

Reliability of 20kV Distribution Network Power Systems Using the Reliability Network Equivalent Approach (RNEA) Method

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Abstract – The reliability of the electrical power distribution system is a major factor in ensuring continuous power supply to customers. This study applies the Reliability Network Equivalent Approach (RNEA) to calculate key reliability parameters for the SGN02 feeder. The analysis results show a SAIDI value of 3.932 hours/customer/year and a SAIFI of 2.18 failures/customer/year. These values indicate that the SGN02 feeder system has met the national standard SPLN 68-2:1986 (SAIDI < 21; SAIFI < 3.2). However, the system has not yet met the international standard IEEE Std 1366-2003, as the SAIDI exceeds 2.3 and SAIFI exceeds 1.45. Overall, this study concludes that system reliability can be improved through the implementation of a semi-loop configuration and the addition of smart reclosers.

Keywords: *Distribution System Reliability, RNEA, SAIDI, SAIFI, SPLN 68-2:1986, IEEE 1366-2003.*



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I. INTRODUCTION

The demand for electricity, particularly at PT PLN (Persero) Magelang Kota, continues to rise steadily each year, in line with economic progress and applicable regulations. Distribution system performance refers to the extent to which a system or its elements successfully achieve the best results under specific conditions and time frames. To assess the performance of a system, a study is required through calculations and evaluations of its effectiveness over a certain period, which is then compared with previously established criteria [1]. Repeated power outages, whether planned or unplanned, emphasize the importance of assessing the reliability of the electricity distribution system. The resilience of the distribution system can be measured using a reliability index and adjusted to national standards, namely PLN Standards [2].

The reliability of the distribution network plays an

important role in ensuring that the electricity distribution system runs normally and meets the established standards. Some of the reliability indices that are often used include the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI) [3]. The reliability of the electrical energy distribution system indicates the system's ability to distribute electricity efficiently and stably to consumers. This aspect is a major component in the electricity distribution process. Disruptions from internal or external factors that cause long-duration and high-frequency outages can reduce the level of system resilience and cause economic losses from unsupplied energy [4]. There are various analysis techniques that can be applied to assess the resilience of the electricity distribution system, including the Reliability Network Equivalent Approach (RNEA) method.

The Reliability Network Equivalent Approach (RNEA) is specifically chosen for this study because it offers a more efficient calculation for complex radial networks compared to other common methods like the Section Technique. RNEA simplifies the network into equivalent series and parallel models, allowing for precise reliability indexing of feeders with high load-point density, such as the SGN02 feeder which consists of 108 load points. This approach ensures that technical bottlenecks are identified systematically without losing computational accuracy.

According to SPLN No.68-2 1986, an electrical energy distribution network system is considered reliable if the SAIDI reliability index value reaches 21 hours/customer/year and SAIFI reaches 3.2 times/customer/year. The SAIDI index measures the total outage time or duration of outages relative to the number of customers in a year, while SAIFI calculates the frequency of outages on the electrical energy distribution network relative to the number of customers in the same period. In a previous study

using the RNEA method, the reliability index obtained did not meet the reliability criteria because its value exceeded the SPLN 68-2 1986 standard limit [5]. Another study with a similar approach showed that the length of the system line is directly proportional to the decrease in resilience value [6]. However, this study has limitations because it did not apply efforts to improve system resilience.

This study was conducted to fill the gap from previous studies that did not specifically apply the RNEA method in distribution network reliability analysis. The focus of the study was on the SGN02 feeder at PT. PLN (Persero) ULP Magelang Kota, which, based on 2024 data, experienced many disturbances due to trees in the network area. Of the 14 feeders, SGN02 is the main feeder directly connected to the Sangrahan Substation (GI) and supplies important loads such as KODIM, KPU, RINDAM, and the Public Service Mall. The complexity of the network structure, which has many branches and switching equipment, makes this feeder relevant for reliability analysis.

The 20 kV power distribution system plays an important role in maintaining continuity of power supply to customers [11]. However, in the field, there are still high frequencies of disruptions and long durations of outages, as occurred in the SGN02 feeder of PT PLN (Persero) ULP Magelang Kota. To address these issues, the author applied the Reliability Network Equivalent Approach (RNEA) method to conduct a comprehensive and efficient analysis of network reliability. The purpose of this study is to calculate the reliability level of the 20 kV SGN02 distribution system based on 2024 outage data and to determine whether the feeder meets the national reliability standard SPLN 68-2:1986 and the international standard IEEE Std 1366-2003, so that the results can be used as a basis for technical evaluation and recommendations for improving the distribution system in the Magelang Kota area.

II. BASIC OF THEORY

The Magelang regional electricity system is interconnected through a 150 KV and 70 KV high-voltage overhead transmission line (SUTT) network between the power plant in Mrica (PLTA) and the power plants in Semarang (PLTG, PLTGU, and PLTU), as well as several power plants that are interconnected through a 20 KV medium-voltage network (JTM) [8].

A. Electric Power Distribution System

The distribution system is part of the electric power system. The distribution system is used to distribute electrical power from the power source to consumers. Electrical power generated by large power plants with voltages ranging from 6 kV to 11 kV to 24 kV is increased by substations with step-up transformers to 150 kV or 500 kV and then distributed through transmission lines. From the transmission lines, the voltage is then stepped down again to 20 kV using

step-down transformers at distribution substations. The electricity is then distributed through primary distribution lines and stepped down using distribution transformers to a low-voltage system, namely 220V/380V.

B. Network Configuration

The primary distribution network configuration is medium voltage (20 kV) for electrical energy from the substation to load centers. The type of network configuration that is often used is a radial pattern. This network is commonly used to serve areas with low load density. The advantages are simplicity in terms of technical aspects and low investment costs. However, the disadvantage is that if a disturbance occurs near the source, all loads on that line will also be shut down until the disturbance can be resolved. The simple radial configuration is considered unable to meet the reliability requirements of a distribution system, so a variation called the loop configuration was developed. The loop configuration is a combination of two radial network structures, where a switch in the form of an ABSW or LBS [10] is installed at the end of the two networks. The following is an illustration of the radial configuration in Figure 1.

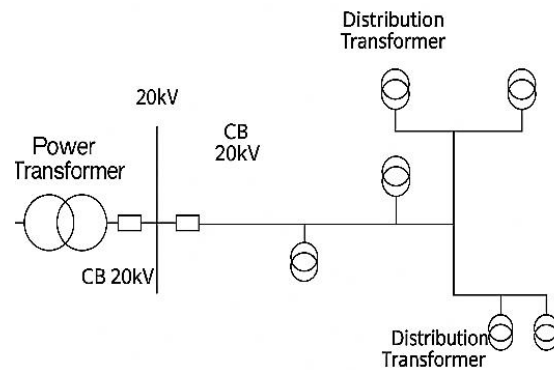


Figure 1. Radial configuration

C. Distribution System Reliability

Distribution system reliability is closely related to load shedding issues resulting from system disturbances. Distribution system reliability is inversely proportional to the level of system load shedding. The higher the frequency of load shedding in the system, the lower the system reliability, and vice versa [9]. A system with high reliability will be able to provide electricity whenever it is needed, while a system with low reliability will have low power availability, i.e., frequent outages [7]. The reliability index is a reliability parameter expressed in a probability quantity, which consists of a system index and a load point index. The reliability indices that are often used are SAIFI (System Average Interruption Frequency Index) and SAIDI (System Average Interruption Duration Index) [12].

III. METHOD

This study uses a quantitative calculation-based approach to determine the resilience index value in distribution network systems through the application

of the Reliability Network Equivalent Approach (RNEA) method. This was carried out on a 20 kV distribution network power system, focusing on the SGN 02 feeder managed by PT. PLN (Persero) Magelang Kota. The data used was historical data on disturbances in the SGN02 feeder over a one-year period, namely 2024. The data included the number of customers at each load point, the total number of customers, and the factors causing the disturbances. Several steps were taken in analyzing the resilience of the distribution system, as follows:

A. Reliability Index

The following equation is used to calculate the frequency and duration of outages

$$\lambda_{LP} = \sum_{i=k} \lambda_i \quad (1)$$

$$U_{LP} = \sum_{i=k} \lambda_i \cdot r_j \quad (2)$$

Explanation :

λ_{LP} = Load point failure frequency

λ_i = Failure rate of each piece of equipment K

K = All types of equipment that affect the load point

U_{LP} = Average annual failure

r_j = Repair time

B. Reliability Network Equivalent Approach Method (RNEA)

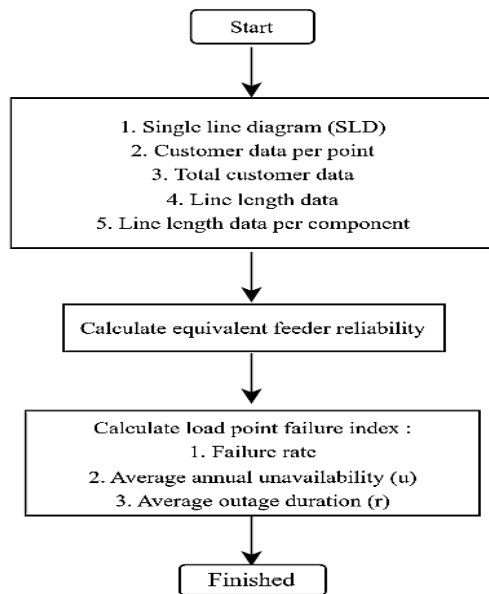


Figure 2. Flowchart RNEA

The failure rate (λ) and repair time (r) data for equipment such as Circuit Breakers (CB), Transformers, and Reclosers are based on the historical performance standards and maintenance records provided by PT PLN (Persero) ULP Magelang Kota. The flowchart in Figure 2 is enhanced by clarifying that the "Calculate equivalent feeder reliability" stage involves grouping components into sections (Sections 1–5) based on their protection zones. In Section 1, the total failure rate (λ) is calculated at 0.289 failures/year, incorporating the

specific failure rates of the CB (0.004) and Transformer (0.005). The failure rate (λ) and repair time (r) data for primary equipment—including Circuit Breakers (0.004), Transformers (0.005), and Reclosers (0.003) are derived from the historical reliability database and maintenance standards of PT PLN (Persero) ULP Magelang Kota. This site-specific data ensures that the equivalent network results reflect the actual environmental and operational conditions of the Magelang electricity system.

The study began with the collection of Single Line Diagram (SLD) data. At this stage, the feeder was simplified to produce an equivalent network. Next, reliability calculations are performed to obtain the values of λ and U . After obtaining these values, the load point failure index is calculated to obtain the failure rate of each load point (λ_{LP}), the annual unavailability of each load point, and the average outage duration (r). The final stage involves obtaining the system resilience index values, namely SAIDI and SAIFI, which are then compared based on the SPLN 68-2 1986 and IEEE 1366-2003 standards.

IV. RESULTS AND DISCUSSION

Secondary data (monitoring data at PT. PLN (Persero) ULP Magelang Kota) was processed by performing calculations using the Reliability Network Equivalent Approach (RNEA) method as follows. Based on SLD Feeder SGN02, there are 108 load points and a total of 14,703 customers on feeder SGN02. There are lines that connect one piece of equipment to another. Table 1 shows data on the length of the SGN02 line, which has 11 lines with a total length of 11.9 km using AAAC 240 mm² conductors. According to SPLN 64: 1985, the AAAC 240 mm² conductor has a positive sequence impedance (ohm/km) of 0.1344 + j0.3158 and a zero sequence impedance (ohm/km) of 0.2824 + j1.6034. To determine the index value, the first step is to calculate the failure rate (λ) of each component [9]. This process determines the number of outages that occurred on the SGN02 feeder during a one-year period. The next step is to determine the annual unavailability value (U) by multiplying the failure rate (λ) of the component by the repair time, which is expressed as r . The λ value can be obtained through equations (14) and (15), while the magnitude of the λ value can be referred to in Tables 1 and 2 below:

Table 1. Calculation Results (λ) Section 1

Equipment	Equipment failure	Line length(km)	Failure rate(λ)
CB	0,004	-	0,004
Trafo	0,005	-	0,005
L1	0,2	0,1	0,020
L2	0,2	0,5	0,100
L3	0,2	0,8	0,160
	TOTAL		0,289

Table 2. Calculation Results (U) Section 1

Equipment	Failure rate(λ)	Repair time (hours)	unavailability (U)
CB	0,004	10	0,04
Trafo	0,005	10	0,05
L1	0,020	3	0,06
L2	0,100	3	0,3
L3	0,160	3	0,48
TOTAL			0,93

Based on the calculation results for Section 1, the total failure rate (λ) is 0.289 failures/year, with an annual unavailability (U) of 0.93 hours/year. These values are influenced by the presence of major system components, including the circuit breaker (CB), distribution transformer, and three line segments (L1–L3). The largest contribution to both λ and U originates from lines L2 and L3, which have longer lengths compared to L1. This indicates that in the initial section of the feeder, line length remains a dominant factor affecting system reliability, even though primary protection devices are already installed.

Table 3. Calculation Results (λ) Section 2

Equipment	Equipment failure	Line length(km)	Failure rate(λ)
Trafo	0,005	-	0,005
L4	0,2	0,4	0,08
L5	0,2	1,2	0,24
L6	0,2	0,7	0,14
TOTAL			0,485

Table 4. Calculation Results (U) Section 2

Equipment	Failure rate(λ)	Repair time (hours)	unavailability (U)
Trafo	0,005	-	0,005
L4	0,2	0,4	0,08
L5	0,2	1,2	0,24
L6	0,2	0,7	0,14
TOTAL			0,485

Proceeding to Section 2, the calculated annual unavailability decreases to 0.485 hours/year, which is lower than that of Section 1. This reduction is primarily due to the absence of a circuit breaker and the relatively shorter cumulative line length in this section. Nevertheless, line L5 contributes the highest failure rate within Section 2 because of its length of 1.2 km, indicating that longer line segments continue to increase the likelihood of disturbances. This condition confirms that, in radial distribution systems, line length is directly proportional to the risk of outages, regardless of the number of protection devices present

Table 5. Calculation Results (λ) Section 3

Equipment	Equipment failure	Line length(km)	Failure rate(λ)
Trafo	0,005	-	0,005
Recloser	0,003	-	0,003
L7	0,2	0,6	0,12
L8	0,2	1,6	0,32
TOTAL			0,918

Table 6. Calculation Results (U) Section 3

Equipment	Failure rate(λ)	Repair time (hours)	unavailability (U)
Trafo	0,005	10	0,05
Recloser	0,003	10	0,03
L7	0,12	3	0,36
L8	0,32	3	0,96
TOTAL			1,4

In Section 3, a significant increase in system unavailability is observed, with a total U of 1.4 hours/year. This increase is attributed to the addition of line L8 (1.6 km) and the presence of a recloser, which, although functioning as an automatic protection device, still contributes to the overall failure rate. This section demonstrates that in the middle part of the feeder, increased network complexity and accumulated line length substantially affect reliability, particularly in terms of outage duration

Table 7. Calculation Results (λ) Section 4

Equipment	Equipment failure	Line length(km)	Failure rate(λ)
Trafo	0,005	-	0,005
Sectionalizer	0,003	-	0,003
L9	0,2	2	0,4
L10	0,2	0,4	0,08
TOTAL			0,488

Table 8 Calculation Results (U) Section 4

Equipment	Failure rate(λ)	Repair time (hours)	unavailability (U)
Trafo	0,005	10	0,05
Sectionalizer	0,003	10	0,03
L9	0,4	3	1,2
L10	0,08	3	0,24
TOTAL			1,52

Furthermore, Section 4 exhibits a higher annual unavailability of 1.52 hours/year, representing one of the highest values among the analyzed sections. This condition is mainly caused by line L9, which has a length of 2 km and constitutes the longest segment in this section. Although a sectionalizer is installed to limit the affected outage area, the excessive line length results in a dominant contribution to system unavailability. This finding indicates that the effectiveness of protection devices must be supported by proper network configuration to significantly reduce outage impacts.

Table 9. Calculation Results (λ) Section 4

Equipment	Equipment failure	Line length(km)	Failure rate(λ)
Trafo	0,005	-	0,005
L11	0,2	3,6	0,72
TOTAL			0,0036

Table 10. Calculation Results (U) Section 5

Equipment	Failure rate(λ)	Repair time (hours)	unavailability (U)
Trafo	0,005	10	0,05
L11	0,72	3	2,16
TOTAL			2,21

Finally, Section 5 records the highest annual unavailability, amounting to 2.21 hours/year, which is predominantly influenced by line L11 with a length of 3.6 km. This section is located at the end of the feeder, making it highly susceptible to external disturbances such as vegetation, weather conditions, and environmental factors. Despite the relatively small number of installed components, the extreme line length leads to prolonged outage durations experienced by customers. This result confirms that end-of-feeder segments represent critical reliability points that require special attention in protection planning and maintenance strategies.

These indices provide an overview of the performance of the distribution system, which depends on the duration and frequency of disruptions experienced by customers over a full year. The SAIDI and SAIFI indices are calculated using equations (7) and (8) as follows.

The calculation to find the SAIDI value, or the average customer outage duration, requires outage data and customer data from ULP Persero Magelang Kota. The SAIDI value is calculated for the 2024 period. Therefore, the outage data required includes the duration of customer outages on a monthly basis and the number of customers experiencing outages on a monthly basis, while the customer data required is the total number of customers served during the year, as explained above.

$$SAIDI = \frac{\sum(U_i \times N_i)}{\sum N_t}$$

$$SAIDI = \frac{57805,366}{17703}$$

$$SAIDI = 3,932 \text{ hours/customer}$$

To find the SAIFI value, or average customer outage frequency, data on disruptions and customer data from ULP Persero Magelang Kota are required. In this study, the SAIFI to be calculated is for the 2024 period.

$$SAIFI = \frac{\sum(\lambda_i \times N_i)}{\sum N_t}$$

$$SAIFI = \frac{32049,954}{14703}$$

$$SAIFI = 2,18 \text{ failures/year}$$

From the results obtained, the reliability index obtained through the RNEA approach shows that SAIDI is 3.932 hours/customer per year, and SAIFI is 2.18 failures/customer per year. This occurs because the feeder has a fairly long route and is made of complex parts or tools.

The disparity in performance between the national and international standards indicates that the existing condition of the SGN02 distribution system can be considered reasonably reliable but not yet optimal. Several key factors contribute to the system's inability to fully meet the IEEE standard, including the total line length of 11.9 km, the radial network configuration without backup feeders, and the limited number and suboptimal placement of automatic protection devices such as reclosers and sectionalizers, particularly at the feeder end segments. In addition, external disturbances such as vegetation and adverse weather conditions also contribute to increased outage duration, even though the interruption frequency remains relatively controlled.

Overall, this comparative analysis indicates that the SGN02 feeder distribution system has met the national reliability standard SPLN 68-2:1986 and is therefore still adequate within the context of national electricity service. Nevertheless, to achieve compliance with the international reliability standard IEEE Std 1366-2003, further improvements are required, particularly in reducing outage duration through network configuration optimization, the addition of automation-based protection devices, and the enhancement of preventive maintenance programs on line segments that contribute most significantly to system disturbances. The resulting data are presented as follows:

Table 11 RNEA calculation results

Indeks	RNEA Result	SPLN	IEEE	SPLN Status	IEEE Status
SAIDI	3,932	21	2,3	Met	Not Met
SAIFI	2,18	3,2	1,45	Met	Not Meet

Based on the results in Table 11, the SAIDI value of 3.932 and SAIFI of 2.18 demonstrate that the SGN02 feeder is reliable under the national SPLN 68-2:1986 criteria. However, the system is considered 'not met' by the stricter IEEE Std 1366-2003 standards (SAIDI limit 2.3; SAIFI limit 1.45). The primary factor contributing to this gap is the cumulative line length of 11.9 km, particularly in Section 5 (L11) which reaches 3.6 km. This extreme length increases the probability of external disturbances such as vegetation and weather, which directly correlates to the higher frequency of interruptions observed at the end-of-feeder segments.

Based on the RNEA calculation, the SGN02 feeder achieves a SAIDI of 3.932 hours/customer/year. While this is well within the SPLN 68-2:1986 limit of 21 hours, it exceeds the IEEE Std 1366-2003 benchmark of 2.3 hours. Furthermore, the SAIFI value of 2.18 failures/customer/year has surpassed the IEEE standard of 1.45, although it remains below the SPLN limit of 3.2. The highest annual unavailability was found in Section 5 (2.21 hours/year) due to the extreme length of line L11 (3.6 km), confirming that line length is the dominant factor in system failure. To mitigate these figures and bring

them closer to international standards, technical simulations suggest that adding automation-based protection can significantly reduce these indices.

However, when these results are compared with the IEEE Std 1366-2003 standard, which specifies a SAIDI limit of 1.45 hours/customer/year and a SAIFI limit of 2.30 interruptions/customer/year, a different conclusion is obtained. The calculated SAIDI value still exceeds the IEEE threshold, indicating that the average outage duration experienced by customers is longer than the international reliability target. Meanwhile, the SAIFI value of 2.18 interruptions/customer/year complies with the IEEE standard, although the margin is relatively small and close to the maximum allowable limit.

System Average Interruption Duration Index (SAIDI) value based on SPLN 68-2:1986 and IEEE 1366-2003 standards. The calculation in Figure 3 shows the SAIDI value calculation results for a one-year period compared to the SPLN 68-2:1986 AND IEEE 1366-2003 standards. It shows a better interruption duration (SAIDI) compared to the SPLN 68-2 1986 standard, even though the value is below the SPLN 68-2 1986 standard limit (21 hours/customer/year). This figure indicates a gap below the IEEE STD 136602003 standard (2.30 hours/customer/year), indicating the need for improvement efforts to maintain low SAIDI values in line with future customer growth.

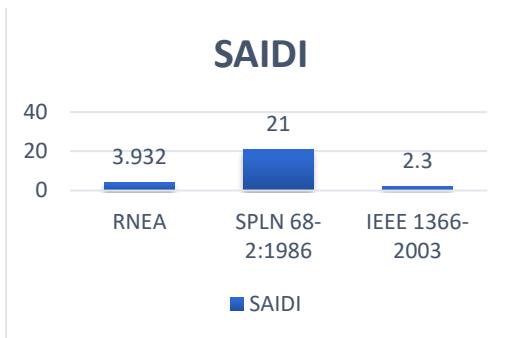


Figure. 3 SAIDI reliability index comparison chart

System Average Interruption Frequency Index (SAIFI) values based on SPLN 68-2:1986 and IEEE 1366-2003 standards. The calculation in Figure 4 shows the results of the SAIDI value calculation for a one-year period compared to the SPLN 68-2:1986 AND IEEE 1366-2003 standards. The calculated SAIFI index value shows a higher frequency of distribution system outages than all established standards, indicating that customers experience more frequent outages. Therefore, the system condition is considered concerning because customers experience outages more frequently.

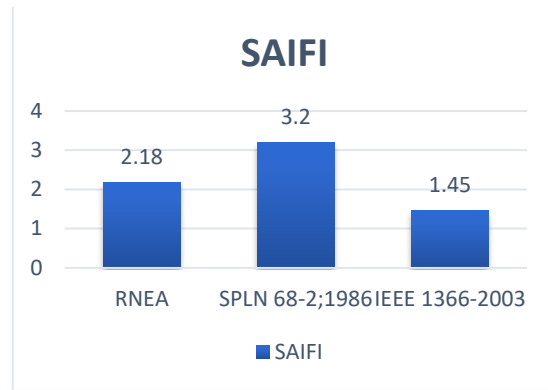


Figure 4. SAIFI reliability index comparison chart

After considering all aspects, the conclusion that can be drawn is that the SAIFI and SAIDI indices in the SGN02 feeder have not yet reached the IEEE 1366-2003 standard due to the influence of a fairly large network length, limited protection tools, radial arrangement, and a level of automation that is not yet optimal. However, this system is still considered reliable nationally according to SPLN 68-2:1986, with the ability to demonstrate a short recovery time and a fault frequency that is still within PLN tolerance. By implementing a semi-loop configuration, adding reclosers, and fully integrating with SCADA, the reliability of the SGN02 system can be improved to approach IEEE standards in the future.

The results of the SAIDI and SAIFI calculations for the 20 kV distribution system of ULP Magelang Kota are presented in Table 12, which compares SAIDI and SAIFI values based on the SPLN 68-2:1986 and IEEE 1366-2003 standards. The SAIFI value shows a significantly higher result compared to the established standards. This high interruption frequency is caused by the load point between L9 and L11, which is classified as a segment with one of the longest line lengths and is located at the end of the feeder, making it highly susceptible to external disturbances such as vegetation, weather conditions, and animals. The length of the line segment is directly proportional to the frequency of disturbances; the longer the segment, the higher the probability of interruptions occurring. The results indicate that the system can be considered reliable according to the radial system configuration standard SPLN 68-2:1986; however, it does not yet comply with the IEEE 1366-2003 standard.

In general, there are two approaches to improving the reliability of an electric power system: the first is reducing the frequency of interruptions, and the second is minimizing the duration of interruptions. Based on the data above, it can be analyzed that most disturbances are caused by external factors or unpredictable events from the utility side, primarily due to natural conditions. However, these disturbances can be mitigated through the following measures:

1. Performing routine maintenance of the medium-voltage distribution equipment (JTM) to reduce the occurrence of interruptions.

2. Install additional reclosers/sectionalizers to anticipate temporary disturbances, particularly in segments L9 and L11.
3. Evaluate the coordination settings of the protection system on the 20 kV system to optimize the performance of safety measures on the distribution network.

V. CONCLUSION

The analysis concludes that the SGN02 feeder at PT PLN ULP Magelang Kota satisfies the national reliability criteria based on SPLN 68-2:1986. Nevertheless, the system does not yet reach the international performance benchmarks of IEEE Std 1366-2003 due to the radial configuration and extensive line segments. To bridge this gap, it is recommended to implement a semi-loop network configuration and install additional smart reclosers in segments L9 and L11 to optimize protection coordination and reduce recovery times.

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