Jurnal Nasional Teknik Elektro dan Teknologi Informasi
Volume 13 Number 4 November 2024

DOI: 10.22146/jnteti.v13i4.12510

Reliability Analysis of 20 kV Electricity Distribution System on CWRU Feeder

Tasma Sucita[1], Maman Somantri[1], Diki Fahrizal[1], Mia Agista[1]

[1]Program Study of Electrical Engineering Education, Faculty of Engineering and Industrial Education, Universitas Pendidikan Indonesia, Bandung 40154, Indonesia
[Received: 14 April 2024, Revised: 14 September 2024, Accepted: 19 November 2024]
Corresponding Author: Tasma Sucita (email: tasmasucita@upi.edu)

ABSTRACT — The electricity demand continues to rise alongside population growth, making the reliable distribution of electrical energy to consumers essential. The reliability of the 20 kV electricity distribution system on the CWRU feeder at the National Electricity Company (Perusahaan Listrik Negara, PT PLN) Customer Service Unit (Unit Layanan Pelanggan, ULP) Pelabuhan Ratu Area Surade was evaluated. The primary purpose was to analyze key reliability indices such as system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), average service availability index (ASAI), and average service unavailability index (ASUI), and to assess the economic impact of disruptions on consumers. Methodologies involved collecting and analyzing field data from PT PLN (Persero) ULP Pelabuhan Ratu's CWRU feeder, utilizing quantitative reliability calculations and qualitative observations to identify internal and external factors affecting system reliability. The results showed that the SAIFI value reached 52.077 times/customer/year, and the SAIDI value was 99.400 hours/customer/year, classifying the system as unreliable based on PLN standards (*standar* PLN, SPLN) 68-2:1986. However, the CAIDI value of 1.813 hours/times/year indicated that the system response time was within acceptable limits. The availability of electricity, with an ASAI of 99.828% and an ASUI of 0.172%, was deemed satisfactory. Internal factors contributed to 10.47% disturbances. In contrast, external factors (weather and tree fall) accounted for 48.84%, and the remaining 40.69% were from unknown causes. Economic losses were calculated at Rp52,432.50/customer because these interruptions. More frequent maintenance and the implementation of additional protective measures are recommended to enhance reliability.

KEYWORDS — Electricity Distribution System Reliability, Reliability Index, SAIFI, SAIDI, Economic Loss Analysis.

I. INTRODUCTION

The demand for electrical energy continues to increase along with population growth. In this modern era, almost all lines of life require energy. Therefore, to meet consumers' electrical energy needs effectively, the process of distributing electricity to consumers is a vital aspect that must be considered to meet consumers' electricity needs optimally [1]. The electric power distribution system, which is a complex network covering generation, transmission, and distribution to load, plays an important role in providing electrical energy to consumers according to their needs [2].

The reliability of an electrical distribution system can be expressed by the reliability index. The reliability index is a setting used as a parameter of service quality and distribution of electrical energy from the production stage to consumers [3]. In the distribution system, several indices are used as references, including as system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), which are included in the customer-oriented reliability index, average service availability index (ASAI), and average service unavailability index (ASUI) as a reliability index related to availability [3], [4]. In addition, there is also a reliability index that refers to loads such as energy not supplied (ENS) and average energy not supplied (AENS) [5].

However, several factors can affect the power distribution process, including disturbances caused by internal factors such as the system's failure and external factors such as weather, lightning, and trees. This disruption can reduce the reliability of electricity distribution to consumers, causing a direct impact in the form of temporary power outages. Therefore, it is essential to evaluate and improve the continuity of the electrical distribution system [6]. The quality of the electrical distribution system can be known by analyzing the reliability of the distribution system. Analysis of the reliability of the electrical distribution system can be calculated by determining the frequency factor of frequent disturbances and the duration of the disturbances that occur [7], [8].

In the power distribution industry, improving system reliability is a key focus for researchers to meet growing energy needs. This previous research focused on reliability analysis for the current and future structure of medium voltage power distribution systems by considering the application of distributed generation (DG) and information and communication technology (ICT) infrastructure [9]. It was found that DG technology and energy source locations significantly affect the reliability of power supplies. However, these studies did not fully consider specific local variations and operational conditions that could impact their effectiveness.

In addition, there have been studies focusing on improving the reliability of electricity distribution networks through optimal DG placement. The results of this study showed that DG placement could significantly improve system reliability by reducing SAIFI values by almost 40%, SAIDI by 25%, and expected energy not supplied (EENS) by 25% after DG was incorporated into the distribution network [10]. This study also sought to find the best location for DG placement using artificial neural network (ANN) and, as a result of validation, the Roy Billinton test system (RBTS). However, to fully understand the relevance and limitations of the methods suggested, additional validation may be required in real-world networks.

Recent research has focused on studying how value-based auto-recloser placement and network remodeling can improve the reliability and efficiency of radial distribution systems. The results showed that network repeat modeling and auto-recloser placement could significantly reduce the duration of outages and improve the reliability of the system [11]. However, in this study, the investment and maintenance costs of auto-recloser might limit its application, especially in areas with limited funds. Further studies are needed to determine how operational costs and reliability benefits are balanced.

The focus of this research was the evaluation of the reliability of the CWRU feeder in the National Electricity Company (Perusahaan Listrik Negara, PT PLN) Customer Service Unit (Unit Layanan Pelanggan, ULP) Pelabuhan Ratu Area Surade, utilizing indices such as SAIFI, SAIDI, and CAIDI. No new solutions or frameworks were proposed in this research, instead a detailed evaluation of the system's current dependability performance was provided. By examining local operational characteristics and external influences, this research presented ideas for increasing preventive maintenance and protective actions to boost system reliability. Additionally, this research included an economic analysis of the disruptions, a topic not generally explored in earlier studies.

Data collected from PT PLN (Persero) ULP Pelabuhan Ratu Surade area indicated that the network setup on the CWRU feeder, a designated distribution line in the electrical network, employed a radial network configuration with an automatic reverse breaker (*pemutus balik otomatis*, PBO) or an automatic section switch (*saklar seksi otomatis*, SSO) to minimize interference frequency and shorten interruption durations. A total of 86 interruptions occurred in the CWRU feeder in 2022, with an average duration of 1 hour and 6 minutes [12]. With the disruption, consumers on CWRU feeders felt the direct impact of a power outage. Therefore, it is necessary to evaluate the continuity and reliability of the electricity distribution system [13].

While indices such as SAIFI, SAIDI, and CAIDI have been widely utilized since they were published in PLN standards (*standar* PLN, SPLN) 68-2:1986, a fresh perspective is provided by research, particularly through the examination of the reliability of the CWRU feeder in the PT PLN (Persero) ULP Pelabuhan Ratu Surade Area. Unlike prior studies that largely focused on the DG installation or other technologies, this study considered local differences and operational variables affecting the distribution system's reliability. Additionally, it combined the economic consequences of disruptions, a component rarely studied in earlier research. Therefore, this study provided a more complete and practical approach, proposing focused solutions addressing the specific needs of the region, which can drive future policy formulation and operational improvements [14].

II. METHODOLOGY

A. RESEARCH DESIGN

In order to streamline the research process, this work follows a distinct series of stages. Figure 1 depicts a research flow diagram that effectively outlines the processes undertaken during the research endeavor.

This research began with the key stage of conceptual development. This step comprised a thorough review of academic work on the dependability of electrical distribution networks, as well as the formulation of theoretical constructs that guided the forthcoming inquiry. Subsequently, the problem identification step was critical for pinpointing specific issues within the CWRU feeder at PT PLN (Persero) ULP Pelabuhan Ratu Surade. The identified problem centered around the frequent interruptions and reliability challenges faced by the CWRU feeder, impacting the continuity of electricity supply to consumers. This identification provided a clear focus for the research, allowing for targeted data collection and analysis aimed at improving system reliability.

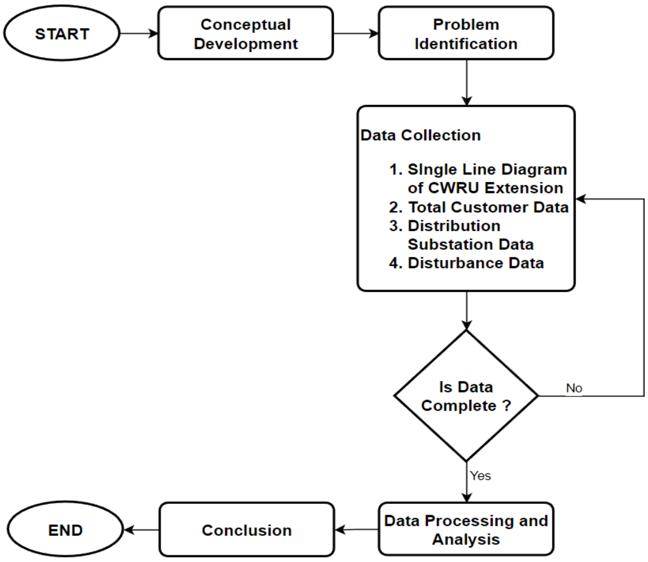

Figure 1. Research flowchart.

Following the construction of a conceptual development, the research shifted to the empirical phase, which began with the thorough collecting of data from the CWRU extension at PT PLN (Persero) ULP Pelabuhan Ratu. Before moving on to the analytical step, where an incisive dissection was undertaken to uncover the root causes of CWRU feeder disruptions, data integrity and completeness must be ensured.

The analytical rigor extended to the computation of a variety of dependability indices, such as SAIFI, SAIDI, and CAIDI. In parallel, indices reflecting service availability of ASAI and ASUI were examined, and the economic consequences of dependability shortfalls were assessed using ENS and AENS. These generated indices were then compared to the SPLN regular reliability benchmarks, providing a comparative view on performance.

Further, the research examined the ASAI and ASUI metrics to determine the amount of power service continuity given to clients. Concurrently, an evaluation of economic losses due to service outages was carried out using the ENS and AENS values as crucial reference points. Such extensive evaluations help to offer a clear picture of the operational efficacy and cost effect of feeder reliability concerns [15], [16].

At the end of the research, many analytical strands were woven together to yield meaningful results. These findings not only mark the end of the research, but they may also pave the way for future research, policy development, and operational improvements in the electrical distribution sector.

B. LOCATION AND OBJECT OF RESEARCH

This research was conducted at PT PLN (Persero) ULP Pelabuhan Ratu, situated in the Surade area on Jl. Bhayangkara No. 11, Pelabuhan Ratu District, Sukabumi Regency, West Java 43364. The focus of the research was exclusively on the CWRU feeder, which is connected to the PRABU gas insulated switchgear (GIS) substation. Data acquisition was authorized under an agreement with PT PLN (Persero) ULP Pelabuhan Ratu, ensuring the research pertained solely to the operational scope of the specified feeder within the utility provider's network.

C. DATA COLLECTION METHODS

Diverse and comprehensive data collection methods were employed to obtain the necessary data, focusing on analyzing the reliability of the 20 kV distribution system in the ULP area of PT PLN (Persero) Pelabuhan Ratu Surade. Field observations were conducted, with the system site visited directly to observe and document the current state of the electrical distribution system and the interactions between its components. These observations provided real-time data on the operation and reliability of the system.

Additionally, interviews were conducted with technicians, managers, and operational staff of PT PLN (Persero), as well as electricity service users in the region. The purpose of these interviews was to gain a better understanding of operational issues, disruption events, and methods for addressing disruptions in the distribution systems. An important part of the data collection process involved conducting a literature review to understand the theoretical framework underpinning the research.

A wide and diverse range of information was collected through a combination of various data collection methods. This information supports an in-depth analysis of the reliability of the electricity distribution system in the ULP area of PT PLN (Persero) Pelabuhan Ratu Surade on the CWRU feeder.

D. FIELD DATA

Significant amount of important field data was collected to analyze the reliability of the electricity distribution system in the ULP area of Pelabuhan Ratu Surade, operated by PT PLN (Persero). The data included detailed information about the number of customers, the capacity and number of distribution transformers, as well as the frequency and duration of interruptions that occurred in CWRU feeders providing a complete picture of the parts of the system.

Specifically, in 2022, there were 2,761 subscribers connected to CWRU feeders. Along the network were installed 137 distribution transformers: 136 are active and 1 is inactive. Overall, these transformers have a capacity of 11,210 kVA, indicating a large capacity that can be used to meet electricity needs in the Sukabumi Regency area. Regarding interference, in the same year, there were 86 incidents of interference on CWRU feeders with a total of 8,510 minutes or 141.833 hours where each disruption lasted an average of 1 hour 6 minutes. To improve reliability, these outages occurred across multiple network segments, with different incident distributions from low network voltage (*tegangan jaringan rendah*, TJR) SSO to local interlocking and operation control (LIOC) SSO. The spread and frequency of these disturbances indicate vulnerable points in the distribution system [17].

In addition, an important tool in the analysis of researchers is the collected single-line diagram of the CWRU feeder. This diagram shows all the components attached to the feeder, provides a better understanding of the system configuration, and makes it easier to find potential sources of interference or weakness in the network. The research relies on collecting field data to perform in-depth reliability analysis with the ultimate goal of identifying and recommending effective improvement strategies [18].

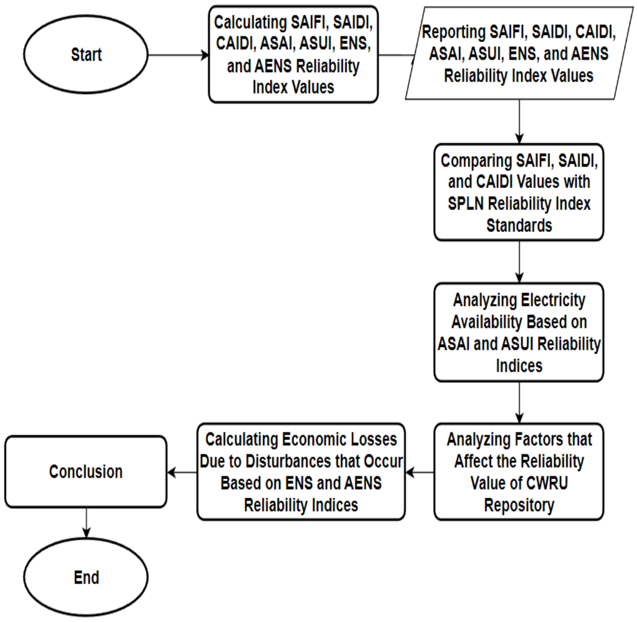

Figure 2. Flow of data analysis.

E. DATA ANALYSIS

The following is a flow diagram of data analysis conducted in research on the reliability of electric power distribution systems in CWRU feeders [19].

Figure 2 illustrates the steps of data analysis used to evaluate the dependability of electric power distribution systems through CWRU feeders. The first step involved calculating the reliability indices SAIFI, SAIDI, CAIDI, ASAI, ASUI, ENS, and AENS using their corresponding mathematical formulas. Microsoft Excel was utilized for the computations, as it is a commonly used tool in data analysis that offers a user-friendly interface and the capability to handle the size of the datasets involved in this research.

After obtaining these reliability values, a comparative analysis is conducted, comparing the calculated SAIFI, SAIDI, and CAIDI with the established SPLN reliability standards [20]. This comparison is crucial for assessing compliance with industry standards. Afterwards, the ASAI and ASUI values are carefully examined to assess the power availability on the CWRU feeder, giving us a better understanding of how the system performs in both normal and demanding situations.

The investigation continued by thoroughly analyzing incident reports and fault data to determine the main factors that impact the reliability of the CWRU feeder [21]. Having a solid grasp of these elements is crucial in identifying the underlying reasons behind system failures.

Finally, the research measured the financial consequences of disruptions by determining the economic losses associated with the operational deficiencies of the CWRU feeder, as shown by the ENS and AENS data. This step demonstrates how technical performance impacts the economy, highlighting the wider effects of reliability on utility economics and consumer costs.

F. STANDARD VALUES OF RELIABILITY INDEX BASED ON SPLN 68-2:1986

The main objective of research was to determine the reliability levels of SAIFI, SAIDI, and CAIDI, as well as electricity availability levels based on the ASAI and ASUI reliability indices for CWRU feeders at PT PLN (Persero) ULP Pelabuhan Ratu Surade Area. The following reliability indices was computed using the Microsoft Excel program [22].

SAIFI, as shown in (1), calculates the average number of system disruptions lasting more than three minutes that a client encounters over the observation period, which is typically one year. The index is a dimensionless number, which may be computed as follows [23], [24]:

$$SAIFI = \frac{\sum_i N_i}{N_T}[1/yr]. \quad (1)$$

SAIDI is detailed in (2). It evaluates the overall length of an interruption lasting more than three minutes for the average customer over a specified period. It is typically assessed over the course of a year and displays customer minutes or hours of disruption. Equation describes the mathematical from of SAIDI [23], [25]:

$$SAIDI = \frac{\sum_i r_i N_i}{N_T}[hr/yr]. \quad (2)$$

The CAIDI, as represented in (3), measures the average time taken to restore service after an outage, indicating how long an average disruption lasts, which is greater than three minutes. It tracks the amount of time the consumer is de-energized each interruption. To compute the CAIDI index as follows [23], [26]:

$$CAIDI = \frac{\sum_i r_i N_i}{\sum_i N_i}[hr]. \quad (3)$$

The ASAI is the chance of having all loads provided. The index is frequently given as a percentage, can be calculated using the formula shown in (4) [23]:

$$ASAI = \frac{N_T \cdot (T) - \sum_i r_i N_i}{N_T \cdot (T)}[pu] \quad (4)$$

where the T is the observation period, which is normally one year in a non-leap year and equals 8,760 hours.

The ASUI, shown in (5), represents the probability of having one or more loads interrupted and can be computed as follows [23]:

$$ASUI = 1 - ASAI = 1 - \frac{N_T \cdot (T) - \sum_i r_i N_i}{N_T \cdot (T)}[pu]. \quad (5)$$

The EENS, detailed in (6), refers to the cumulative energy that is anticipated to not be provided to the intended recipients. The index may be derived using (6) [23], [27]:

$$EENS = \sum_i r_i P_{avg,i}\,[MWh/yr] \quad (6)$$

where $P_{avg,i}$ is the average power connected during each outage.

When evaluating the performance of electrical power distribution systems in Indonesia, it is crucial to compare them to the reliability indices set by PT PLN (Persero). These standards are based on SPLN 68-2:1986, which outlines various standard values based on the configuration of the electric power distribution network [28]. Table I shows the SPLN Reliability Index Standard, which showcases the acceptable thresholds for power interruptions in different network configurations.

The Table I provides an overview of the performance metrics for medium voltage air line (*saluran udara tegangan menengah*, SUTM), with and without pre-break opening (PBO), medium voltage cable line (*saluran kabel tegangan menengah*, SKTM) with and without distribution network conductor restoration (*pemulihan penghantar jaringan distribusi*, PPJD), and SKTM configurations that include clusters. As an example, a radial SUTM configuration generally resulted in a SAIFI of 3.2 times/year, a SAIDI of 21 hours/year, and a CAIDI of 0.65 hours/interruption. Adding PBO was found to improve the system reliability, as evidenced by the decrease in SAIFI and SAIDI values.

TABLE I
SPLN RELIABILITY INDEX STANDARD

Network Configuration	SAIFI (times/year)	SAIDI (hours/year)	CAIDI (hours/times/ year)
Radial medium voltage overhead lines (*saluran udara tegangan menengah*, SUTM)	3.2	21	0.65
Radial SUTM with PBO	2.4	12.8	5.33
Medium voltage cable line (*saluran kabel tegangan menengah*, SKTM) without a distribution network conductor restoration (*pemulihan penghantar jaringan distribusi*, PPJD)	1.2	4.36	3.63
SKTM with PPJD	1.2	3.33	2.78
SKTM with clusters	0.6	1.75	2.92

SKTM networks without PPJD showed a lower SAIFI of 1.2 times/year, but they had higher CAIDI values, suggesting longer average interruption durations per incident. By incorporating PPJD, there was a significant improvement, resulting in lower SAIDI and CAIDI values. The SKTM with clusters demonstrated superior reliability performance compared to the other configurations, with a SAIFI of 0.6 times/year and the shortest SAIDI of 1.75 hours/year.

These standard values serve as benchmarks for the distribution network performance and are critical in evaluating the reliability of the electrical supply to the end consumers. By comparing the actual performance data from the CWRU repeater with these standards, the study could identify areas of improvement and devise strategies to enhance the overall reliability of the power distribution system.

III. RESULTS AND DISCUSSION

A. CUSTOMER – BASED RELIABILITY INDEX (SAIFI, SAIDI, and CAIDI)

Research data obtained from PT PLN (Persero) ULP Pelabuhan Ratu showed that CWRU feeders supplied as many

TABLE II
COMPARISON SAIFI AND SAIDI VALUE

No	Month	SAIFI	SAIDI
1	January	1.501	1.356
2	February	12.560	24.739
3	March	3.939	6.503
4	April	3.446	14.778
5	May	5.571	7.890
6	June	2.145	2.343
7	Jully	3.606	4.730
8	August	2.465	8.859
9	September	4.465	3.759
10	October	3.829	4.886
11	November	2.0	4.817
12	December	6.550	9.740

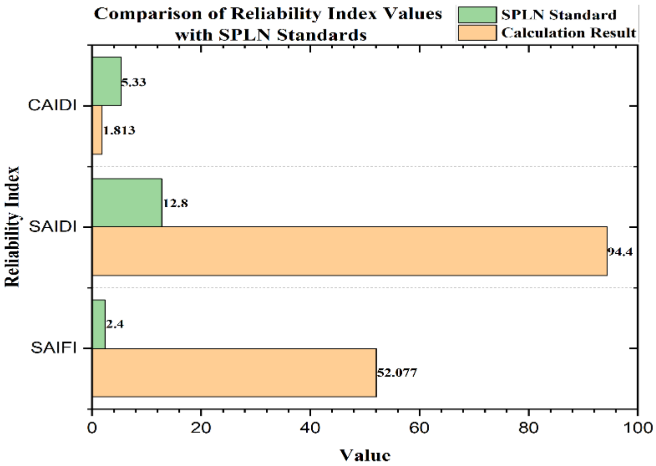

Figure 3. Comparison graph of reliability index values with SPLN.

as 137 distribution substations with one substation being inactive. In addition, the research findings obtained were the results of calculating customer-based reliability index values including SAIFI, SAIDI, and CAIDI values.

Table II shows the value of the reliability index of the power distribution system for each month of the year by measuring how frequent and how long the average outages experienced by CWRU feeder customers. The SAIFI value indicates the average frequency per customer, while SAIDI indicates the total outage duration per customer.

Figure 3 offers a comparison of SAIFI, SAIDI, and CAIDI results with SPLN. Data displayed in Table II and Figure 3 present an overview of the power distribution system's performance. By reviewing the monthly breakdown of SAIFI and SAIDI values in Table II, it is easy to pinpoint specific periods, such as February and May, which suffered the highest frequency and duration of outages. These months showed the times with the largest disruptions and should be prioritized for repair or maintenance activities at PT PLN (Persero) ULP Pelabuhan Ratu. The research helped to find the most essential months for system adjustments targeted at enhancing overall reliability.

Figure 4 displays a graph depicting the monthly values of SAIFI throughout 2022. The SAIFI value of 52.077 times/customer/year is included in the unreliable category because it has a value greater than the reliability index standard set by SPLN. SAIFI is said to be reliable if it has a value below 2.4 times/customer/year. This value was influenced by the frequency of interference that occurs in CWRU feeders, which

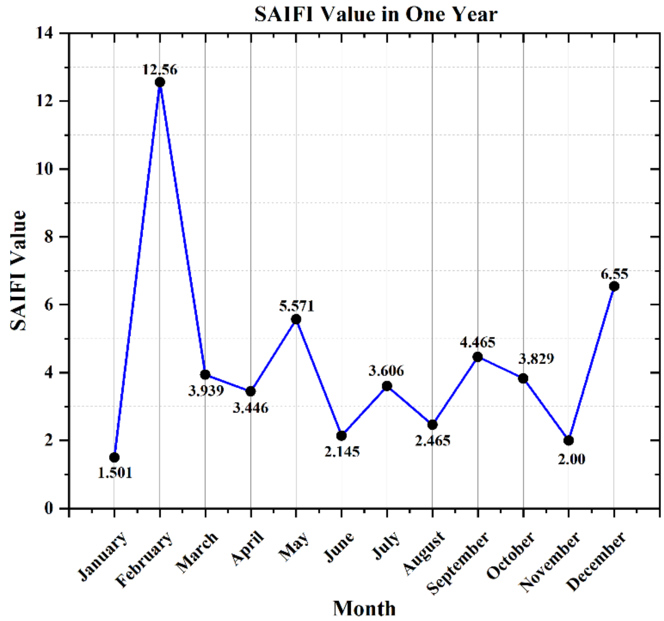

Figure 4. Graph of SAIFI reliability index value.

was 86 times the interference during 2022. In addition, disruptions often occurred in the recloser (REC) breaker control relay (BCR) segment, causing all customers to experience the impact of the disruption. In addition, the highest SAIFI reliability index value was in February at 12.560 times/customer (Figure 4). Meanwhile, the lowest SAIFI reliability index value occurred in January at 1.501 times/customer.

In January, the network experienced minimal disruption, with only five occurrences contributing to a SAIFI value of 1.501 times/customer. This lower value suggested that the disruptions were limited in both frequency and scope, affecting a smaller proportion of the customer base.

In stark contrast, February saw a significant spike in disruptions, with the SAIFI value escalating to 12.560 times/customer. The heightened frequency, with nineteen interruptions recorded within the month, coupled with the fact that these occurrences had a more widespread impact on the whole customer base, suggesting a period of elevated system strain. Such disruptions highlight the need for a review of the network design and maintenance protocols, especially in segments that experienced complete outages, to bolster system reliability.

The value of SAIDI on CWRU feeders is in the unreliable category because it has a value of 94.400 hours/customer/year (Figure 5). This value is higher than the reliability index standard set by SPLN. SAIDI can be said to be reliable if it has a value lower than 12.8 hours/customer/year. This value was influenced by the duration of the disturbance occurring quite long, with an average duration of interruption for 1 hour 6 minutes. In addition, the frequency of disruptions that often occurred in the REC BCR segment had an impact on the overall customer.

An evaluation of the SAIDI revealed a discrepancy in the duration of power outages experienced by users of the CWRU feeders. In January, the impact of interruptions was relatively light, with the SAIDI value recorded at 1.356 hours/customer. This indicates that the outages, though infrequent, were resolved quickly, minimizing the duration of customer inconvenience.

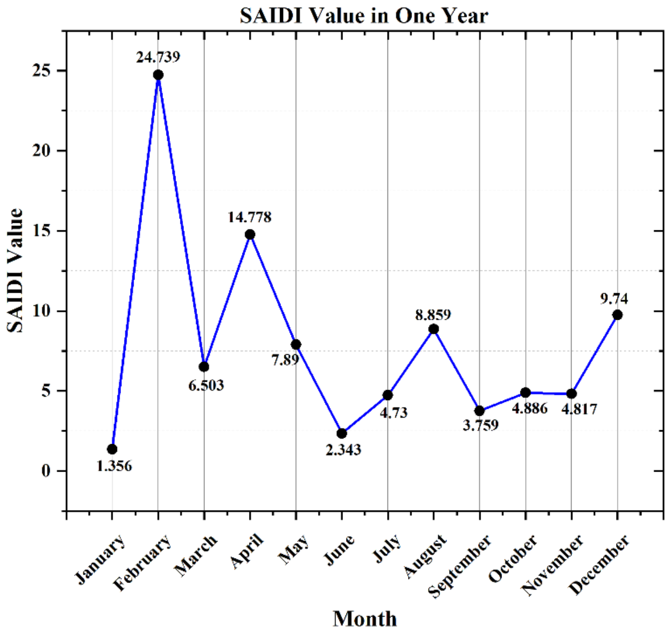

Figure 5. SAIDI reliability index value graph.

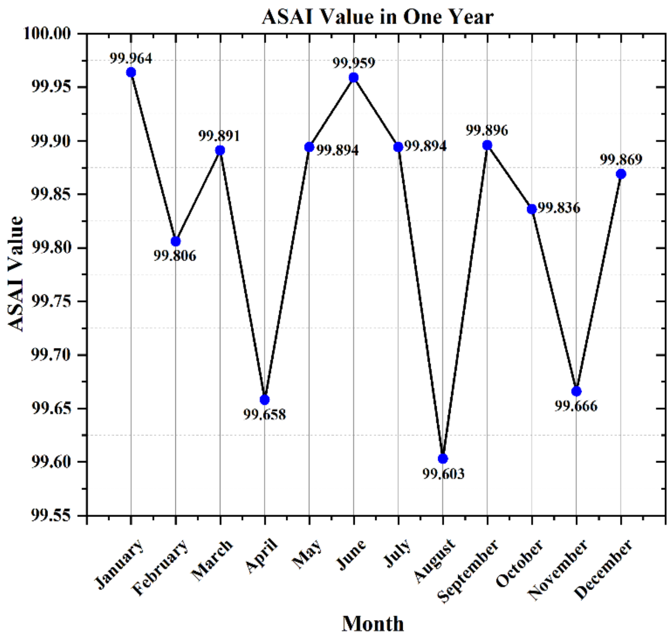

Figure 6. ASAI reliability index value graph.

Conversely, February marked a significant escalation in the duration of service interruptions, as evidenced by a SAIDI value of 24.739 hours/customer. This alarming figure highlights the challenges faced in this month, including a high frequency of interruptions and longer durations to restore service, resulting in a pressing need for network analysis and strategic improvements.

Additionally, the CAIDI which provides insight into the average outage duration experienced per interruption, indicated a value of 1.813 hours/incident for the year. Standing below the SPLN threshold of 5.33 hours/incident, this index refers to effective restoration methods when outages occur, despite the challenges highlighted by SAIFI and SAIDI figures. Overall, while the CAIDI index suggests effective service recovery protocols, the heightened SAIDI values, particularly in February, emphasize a crucial opportunity for enhancing the robustness of the electrical distribution system to reduce both the frequency and the duration of future outages.

B. RELIABILITY INDEX BASED ON AVAILABILITY (ASAI AND ASUI)

Based on the calculation results, the average value of the ASAI reliability index on the CWRU feeder was 99.828% and the average ASUI reliability index was 0.172%. This shows that the system's response was very fast in overcoming the disturbances that occurred. Therefore, it can be said that the availability of electric power in CWRU feeders is in the category of sufficient. Figure 6 shows ASAI values for each month during 2022. The highest ASAI value was 99.964% in January and the lowest ASAI value was 99.603% in August (Figure 6). However, the monthly ASAI value was still in the range of 99%.

C. FACTORS AFFECTING THE RELIABILITY INDEX VALUE ON CWRU FEEDERS

Based on the results of the analysis conducted, the value of the reliability index on the CWRU feeder was influenced by disturbances that occurred in the electric power distribution system. These disorders were divided into two based on the causative factor. The following are the disturbances that occur in CWRU feeders based on internal and external factors.

The results of the CWRU feeder system reliability analysis, based on Figure 7, show two main categories and one category that has not been identified. Internal factors were responsible for 10.47% of disorders. Inter-phase collisions, burning phases, and severed or damaged parts are examples of special incidents. To reduce the amount of this internal interference, it is recommended that all components be kept in good condition and function normally through regular maintenance and component inspections.

In contrast, 47.67% of incidents stemmed from external disturbances, with fallen trees as the main cause, followed by lightning strikes, animal disturbances, poles collapsed by landslides, and incidents caused by human actions, such as NYM cable throwing by the community. This finding indicates that trees require regular maintenance and periodic cutting and are equipped to reduce external disturbances, especially in the REC BCR segment, which often experiences problems.

Meanwhile, 41.86% of disorders were still unidentified. Potential causes can include network maintenance or human error. For this reason, PT PLN (Persero) must conduct a thorough inspection and record every time a disturbance occurs. In the future, perhaps this will be a more effective evaluation to improve system reliability and make it easier to handle disruptions. Considering the causes of this disorder, repair and prevention can be more accurately targeted, which will result in a significant improvement in the reliability of CWRU feeders.

D. ECONOMI LOSS VALUE BASED ON ENS AND AENS

Figure 8 displays the amount of ENS due to interference in the CWRU feeder for one year. The magnitude of the ENS value was obtained by calculating the active power multiplied by the duration of the disturbance in one hour. After calculations, it was found that the CWRU feeder had an overall ENS of 1,004,998.833 kWh. Then, the AENS was obtained by dividing the resulting ENS value by the total number of customers.

$$AENS = \frac{ENS}{N_T} = \frac{1{,}004{,}998.833\ kWh}{27.691} = 36{,}293.34\ kWh.$$

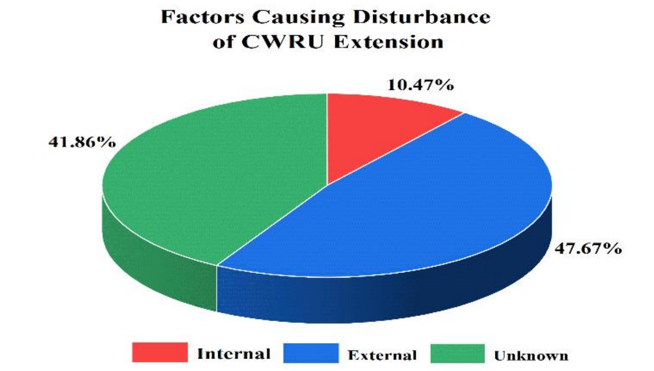

Figure 7. Causative Factors Graph of Interference in CWRU Feeder

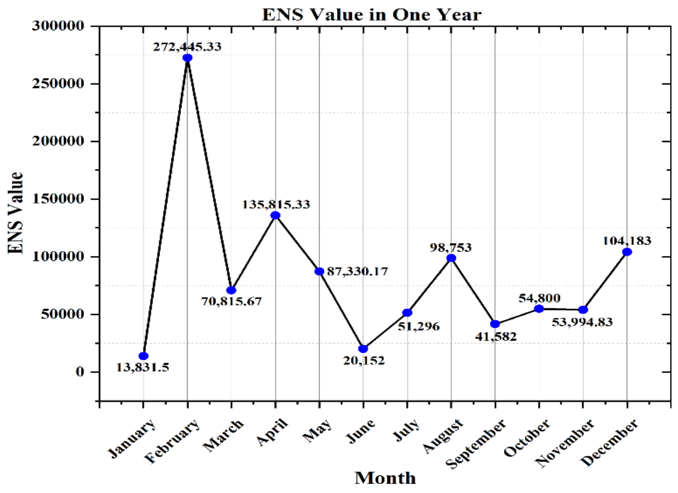

Figure 8. ENS value in one year.

Based on the results of the ENS reliability index, the value of energy lost during interference with the CWRU feeder was 1,004,998.833 kWh in 2022. Meanwhile, the average value of energy that was not distributed to customers or AENS had a value of 36,293.34 kWh/customer.

In 2022, the price of electricity for customers was IDR1,444.70/kWh, so the number of economic losses caused by disruptions to CWRU feeders during the year 2022 was IDR1,451,921,814.00 or IDR52,432.50/customer. Reducing the value of economic losses can be done by reducing the frequency of interference that occurs and reducing the duration of interference [29], [30].

IV. CONCLUSION

The customer-based reliability index on CWRU feeders in 2022 obtained a SAIFI value of 52.077 times/year in the unreliable category because the value exceeded the SPLN standard index value. The result of SAIDI value in the CWRU feeder in 2022 was 94.400 hours/customer/year with an unreliable category because it has a higher value than the standard index value set by SPLN. The CAIDI value on the CWRU repeater in 2022 received a value of 1.813 hours/times/year in the reliable category because the value is below the SPLN standard index value (meeting the standard). Meanwhile, the reliability index value based on the availability of CWRU repeaters in 2022 was said to be reliable because the availability of electricity for CWRU feeders meets the ASAI reliability index, reaching 99.828% and ASUI at 0.172%. The availability of electrical energy in CWRU feeders is included in the sufficient category characterized by the rapid response of the system in overcoming disturbances that occur. This value is influenced by the disturbances that occur in the system. Interference that occurs in CWRU feeders was predominantly caused by external factors with a percentage of 47.67%. Meanwhile, disorders caused by internal factors were fairly rare with a percentage of 10.47% and other disorders of 41.86% had unknown causative factors. Meanwhile, the value of economic losses caused by disruptions to CWRU feeders during 2022 was IDR1,451,921,814.00 or IDR52,432.50/customer.

Despite the contradicting results where SAIFI and SAIDI values imply unreliability, while CAIDI, ASAI, and ASUI values satisfy acceptable limits, the overall system status might be read as follows. The high SAIFI and SAIDI values show that customers encounter frequent and extended outages, indicating difficulties with the frequency and duration of interruptions. However, the appropriate CAIDI rating suggests that when outages occur, the utility responds efficiently to restore service. The high ASAI and low ASUI scores suggest that the system maintains a high level of availability overall. Therefore, it can be stated that while the system is effective in restoring power and sustaining availability, there is a considerable need to address the reasons causing frequent and extended outages to improve overall reliability.

In addition to evaluating traditional reliability indices such as SAIFI, SAIDI, and CAIDI, this study also highlighted the importance of local variations and operational conditions that significantly influenced the reliability of the distribution system in the PT PLN (Persero) ULP Pelabuhan Ratu Surade area. Unlike prior studies that focused largely on technical solutions such as DG, this research offered a more holistic approach by combining the economic cost of system interruptions, providing a fresh perspective in the evaluation of power distribution reliability. The findings and recommendations from this study offer realistic and focused improvements that can guide future policy and operational strategies, notably in managing external disturbances and optimizing maintenance procedures.

V. AUTHORS' CONTRIBUTIONS

Conceptualization, Tasma Sucita and Mia Agista; methodology, Maman Somantri and Mia Agista; software, Diki Fahrizal and Mia Agista; validation, Mia Agista; investigation, Tasma Sucita and Mia Agista; resources, Maman Somantri and Mia Agista; data curation, Diki Fahrizal and Mia Agista; writing—original draft preparation, Mia Agista; writing—review and editing, Diki Fahrizal; visualization, Mia Agista; supervision, Tasma Sucita and Maman Somantri; project administration, Tasma Sucita; funding acquisition, Tasma Sucita.

ACKNOWLEDGMENT

Gratitude is extended to all parties who actively contributed to the successful completion of this research, ensuring that the expected outcomes were achieved.

REFERENCES

[1] A.R. Misari, J.B. Leite, D. Piasson, and J.R.S. Mantovani, "Reliability-centered maintenance task planning for overhead electric power distribution networks," *J. Control Autom. Electr. Syst.*, vol. 31, no. 5, pp. 1278–1287, Oct. 2020, doi: 10.1007/s40313-020-00606-8.

[2] P. Li, M. Yang, and Q. Wu, "Confidence interval based distributionally robust real-time economic dispatch approach considering wind power accommodation risk," *IEEE Trans. Sustain. Energy*, vol. 12, no. 1, pp. 58–69, Jan. 2021, doi: 10.1109/TSTE.2020.2978634.

[3] S. Kumar *et al.*, "Reliability enhancement of electrical power system including impacts of renewable energy sources: A comprehensive review,"

IET Gener. Transm. Distrib., vol. 14, no. 10, pp. 1799–1815, May 2020, doi: 10.1049/iet-gtd.2019.1402.

[4] M. Jooshaki *et al.*, "Reliability-oriented electricity distribution system switch and tie line optimization," *IEEE Access*, vol. 8, pp. 130967–130978, Jul. 2020, doi: 10.1109/ACCESS.2020.3009827.

[5] B.M. Enyew *et al.*, "Techno-economic analysis of distributed generation for power system reliability and loss reduction," *Int. J. Sustain. Energy*, vol. 42, no. 1, pp. 873–888, Aug. 2023, doi: 10.1080/14786451.2023.2244617.

[6] A. Pahwa and M. Jaller, "Assessing last-mile distribution resilience under demand disruptions," *Transp. Res. E, Logist. Transp. Rev.*, vol. 172, pp. 1–25, Apr. 2023, doi: 10.1016/j.tre.2023.103066.

[7] X. Ren *et al.*, "Design of multi-information fusion based intelligent electrical fire detection system for green buildings," *Sustainability*, vol. 13, no. 6, pp. 1–15, Mar. 2021, doi: 10.3390/su13063405.

[8] N. Bhusal, M. Abdelmalak, M. Kamruzzaman, and M. Benidris, "Power system resilience: Current practices, challenges, and future directions," *IEEE Access*, vol. 8, pp. 18064–18086, Jan. 2020, doi: 10.1109/ACCESS.2020.2968586.

[9] M. Parol *et al.*, "Reliability analysis of MV electric distribution networks including distributed generation and ICT infrastructure," *Energies*, vol. 15, no. 14, pp. 1–34, Jul. 2022, doi: 10.3390/en15145311.

[10] S. Ahmad and A.U. Asar, "Reliability enhancement of electric distribution network using optimal placement of distributed generation," *Sustainability*, vol. 13, no. 20, pp. 1–16, Oct. 2021, doi: 10.3390/su132011407.

[11] B. Ghosh, A.K. Chakraborty, and A.R. Bhowmik, "Reliability and efficiency enhancement of a radial distribution system through value-based auto-recloser placement and network remodelling," *Prot. Control Mod. Power Syst.*, vol. 8, pp. 1–14, Jan. 2023, doi: 10.1186/s41601-022-00274-7.

[12] R.P. Gomes, P.C.C. Vieira, E.G. Domingues, and A.L.F. Filho, "Analysis of the impact of integrating photovoltaic solar generation on the reliability of distribution systems," in *2023 Workshop Commun. Netw. Power Syst. (WCNPS)*, 2023, pp. 1–7, doi: 10.1109/WCNPS60622.2023.10345158.

[13] M.S. Hossain, N.A. Madlool, A.W. Al-Fatlawi, and M.E.H. Assad, "High penetration of solar photovoltaic structure on the grid system disruption: An overview of technology advancement," *Sustainability*, vol. 15, no. 2, pp. 1–25, Jan. 2023, doi: 10.3390/su15021174.

[14] J.L. López-Prado, J.I. Vélez, and G.A. Garcia-Llinás, "Reliability evaluation in distribution networks with microgrids: Review and classification of the literature," *Energies*, vol. 13, no. 23, pp. 1–31, Dec. 2020, doi: 10.3390/en13236189.

[15] A. Durgadevi and N. Shanmugavadivoo, "Availability capacity evaluation and reliability assessment of integrated systems using metaheuristic algorithm," *Comput. Syst. Sci. Eng.*, vol. 44, no. 3, pp. 1951–1971, Aug. 2023, doi: 10.32604/csse.2023.026810.

[16] M. Ghanbari-Ghalehjoughi, K. Taghizad-Tavana, and S. Nojavan, "Resilient operation of the renewable energy and battery energy storages based smart distribution grid considering physical-cyber-attacks," *J. Energy Storage*, vol. 62, pp. 1–17, Jun. 2023, doi: 10.1016/j.est.2023.106950.

[17] S.R. Pani, M.K. Kar, and P.K. Bera, "Reliability assessment of distribution power network," in *2022 2nd Odisha Int. Conf. Elect. Power Eng. Commun. Comput. Technol. (ODICON)*, 2022, pp. 1–5, doi: 10.1109/ODICON54453.2022.10010301.

[18] Nazaruddin *et al.*, "Reliability analysis of 20 KV electric power distribution system," in *2nd Int. Conf. Sci. Innov. Eng.*, 2020, pp. 1–8, doi: 10.1088/1757-899X/854/1/012007.

[19] A. Azizi, B. Vahidi, and A.F. Nematollahi, "Reconfiguration of active distribution networks equipped with soft open points considering protection constraints," *J. Mod. Power Syst. Clean Energy*, vol. 11, no. 1, pp. 212–222, Jan. 2023, doi: 10.35833/MPCE.2022.000425.

[20] M.J. Abed and A. Mhalla, "Reliability assessment of grid-connected multi-inverter for renewable power generation sector," *Arab Gulf J. Sci. Res.*, vol. 42, no. 1, pp. 68–84, Jan. 2024, doi: 10.1108/AGJSR-08-2022-0149.

[21] H. Patel, B.K. Saw, A.K. Bohre, and O. Yadav, "Analyze the impact of distributed generation units on distribution system performances," in *2023 IEEE Int. Conf. Power Electron. Smart Grid Renew. Energy (PESGRE)*, 2023, pp. 1–6, doi: 10.1109/PESGRE58662.2023.10404345.

[22] O. Toirov and S. Khalikov, "Analysis of the safety of pumping units of pumping stations of machine water lifting in the function of reliability indicators," in *E3S Web Conf. IV Int. Sci. Conf. Constr. Mech. Hydraul. Water Resour. Eng. (CONMECHYDRO - 2022)*, 2023, pp. 1–8, doi: 10.1051/e3sconf/202336504010.

[23] H.M. Salman, J. Pasupuleti, and A.H. Sabry, "Review on causes of power outages and their occurrence: Mitigation strategies," *Sustainability*, vol. 15, no. 20, pp. 1–34, Oct. 2023, doi: 10.3390/su152015001.

[24] M.B. Shafik *et al.*, "Distribution networks reliability assessment considering distributed automation system with penetration of DG units and SOP devices," *Energy Rep.*, vol. 9, pp. 6199–6210, Dec. 2023, doi: 10.1016/j.egyr.2023.05.224.

[25] M. Qawaqzeh *et al.*, "The assess reduction of the expected energy not-supplied to consumers in medium voltage distribution systems after installing a sectionalizer in optimal place," *Sustain. Energy Grids Netw.*, vol. 34, pp. 1–8, Jun. 2023, doi: 10.1016/j.segan.2023.101035.

[26] S. Wang, F. Li, G. Zhang, and C. Yin, "Analysis of energy storage demand for peak shaving and frequency regulation of power systems with high penetration of renewable energy," *Energy*, vol. 267, pp. 1–17, Mar. 2023, doi: 10.1016/j.energy.2022.126586.

[27] D. Yang *et al.*, "A digital twin-driven life prediction method of lithium-ion batteries based on adaptive model evolution," *Materials*, vol. 15, no. 9, pp. 1–22, May 2022, doi: 10.3390/ma15093331.

[28] V. Vita *et al.*, "Predictive maintenance for distribution system operators in increasing transformers' reliability," *Electronics*, vol. 12, no. 6, pp. 1–23, Mar. 2023, doi: 10.3390/electronics12061356.

[29] H. Prasad C, K. Subbaramaiah, and P. Sujatha, "Optimal DG unit placement in distribution networks by multi-objective whale optimization algorithm & its techno-economic analysis," *Electr. Power Syst. Res.*, vol. 214, pp. 1–11, Jan. 2023, doi: 10.1016/j.epsr.2022.108869.

[30] G.A. Putri, A.K. Widagdo, and D. Setiawan, "Analysis of financial technology acceptance of peer to peer lending (P2P lending) using extended technology acceptance model (TAM)," *J. Open Innov., Technol. Mark. Complex.*, vol. 9, no. 1, pp. 1–12, Mar. 2023, doi: 10.1016/j.joitmc.2023.100027.