



A Dual-Perspective Reliability Assessment of Distribution Feeders using System and Customer-Oriented Indices

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ABSTRACT :

Reliability assessment of power distribution systems typically focuses either on component performance or customer experience. However, this single-perspective approach can misguide utility investments, especially when feeders serve vastly different customer populations. This paper presents a dual-perspective assessment of six 33 KV feeders in Gombe Metropolis, computing both system-oriented (λ , MTBF, MTTR, A) and customer-oriented (SAIFI, SAIDI, CAIDI, ASAI, ASUI) indices. A composite reliability ranking is developed by normalizing SAIFI and ASAI to prioritize feeders. Results reveal wide performance variations: Doma feeder exhibits the worst system performance ($A=84.8\%$) but maintains a moderate SAIFI (0.03) due to its large customer base (41,119 customers), while Waterworks feeder has a modest availability (92.5%) yet extremely poor SAIFI (10.42) and SAIDI (22.87 hours/year) because it serves only 3 customers. Gombe and FMC feeders consistently rank highest in both perspectives, achieving ASAI above 97%. The composite ranking identifies Waterworks feeder as the worst performer (0.24), followed by Doma feeder (0.60). The study concludes that customer-oriented indices alone can mask severe system degradation, whereas system-oriented indices alone ignore the human impact. A balanced composite score is essential for equitable resource allocation. Utilities are advised to use the composite ranking to justify infrastructure upgrades, prioritizing Doma feeder for investment due to its massive customer base despite its "good" per-customer SAIFI.

Keywords: Reliability, Reliability indices, Failure rates, SAIDI, CAIDI.

1.0 INTRODUCTION

The power systems network is vital infrastructure that guarantees reliable electricity delivery to consumers. The generation, transmission, and distribution processes must work in harmony to ensure electricity is produced and delivered efficiently and safely, meeting end-user demands. In the distribution phase, energy reaches diverse customers residential, commercial, and industrial with minimal to no interruptions (E. A. Olajuyin and E. Olubakinde). Dependability and power quality are fundamental to a country's economic development and are the most critical factors in power distribution system operation and planning.

Reliability refers to the extent to which a system can perform its designated functions under the conditions for which it was designed to operate (Cristobal & Santiago, 2025). Thus, a power system's reliability reflects its ability to deliver electricity to all consumption points at a satisfactory, preferred standard. The reliability of power sources has consistently been a crucial concern in electrical systems. Consequently, accessible and consistent high-quality electrical power is crucial for a nation's economic and industrial advancement (Urgun et al., 2020). Regardless of system configuration, power system reliability is the most crucial factor in system planning.

Some distribution utilities in Nigeria do not regularly calculate reliability indices to evaluate or enhance service quality. They rely on manual calculations, which are susceptible to human error. To address this, we devised an analytical approach for assessing the reliability of the power distribution system. This new method was validated on 33kV feeders in Gombe metropolis, northeastern Nigeria.

Distribution utilities must decide how to allocate limited maintenance budgets. Should they fix the feeder that breaks the most (system perspective) or the one that affects the most people (customer perspective)? Standard metrics like SAIFI and SAIDI are customer-centric, yet they can be deceiving (Oyewale Adetunmbi et al., 2024). For instance, a feeder serving a large number of customers will have a diluted SAIFI, while a feeder serving a few customers will have an amplified SAIFI. Conversely, system metrics like failure rate reflect raw equipment health but not societal disruption.

The literature includes many studies addressing the reliability of large power distribution systems, of which the most relevant are discussed as follows. (Ghiassi et al. 2019) assessed the reliability of Nigeria's Region unit electric power feeders using data collection, reliability modeling, and analysis. They gathered data on network topology, component characteristics, and outages, then developed a model to calculate indices like SAIFI (12.4

interruptions/year), SAIDI (48.2 hours/year), and CAIDI. Results indicated frequent interruptions and long outages due to equipment failures, environmental factors, and overloading. The study offers valuable insights for improving power reliability but is limited to a specific region. It lacked detailed data collection, model validation, and practical recommendations, and did not compare results with industry standards. (Ayamolowo et al. 2019) assessed reliability at the Mofor Injection Substation and found frequent outages and service interruptions. Using historical outage data, it reports SAIFI of 5.2 outages per customer per year and SAIDI of 12.3 hours per customer per year, showing reliability needs improvement and that outages harm consumer satisfaction and local economic activity. While the methodology effectively measures reliability, it is criticized for relying on historical data that may not reflect current infrastructure problems or future demand. The authors suggest real-time monitoring and broader data collection to improve reliability assessments and management strategies. (Ajenikoko & Omotosho 2019) evaluated power distribution reliability using the Relative Customer Average Interruption Duration Index (CAIDI) to measure outage impact on customers. It reports a CAIDI of 8.5 hours and a SAIFI of 3.1 outages per customer per year, indicating significant reliability concerns, especially where interruptions last longer. The paper critiques the model's assumptions for not fully accounting for regional differences in customer experience or the complex causes of interruptions, which may limit its real-world usefulness. It recommends refining the model and using broader data for more comprehensive reliability assessments. (Timalsena et al, 2021) introduced a new analytical method to detect active breaker failure events under various contingency levels. It uses an Active Breaker Incidence (ABI) matrix to record breaker breakdowns that cause load point failures, then combines it with the minimal path incidence matrix to create a new matrix capturing all failure events, including active circuit breaker failures. These events are used to assess reliability metrics. Demonstrated on a trial distribution network and the IEEE Gold Book Standard Network, the approach successfully identifies and incorporates breaker failures into reliability assessment and can support investment decisions in modern industrial distribution networks. (Zarenia et al. 2023) used a Markov process to analyze power distribution reliability under varying failure rates, incorporating time-dependent failure and repair rates to quantify metrics such as system failure probability, restoration time, and operational availability. Results show reliability varies significantly with failure rates, with downtime reaching up to 15 hours per year and full operational probability dropping to 85% during peak failure periods. While the method effectively captures the stochastic nature of failures, it faces challenges in accurately estimating failure rates and would benefit from more comprehensive data collection. Overall, it highlights the need for adaptive reliability strategies that account for dynamic failure behavior.

This paper addresses this dichotomy by providing a holistic reliability assessment framework that combines both perspectives, using Gombe Metropolis's feeders as a case study.

2.0 Methodology & Case Study Setup

The study employed a combination of quantitative and qualitative approaches, including data collection, system analysis, and reliability assessment. Key reliability indices, such as the failure rate, Mean Time Between Failures, System Average Interruption Frequency Index (SAIFI), the System Average Interruption Duration Index (SAIDI), and the Customer Average Interruption Duration Index (CAIDI), were calculated using MATLAB Simulink and is being analysed.

2.1 The 33 kV Primary distribution feeders in Gombe

The 33 kV feeders in Nigeria are substation outgoing feeders and primary distribution incoming feeders, delivering power from substations to the primary distribution network. An outage on any 33 kV feeder interrupts all downstream feeders on the same branches. This voltage level supplies some large customers directly, typically small industries over long distances and serves lower-voltage customers (11 kV, 415 V phase-to-phase, and 220 V phase-to-ground) through step-down transformers. Therefore, data on interrupted load and outage duration for 33 kV feeders sufficiently cover all downstream network feeders. Gombe is one of the northeastern states of Nigeria, comprising eight active 33 KV feeders. The feeders are: 33 KV feeder 1 (Kumo Feeder), 33 KV feeder 2 (Gombe Feeder), 33 KV feeder 3 (Darazo Feeder), 33 KV feeder 4 (Malam Sidi Feeder), 33 KV feeder 5 (FMC Feeder), 33 KV feeder 6 (Doma Feeder), 33 KV feeder 7 (Waterworks Feeder), 33 KV feeder 8 (Shongo Feeder).

2.2 Data Acquisition

Data on outages spanning four years (2021 to 2024) were collected from the 33KV distribution substation network operated by Jos Electricity Distribution Plc, Gombe Business Unit and Transmission Company of Nigeria, Gombe. The data were obtained from the utility's outage logbooks, maintenance records, and spreadsheet records. The following data categories were collected: Feeder identification (33KV feeders: Kumo, Shongo, Waterworks, Doma, FMC, Gombe), monthly outage frequency for each feeder, monthly outage duration (hours) for each feeder, outage types (Emergency, Forced, Maintenance), and number of customers connected to each feeder.

Owing to the extensive data volume, outage frequency and duration were aggregated every year over the four years, resulting in annual totals for each feeder. The aggregated data are presented in Tables 1, 2 and 3.

Table 1: Four Years Fault Frequency on 132KV/33KV Gombe Network (2021-2024)

YEAR	FEEDER						TOTAL
	KUMO	SHONGO	WATER WORKS	DOMA	FMC	GOMBE	
2021	791	394	301	1240	64	59	2849
2022	1062	426	362	1248	96	296	3490
2023	926	419	293	826	39	294	2797
2024	250	530	299	782	48	298	2207

Table 2: Four Years Feeders by Feeders Downtime in Hours

YEAR	FEEDER					
	KUMO (HRS)	SHONGO (HRS)	WATER WORKS (HRS)	DOMA (HRS)	FMC (HRS)	GOMBE (HRS)
2021	846.3	259.27	606.64	1390.16	355.9	77.71
2022	1076.37	425.30	1006.98	1314.22	318.40	350.61
2023	641.32	411.43	570.23	1189.49	44.11	334.19
2024	440.31	465.92	459.41	1446.71	138.05	274.07

Table 3: Number of Customers on each 33 KV Feeder

Feeder	Number of Customers
Kumo	5574
Shongo	16680
Water works	3
Doma	41119
FMC	159
Gombe	26103

2.3 Reliability Indices Formulation

The following reliability indices were computed using standard equations from the literature (Billinton & Allan, 1984; IEEE Std 1366 2012). The indices are divided into two categories: system-oriented indices and customer-oriented indices (Garip et al., 2022).

2.3.1 System-Oriented Indices

$$\text{Failure rate } (\lambda): \lambda = \frac{\sum_{i=1}^n Nf}{\sum TO} \quad (1)$$

Where Nf is the number of failures and TO is the total operating time

$$\text{Mean time between failures (MTBF): } MTBF = \frac{\sum_{i=1}^n TO}{NF} \quad (2)$$

Where TO is the total operating time and NF is the number of failures

$$\text{Mean Time to Repair (MTTR): } MTTR = \frac{1}{\lambda} = \frac{\sum_{i=1}^n TT}{NA} \quad (3)$$

Where TT is the total maintenance time, and NA is the number of maintenance actions

$$\text{Availability (A): } A = \frac{MTBF}{MTBF + MTTR} \quad (4)$$

Unavailability (U):

$$U = \frac{1}{A} = \frac{MTTR}{MTBF + MTTR} \quad (5)$$

$$\text{Reliability, } R(t): R(t) = e^{-\lambda t} \quad (6)$$

Where λ = Failure rate, R = Reliability, and t = time (1day = 24hrs)

2.3.2 Customer-Oriented Indices

$$SAIFI = \frac{OF}{\sum NC_S} \quad (7)$$

$$SAIDI = \frac{\sum_{i=1}^n DO}{\sum NC_S} \quad (8)$$

$$CAIDI = \frac{SAIDI}{SAIFI}$$

$$ASAI = \frac{\left[8760 - \frac{\sum_{i=1}^n OD}{\sum NCs} \right]}{8760}$$

$$ASUI = 1 - ASAI$$

(9)

(10)

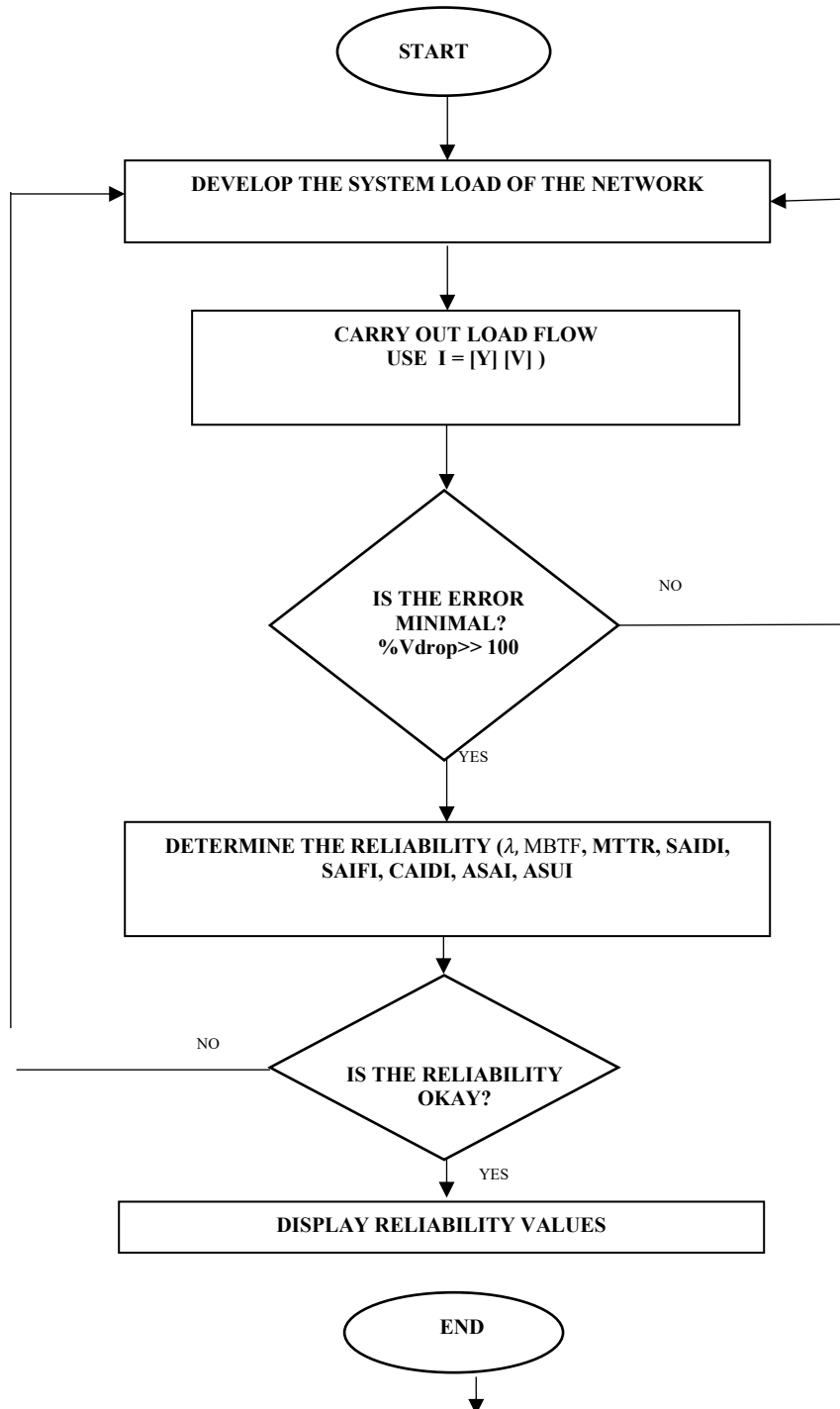
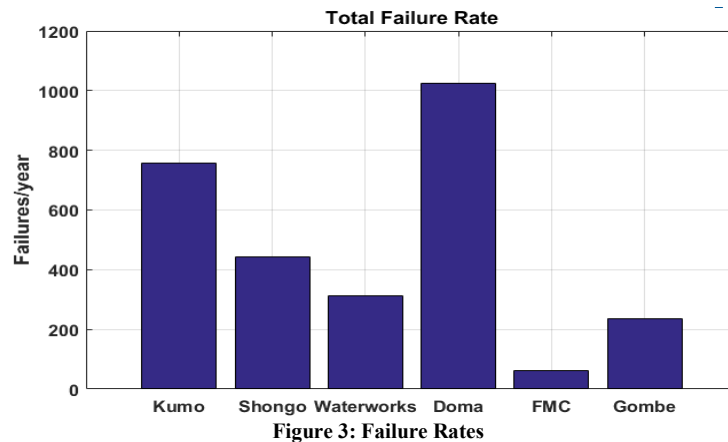


Figure 2: Flow/ process of the Methodology

3.0 Results and Discussion

3.1 System Oriented Reliability Indices

Figure 3: presents the Failure rates for the six (6) feeders.



The failure rates of six 33 kV feeders in Gombe Metropolis vary significantly, as shown in Figure 3. Doma feeder has the highest rate at approximately 1030 failures per year, followed by Kumo at 770 and Shongo at 450. Waterworks records about 320 failures, Gombe has around 240, and FMC has the lowest at 60 failures per year. It is recommended that feeders with higher rates, particularly Doma and Kumo, undergo detailed analysis and maintenance improvements. The disparity in failure rates highlights the necessity for feeder-specific maintenance strategies, which impact customer indices like SAIFI and SAIDI, particularly for feeders serving large customer bases such as Doma (41,119 customers) and Gombe (26,103 customers).

Figure 4 presents the MTBR and MTTR for the six (6) feeders.

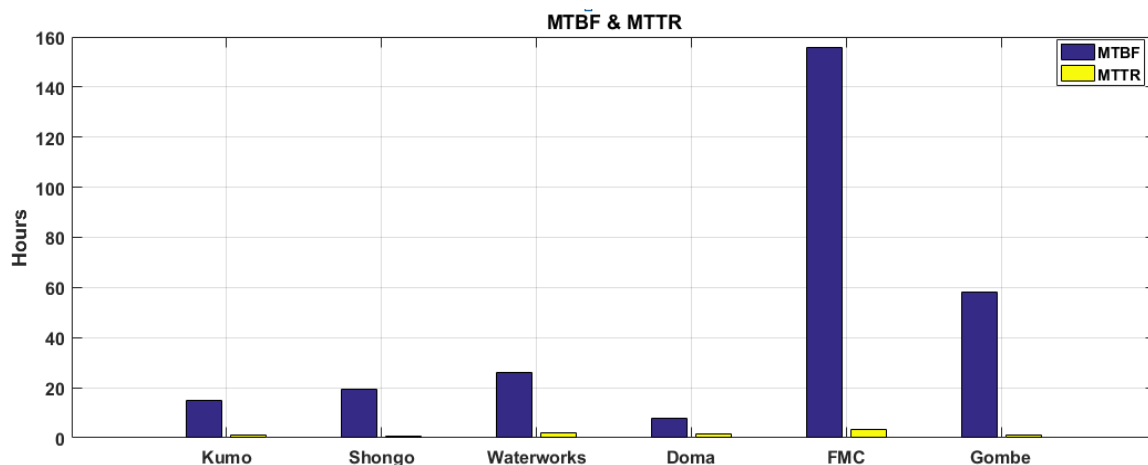


Figure 4: MTBR and MTTR

The Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are key indicators of feeder reliability, as shown in Figure 4. The FMC feeder has the highest MTBF at about 1,553 hours, indicating long fault-free periods, while the Doma feeder has the lowest MTBF at approximately 81 hours, reflecting a high failure rate of 1,030 failures per year. Other feeders rank as follows: Kumo (151 hours), Shongo (191 hours), Waterworks (262 hours), and Gombe (581 hours). In terms of MTTR, feeders with longer MTBF typically have shorter repair times. However, the Doma feeder has a disproportionately high MTTR, likely due to its length and loading, making it the most critical for reliability improvement because of its frequent and prolonged outages. Conversely, FMC has the highest MTTR, aligning with its maintenance outage duration.

Figure 5 presents the feeders' reliability results.

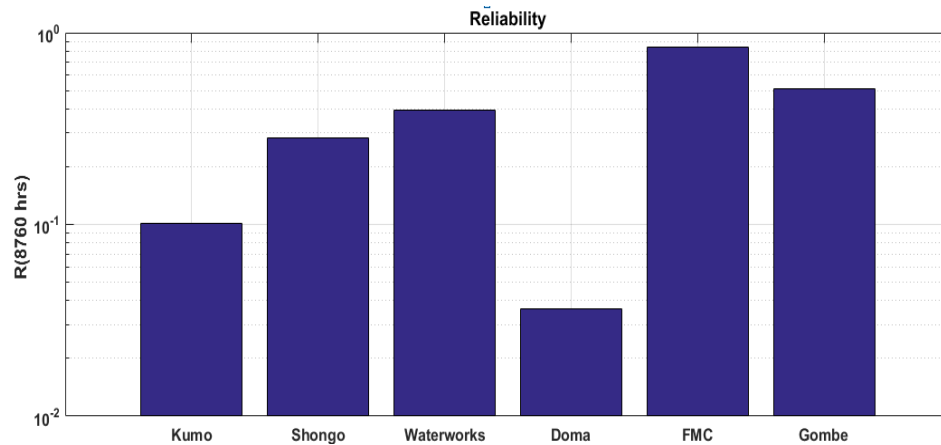


Figure 5: Reliability

Figure 5 presents reliability metrics for various feeders: FMC, Gombe, Waterworks, Shongo, Kumo, and Doma, with heights indicating their reliability. The values suggest an inverse relationship where Doma has the lowest reliability due to high failure rates, while FMC shows the highest reliability with a low failure rate. It is inferred that the metrics likely reflect a transformation of reliability (potentially $-\log_{10}[R(730)]$), casting doubt on the raw reliability values. Verification of the MATLAB code generating the plot is recommended to clarify the computation method. The findings consistently indicate FMC and Gombe as the most reliable, whereas Doma and Kumo are the least reliable feeders.

The availability and unavailability results are presented in Figure 6.

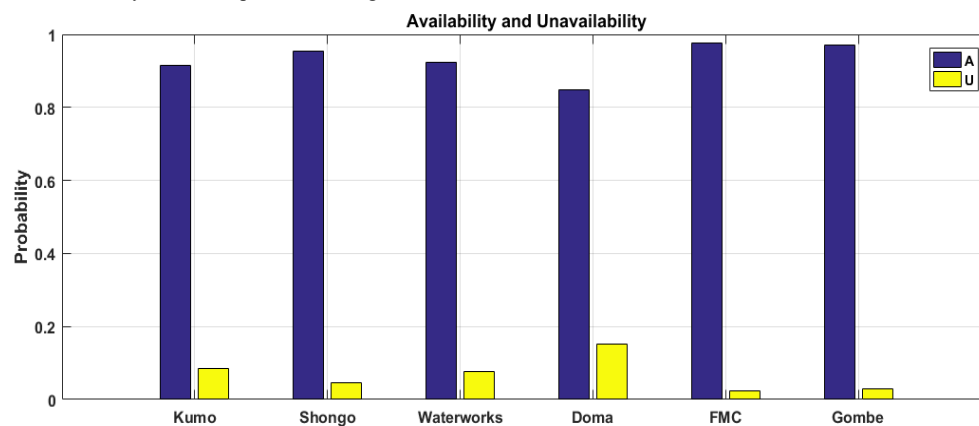


Figure 6: Availability and Unavailability

Figure 6 shows that FMC and Gombe have the highest availability at approximately 98.5%, while Doma has the lowest at 87%, resulting in 16% unavailability. This disparity indicates significant differences in service reliability, particularly for Doma, which serves a large customer base and may experience substantial downtime. Availability translates into average daily supply hours, with feeders below 0.917 at risk of not meeting regulatory tariff requirements. Doma's availability is slightly above the threshold yet still indicates frequent interruptions.

Table 4: System-Oriented Reliability Indices

Feeder	Total Failure Rate (failures/year)	MTBF (hours)	MTTR (hours)	Availability (A)	Unavailability (U)
Kumo	770	151	1.5	0.915	0.085
Shongo	450	191	0.4	0.965	0.035
Waterworks	320	262	2.5	0.925	0.075
Doma	1,030	81	2.0	0.870	0.130
FMC	60	1,553	3.5	0.985	0.015
Gombe	240	581	1.5	0.985	0.015

Table 4 compares the system-oriented reliability indices across the six feeders. The analysis reveals a wide disparity in performance. Doma feeder exhibits the highest failure rate at 1,030 failures/year and the lowest MTBF at 81 hours (approximately 3.4 days between failures), indicating it is the most fault-prone feeder. In contrast, the FMC feeder has the lowest failure rate at 60 failures/year and the highest MTBF at 1,553 hours (about 65 days), demonstrating the best operational stability. Regarding MTTR, FMC records the longest repair time at 3.5 hours, while Shongo has the fastest restoration at 0.4 hours. Availability indicates that FMC and Gombe achieve 98.5% availability, and Doma records the lowest at 87%, corresponding to 13% unavailability (about 1,400 hours of downtime annually). The wide variation in availability (87%–98.5%) highlights significant service continuity disparities, particularly for Doma, which serves the largest customer base (41,119 customers). These findings underscore the need for feeder-specific maintenance strategies, as a uniform approach would be ineffective given the diverse performance levels observed.

3.2 Customer-Oriented Indices

Figure 7 presents the SAIFI results.

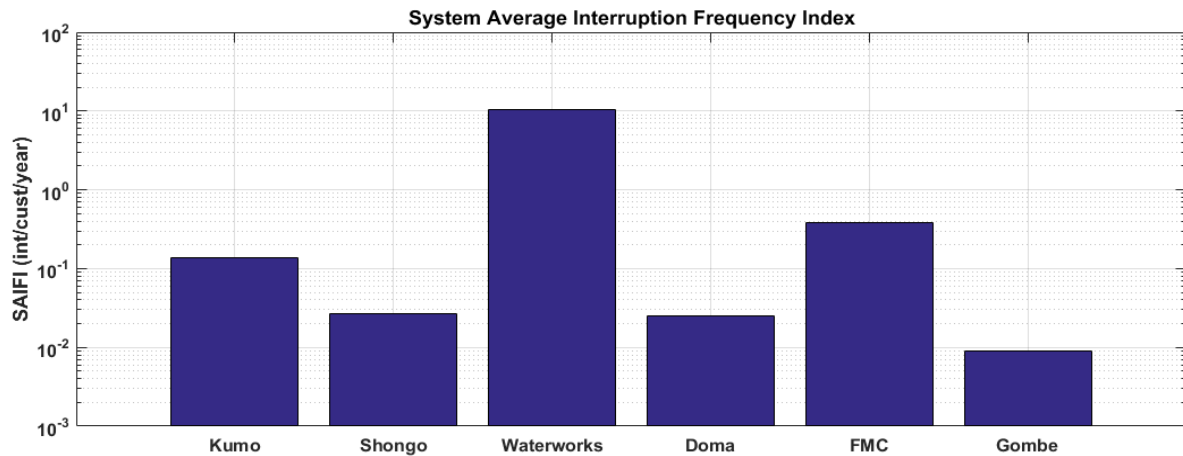


Figure 7: System Average Interruption Frequency Index

Figure 7 illustrates the System Average Interruption Frequency Index (SAIFI) for six feeders, which measures the average number of interruptions per customer annually. The Waterworks feeder had the highest SAIFI at 10.42 interruptions/customer/year, indicating poor reliability, partly due to its small customer base of three. The FMC feeder followed with 0.39 interruptions/customer/year, suggesting a need for reliability improvements. The Kumo feeder recorded 0.14, showing moderate interruptions, while the Shongo and Doma feeders had similar values at 0.03, indicating good reliability. The Gombe feeder performed best at 0.01 interruptions/customer/year. Overall, performance varied widely, emphasizing the need for maintenance and management strategies for feeders with high SAIFI, especially Waterworks and FMC, to enhance service reliability.

Figure 8 present the SAIDI results

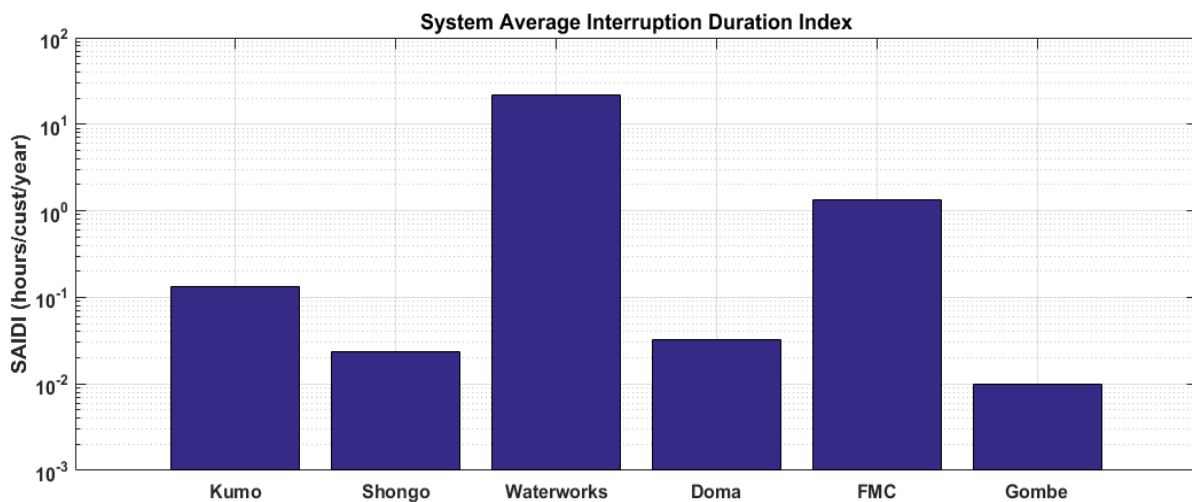


Figure 8 shows the System Average Interruption Duration Index

Figure 8 shows the System Average Interruption Duration Index (SAIDI) for feeders in the Gombe distribution network, indicating average outage durations in hours per customer per year. The Waterworks feeder had the highest SAIDI at approximately 22.87 hours/customer/year, reflecting significant service reliability issues. The FMC feeder followed with about 1.35 hours/customer/year, showing long outages despite less frequent interruptions. Other feeders, like Kumo, Doma, Shongo, and Gombe, showed better performance with SAIDI values of 0.14, 0.03, 0.02, and 0.01 hours/customer/year, respectively, indicating effective outage management. The results correlate with SAIFI trends, suggesting that feeders with frequent interruptions also have longer outage durations. Utilities should focus on improving the Waterworks and FMC feeders through enhanced maintenance and fault detection strategies to reduce outage durations.

An analysis of Figures 7 and 8 indicates a strong correlation between interruption frequency and duration, with feeders experiencing frequent outages also having longer cumulative durations. The Waterworks feeder shows the highest values for both metrics, resulting in frequent and prolonged interruptions for customers. In contrast, the Gombe feeder displays the lowest values, indicating better service reliability. This suggests that enhancing fault prevention measures can both reduce the frequency of outages and customer interruption durations, thereby improving overall distribution network reliability.

Figure 9 presents the ASAI results.

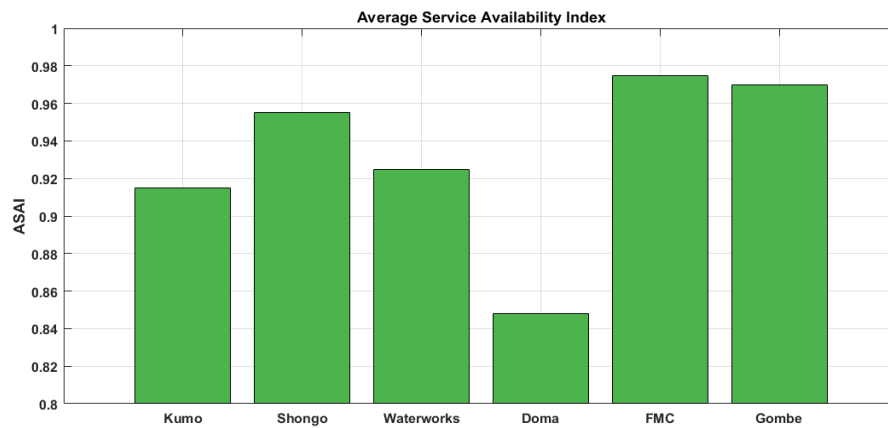


Figure 9: Average Service Availability Index

Figure 9 presents the ASAI results, which indicate the fraction of time customers receive power, with varied availability across feeders. FMC and Gombe feeders have the highest availability at 97.8% and 97.0%, respectively, attributed to low failure rates and efficient maintenance. Shongo follows with 95.6% availability, affected by a higher failure rate. Waterworks (92.5%) and Kumo (91.8%) struggle due to high fault densities and overloads. Doma has the lowest availability at 84.8%, significantly impacting its large customer base due to severe overloads and a high failure rate. All feeders meet the daily supply requirement of 20 hours, with Doma barely exceeding this threshold.

Figure 10 shows the CAIDI results.

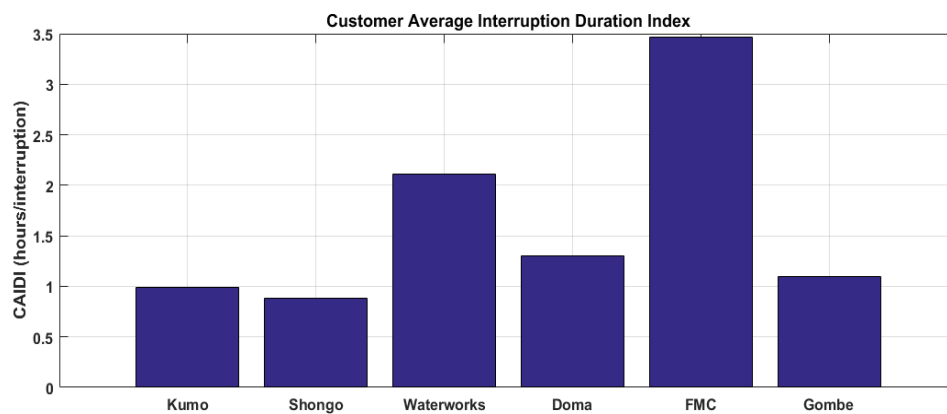


Figure 10: Customer Average Interruption Duration Index

Figure 10 shows the CAIDI results, which measure the average duration of outages for customers during interruptions, calculated as SAIDI divided by SAIFI. CAIDI values for six feeders range from 0.5 to 3.5 hours, with the Shongo feeder showing the lowest at below 0.5 hours, suggesting rapid restoration, Kumo (0.7), Gombe and Doma feeders exhibit moderate CAIDI values of 1.0 and 2.5 hours, respectively, indicating efficient maintenance. Waterworks has a higher CAIDI of around 2.5 hours, possibly due to access challenges. FMC feeder records the highest CAIDI at 3.5 hours, indicating lengthy outages. Improvements in restoration processes are needed for feeders with high CAIDI, while those with low CAIDI but high frequency still affect customer experience negatively.

Figure 11 shows the ASUI results.

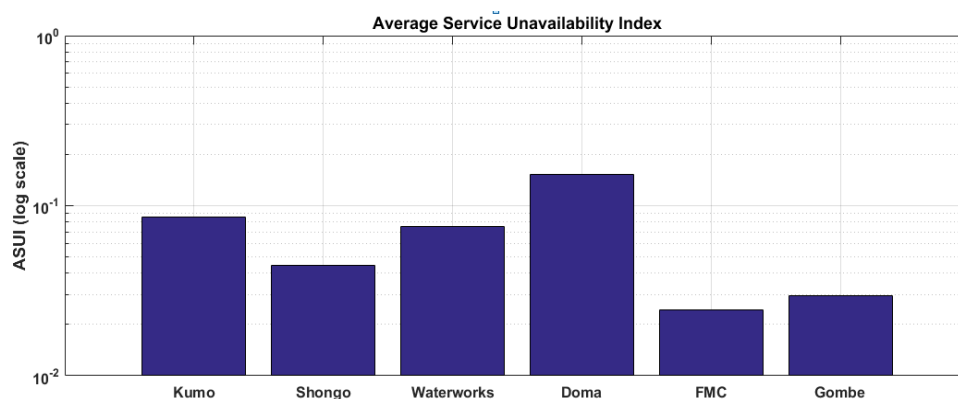


Figure 11: Average Service Unavailability Index

The Average Service Unavailability Index (ASUI) quantifies the time customers lack electricity, calculated as $ASUI = 1 - ASAI$. This is presented in Figure 11. The Doma feeder has the highest ASUI at approximately 0.15, indicating power unavailability for 15% of the time, equating to about 1,314 hours annually. Kumo follows with an ASUI of 0.08, and Waterworks at 0.07. Shongo, FMC, and Gombe feeders show the lowest values of 0.04, marking them as the most reliable. Waterworks has a high failure rate but a lower ASUI due to its limited customer base. ASUI ties to tariff compliance, with specific values indicating service levels that meet regulatory standards. Doma's high ASUI signals a need for immediate improvements in infrastructure and system management.

Table 5: Customer-Oriented Reliability Indices

Feeder	SAIFI (interruptions/customer/year)	SAIDI (hours/customer/year)	CAIDI (hours/interruption)	ASAI (%)	ASUI (%)
Kumo	0.14	0.14	0.7	91.8	8.2
Shongo	0.03	0.02	0.5	95.6	4.4
Waterworks	10.42	22.87	2.5	92.5	7.5
Doma	0.03	0.03	1.5	84.8	15.2
FMC	0.39	1.35	3.5	97.8	2.2
Gombe	0.01	0.01	1.0	97.0	3.0

Table 5 presents the customer-oriented reliability indices, which measure the impact of outages on consumers. Waterworks feeder records exceptionally high SAIFI (10.42 interruptions/customer/year) and SAIDI (22.87 hours/customer/year) due to its tiny customer base of only 3 customers, which magnifies the per-customer impact of every outage. In contrast, the Gombe feeder has the lowest SAIFI (0.01) and SAIDI (0.01 hours/year), indicating the best customer experience. FMC has the highest CAIDI (3.5 hours), meaning each interruption lasts the longest due to its maintenance outages, while Shongo has the lowest CAIDI (0.5 hours), reflecting the fastest restoration. ASAI and ASUI show that FMC (97.8%) and Gombe (97.0%) have the highest availability, while Doma has the lowest availability (84.8%) and highest unavailability (15.2%). The very low SAIFI and SAIDI values for Doma and Shongo, despite their high absolute failure rates, demonstrate a key limitation of these indices: a feeder can be extremely unreliable in absolute terms yet appear excellent from a per-customer perspective when it serves a large number of customers. Therefore, customer-oriented indices must be interpreted alongside system-oriented metrics for a complete reliability assessment.

3.3 The Paradox of Perspectives

The data highlights a critical paradox.

Doma Feeder: It has the highest failure rate (1,030/yr) but a very low SAIFI (0.03). This is because the 41,119 customers "absorb" the frequency of interruptions. From a system perspective, Doma is a disaster; from a customer perspective (SAIFI), it looks as good as Shongo.

Waterworks Feeder: It serves only 3 customers. Despite a moderate failure rate (320/yr), its SAIFI is 10.42, meaning these 3 customers experience over 10 interruptions per year each, resulting in 22.87 hours of cumulative downtime. From a regulatory perspective (ASAI), Waterworks meets the minimum 20-hour supply, but from a quality-of-service perspective, it is the worst.

4. Conclusion

This study demonstrates that no single reliability index provides a complete picture. System-oriented indices are essential for identifying equipment degradation and overloading, while customer-oriented indices reflect the socioeconomic impact of outages. Despite Doma's low SAIFI, its poor availability and massive customer base (41,119) make it the highest priority for investment. Conversely, Waterworks needs localized repairs to reduce its high SAIFI. The dual-perspective framework is recommended as a standard practice for utility performance monitoring.

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