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Evaluation of Reliability and Energy Not Supplied in the 20 kV Distribution System at the Tanjung Api-Api Substation

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ABSTRACT

The reliability of the electric power distribution system is essential for life, economy, health and safety. This reliability can be assessed from several indicators, including SAIDI, SAIFI, and ENS which can describe the economic impact of blackouts. The results of the calculation in this study show that the SAIDI and SAIFI values for four Feeders at the Tanjung Api-api Substation are in a reliable state when viewed from the PLN Target that has been set, and are not reliable for Feri Feeders, namely SAIDI at Feri Feeders of 6.003570985 hours/year, Kargo Feeders of 0.272152778 hours/year, Pinisi Feeders of 0.771065263 hours/year and Roro Feeders of 1.477902547 hours/year. As for SAIFI on Feri Feeders amounting to 3.230883689 times/customer/year, Kargo Feeders 0.16666667 times/customer/year, Pinisi Feeders 0.836271676 times/customer/year and Roro Feeders 1.67529189 times/customer/year. For the ENS value index on the four Feeders based on the calculation results, 396,201.8423 kWh was obtained with a loss of Rp. 536,118,758.6 kWh, in the Feri Feeders that was not distributed energy of 319,128.4392 kWh with a loss of Rp. 431,461,649.8, in the Kargo Feeders of 4,896.091948 kWh with a loss of Rp. 7,073,384,037, in the Pinisi Feeders of 7,136.846081 kWh with a loss of Rp. 9,649,015,901 and in the Roro Feeders of 65,040.46513 kWh with a loss of Rp. 87,934,708.86. The results show that the higher the unchanneled energy, the greater the losses experienced by PT. PLN (Persero).

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1. INTRODUCTION

Electricity is secondary energy that is generated and distributed to meet daily needs. An electric power system involves three main components: generation, transmission, and distribution. Power plants generate electrical energy from mechanical energy through generators that are rotated by turbines. The transmission transports electricity from the plant to the substation by raising the voltage to reduce power loss. This process uses high voltage air ducts (SUTT) or extra high air ducts (SUTET) [1]. Distribution distributes electricity from substations to consumers. It consists of a primary distribution that lowers the voltage from 20 kV to medium voltage, and a secondary distribution that lowers the voltage further to 220/380V for end use. Distribution is carried out through feeders in air ducts or underground cables [2].

The 20 kV Distribution System is a key element in the electrical infrastructure that connects the transmission network with customers [3]. The reliability and quality of these systems greatly affect the electricity supply to customers. Reliability involves probability, performance, time period, and operating conditions, and aims to ensure continuity, minimize outages, and maintain low voltage quality and loss. Reliability refers not only to the likelihood of failure but also to the number, duration, and frequency of failures, and can be analyzed with probability theory. Reliability also considers the failure mode and its impact for system comparison [4] [5].

PT. PLN (Persero) is responsible for the distribution and supply of electricity in Indonesia, with PT. PLN UP2D S2JB manages distribution in certain areas. The performance of these units is measured by the

SAIFI and SAIDI indices, which assess the frequency and duration of outages. Moreover Energy Not Supplied (ENS) is also used to measure system reliability based on unsupplied energy [6] [7]. Previous research has been conducted and discussed reliability indexes on 20 kV distribution systems but did not address ENS [8]. This study will analyze the reliability and ENS of the 20 kV Distribution System at the Tanjung Api-api Substation, by comparing the results with IEEE standards and the cost of losses due to blackout disruptions in 2022.

2. METHOD

The research was carried out by case study, conducting an assessment of technical data that occurred at the Tanjung Api-api Substation. The data obtained will then be evaluated by performing mathematical calculations to obtain reliability index values and compare the results with the PLN Target in 2022 and IEEE 2022 standards.

2.1 PLN’s Target for 2022 and IEEE Standards for 2022

PLN's 2022 target and IEE Standards for 2022 for the SAIDI and SAIFI reliability indices can be seen in Table 1 and Table 2 below [9][10]:

Table 1. PLN's Target in 2022

	PLN's Target in 2022			
SAIDI	858,5	Minutes/Customers/Years	14, 30833333	Hours/Subscribers
SAIFI	8,26	Times/Customers/Years		

Table 2. IEEE Standards in 2022

	IEEE Std 1366-2022			
SAIDI	125,7	Minutes/Subscribers/Years	2,095	Hours/Subscribers
SAIFI	1,1	Times/Customers/Years		

2.2 SAIDI (System Average Interruption Duration Index)

SAIDI is an indicator of the reliability of the electric power distribution system which is calculated by dividing the total time of the system outage and the number of customers who experience an outage by the number of customers with the unit of time/customer [6].

$$SAIDI = \frac{\sum(ri \times Ni)}{\mathrm{Nt}} \quad (1)$$

where

ri = Average duration of outage per year (hours/year)
Ni = Number of customers outgoing
Nt = Total number of customers

2.3 SAIFI (System Average Interruption Frequency Index)

SAIFI is a reliability index whose calculation consists of multiplying the frequency of Feeder outages by the total number of customers. The unit of calculation for the SAIFI index is per customer by default with the unit of times/customer [6].

$$SAIFI = \frac{\sum \mathrm{Ni}}{\mathrm{Nt}} \quad (2)$$

where

Ni = Number of customers outgoing
Nt = Total number of customers

2.4 ENS (Energy Not Supplied)

ENS is unchanneled or delivered energy, which refers to the amount of energy allocated to customers that is lost due to a network outage or failure. This index represents the total energy that is not distributed by the system [6][11].

$$ENS = \sum Lavg \times ri \quad (3)$$

where

$Lavg$ = Active Power
ri = Duration of blackout time

Cost Loss = kWh x TDL (4)

where

kWh = Results obtained from ENS

TDL = Basic electricity tariff which is subsidized by PT. PLN (Persero)

This research process is carried out based on the research flow diagram depicted in Figure 1 below:

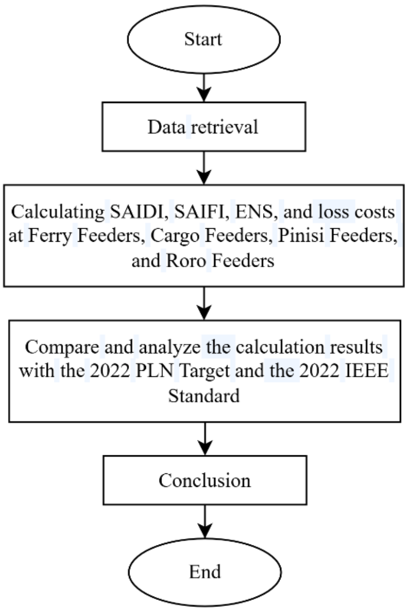

Figure 1. Research Flow Diagram

3 RESULTS AND DISCUSSION

3.1. Tanjung Api-Api Substation Data

In this study, the author only used data from the Tanjung Api-api Substation which is located in the South Sumatra region, precisely the city of Palembang which consists of 4 Feeders, namely Feri Feeders, Kargo Feeders, Pinisi Feeders and Roro Feeders.

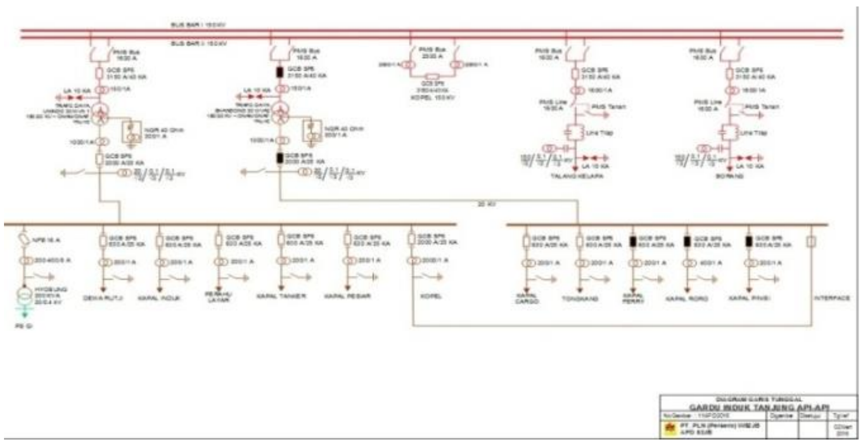

Figure 2. Tanjung Api-Api Substation

3.2. Data on the Number of Customers Outgoing at Tanjung Api-Api Substation

Table 3 is data on the number of customers at Feri Feeders, Kargo Feeders, Pinisi Feeders, and Roro Feeders, with the number of each outage that occurred in 12 months during 2022.

Table 3. Number of Customers Outgoing at Tanjung Api-Api Substation

Feeder	Number of Customers	Number of Customers Outgoing in the Month of											
		1	2	3	4	5	6	7	8	9	10	11	12
Feri	10.641	5	2	3	5	1	6	8	10	4	5	2	7
Kargo	3	0	0	0	1	0	1	0	0	0	0	0	0
Pinisi	3.460	1	4	0	0	0	0	1	0	1	3	1	1
Roro	3.169	3	2	4	2	3	3	0	2	1	8	4	7
Total	17.273	9	8	7	8	4	10	9	12	6	16	7	15

3.3. Blackout Time Data at Tanjung Api-Api Substation

Table 4 is data on the number of outage times in hours that occurred at Feri Feeders, Kargo Feeders, Pinisi Feeders, and Roro Feeders that occurred for 12 months in 2022.

Table 4. Blackout Time at Tanjung Api-Api Substation

Month	Feeder			
	Feri	Kargo	Pinisi	Roro
January	16,33305556	Not Blackout	1,486388889	1,652222222
February	4,605277778	Not Blackout	4,376944444	2,423888889
March	5,145	Not Blackout	Not Blackout	2,865555556
April	10,12361111	1,665833333	Not Blackout	0,736666667
May	0,72	Not Blackout	Not Blackout	3,253055556
June	14,16388889	1,6	Not Blackout	2,8066666667
July	7,852777778	Not Blackout	0,600833333	Not Blackout
August	18,9975	Not Blackout	Not Blackout	2,016666667
September	6,320277778	Not Blackout	1,890555556	0,373055556
October	6,8125	Not Blackout	1,814166667	12,53222222
November	2,273888889	Not Blackout	0,713888889	2,71
December	7,943888889	Not Blackout	0,986111111	6,373333333

3.4. Calculation of the SAIDI and SAIFI Reliability Index

3.4.1. Feri Feeders

Table 5 is a reliability index data consisting of data on the number of outage times in hours, data on the total number of customers and data on customers who experienced outages that occurred at Feri Feeders, which occurred for 12 months in 2022.

Table 5. Reliability Calculation Data at Feri Feeders

Month	Blackout Time x Customer Outgoing	Number of Customers Served	Customers Outgoing	SAIDI	SAIFI
January	129106,0956	10.641	37465	12,13289123	3,520815713
February	30882,99278	10.641	13412	2,902264146	1,260407856
March	41410,48111	10.641	24053	3,891596759	2,260407856
April	93558,25278	10.641	41400	8,792242532	3,890611785
May	4828,32	10.641	6706	0,453746828	0,630203928
June	94983,03889	10.641	40236	8,926138416	3,781223569
July	52660,72778	10.641	53648	4,948851403	5,041631426
August	162589,2517	10.641	74930	15,27950866	7,041631426
September	42383,78278	10.641	26824	3,983063883	2,520815713
October	45684,625	10.641	33530	4,293264261	3,151019641
November	15248,69889	10.641	13412	1,43301371	1,260407856
December	53271,71889	10.641	46942	5,006269983	4,411427497
Sum	766607,9862	10641	412558	72,04285181	38,77060427

To find the value of the SAIDI index per year using equation (1), then divide by the number of customers served (Nt) and divide by 12 months, as follows:

SAIDI = = $\frac{766607,9862}{10.641}$ = 72.04285181

SAIDI = $\frac{72,04285181}{12} = 6.003570985$ hours/year

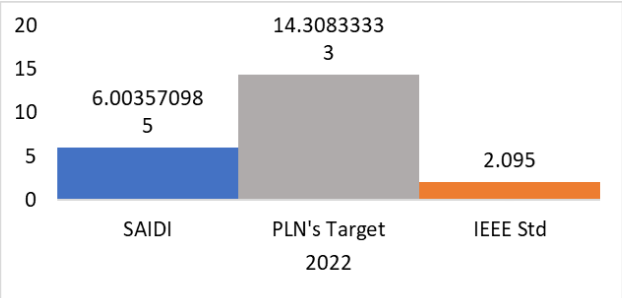

Figure 3. SAIDI Achieved VS PLN Target VS IEEE Standard for Feri Feeders

To find the value of the SAIFI index per year using equation (2), then divide by the number of customers served (Nt) divided by 12 months, as follows:

SAIFI = $\frac{412558}{10.641}$ = 38.77060427

SAIFI = $\frac{38{,}77060427}{12}$ = 3.230883689 times/customer/year

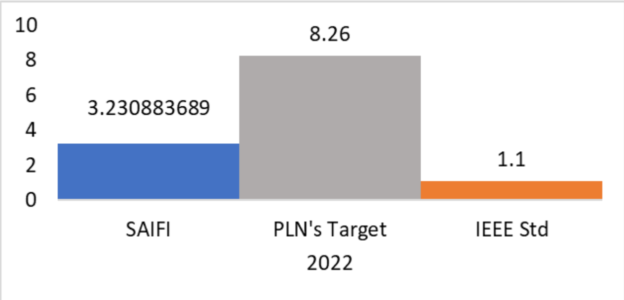

Figure 4. SAIFI Achieved VS PLN Target VS IEEE Standard for Feri Feeders

Analysis of the reliability index on the SAIDI indicator on the 2022 Feri Feeders is 6.003570985 hours/year, showing that the reliability of the Feri Feeder is in a reliable state when compared to the PLN 2022 target, but when compared to the IEEE 2022 standard, this index is categorized as unreliable. The SAIFI Indicator of 3.230883689 times/customer/year, shows that this value is reliable when compared to the PLN 2022 target and unreliable when compared to IEEE standards.

3.4.2. Kargo Feeders

Table 6 is a reliability index data consisting of data on the number of outage times in hours, data on the total number of customers and data on customers who experienced outages that occurred at Kargo Feeders, for 12 months in 2022.

Table 6. Reliability Calculation Data at Kargo Feeders

Month	Blackout Time x Customer Outgoing	Number of Customers Served	Customers Outgoing	SAIDI	SAIFI
January	0	3	0	0	0
February	0	3	0	0	0
March	0	3	0	0	0
April	4,9975	3	3	1,66583	1
May	0	3	0	0	0
June	4,8	3	3	1,6	1
July	0	3	0	0	0
August	0	3	0	0	0
September	0	3	0	0	0
October	0	3	0	0	0
November	0	3	0	0	0
December	0	3	0	0	0
Total	9,7975	3	6	3,26583	2

To find the value of the SAIDI index per year using equation (1), then divide by the number of customers served (Nt) and divide by 12 months, as follows:

SAIDI = = $\frac{9{,}7975}{3}$ = 3.26583

SAIDI = $\frac{3{,}26583}{12}$ = 0.272152778 hours/year

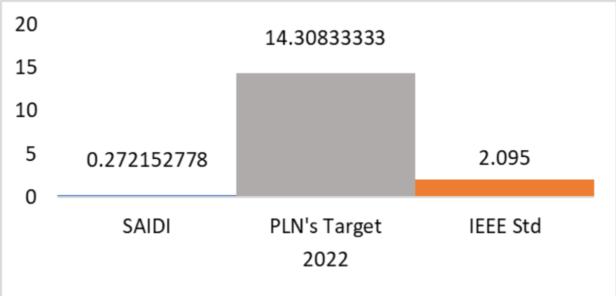

Figure 5. SAIDI Achieved VS PLN Target VS IEEE Standard for Kargo Feeders

To find the value of the SAIFI index per year using equation (2), then divide it by the number of customers served (Nt) and divide by 12 months, as follows:

SAIFI $= \frac{6}{3} = 2$

SAIFI $= \frac{2}{12} = 0.166666667$ times/customer/year

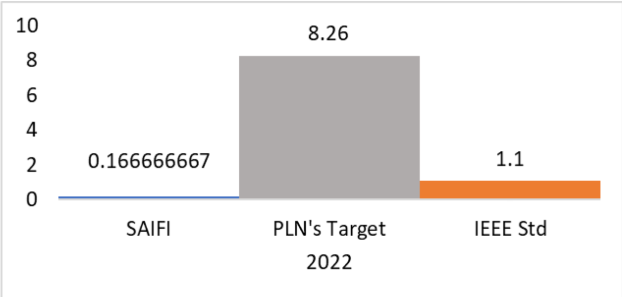

Figure 6. SAIFI Achieved VS PLN Target VS IEEE Standard for Kargo Feeders

Analysis of the reliability index on the SAIDI and SAIFI indicators on Kargo Feeders in 2022 is 0.27215227 hours/year and 0.166666667 times/customer/year, these values show that the Kargo Feeder system is in a reliable state when compared to the PLN 2022 target and IEEE 2022 standards.

3.4.3. Pinisi Feeders

Table 7 is a reliability index data consisting of data on the number of outage times in hours, data on the total number of customers and data on customers who experienced outages that occurred at Pinisi Feeders, for 12 months in 2022.

Table 7. Reliability Calculation Data at Pinisi Feeders

Month	Blackout Time x Customer Outgoing	Number of Customers Served	Customers Outgoing	SAIDI	SAIFI
January	3458,826944	3460	2327	0,99966	0,672543353
February	11035,84389	3460	10441	3,18955	3,017630058
March	0	3460	0	0	0
April	0	3460	0	0	0
May	0	3460	0	0	0
June	0	3460	0	0	0
July	2078,883333	3460	3460	0,60083	1
August	0	3460	2327	0	0,672543353
September	4399,322778	3460	10380	1,27148	3
October	6277,016667	3460	0	1,81417	0
November	2470,055556	3460	3460	0,71389	1
December	2294,680556	3460	2327	0,6632	0,672543353
Total	32014,62972	3460	34722	9,25278	10,03526012

To find the value of the SAIDI index per year using equation (1), then divide by the number of customers served (Nt) and divide by 12 months, as follows:

SAIDI = $\frac{32014,62972}{3460}$ = 9.25278

SAIDI = $\frac{9,25278}{12}$ = 0.771065263 hours/year

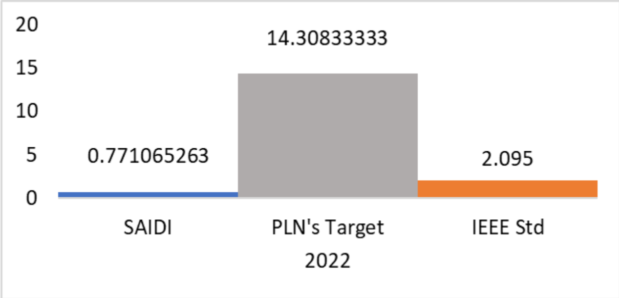

Figure 7. SAIDI Achieved VS PLN Target VS IEEE Standard for Pinisi Feeders

To find the value of the SAIFI index per year using equation (2), then divide it by the number of customers served (Nt) and divide by 12 months, as follows:

SAIFI = $\frac{34722}{3460}$ = 10.0352601

SAIFI = $\frac{10,0352601}{12}$ = 0.83627168 times/customer/year

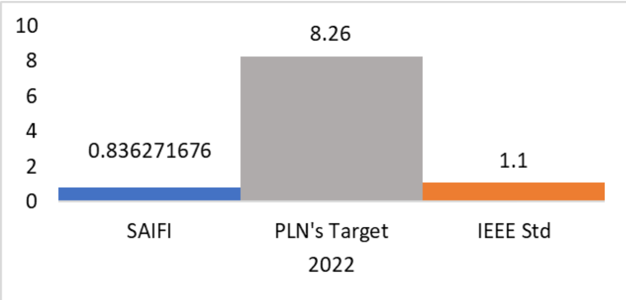

Figure 8. SAIFI Achieved VS PLN Target VS IEEE Standard for Pinisi Feeders

Analysis of the reliability index on the SAIDI and SAIFI indicators in the 2022 Pinisi Feeders is 0.771065263 hours/year for SAIDI and 0.836271676 times/customer/year, where this value shows that the Feeders system is in a reliable state.

3.4.4. Roro Feeders

Table 8 is a reliability index data consisting of data on the number of outage times in hours, data on the total number of customers and data on customers who experienced outages that occurred at Roro Feeders for 12 months in 2022.

Table 8. Reliability Calculation Data at Roro Feeders

Month	Blackout Time x Customer Outgoing	Number of Customers Served	Customers Outgoing	SAIDI	SAIFI
January	2977,304444	3.169	5406	0,93951	1,705900915
February	2223,821111	3.169	1828	0,70174	0,576838119
March	2410,931111	3.169	5432	0,76079	1,714105396
April	1327,473333	3.169	3604	0,41889	1,137267277
May	6250,461944	3.169	6773	1,97238	2,137267277
June	5165,733333	3.169	5406	1,63008	1,705900915
July	0	3.169	0	0	0
August	3634,033333	3.169	3604	1,14674	1,137267277
September	672,2461111	3.169	1802	0,21213	0,568633638
October	16526,31111	3.169	12231	5,21499	3,859577154
November	6376,628889	3.169	8560	2,01219	2,701167561
December	8636,733333	3.169	9062	2,72538	2,859577154
Total	56201,67806	3.169	63708	17,7348	20,10350268

To find the value of the SAIDI index per year using equation (1), then divide by the number of customers served (Nt) and divide by 12 months, as follows:

$$SAIDI = \frac{56201,67806}{3169} = 17.7348$$

$$SAIDI = \frac{17,7348}{12} = 1.477902547 \text{ hours/year}$$

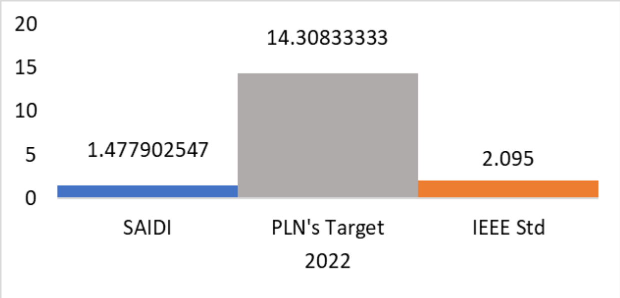

Figure 9. SAIDI Achieved VS PLN Target VS IEEE Standard for Roro Feeders

To find the value of the SAIFI index per year using equation (2), then divide it by the number of customers served (Nt) and divide by 12 months, as follows:

$$SAIFI = \frac{63706}{3169} = 20.10350268$$

$$SAIFI = \frac{20,10350268}{12} = 1.67529189 \text{ times/customer/year}$$

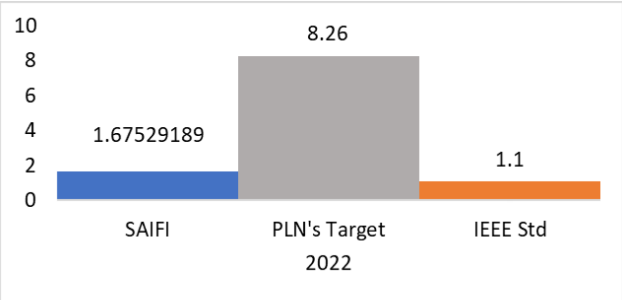

Figure 10. SAIFI Achieved VS PLN Target VS IEEE Standard for Roro Feeders

Analysis of the reliability index on the SAIDI indicator at the Roro Feeders in 2022 is 1.477902547 hours/year, when compared to the PLN 2022 target and the IEEE standard, this value is reliable. At the SAIFI index of 1.67529189 times/customer/year, this value is reliable in PLN's target but not reliable when compared to IEEE standards.

3.5. Calculation of ENS and Cost Loss on Feeders at Tanjung Api-Api Substation

Feri Feeders, Kargo Feeders, Pinisi Feeders, and Roro Feeders experienced several blackouts during one year which resulted in energy not being distributed to consumers or Energy Not Supplied (ENS) resulting in losses to PT. PLN (Persero). Not only losses in the form of energy of PT. PLN (Persero) but also suffered cost losses.

The calculation shows the calculation of the unchanneled energy (ENS) and the cost of loss to the feeder using equations (3) and (4) as follows:

$ENS = \sqrt{3} \times 20 \text{ V} \times 94 \text{ A} \times 0.85 \times 4.08$

$ENS = 11292.69415 \text{ kWh}$

Cost Loss = 11292.69415 x Rp. 1,352.00

Cost Loss = Rp. 15,267,722.49

Table 9 shows the calculation of unchanneled energy and cost losses on Feri Feeders, Kargo Feeders, Pinisi Feeders, and Roro Feeders during 2022. The analysis shows that the more frequent the blackout, the higher the value of the ENS index and the cost of losses for PLN. However, if the SAIDI and SAIFI values remain reliable, this can reduce the ENS value and the cost of loss due to interference.

Table 9. Results of Cost Loss Calculation at the Tanjung Api-Api Substation in 2022

Feeders Name	ENS	Power Limits	Goal. Fare	Basic Electricity Tariff (TDL)	Cost of Loss (Rp)
Feri	319.128,4392	900 VA-RTM	R-1/TR	IDR 1,352.00	Rp. 431,461,649.8
Kargo	4.896,091948	6,600 VA to 200 kVA	B-2/TR	IDR 1,444.70	Rp. 7,073,384,037
Pinisi	7.136,846081	900 VA-RTM	R-1/TR	IDR 1,352.00	Rp. 9,649,015,901
Roro	65.040,46513	900 VA-RTM	R-1/TR	IDR 1,352.00	Rp. 87,934,708.86

4 CONCLUSION

The results of the calculation in this study show that the SAIDI and SAIFI values for four Feeders at the Tanjung Api-api Substation are in a reliable state when viewed from the PLN Target that has been set, and are not reliable for Feri Feeders, namely SAIDI at Feri Feeders of 6.003570985 hours/year, Kargo Feeders of 0.272152778 hours/year, Pinisi Feeders of 0.771065263 hours/year and Roro Feeders of 1.477902547 hours/year. As for SAIFI on Feri Feeders amounting to 3.230883689 times/customer/year, Kargo Feeders 0.16666667 times/customer/year, Pinisi Feeders 0.836271676 times/customer/year and Roro Feeders 1.67529189 times/customer/year.

For the ENS value index on the four Feeders based on the calculation results, 396,201.8423 kWh was obtained with a loss of Rp. 536,118,758.6 kWh, in the Feri Feeders that was not distributed energy of 319,128.4392 kWh with a loss of Rp. 431,461,649.8, in the Kargo Feeders of 4,896.091948 kWh with a loss of Rp. 7,073,384,037, in the Pinisi Feeders of 7,136.846081 kWh with a loss of Rp. 9,649,015,901 and in the Roro Feeders of 65,040.46513 kWh with a loss of Rp. 87,934,708.86. The results of the ENS calculation were obtained that the higher the value of unchanneled energy, the greater the cost of losses that will be experienced by PT. PLN (Persero).

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