeder current, were addressed by cross-verifying logs with consumer reports and recorded maintenance activities. Any missing values in the dataset were interpolated where possible, ensuring consistency and reducing the risk of misinterpretation. Errors in voltage and current readings were reviewed manually, and necessary adjustments were made to align the data with known substation operational trends. The cleaned dataset was then formatted for further analysis, allowing for a comprehensive evaluation of reliability trends and outage patterns.

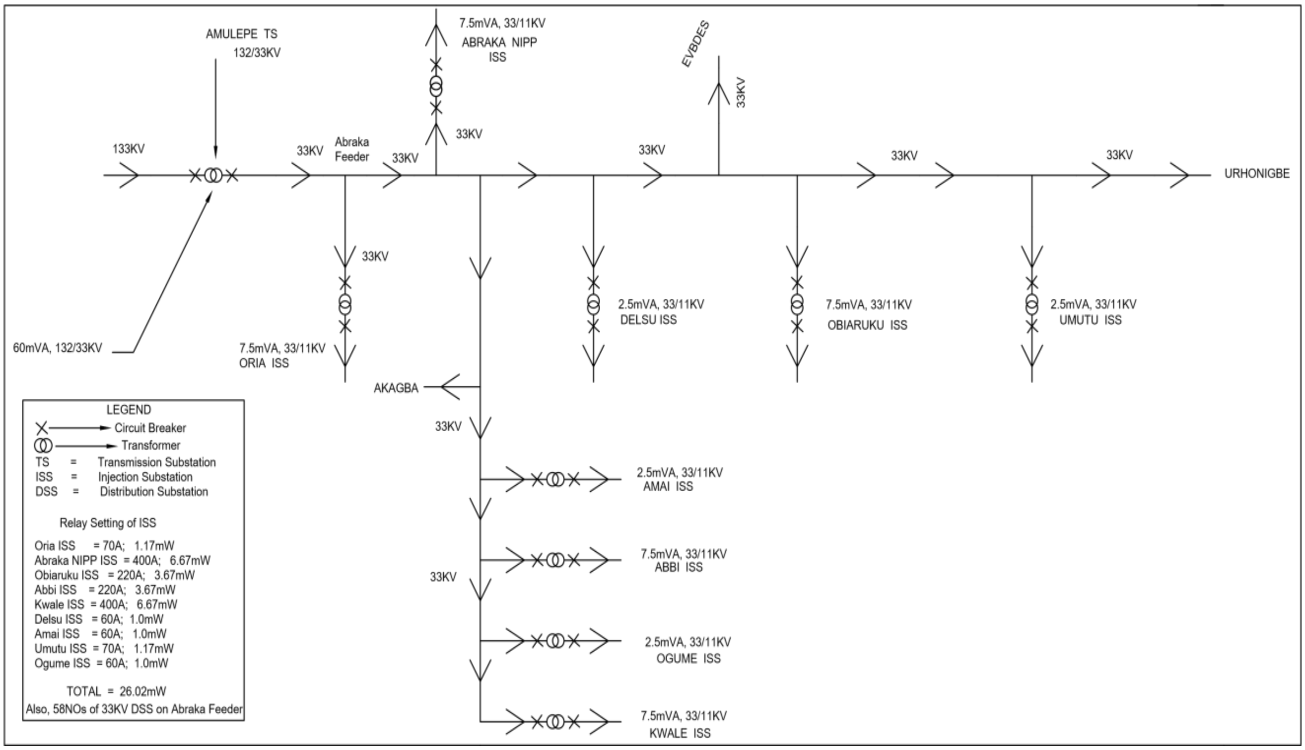

Figure 1: Layout network which includes Oria-Abraka 11kV Feeder

2.2 Power Supply and Load Trend Analysis

To analyze power availability at the Oria Abraka feeder, the total duration of power supply was computed by summing the daily hours during which the feeder was active for each month. This approach provided insight into how consistently the feeder received power and highlighted fluctuations in supply stability. The analysis also considered the number of days per month when the feeder experienced complete outages, offering a clearer understanding of supply reliability. The months with the most frequent outages were identified, revealing seasonal and operational trends in power distribution reliability. The total supplied power was analyzed by aggregating daily power values in megawatts to determine monthly and yearly supply trends. By computing these values, it was possible to evaluate whether supply levels improved or worsened over time. Additionally, an assessment of feeder loading was conducted by examining the total amperes drawn from the feeder**.** The variations in current flow across different periods provided an indication of whether the substation faced overload conditions or operated within stable limits.

Key calculations included:

$$\textbf{Monthly Power Availability } (\textbf{hours/month}) = \sum(\textbf{Daily power supply hours}) \quad (1)$$

$$\textbf{Percentage Power Availability } (\%) = (\textbf{Total available hours per year/Total hours in a year}) \times 100 \quad (2)$$

$$\textbf{Total Monthly Available Power } (\textbf{MW}) = \sum(\textbf{Daily MW supplied when power was available}) \quad (3)$$

$$\textbf{Average Current Load } (\textbf{A}) = \sum(\textbf{Daily current readings}) \;/\; \textbf{Number of days with supply} \quad (4)$$

These calculations provided a quantitative basis for evaluating power supply consistency and the operational performance of the 33/11 kV feeder.

Data visualization was primarily conducted in Excel, where supply trends were plotted to identify patterns in power availability and load fluctuations. Monthly and yearly variations in power input, outage duration, and feeder current were represented graphically, making it easier to interpret supply dynamics. The visual analysis facilitated the identification of anomalies, trends, and areas requiring further investigation.

2.3 Fault Tree Analysis for Power Reliability Assessment

To investigate the underlying causes of power outages, a Fault Tree Analysis (FTA) was conducted, which mapped out failure pathways within the distribution network. The analysis categorized power outages based on three main contributing factors: technical failures, operational inefficiencies, and external influences. Transformer overloading, voltage fluctuations, and recurrent cable faults were identified as key technical challenges that caused unexpected feeder trips and prolonged downtimes. Operational inefficiencies, including delayed switching operations, inadequate maintenance schedules, and excessive feeder loading**,** were observed to exacerbate reliability issues. External influences such as severe weather conditions, unauthorized power tapping, and upstream grid failures further complicated power availability, often leading to extended periods of supply interruptions.

The fault tree model helped to visualize how each of these factors interacted to affect the overall reliability of the Oria Abraka feeder. The analysis revealed that a combination of these failure modes significantly impacted supply consistency. The findings from this assessment informed the need for reliability improvements through enhanced maintenance practices, better load balancing, and mitigation strategies for external disruptions.

2.4 Reliability Assessment Metrics

To quantify the reliability of power supply at the Oria Abraka substation**,** key industry-standard performance metrics were computed, including System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI)**.** These indices provided an objective measure of the average duration, frequency, and impact of power interruptions on consumers. SAIDI measured the total duration of outages experienced by consumers in a year, while SAIFI captured the average number of interruptions per consumer over the same period. CAIDI was derived by dividing SAIDI by SAIFI, providing insight into the average restoration time for each outage event. The computation of these indices was performed using Microsoft Excel, where outage data was aggregated and structured into yearly reliability trends.

The reliability metrics were calculated as follows:

$$\mathbf{SAIDI}\ \left(\mathbf{hrs/year}\right)=\left(\mathbf{Total\ outage\ hours\ per\ year}\right)\ /\ \left(\mathbf{Total\ connected\ customers}\right) \tag{5}$$

$$\mathbf{SAIFI}\ \left(\mathbf{interruptions/year}\right)=\left(\mathbf{Total\ number\ of\ interruptions}\right)\ /\ \left(\mathbf{Total\ connected\ customers}\right) \tag{6}$$

$$\mathbf{CAIDI}\ \left(\mathbf{hrs/interruption}\right)=\mathbf{SAIDI}\ /\ \mathbf{SAIFI} \tag{7}$$

The results of these calculations were used to compare the Oria Abraka feeder against national and international benchmarks, providing a broader perspective on its reliability standing. The analysis helped to quantify the extent of service disruptions and informed recommendations for improving substation reliability.

2.5 Power Flow Analysis

The power flow analysis of the Oria Abraka 33/11 kV feeder was conducted to examine voltage stability, current loading, and energy losses across the distribution network. This assessment was critical in understanding how effectively power was transmitted and whether inefficiencies existed within the system. The study specifically evaluated voltage drop distribution, analyzing variations in voltage levels across different sections of the feeder. By identifying points where voltage dropped significantly, it was possible to determine areas experiencing excessive resistive losses, which could contribute to supply inconsistencies.

The relationship between power loss and line current was also examined, with trends in energy dissipation evaluated under different load conditions. The correlation between voltage drop and current flow provided insight into how system stress influenced power quality. These analyses were conducted using Python**,** where scatter plots and trend graphs were generated to visualize the extent of voltage deviations and power losses. The visualization of voltage stability and current variations enabled a clearer understanding of operational constraints within the substation and highlighted areas requiring intervention.

The power flow analysis confirmed that during peak demand periods, voltage drops became more pronounced, leading to unstable power supply conditions**.** The findings demonstrated that overloaded conductors, aging infrastructure, and imbalanced load distribution were significant contributors to power losses. This assessment provided valuable insights into the performance of the feeder and underscored the need for enhanced voltage regulation strategies, transformer load balancing, and improved distribution line efficiency**.**

3. Results and Discussion

3.1. Power Availability and Load Analysis

This section presents and discusses results obtained from the power supply analysis of the Oria Abraka 33/11 KV feeder substation. Figure 2 shows the total monthly duration in hours, that the feeder received power, from 2017 to 2022. This was estimated by summing the total number of hours that the feeder was supplied with power for the month. The daily hours of power supply to the feeder were added to obtain the total monthly hours that the feeder was fed with power. This is taken as input into the feeder. It gives an indication of the total duration that the 33/11kV feeder was fed with power from the 132/33kV line. It should be noted that there were several days during the month that there was no supply to the feeder, see Figure 3.

Figure 3 helps to visualize the total duration (days) within the month, that there was no power supply to the 33/11kV feeder. Figure 3 helps to capture days for which there was zero power supply to the feeder throughout the day. The months of March, May, August, September and November showed a high number of days of complete power outage for most of the years considered.

All the years under consideration showed very low total hours (< 208 hours) of available power per month. The highest available supply duration (207.9 hours) to the feeder was obtained in January 2020 and this translates to a daily average of 6.68 hours. This implies the feeder gets an average of less than 7 hours daily power supply throughout the time horizon. For the same month of January 2020 which was the highest available supply duration for the entire period considered, the percentage of time power was available on a monthly average was 27.9%. This is clearly a high level of unavailability of the power supply system as the absence of power to the feeder implies there is no possibility of power supply from the feeder to the feeder outlets during such outages.

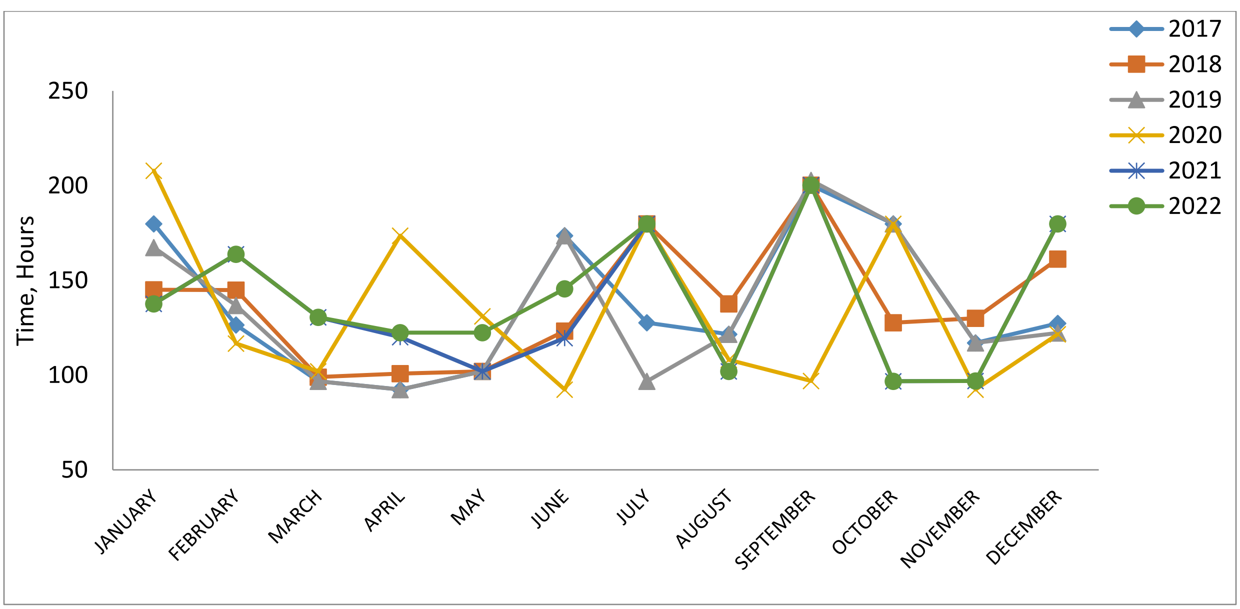

Figure 2: Total monthly available power duration (Hours) from 2017 to 2022

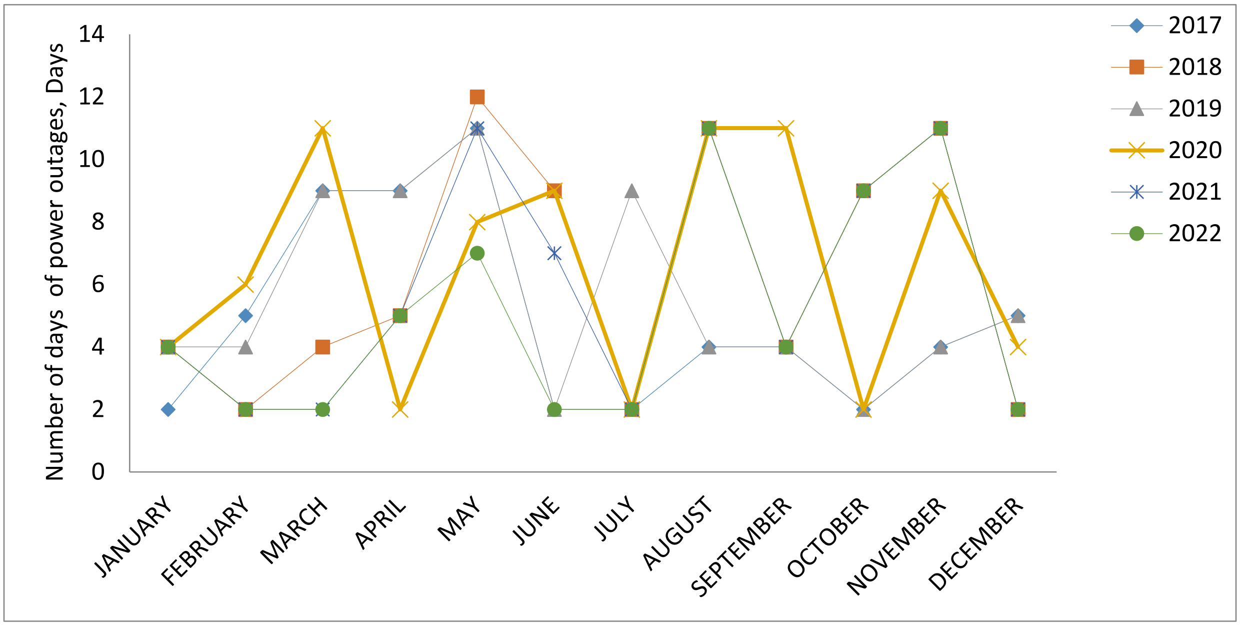

Fig 3: Number of days of power outages per month from 2017 to 2022

Figure 4 shows the total Monthly available power at the feeder when it was being supplied with power for the year 2017 to 2022. This was estimated by summing for the entire month, the total number of daily power available (in MW) when the feeder was supplied with power. This is taken as input into the feeder. It is an estimate of the power capacity fed into and available at the feeder during the month. For the entire period under consideration, the highest total monthly available power of 147.9MW was obtained in December 2022. This translates to a total daily average available power of 4.77MW. This is the best estimate of the average power available at the feeder, daily, when it receives power. In essence, the average power available is much smaller since the highest value for the month of December 2022 has been used to arrive at the estimated value of 4.77MW.

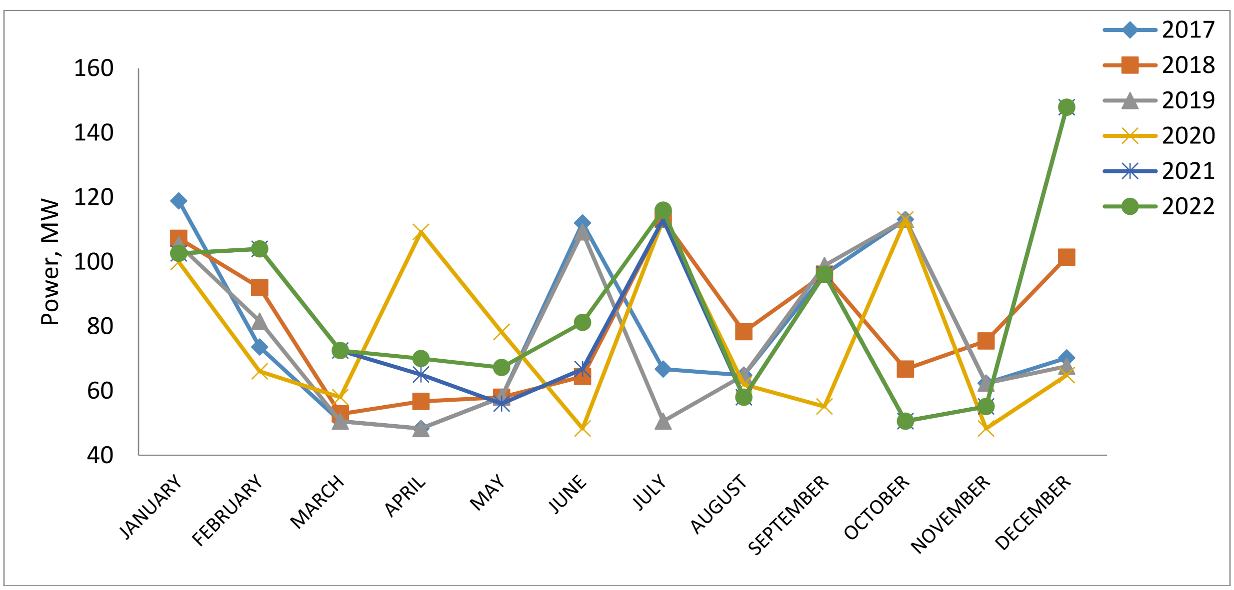

Figure 4: Total monthly available power for the year 2017 to 2022

Figure 5 shows the total monthly amperes delivered by the feeder to its outlets for the years under consideration. For all the years considered the range of the total monthly amperes drawn from the feeder is 921.9 A to 1406.5A. This is an indication of the loading of the feeder. Coincidentally, these two extreme values were obtained in the months of April and January, respectively, of the same year (2018) and this translates to a daily average of 30.73A (minimum) and 45.37A (Maximum). Figure 6 shows the yearly average of the available power duration supplied to the feeder in hours. The graph shows a sharp decline for the years 2019 and 2020 after which it experienced an increase in the years 2021 and 2022. Figure 6 helps us visualize the total hours in the year when power is supplied to the 33/11KV feeder. It can clearly be seen that for all the years considered, power availability is very low. Using the highest figure obtained (1678 hours), which is for the year 2022, the percentage time power is supplied to the 33/11KV feeder is estimated at 19.2%. This is a very low value calling for serious measures to be put in place to improve on the reliability of the supply.

Figure 7 shows the available power in MW at the feeder for the years considered. Figure 7 shows a similar trend to that of Figure 6. This is reasonable as there is a strong correlation between duration when power is supplied to the feeder and the power available at the feeder for the period studied. Figure 8 shows the total yearly amperes drawn from the 33/11KV feeder. This graph shows a sharp contrast from the graph of Figure 6 and Figure 7. The total yearly current (amperes) being drawn from the feeder was declining over the years considered showing the lowest value in 2021 (12478.3A for the entire year). Amperes drawn from the feeder is declining despite increasing population. This could be the results of load shedding due to faults at the 415 distribution lines which forces some units to be cut off from supply despite power being available at the 33/11KV feeder. However more data at the 415 V distribution network is needed to come to a good conclusion on this.

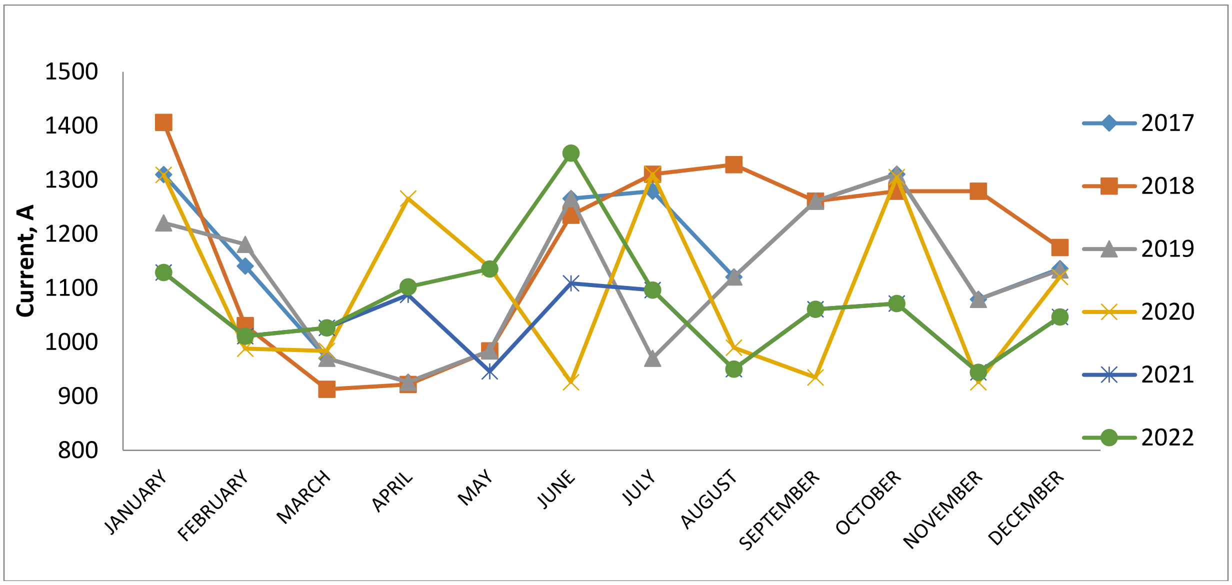

Figure 5: Total monthly current delivered by the feeder

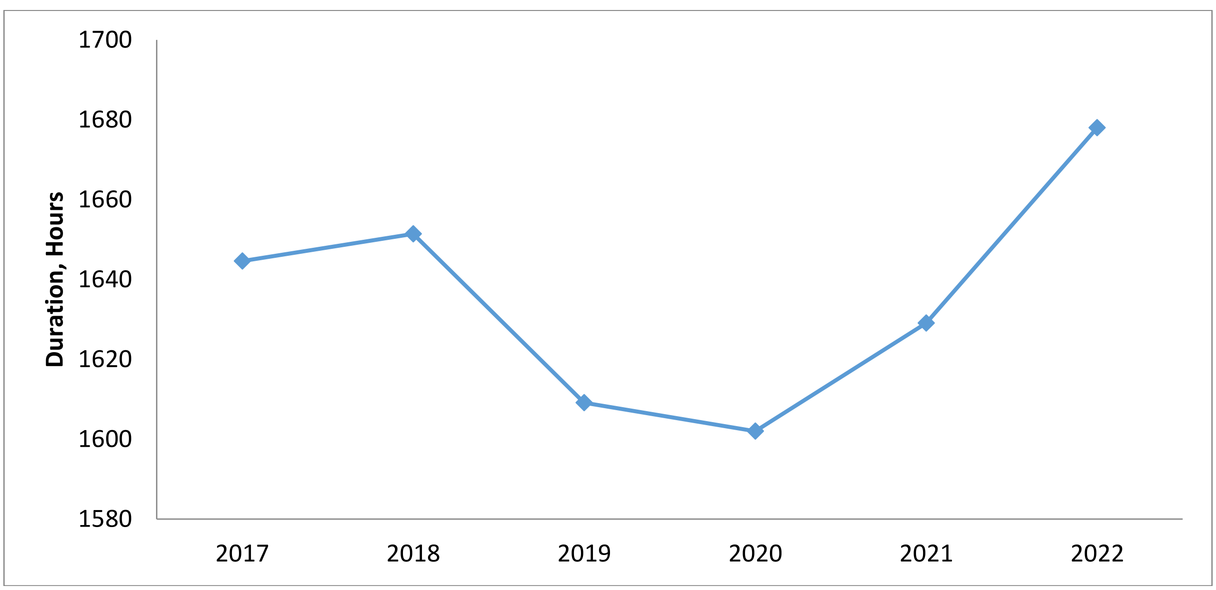

Figure 6: Total Yearly Available Power Duration (Hours)

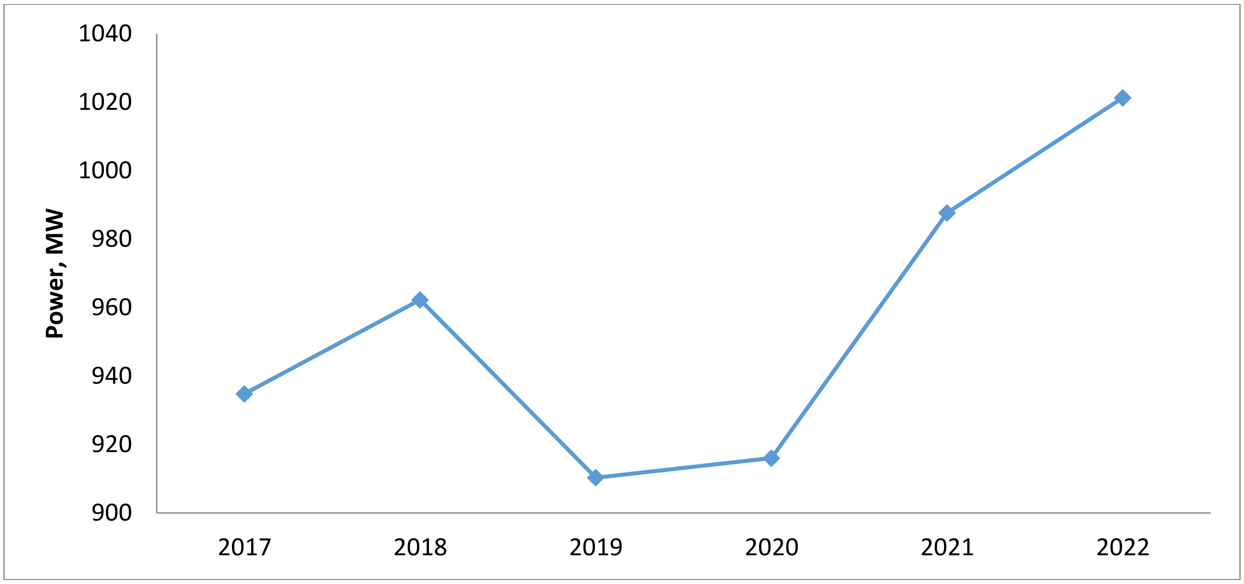

Figure 7: Total yearly available power at the feeder

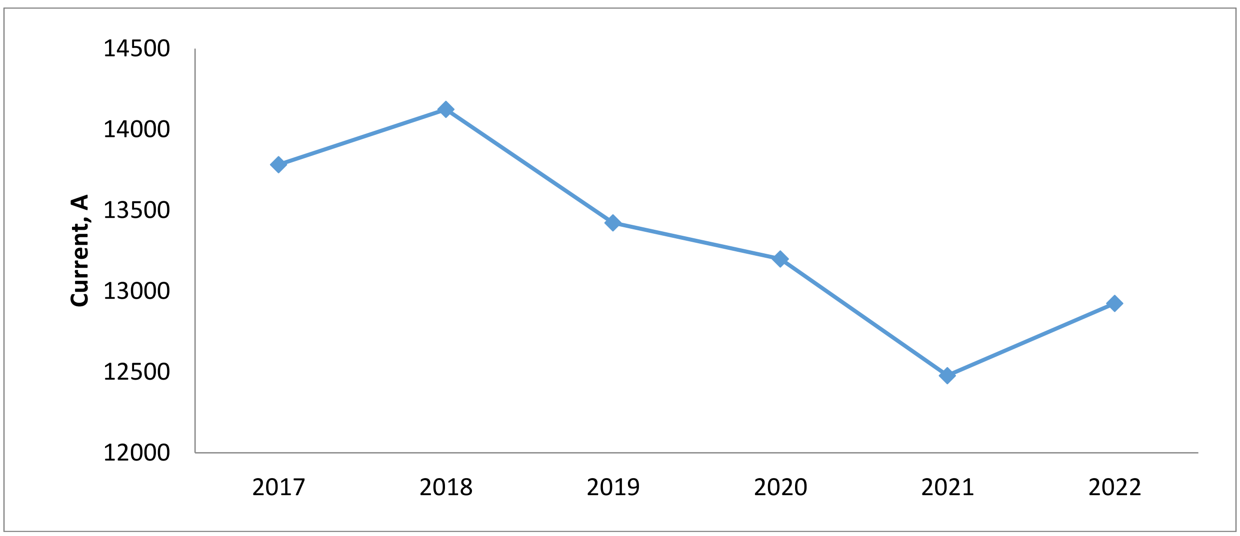

Figure 8: Total yearly current in ampere

3.2 Fault Tree Analysis of Power Outages

To identify the root causes of power outages at the Oria Abraka 33/11 kV substation, a Fault Tree Analysis (FTA) was conducted. The results revealed that outages arise from three primary categories: technical failures, operational inefficiencies, and external factors.

The most frequent technical issues include transformer overloading, voltage fluctuations, and cable faults. These failures result in unplanned power trips and excessive downtime, significantly affecting service reliability. Operational Inefficiencies like Poor maintenance schedules, delayed switching operations, and overloaded feeders further contribute to power instability. The absence of automated fault detection mechanisms leads to longer restoration times, exacerbating outage durations. External Factors such as Severe weather conditions, unauthorized power connections, and upstream grid supply failures also impact power availability and substation performance.

The FTA diagram in Figure 9 illustrates these failure pathways, highlighting areas requiring urgent intervention.

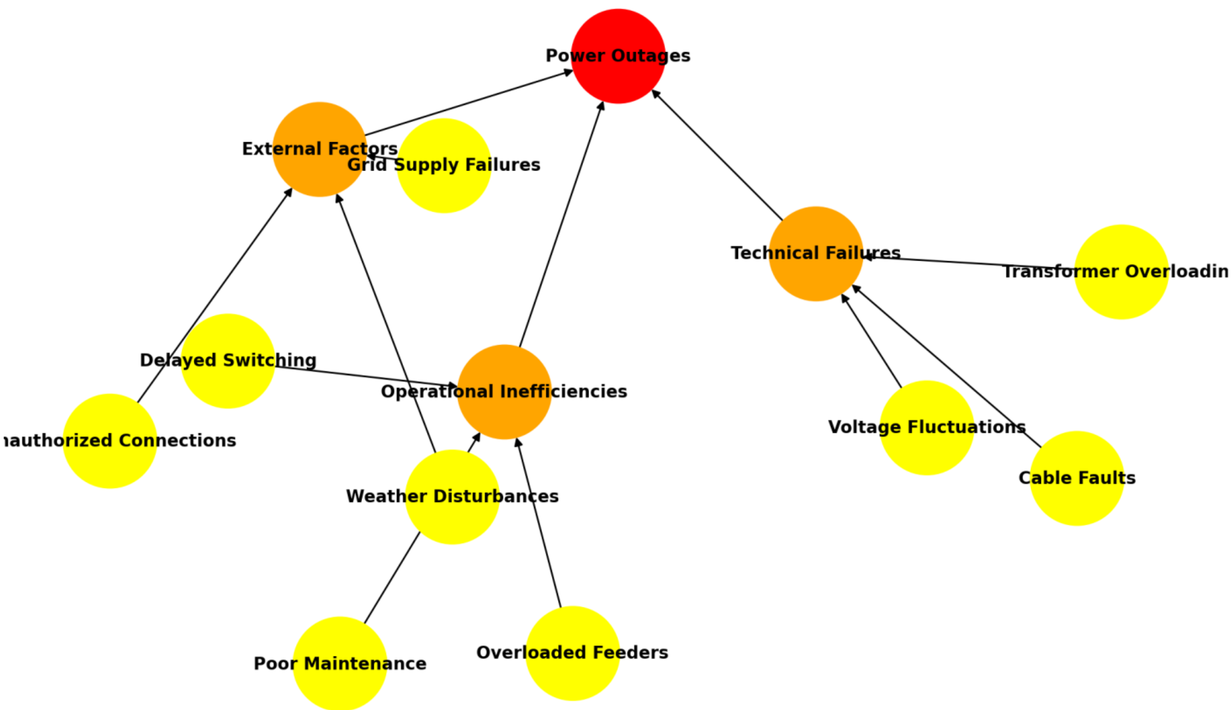

Figure 9: Fault Tree Analysis

3.3 Reliability Assessment

To further evaluate the reliability of the Oria Abraka 33/11 kV feeder**,** key power reliability metrics were computed, including **the** System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI) shown in Table 1.

Table 1: Reliability Assessment (SAIDI, SAIFI, CAIDI)

Metric	Value
SAIDI (hrs/year)	11.556589906908378
SAIFI (interruptions/year)	0.4082
CAIDI (hrs/interruption)	28.31109727317094

These indices provide insight into how frequent and severe power outages are in the distribution system, enabling better assessment of the substation's performance and service quality.

The results show that the SAIDI value is 11.56 hours per year, meaning that, on average, a customer experiences approximately 11.56 hours of power outages annually. This value is relatively high when compared to international reliability standards, where power distribution networks in developed countries often maintain SAIDI values below 2 hours per year. The prolonged outage duration suggests that the substation experiences significant downtime, either due to faulty equipment, extended repair times, or slow restoration procedures.

The SAIFI value, which measures the average number of interruptions per customer per year, is 0.41, indicating that each consumer experiences less than one power outage per year on average. While this frequency appears low, the real concern lies in the duration of outages, as reflected by the CAIDI value of 28.31 hours per outage. The CAIDI metric highlights that once an outage occurs, it takes an average of over a day (28.31 hours) for power to be restored, suggesting that the substation faces severe challenges in fault response and maintenance efficiency.

This prolonged restoration time is a critical issue, as it can have significant economic and operational impacts on both residential and industrial consumers. Businesses that rely on continuous electricity supply for production, telecommunications, and essential services would face considerable disruptions and financial losses due to extended outages. Furthermore, households may struggle with inconsistent power availability, affecting their overall quality of life. Table 2 shows the benchmarking of Power Reliability with other substation.

Table 2: Benchmarking Power Reliability; Oria Abraka 33/11 kV Feeder vs. Other Substations

Substation/Region	SAIDI (hrs/year)	CAIDI (hrs/interruption)	Power Availability (%)	Challenges Identified	Ref
Oria Abraka 33/11 kV (Nigeria)	11.56	28.31	27.9	Transformer Overloading, Feeder Congestion	Current Study
Ugbowo 33/11 kV (Nigeria)	7.245	5.626	46.2	Frequent Outages, Poor Voltage Stability	[11]
Asaba 33/11 kV (Nigeria)	12.774	16.108	Data Not Available	Aging Infrastructure, Maintenance Gaps	[12]
Electricity Distribution Network Operators (UK)	0.3	Data Not Available	99.9966	Aging Infrastructure, Renewable Energy Integration, Climate Change Impacts	[13]
United States (Average)	1.5	2.1	> 99	High Reliability, Predictive Maintenance	[14]

3.4. Power Flow Analysis

The power flow analysis of the Oria Abraka 33/11 kV feeder provides crucial insights into voltage stability, current loading, and power losses within the distribution network. The results indicate significant voltage drops across the feeder under high-load conditions, leading to unstable power supply and increased losses. The relationship between line current, voltage drop, and power loss highlights key inefficiencies that impact network performance.

The voltage drop distribution analysis in Figure 10 reveals that voltage deviations are not uniform across the feeder, with some sections experiencing drops as high as 43.3 V. This suggests that increased line impedance contributes to excessive resistive losses, especially during peak load periods. The absence of adequate voltage regulation mechanisms results in fluctuations that affect power quality. The correlation between high current levels and severe voltage drops confirms that system stress increases significantly during peak demand. This trend aligns with field observations of frequent voltage sags, which disrupt power-sensitive appliances and industrial processes. The findings suggest that feeder length and load distribution play a significant role in voltage instability, as increased transmission distances exacerbate voltage drops.

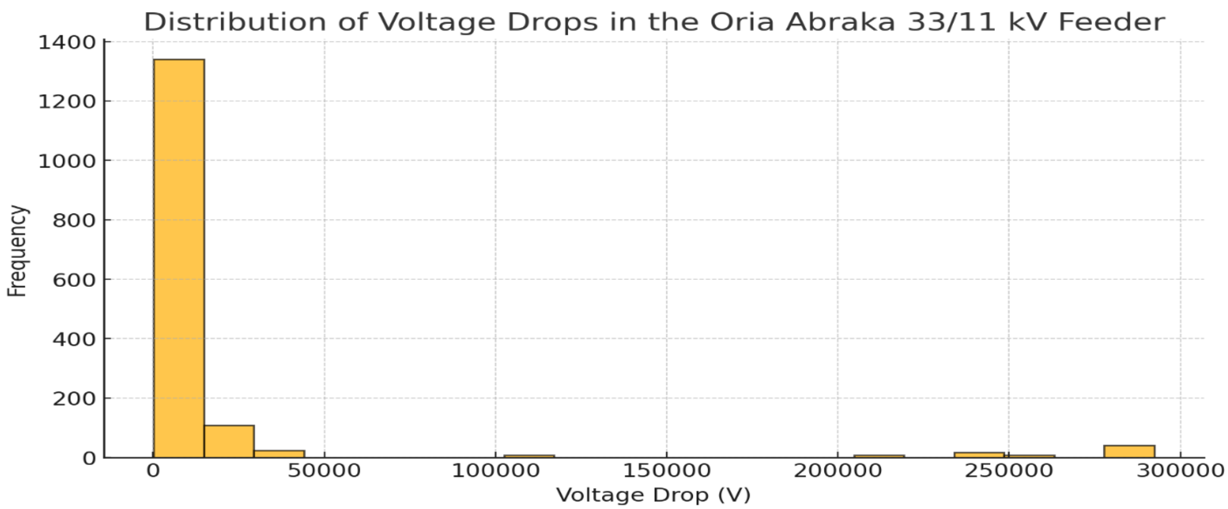

Figure 10: voltage drop distribution analysis

The analysis of power loss and line current in Figure 11 highlights the inefficiencies in energy transmission within the substation network. As current flow increases, power losses become more pronounced, indicating that the existing distribution infrastructure struggles to maintain efficiency at higher loads. At peak current levels, losses exceed 0.5 MW, which contributes to overall system inefficiencies. The excessive I^2R losses in feeder lines suggest that transmission conductors may not be optimized for the load they carry. Overloaded transformers and distribution lines further exacerbate power losses, leading to higher energy dissipation. The inability to maintain stable voltage levels under fluctuating demand conditions confirms that reactive power consumption is inadequately compensated, which increases transmission losses.

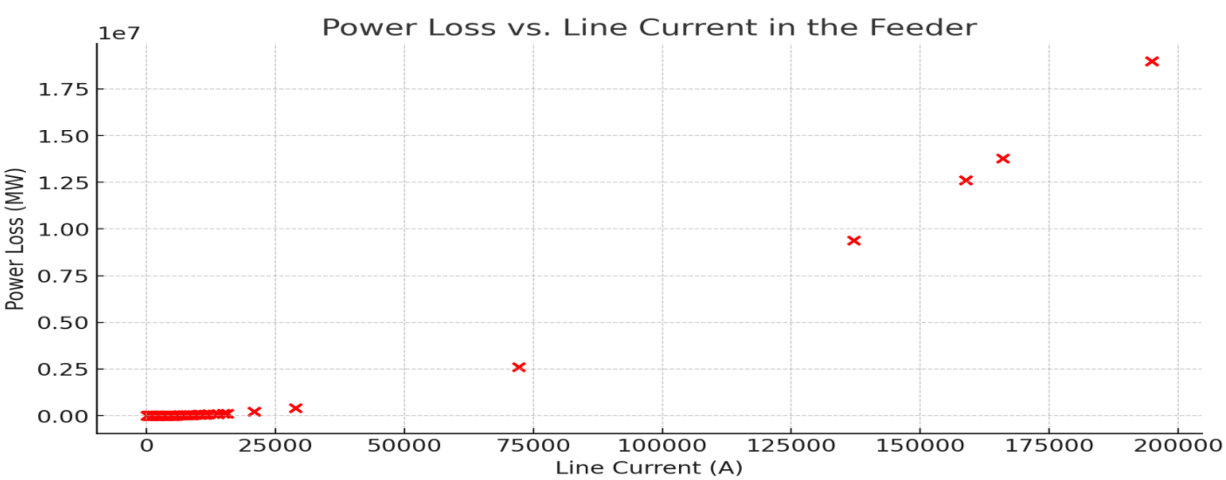

Figure 11: Power loss vs Line current

The scatter plot of voltage drops against line current in Figure 12 provides further insight into the operational constraints of the feeder network. As line current increases, voltage drop becomes more severe, suggesting that transformers are frequently operating near or above their rated capacity. This trend indicates that the substation's existing transformer infrastructure is struggling to meet the load demand efficiently. High levels of reactive losses contribute to poor voltage regulation, which negatively affects the overall power quality delivered to consumers. The results suggest that distribution lines experience significant impedance, which, when combined with load variations, increases the likelihood of equipment degradation and service disruptions.

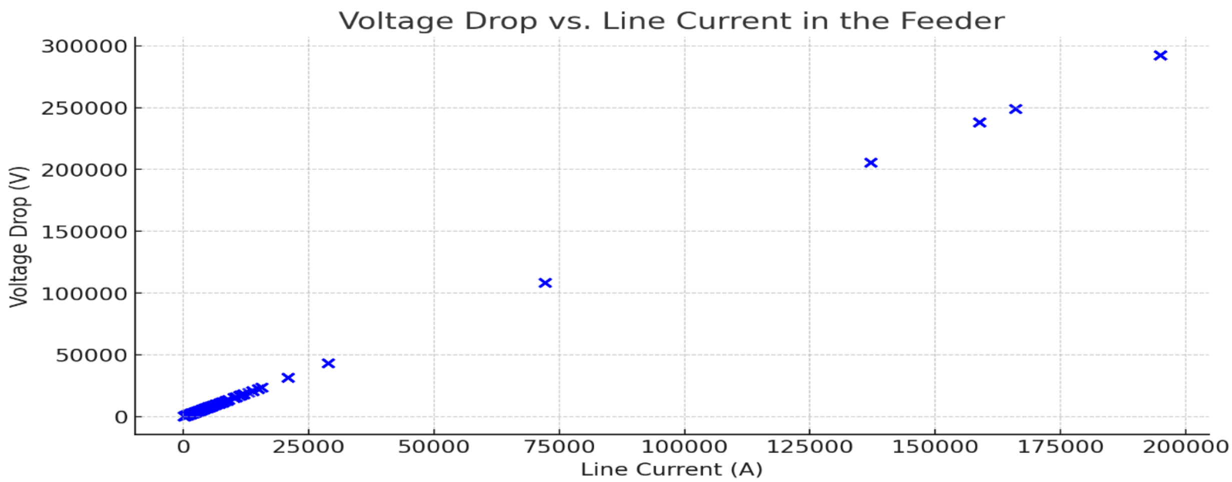

Figure 12: Voltage Drop VS Line current

The relationship between line current and power supplied in Figure 13 reveals that as the substation injects more power into the network, current levels rise disproportionately. This finding suggests that the network operates close to or beyond its ideal capacity, making it vulnerable to load imbalance and increased system stress. The increasing demand on the feeder places additional strain on the distribution components, particularly transformers and conductors. The observed patterns indicate that the system is highly dependent on a single feeder configuration, which increases the risk of failure during peak periods. The data confirms that as power delivery increases, the substation experiences escalating current levels, leading to further power dissipation and inefficiencies in supply distribution.

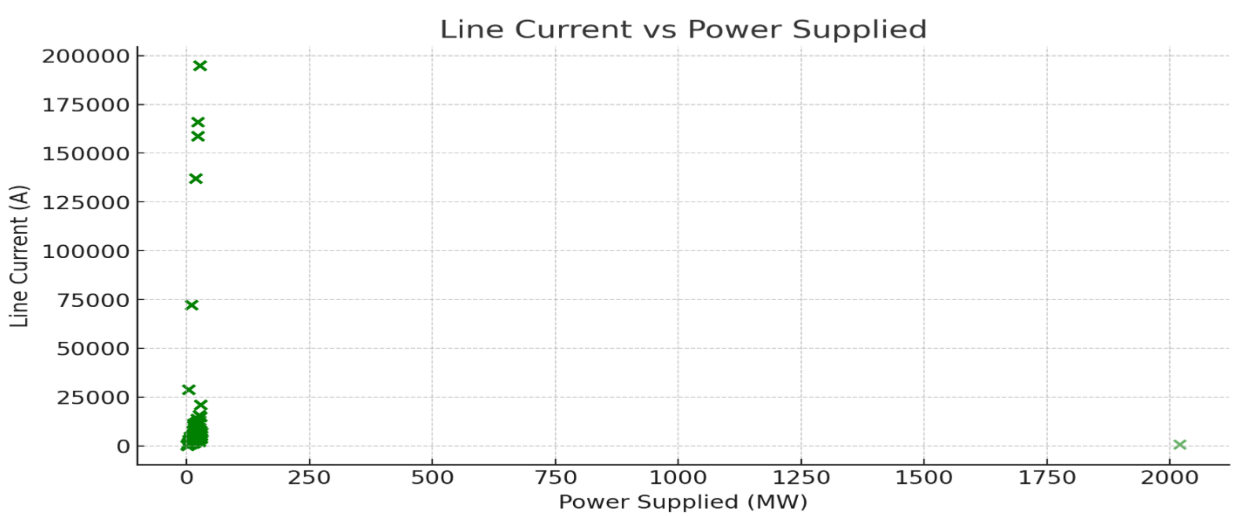

Figure 13: Line current Vs Power supplied

3.5 Policy and Technical Recommendations for Power Reliability Improvement

The findings from this study highlight several challenges affecting power supply reliability at the Oria Abraka 33/11 kV feeder substation, including frequent outages, prolonged restoration times, high voltage drops, and excessive power losses. To address these issues, targeted policy and technical interventions are necessary to enhance system performance, improve reliability metrics, and mitigate supply disruptions. These recommendations are directed at power distribution companies, government agencies, regulatory bodies, policymakers, and consumers, all of whom play critical roles in achieving a more stable and efficient electricity distribution network.

Power distribution companies, including the Benin Electricity Distribution Company (BEDC), need to implement automated fault detection and response systems to reduce downtime. The high CAIDI value (28.31 hours per outage) indicates significant delays in power restoration, which could be minimized by adopting smart grid technologies for real-time monitoring and fault isolation. In addition, transformer overloading and feeder congestion have been identified as major causes of system inefficiency. The power flow analysis shows that voltage drops become severe under high current conditions, indicating that the distribution infrastructure is operating beyond its rated capacity. Upgrading transformer capacities and redistributing loads across multiple feeders would help reduce network congestion and improve voltage stability. Power utilities should also enhance preventive maintenance practices to mitigate failures caused by aging infrastructure and poor servicing schedules. Regular substation inspections, thermal imaging for transformers, and proactive component replacements would contribute to a more reliable power supply system.

Government and regulatory agencies have a crucial role to play in strengthening electricity distribution policies and infrastructure investment. The high SAIDI value (11.56 hours per year) confirms that power reliability is significantly lower than international benchmarks, necessitating large-scale network expansion projects and private sector partnerships to improve distribution efficiency. Investment in modern grid infrastructure, alternative transmission routes, and additional feeder substations would alleviate supply constraints. The Nigerian Electricity Regulatory Commission (NERC) should establish minimum service reliability standards, mandating that distribution companies meet specific SAIDI and SAIFI targets to ensure improved customer satisfaction. Additionally, decentralizing power distribution by encouraging the development of embedded generation projects and mini-grid solutions would help reduce the load on the national grid and improve localized power availability.

Policymakers and consumers must also take steps to improve energy reliability and efficiency. The study indicates that power availability at the feeder is below 30% per month, which necessitates the implementation of demand-side management programs to optimize energy consumption. Businesses and industries can adopt load scheduling, energy storage systems, and alternative power sources to reduce dependence on the grid during peak demand hours. Policies promoting solar power adoption, net metering, and energy efficiency incentives should be introduced to encourage investment in sustainable energy solutions. Another major challenge in power distribution is the impact of unauthorized connections and electricity theft, which distort supply-demand balance and increase technical losses. Strengthening enforcement measures against power theft and illegal grid access, alongside promoting smart metering systems, would enhance billing accuracy and improve financial sustainability for distribution companies.

Implementing these recommendations would contribute significantly to enhancing power reliability at the Oria Abraka 33/11 kV feeder substation, ensuring reduced outage durations, improved voltage stability, and more efficient energy distribution. By addressing technical, regulatory, and operational shortcomings, these interventions would create a more resilient and sustainable electricity supply system for both industrial and residential consumers.

3.6. Industrial Applications of the Study

The findings from this study have significant industrial applications, particularly in improving power system reliability, load management, capacity planning, and energy efficiency. By leveraging the insights gained from analyzing power availability and outage trends, businesses and utility companies can implement strategic measures to enhance operational efficiency and resilience.

Analyzing power outage durations and electricity availability allows utility companies to implement predictive maintenance strategies that anticipate potential equipment failures. By monitoring current fluctuations and identifying deviations from normal operating conditions, faults can be detected before they escalate into major failures. This proactive approach minimizes unplanned downtime, enhances equipment lifespan, and improves overall service reliability.

Industries can enhance load distribution strategies by studying power availability trends and peak demand periods. Identifying periods of high and low energy supply enables businesses to adjust production schedules, implement load shedding strategies, or shift energy-intensive operations to off-peak hours. These optimizations help industries reduce electricity costs, improve power utilization efficiency, and prevent excessive demand on the distribution network.

The study provides insights into power availability patterns and outage frequencies, allowing industries to make data-driven decisions regarding capacity expansion and infrastructure investments. By understanding demand trends and supply limitations, businesses can strategically plan facility upgrades, transformer reinforcements, or alternative energy sources to meet future operational needs. This ensures that industrial growth aligns with power availability, preventing supply constraints and production disruptions.

Assessing outage durations and electricity supply patterns enables enterprises to evaluate the resilience of their power distribution systems. By identifying weak points in the electrical network, businesses can develop contingency plans such as deploying backup generators, investing in renewable energy solutions, or integrating energy storage systems. These measures enhance energy security, minimize financial losses from power interruptions, and ensure uninterrupted industrial operations. A data-driven approach to energy usage analysis allows industries to identify areas for improving efficiency and reducing energy wastage. By monitoring load consumption trends, businesses can adopt energy-saving practices, upgrade inefficient equipment, and implement smart automation systems to optimize power usage. These improvements result in lower operational costs, reduced environmental impact, and enhanced sustainability of industrial processes. By implementing these industrial applications, businesses and utility providers can improve power reliability, optimize energy consumption, and enhance the overall resilience of the electricity distribution system.

4. Conclusion

The study findings critically outline the challenges affecting the reliability and efficiency of power distribution at the Oria Abraka 33/11 kV feeder substation. Power availability trends analysis reveals that there are long term outages on the feeder; there is an average of less than seven hours per day supply to consumers hence massive service disruption. From computed reliability indices, the channels of supply disruptions proved how adverse the situation gets with SAIDI standing at 11.56 hours per year, SAIFI at 0.41 interruptions per year, and CAIDI at 28.31 hours per outage. These figures above really buttress how long the outages are besides delayed restoration of faults which indeed means higher system reliability.

It was through FTA that insights into the root causes of power outages were drawn. These include technical failure, inefficiency in operations, and disturbance from the outside. Other more specifying reasons for service interruption would be the conditions of transformer overloading, voltage drop, and unbalanced load; improper maintenance in addition to tardy switching, as well as no automatic fault detection, further complicates the issue, respectively. The findings of power flow analysis are high transmission losses, voltage drop, and overloaded conductors which contribute to inefficiencies in power delivery thereby leading to unstable supply conditions; this basically need[s] reinforcement because the infrastructure already in place can't support the inducement of more demand to the system.

The Benin Electricity Distribution Company should help improve power reliability at the Oria Abraka 33/11 kV substation by seeing to transformer upgrades and feeder reconfigurations to distribute loads more effectively. In doing so, they will be able to ensure mitigation of overloading of transformers and voltage drops, and hence overall power quality. Real-time monitoring systems and smart grid technologies would improve outage response times significantly. Automated switching, together with remote diagnostics, might also reduce delay in fault restoration and, therefore, lower CAIDI values while also tending to enhance system reliability. Regular maintenance schedules, thermal imaging for transformers, and real-time power loss assessments should be coordinated at all levels to immediately check what faults could have happened. Upgrading distribution conductors and voltage regulation equipment will also help greatly in minimizing energy losses as well as enhancing more stable voltage upon the feeder.

These strategies would help reduce peak demand stress on the feeder, ensuring a more balanced and sustainable distribution network.

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