Analysis of Distribution Network Losses of Nr.04 Feeders At Namorambe Substation (PLN ULP Johor Case Study)

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Abstract

Efficiency is one of the important aspects in transformers to optimize the distribution of electrical energy. The study analyzed and tested losses in transformers. This test was carried out by measuring the voltage, output current of the transformer each day and night. The results of the study showed that the losses incurred included, the peak load that occurred at night was 32% and during the day was 2.04%. The value of power losses caused by neutral current during the day was 0.037 kVA percentage of 0.02%, while at night it was 0.346 kVA with a percentage of 0.22%. Power losses due to grounding current during the day were 0.256 kVA percentage of 0.16%, at night it was 0.586 kVA with a percentage of 0.3%, kWh saved at JTM was 124.2209 percentage of shrinkage reduction in JTR after being balanced, at peak load conditions of 84% and outside peak load conditions of 73%. Based on the results of the analysis, the transformer tested is suitable for use and the losses are still within the SPLN standard limits.

Keywords: **Transformer, Power Losses, Efficiency, Electric Power**

Introduction

In order to meet the electricity needs in the Medan Johor area of North Sumatra, the source of electrical energy is taken from the Namorambe Main Substation, the NR-04 feeder with a capacity of 20 kV. The energy is then distributed directly to the distribution substation. The distribution channel is an important part of the power distribution process that is directly connected to the load consumed by the community [1], [2]. Therefore, load imbalance has a major impact on the performance of the system. The electrical power that reaches the load is not always in line with the amount of power generated due to voltage drops or power losses [3], [4], [5].

In the distribution system, the demand for power from consumers continues to increase, and large imbalances in power demand cause uneven load distribution. This condition requires the distribution of the load on each phase to be kept balanced. However, in reality, the loading on each phase is not always balanced, and one of the causes is the uneven operation of single-phase loads [6], [7], [8].

The electricity distribution system at the Nomorambe Substation is an example of a case that is not free from these problems, so it is deemed necessary to analyze and find the right solution or resolution to these problems. One of the problems of the distribution system is the loss of electrical power. This loss of electrical power cannot be avoided, while the amount of loss is not yet known with certainty through calculations. As a result, the losses that arise cannot be known whether they are still within the permitted limits or have exceeded the limits of electrical power loss [9], [10], [11]. This is because there is a current flowing in the distribution network, both primary and secondary distribution, which is very large [12]. The primary distribution network is part of the distribution system that starts from the secondary side of the substation to the primary side of the distribution transformer [13]. While the secondary distribution network is a distribution network that starts from the secondary side of the distribution transformer to the load [14].

In general, to reduce power losses, additional investment costs are required. As a result, the selling price of electricity may increase. Conversely, if power losses are allowed to be large, the price of electricity will also be relatively expensive [8]. To serve the increasing load needs, it is necessary to expand the distribution network ([7]. In this regard, the amount of power losses that occur in the distribution network must be considered, both in planning and in the operation of the network. Thus, electricity problems are expected to meet good procurement and service levels [15]. Several previous studies on power losses have shown that load imbalance is the main factor causing power losses in the electric power system channel. Therefore, a power loss analysis is needed in the electric power system to determine the amount of load losses in the distribution transformer [3]. This is the initial step in finding a solution to balance the load through rearranging the medium voltage network, with the hope that the load distribution between phases will be balanced and reduce power losses due to the emergence of neutral currents.

Literature Review

2.1 Electric Power System

The electric power system is a unit of several tools used to change and move energy that plays an important role in providing energy needs in the world. The system. integrated electric power from the power generation unit, the electricity transmission unit to the electricity distribution unit, and not many other readings add substations (main substations) to the electric power system [1].

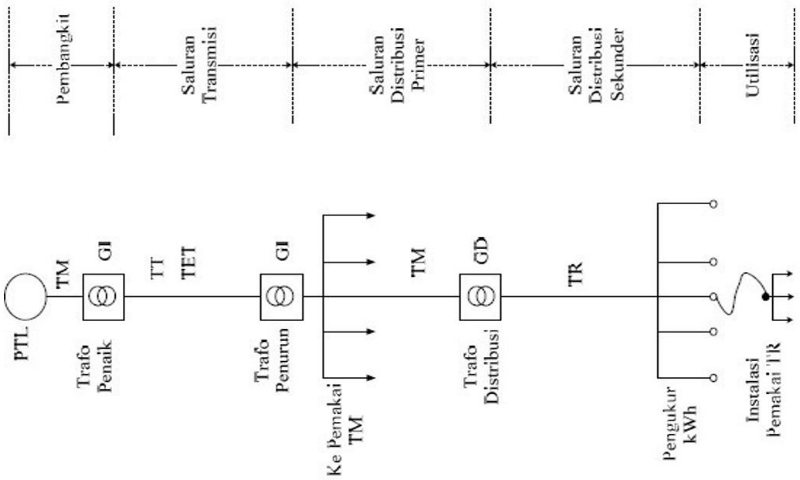

Figure 1. Electrical Energy Distribution System

2.2 Losses of Electric Power Distribution System

The electric power distribution system is one part of an electric power system that functions to distribute power from the GI to the load. The main substation as the center of the load to customers directly or through distribution substations (transformer substations) with adequate quality according to applicable service standards.

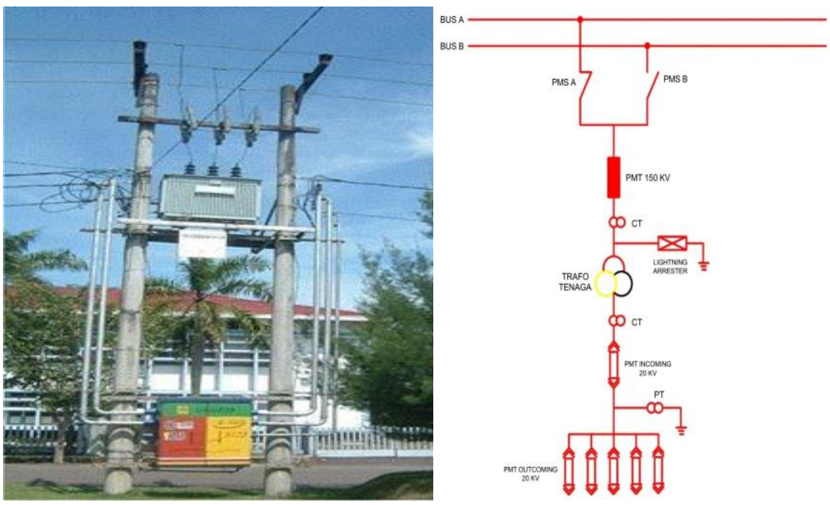

Figure 2. Distribution Transformer Circuit and Distribution Transformer Line Diagram

Voltage drop is the amount of voltage loss that occurs through all or part of a circuit due to impedance. The occurrence of voltage drop can be prevented or eliminated. Voltage drop in an electrical circuit usually occurs when current passes through a cable. This is related to the resistance or impedance to current flow with passive elements in the circuit including cables, contacts, and connectors that affect the level of voltage loss. The longer the circuit or cable length, the greater the voltage loss. According to SPLN No. 72 of 1987, the amount of power loss allowed to determine reliability in a distribution system is 10% for voltage loss and 5% for power loss. To determine reliability in the system, the value of power loss must not exceed the permitted standard by 10% (Elektro et al., 2023), (Anisah, Asih, et al., 2020). If it exceeds the permitted standard, it will cause losses to the electricity distributor. Therefore, it can be concluded that power losses are a form of electrical energy loss that comes from a number of energy sold to consumers and disrupts the efficiency of the electricity distribution system. While the load imbalance tolerance limit according to SPLN D5.004-1: 2012 is 2%.

2.3 Transformer Full Load Current Calculation

The transformer power can be formulated as follows from the high voltage (primary) side:

$$S = \sqrt{3}.V.I$$

Where:
S = Transformer Power (kVA)
V = Transformer Primary Side Voltage (kV)
I = Grid Current (A)
And to calculate the full load current can be formulated as follows:

$$I_{FL} = \frac{S}{\sqrt{3}.V}$$

Where:
IFL = Full load current (A)
V = Transformer Primary Side Voltage (kV)
I = Grid Current (A)

2.4 Transformer Loading Percentage

To find the percentage of transformer loading usage, the formula can be:

$$\frac{I\ rata-rata}{I_{FL}} x\ 100$$

Where:
IFL = Full load current (A)

Losses (losses) Due to Neutral Current Appearing on the Neutral Conductor in the Transformer. Due to the imbalance of the load on the phase in the secondary transformer R, S, and T, it causes current to flow in the neutral conductor of the transformer. The current in the neutral conductor of the transformer causes losses. The percentage of power losses caused by the neutral current of the transformer can be formulated:

$$\%\ P_N = \frac{PN}{P}\ x\ 100$$

Where :
PN = Transformer Neutral Conductor losses
P = Active power of transformer

2.5 Percentage of Load Unbalance on Transformer

To find out how big the load imbalance is, it can be determined by determining the amount of current in each phase which is expressed in the coefficients a, b, and c to find the percentage of load imbalance.

[IR] = a [I]
[IS] = b [I]
[IT] = c [I]

The currents IR, IS, and IT are respectively the currents in the R, S, and T phases. The coefficients a, b, and c can be known in magnitude where the current in the phase in a balanced state (equal to 1) is equal to the average current (Iaverage) and the following formula can be used.

IR= a x Iaverage, a= IR/(Iaverage)
IS= b x Iaverage, b= IS/(Iaverage)
IR= c x Iaverage, c= IT/(Iaverage)

A transformer is said to be balanced if it has coefficient values a, b, and c = 1.

2.6 Load Imbalance Analysis

In the distribution system, there are many problems with load imbalance that can cause losses in the system. What is meant by a balanced load condition is a condition where:

1. The three current/voltage vectors are the same size
2. The three vectors form an angle of 120º

The image below shows the current phasor diagram in a balanced current condition.

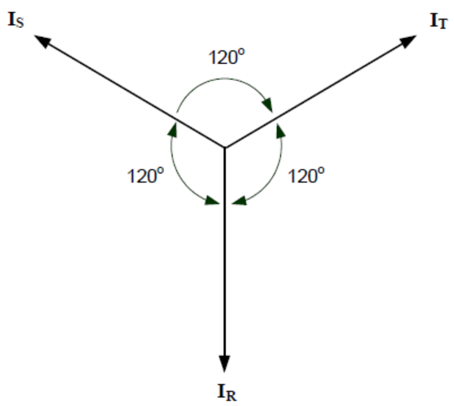

Figure 3. Load Diagram in a Balanced State

From the image above, it can be seen that all angles are the same size, which forms an angle of 120°, indicating that all loads are in a balanced state between the current phasors IR, IS, and IT. Meanwhile, an unbalanced state is a state where one or both of the conditions for a balanced state are not met [16]. there are three possibilities for an unbalanced state, namely:

1. The three vectors are the same size but do not form an angle of 120°
2. The three vectors are not the same size but form an angle of 120°
3. The three vectors are not the same size and do not form an angle of 120°.

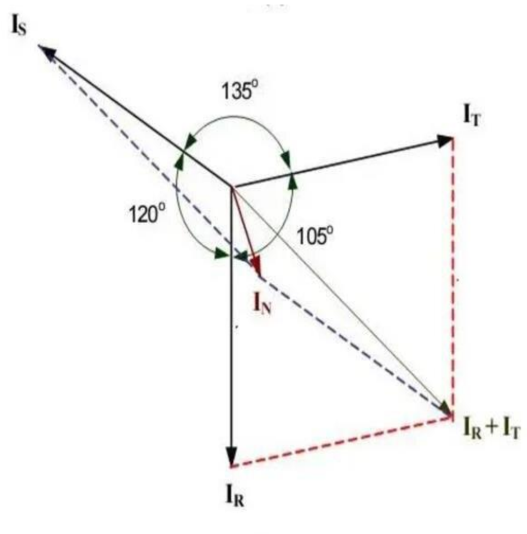

Figure 4. Load Diagram in an Unbalanced State

From the image above shows the current diagram vector in an unbalanced state. Here it can be seen that the sum of the three current phasors (IR IS IT) is not equal to zero so that a quantity appears, namely the neutral current (IT) whose size depends on how big the imbalance factor is.

2.7 Losses (Power Losses) Due to Neutral Current

Load imbalance between phases on the secondary side of the transformer can cause current flow in the neutral conductor of the transformer. The neutral conductor of the transformer that is flowed by this current, vectorically experiences a resultant vector shift from the zero point. In addition, the result is losses (power losses). Losses in the neutral transformer are calculated using the following formula:

$$PN = {I_N}^2 \, x \, R_N$$

Where :
PN = power loss (losses) on the neutral conductor (W)
IN = current flowing on the neutral side (A)
RN = resistance of the neutral conductor (Ω/km)

Standard or permissible voltage limit in distribution system The selection of voltage in the network is determined by the size of the load and the distance of its power distribution. Maximum +5% and minimum 10% (for JTR 198 to 231 V while for JTM 18 to 21 kV). Often in the process of delivering electric power, there is a lot of loss of electric power before it reaches the consumer. Losses (Power Loss) Due to Current in the Grounding Conductor. Another consequence of load imbalance is the current flowing in the grounding conductor. While the power loss caused can be calculated using the equation:

$$PG = {I_G}^2 \, x \, R_G$$

Where :
PG = power loss due to neutral current flowing to the ground (W)
IG = current flowing on the neutral side (A)
RG = neutral conductor resistance (Ω)
Medium Voltage and Low Voltage Losses

The calculation of medium voltage and low voltage losses is carried out on each phase for each distribution substation.

Channels/Conductors:

$$P_{Chanel} = I_{TM}^{2}.r.l$$

$$S_{Chanel} = \frac{P_{Chanel}}{Cos\ \Phi}$$

Medium Voltage Side:

$$S_{TM} = S_{TM`} + S_{Trafo}$$

$$I_{TM} = \frac{S_{TM}}{V_{TM}} \quad I_{TM'} = \frac{V_2}{V_1} = I_{TR}$$

$$V_{TM'} = \frac{V_1}{V_2} V_{TR}$$

$$S_{TM'} = V_{TM'}.I_{TM'}$$

Transformator

$$P_{Trafo} = P_{fe} + P_{cu}$$

$$S_{trafo} = \frac{P_{trafo}}{Cos\ \Phi}$$

Low Voltage Side

$$S_{TR} = V_{TR}.I_{TR}$$

Where:

ITM: Current on medium voltage line
VTM: Voltage on medium line
STM: Power on medium voltage line
ITR: Current on low voltage line
VTR: Voltage on low line
STR: Power on low voltage line

The equation above shows the stages of calculating power losses along with the formulas used. Low voltage side load data is obtained from measurements at each distribution substation and measured for each phase, namely load current (ITR), load voltage (VTR), and sometimes load power (STR) or calculated. While the load data on the medium voltage side is obtained from the transformation of values on the low voltage side to the ratio of the transformer's rated voltage.

2.8 Load Management Demand Side

Demand Side Load Management or electricity load management on the customer side is the load management carried out by customers, especially customers with large power, namely above 200 kVA. The benefits of load management on the customer side for customers are that what is obtained is maximizing the use of electricity according to the contract power, maintaining the life of the transformer and installation safety [13,14].

Research Methodology

In this study, the data collection process was carried out by measuring the voltage and current on the secondary side of the distribution transformer at the Pandaan Special Substation for 24 hours. The research was carried out at the Namorambe Main Substation (Case Study of Pln Ulp Johor) From the available transformer data, 3 transformer units will be analyzed, where the measurement results of the 3 transformer units obtained the following data:

Transformer brand: TRAFINDO
Power: 160 kVA
Cos φ: 0.95
Impedance: 4%
Core loss (no load losses): 300 watts
Copper loss (on load losses): 2000 watts
Primary voltage: 20000 volts
Secondary voltage: 400 volts

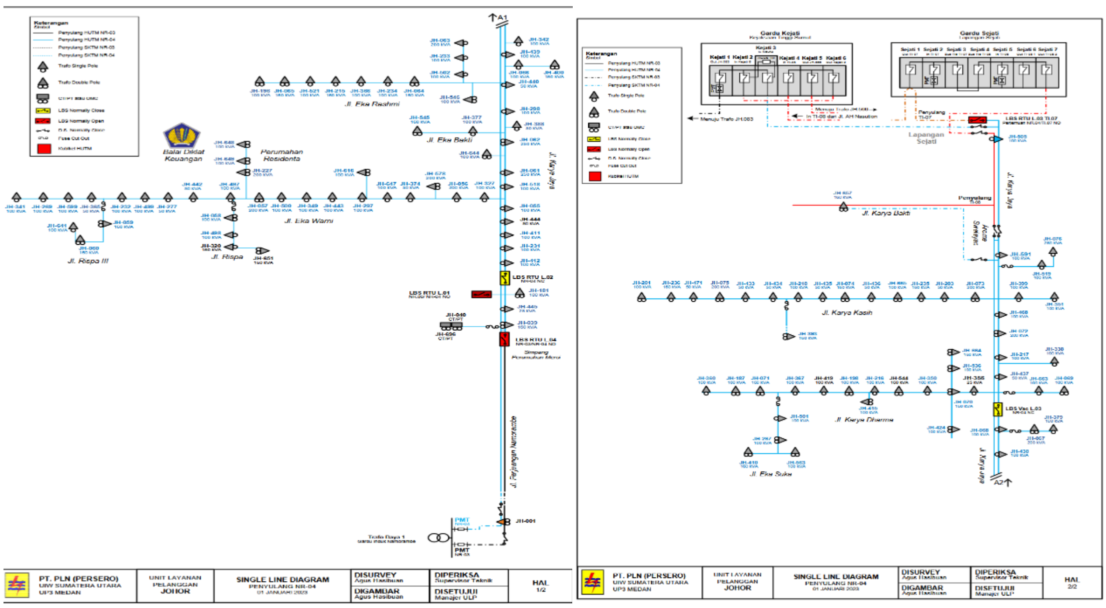

Figure 5. Feeder Line Diagram of Namorambe Substation NR-04 Feeder

Based on the data presentation above, data collection was carried out through measurements, the measurement results were grouped into 2 categories, namely daytime measurements and nighttime measurements. For the daytime group starting at 06.00 am to 18.00

and for the night group it is at 18.01 to 05.59 local time. From the measurement results in both categories, the following results were obtained:

Table 1. Voltage and Cos φ Measurement

Phase	Day		Night	
	Teg (V)	Cos φ	Teg (V)	Cos φ
R-N	226	0,68	388	0,85
S-N	223	0,68	389	0,86
T-N	219	0,69	395	0,85

Table 2. Current Measurement

Power Conduktor	Curent (Ampere)	
	Day	Naight
Fasa R	59	115
Fasa S	59	119
Fasa T	58	114
Netral (N)	20	61
Grounding (G)	5,7	8,62

Table 3. JTM Shrinkage Measurement

SUSUT	JTM				
	Penyulang NR 4				
Ukuran	Jenis	p	l	A	R
35	AAAC	0.03	58.01	961.625	0.0018097
70	AAAC	0.03	58.01	3846.5	0.0004524
150	AAAC	0.03	58.01	17662.5	0.0000985
240	AAAC	0.03	58.01	45216	0.0000384

Based on the results of measurements carried out on low voltage networks, the following results were obtained:

Table 4. JTR Shrinkage Measurement

SUSUT	JTR				
	Gardu JH 201				
Ukuran	Jenis	p	l	A	R
35	AAAC	0.03	0.7	961.625	0.000021838
70	AAAC	0.03	0.7	3846.5	0.000005459
150	AAAC	0.03	0.7	17662.5	0.000001189
240	AAAC	0.03	0.7	45216	0.000000464

Results

4.1 Load Imbalance Analysis

Tables 1 and 2 show the results of voltage and current measurements with average values in the day and night groups. From the measurement results in table 2, the calculation of load imbalance is carried out by applying the equation:

a. During the day

$$I_{rata-rata\,siang} = \frac{59 + 59 + 58}{3} = 58{,}6\,A$$

Furthermore, the coefficients a, b and c in each phase can be determined.

$$IR = a\,x\,I_{rata-rata\,siang}$$

$$a = \frac{59}{58{,}6} = 1{,}06\,A$$

$$b = \frac{59}{58{,}6} = 1{,}06\,A$$

$$c = \frac{58}{58{,}6} = 0{,}98\,A$$

so that the percentage of load imbalance during the day is:

$$\frac{(1{,}06 - 1) + (1{,}06 - 1) + (0{,}98 - 1)}{3} x100$$
$$= 2{,}04\%$$

b. At Night

$$I_{rata-rata\,malam} = \frac{115 + 119 + 114}{3} = 116\,A$$

Furthermore, the coefficients a, b and c in each phase can be determined.

$$IR = a\,x\,I_{rata-rata\,siang}$$

$$a = \frac{115}{116} = 0{,}99\,A$$

$$b = \frac{119}{116} = 1{,}02\,A$$

$$c = \frac{114}{116} = 0{,}98\,A$$

so that the percentage of load imbalance at night is:

$$\frac{(0{,}99 - 1) + (1{,}02 - 1) + (0{,}98 - 1)}{3} x100$$
$$= 32\%$$

Based on the results above, the transformer load imbalance at the Namo Rambe Substation with the Johor ULP Case Study during the day still meets the standard, namely less than 2%, while at night it does not meet the set standards.

4.2 Analysis of Losses Due to Neutral Current

Referring to the data in Table 2, the amount of losses caused by neutral current can be calculated using data related to the conductor installed on the neutral side of the transformer, which is type NYY 1 x 240 mm2 and referring to data from Kabel Metal Indonesia (KMI), the conductor has a resistance of 0.093 Ω/km.

$PN = IN^2 \times RN$

Daytime Power Loss

$PN = (20)^2 \,.\, 0{,}093$
$= 37{,}2$ W atau 0,037 kVA

Night Power Loss

$PN = (61)^2 \,.\, 0{,}093$
$= 346{,}05$ W atau 0,346 kVA

4.3 Analysis of Losses Due to Grounding Current

The results of measuring the transformer grounding resistance using the KYORITSU Model 4200 earth tester obtained a value of 7.88 Ω. The conductor connecting to the ground rod is a type of AAAC 70 mm2 while the results of measuring the current passing through it are 0.7 A during the day and 3.84 A at night. with the resistance of the AAAC 70 mm2 conductor is 0.438 Ω/km.

The calculation of power losses due to grounding current can be analyzed through the following calculation:

$PG = IG^2 \times RG$

Daytime Power Loss

$PG = (5{,}7)^2 \,.\, 7{,}88$
$= 256{,}02$ W atau 0,256 kVA

Night Power Loss

$PG = (8{,}62)^2 \,.\, 7{,}88$
$= 585{,}5$ W atau 0,586 kVA

When the condition of unbalanced load occurs, the current flowing to the neutral conductor and grounding channel is a condition that cannot be avoided. This has an impact on the emergence of power losses whose magnitude is greatly influenced by the value of the flowing current, the type and diameter of the neutral conductor. If the real power of the transformer is stated in P and the apparent power in S, then from table 1 it can be calculated with the following equation:

P = S . Cos φ
P = 160 kVA x 0,95 = 152 kVA

So the percentage of losses or power losses due to neutral current and grounding current is calculated by comparing each with the power. the real transformer, as in the following equation:

$$\%PN = \frac{PN}{P} x\ 100$$

%PN Day is:

$$\%PN = \frac{0{,}037}{152} x\ 100 = 0{,}02\ \%$$

%PN Night is:

$$\%PN = \frac{0{,}346}{152} x\ 100 = 0{,}22\ \%$$

$$\%PG = \frac{PG}{P} x\ 100$$

%PG Day is:

$$\%PG = \frac{0{,}256}{152} x\ 100 = 0{,}16\ \%$$

%PG Night is:

$$\%PG = \frac{0{,}585}{152} x\ 100 = 0{,}3\ \%$$

Table 5. Power Loss Analysis During Day and Night

	Power Losses			
	PN kVA	**%PN**	**PG kVA**	**%PG**
Day	0,037	0,02	0,2	0,16
Night	0,34	0,2	0,5	0,3

Based on the analysis results in the table above, it was found that the amount of losses is within the threshold that is still permitted according to the SPLN standard of a maximum of +5% and a minimum of -10%.

4.4 Analysis of Losses in Medium Voltage Networks

Based on the measurement results that have been carried out on medium voltage networks referring to the measurement data in table 3, the results obtained after UP Rating and before Up Rating of the transformer, the amount of losses in the medium voltage network is as follows:

Table 6. Results of JTM NR 04 70 Shrinkage after Uprating

Losses Conductor NR 04		70
	I^2 RT	P (kWH)
73	LWBP	45.80973
100	WBP	85.96308

Table 7. Results of JTM NR 04 150 Shrinkage after Uprating

Losses Conductor NR 04		150
	I^2 RT	P (kWH)
73	LWBP	2.625353
100	WBP	4.926539

Based on the analysis results in the table above, it was found that the amount of medium voltage network losses is at the threshold that is still permitted according to the SPLN standard, namely 18 to 21 kV.

Table 8. Results of Difference in Shrinkage Before and After Uprating from 70 to 150

Losses Conductor NR 04	
LWBP (kWH)	43.18437
WBP (kWH)	81.03654
Total KWH Terselamatkan	124.2209

4.5 Analysis of Low Voltage Network Losses

Based on the measurement results, the amount of losses in the low voltage network is as follows:

Table 9. Measurement of JTR Loss of JH 201 Substation

Susut Gardu JH 201	
Susut Sebelum Uprating JTR	
LWBP	0.10064 kWH
WBP	0.22318 kWH
Susut Setelah diseimbangkan Beban Trafo sebesar	
LWBP	0.027414 kWH
WBP	0.035335 kWH
Selisih Susut setelah diseimbangkan	
LWBP	0.07322 kWH
WBP	0.18784 kWH
% Penurunan Susut setelah diseimbangkan	
LWBP	73%
WBP	84%

Based on the analysis results in the table above, it was found that the magnitude of low voltage network losses is at the threshold that is still permitted according to the SPLN standard of 198 to 231 V.

Conclusion

Based on the calculation results that have been carried out, the following conclusions can be drawn:

1. The peak load that occurs on the analyzed transformer occurs at night with a loading of 32% while the percentage of loading during the day is 2.04%.
2. Based on the results of the calculation analysis of the value of power losses that caused by neutral current during the day is 0.037 kVA with a percentage of 0.02%, while at night it is 0.34 kVA with a percentage of 0.22.
3. The results of the analysis of the calculation of the value of power losses caused by grounding current during the day are 0.256 kVA with a percentage of 0.16%, while at night it is 0.586 kVA with a percentage of 0.3%.
4. Based on the results of the analysis, the amount of kWH saved in the medium voltage network is 124.2209 while the percentage of shrinkage reduction in the low voltage network after being balanced, at peak load times is 84% and outside peak load times is 73%.

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