Analysis of JTR Voltage Drop Improvement Using Simulation-Based Insert Transformer and Cable Uprating Method

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Abstract

The electrical system in Kenari Hamlet is supplied by the PR 072 distribution transformer through PU.08 feeders. The PR 072 transformer is located on Jalan Melati, Desa Melati II with a capacity of 160 kVA which is used to supply electricity to the Dusun Nangka area. Based on the results of the measurements that have been made, it is found that the low voltage value in the Dusun Nangka area is 170 volts against the one-phase source voltage to neutral (226 V) and occurs during peak loads or in other words the voltage drop. According to SPLN 1: 1995, the service line voltage tolerance (SP) is + 5% of the standard low voltage stress at the base side and -10% at the end side. At 19.00 when there is a peak load, consumers cannot make electronic devices such as water pumps, refrigerators, air conditioners and others. With such conditions, it is necessary to simulate ETAP 12.6.0 to make improvements, namely the construction of an in-line transformer and uprating the HUTR 3x35mm2 + 1x25mm2 to 3x70mm2 + 1x50mm2 in that area. For this reason, several assumptions are made, namely direct measurement calculations and simulations so that the low voltage value in the area is 219 Volts.

Keywords: ***Voltage Drop, Etap 12.6.0, Network Repair***

Introduction

The need for electrical energy is increasing day by day with the times. Electricity has become a crucial requirement for all people around the world, from households to industry, and across various other sectors. In Indonesia, providing electricity requires a state-owned electricity provider. PT. PLN (Persero) is a state-owned enterprise that supplies and distributes electricity so that it can be enjoyed by the Indonesian people. Electrical energy must be properly distributed to the public without experiencing voltage drops. However, sometimes voltage drops exceed PLN's standard limits. Voltage drops are a common problem in electricity distribution, often caused by the length of the low-voltage distribution lines from the electricity supply. If the voltage drops exceed the standard limits, they can cause losses to both the public and PLN itself [1]. In general, consumers expect a continuous and high-quality electricity service system. One of the requirements for a reliable electricity distribution system is good and stable voltage quality. Although the continuity of the electricity supply is guaranteed, it does not necessarily maintain a stable voltage [2]. Distribution substations are a means of distributing electricity from PLN to customers. With a primary voltage of 20 kV, it is then converted by a transformer to a secondary voltage of 400 V (between phases) or 231 V (phase-neutral). Voltage drop is the difference in voltage on the sending side and the voltage on the receiving side. Communities in areas far from distribution substations tend to receive lower voltages than those in areas close to the distribution substation. According to SPLN 1:1995, the voltage tolerance for Service Lines (SP) is +5% of the standard low-voltage voltage at the base and -10% at the end. The background of the author's choice of the title is the large amount of information and public complaints regarding the electric power system. So there is a need for improvements to the electric power system network [3].

Literature Review

2.1 Electric Power Distribution System

The distribution system is part of the electric power system. This distribution system is useful for delivering electric power from large power sources (Bulk Power Sources) to consumers. Therefore [4], the function of electric power distribution is:

a. Distributing or distributing electric power to several locations (customers).
b. Conveying electric power directly to customers.

Electric power generated by large power plants with voltages ranging from 11 kV to 24 kV is increased in voltage by substations using step-up transformers to 150 kV, 250 kV, or 500 kV, and then distributed through transmission lines. The purpose of increasing the voltage is to minimize power losses in the transmission line, where power losses are proportional to the square of the flowing current (I2R). For the same power, increasing the voltage reduces the current, thus reducing power losses [5].

From the transmission line, the voltage is reduced again to 20 kV with a step down transformer at the distribution substation, then with this voltage system the distribution of electric power is carried out by the transmission line.

Primary distribution. From these primary distribution lines, distribution substations take the voltage and step it down using distribution transformers to a low-voltage system, namely 220/380 volts. This is then distributed via secondary distribution lines to consumers. This clearly makes the distribution system a crucial component of the overall power system. Long-distance power distribution systems always use the highest possible voltage using step-up transformers. This extremely high voltage has several consequences, including environmental hazards and high equipment costs, in addition to being incompatible with the voltage requirements of the load [6]. Based on these limitations, it is known that the material portion of the distribution system is Regions III and IV, which can basically be classified in several ways, depending on the aspect from which the classification is made.

Revealing that the secondary distribution system is one part of the distribution system, namely starting from the transformer substation to the end user or consumer. Seeing its location, this distribution system is the part that is directly connected to consumers, so this system functions to receive electrical power from the power source (distribution transformer), also will transmit and distribute the power to consumers. The electrical power distribution system in the low voltage network can be divided into two, namely as follows:

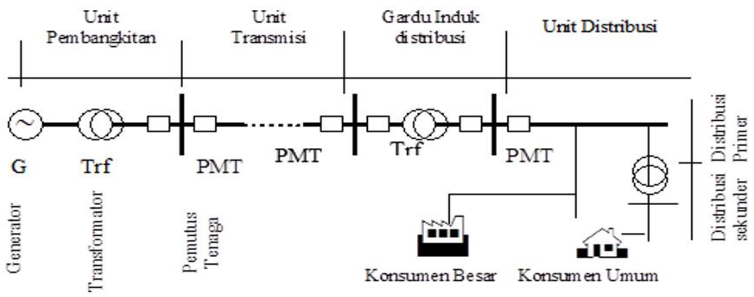


Figure 1. Division/Grouping of Electric Power System Voltage

2.2 Concrete Distribution Substation

This type of distribution substation is constructed of concrete (a mixture of sand, stone, and cement). Concrete substations are considered indoor substations because generally all connecting/disconnecting equipment, separators, and distribution transformers are located within the concrete structure. During construction, all equipment is designed and installed on-site according to the dimensions of the substation. The figure shows a concrete distribution substation.

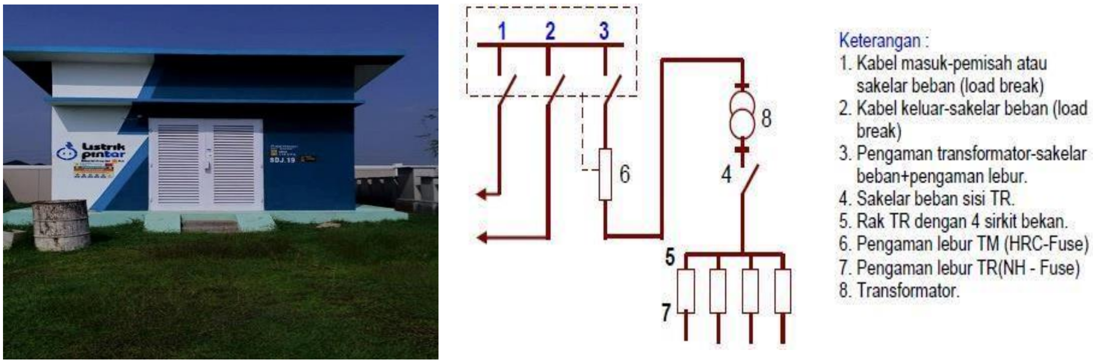


Figure 2. Distribution Substation and One Line Diagram

Portal pole substation, namely a distribution substation whose protective structure or support is made of poles. In this case, the distribution transformer is located at the top of the pole. Because the distribution transformer is located at the top of the pole, the pole substation can only serve limited electrical power, considering the relatively high weight of the transformer, so it is impossible to place a large capacity transformer at the top of the pole (approximately 5 meters above the ground). For pole substations with single-phase transformers, the maximum capacity is 50 KVA, while pole substations with three-phase transformers have a maximum capacity of 400 KVA [7]. There are two types of three-phase transformers for pole-mounted substations: single-phase and three-phase. A portal substation is an outdoor substation that uses a pole/tower construction with the transformer positioned at least 3 meters above the platform. It generally uses 2x500 daN concrete poles.

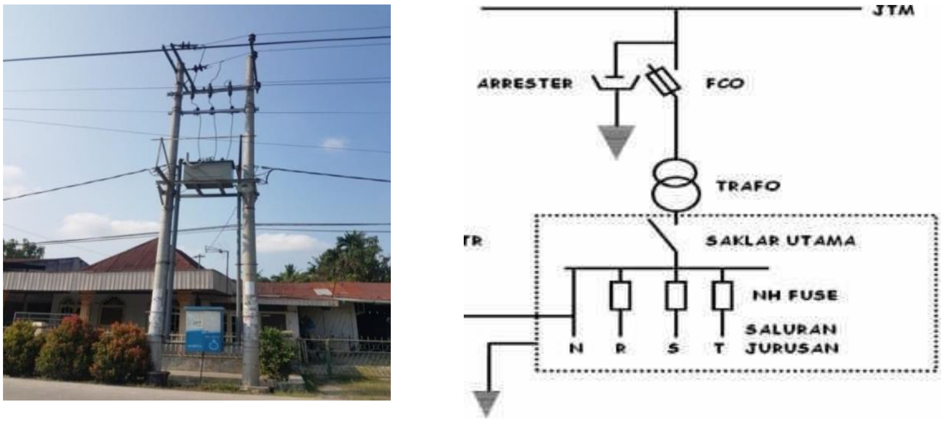


Figure 3. Single Line Diagram of Portal Type Pole Substation

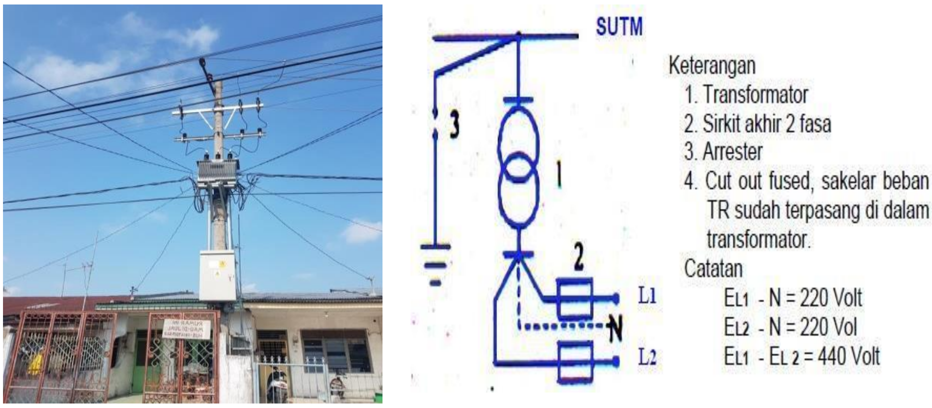


Figure 4. One-line diagram of a Cantol type pole substation

2.3 Voltage drop in the low voltage network (JTR)

Voltage drop is the difference between the voltage at the sending end and the receiving end of the electrical power. The causes of voltage drop are:

a. Peak load current (amperes);
b. Line resistance (ohms/km);
c. Line length (km)

The term "voltage drop" here refers to the voltage drop at the end of the low voltage network (JTR), namely the voltage drop in the JTR line, which causes a voltage drop at the consumer end of the line. (According to SPLN No. 72 of 1987) concerning voltage regulation and voltage drops, the permissible voltage drop in distribution transformers is 3% of the operating voltage, the voltage drop in STRs is allowed up to 4% of the operating voltage, and the voltage drop in SRs is allowed up to 1% of the nominal voltage. To calculate the voltage drop, the reactance and power factor are taken into account, which are not equal to one. The following is an explanation of the calculation method. To simplify the calculation, it is assumed that the loads are balanced three-phase loads and the power factor (Cos φ) is between 0.6 and 1.0. 0.85 [6]. The stress can be calculated based on the following relationship approach formula:

$$(Vr) = (\sqrt{3} \text{ x } \rho \text{ x } L \text{ x } I \text{ x Cos phi}) : A$$

Where:

I = Load current (Amperes), ρ = Resistivity (Ohm/m), A = Cross-sectional area (m), φ = Power factor, L = Cable length (m)

Voltage drop (ΔV) is the difference between the sending voltage (Vs) and the receiving voltage (Vr). Therefore, voltage drop can be defined as

$$\Delta V = (Vs) - (Vr)$$

Due to the resistance in the conductor, the voltage received by the consumer (Vr) will be smaller than the sending voltage (Vs), so that the voltage drop (Vdrop) is the difference between the voltage at the sending end and the voltage at the receiving end of the electric power. relatively called VR (voltage regulation) and is expressed by the formula:

$$\Delta V = \frac{VS - VR}{Vr}\ x\ 100\%$$

Where: Vs = voltage at the sending end Vr = voltage at the receiving end Insertion Substation Equipment

According to PT PLN (Persero) Directorate General Decree No. 605.K/DIR/2010, the main components of a distribution substation are as follows:

a. The transformer functions as a power transformer, converting medium voltage (20 kV) to low voltage (380/200) Volts.
b. The PHB-TR functions as low-voltage connection equipment, interconnected with control, measuring, and safety equipment. The entire structure is assembled with a complete wiring and mechanical system for the supporting components. Insertion substations have a maximum of two routes, with a disconnector switch on the input side and a fuse.
c. The arrester protects the transformer against overvoltages caused by lightning strikes and switching.

2.4 Transformers

Transformer is an electrical device used to transfer power or electrical energy from one part of a circuit to another by induction, with varying voltage and current at a constant frequency (through a magnetic coupling and electromagnetism principles). In electrical power, transformers are structurally classified as consisting of two coils: primary and secondary. When the primary coil is connected to an alternating voltage source, alternating flux is generated in the primary coil. This flux then flows through the transformer core, which then induces magnetic flux in the secondary coil, resulting in a voltage being generated. A load is the final circuit of an electrical power grid, meaning the place where electrical energy is converted into other forms of energy, such as light, heat, movement, magnetism, and so on. A load is the final circuit of an electrical power grid that must be served by the electrical power source to be converted into other forms of energy. Therefore, service to the load must be guaranteed to be continuous to maintain the reliability of the electrical power system. To achieve a reliable state Therefore, an electric power system must be able to handle all disturbances without shutting down its load [8], [9].

Distribution transformers should be kept underloaded to a level exceeding 80% or below 40%. If the load exceeds or falls below these values, the transformer is considered overloaded or underloaded. Transformer loads should be kept within these limits. If the load is too high, replacement, insertion, or mutation of the transformer are necessary. The following formula can be used to determine the capacity of a distribution transformer:

kVAload = (I_r x V_{R-N}) + (I_s x V_{T-N})

$$\%\ \text{Percentase Load Transformator} = \frac{KVA\ load}{KVA\ trafo}\ x\ 100\%$$

2.5 Electrical Power

(According to Lukman, Budi, et al., 2010), in electrical power systems, there is a distinction between power and energy. Energy is power multiplied by time, while electrical power is the product of voltage and current. The unit of electrical power is the watt, which represents the amount of electrical energy flowing per unit time [Joule/s]. Electrical power [P] is produced by an electric current [i] at a voltage [v]

$$\boldsymbol{P = V\ x\ I}$$

Active power (Active Power) is also called apparent power, which is the power required by the load. The unit of active power is the Watt, expressed as:

For 1 phase $\boldsymbol{P} = \boldsymbol{V\ x\ I\ x\ cos\varphi}$
For 3 phase $\boldsymbol{P} = \sqrt{3}\ \boldsymbol{x\ VL\ x\ IL\ x} \cos \boldsymbol{\varphi}$
Reactive power is power that arises due to the effect of electromagnetic induction by a load that has an inductive value (current phase). lagging or capacitive (leading current phase). The unit of reactive power is Var, expressed as,
For 1 phase $\boldsymbol{Q} = \boldsymbol{V\ x\ I\ xsin\ \varphi}$ (2.9)
For 3 phase $\boldsymbol{Q} = \sqrt{3}\ \boldsymbol{x\ VL\ x\ IL\ x} \sin \boldsymbol{\varphi}$
Apparent power is the vectorial sum of active power and reactive power. The unit of this power is VA, expressed as,
$\boldsymbol{S} = \boldsymbol{V\ I}$

2.6 Electrical Power Losses

Explains that power losses are losses that occur due to power loss in the network, such as active and reactive power. The longer the line, the greater the resistance and reactance of the network, resulting in greater losses in both active and reactive power losses. Every electrical device in use does not always operate perfectly. The longer it is used, the less efficient the equipment will be, resulting in greater losses. The power loss of a line is the product of the current squared and the resistance or reactance of the line. These losses can be expressed as follows:
Real power loss = I2 . R (watts)
Reactive power loss = I2 . X (watts)
Apparent power loss = $\sqrt{(I2\ x\ R)2 + (I2x\ X)2}$

2.7 ETAP Standards

ETAP has two standards used for electrical analysis: IEC and ANSI. The difference between these two standards lies in the frequencies used, which results in different equipment specifications that are compatible with those frequencies. The electrical element symbols used in ETAP analysis also differ [6], [10], [11].

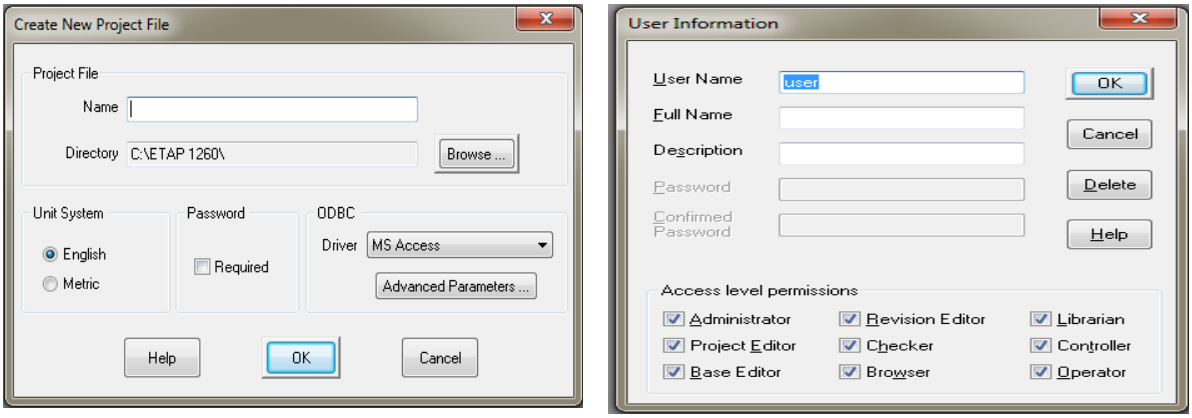


Figure 5. User Information

Research Methodology

Before calculating and analyzing voltage drop, we first need to know what data is required. This data includes distribution transformer capacity (rating), a one-line diagram of the low-voltage network, data on the low-voltage network end conductors, and the load at the end of the low-voltage network. The following data is required.

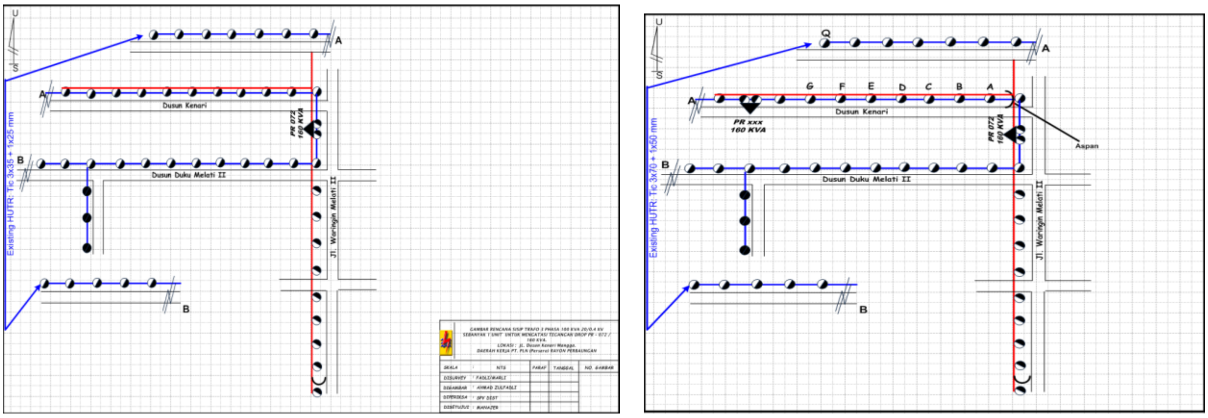


Figure 6. Single Line Distribution System

Table 1. Capacity of PR 072 Distribution Transformer and Insert Transformer

NO	Kode Trafo	Kapasita (KVA)
1	PR 072	160
2	Trafo Sisip	160

The following is a single-line diagram of the low-voltage network for the PR 072 distribution transformer before the insertion transformer is added. The following is a single line diagram of the low voltage network of the PR-072 distribution transformer after the addition of an insert transformer. The following table lists the types, lengths, and cable sizes of low-voltage distribution networks.

Table 2. Low Voltage Network Conductor Data

No	Point	Channel Length (m)	Conduktor	
			Type	Size (mm2)
1	A-C	145	LVTC	3x35 + 1x25
2	C-E	91	LVTC	3x35 + 1x25
3	E-H	133	LVTC	3x35 + 1x25
4	H-J	92	LVTC	3x35 + 1x25
5	J-L	92	LVTC	3x35 + 1x25
6	L-O	139	LVTC	3x35 + 1x25
7	O-Q	96	LVTC	3x35 + 1x25

The following table shows the current and voltage measurement data at the transformer distribution substation.

Table 3. Distribution Transformer Substation Measurement Data

No	Tanggal	Jam	Arus (Ampere)			Tegangan (Volt)		
			IR	IS	IT	R-N	S-N	T-N
1	5/10/2020	19.00	195	183	194	226	227	224

2	7/10/2020	19.00	197	190	195	225	227	222
3	9/10/2020	19.00	205	190	210	222	224	223
Rata- Rata PengukuranArus dan Tegangan			199	188	200	224	226	223

3.1 Low Voltage Network Load Data

Average load data table on low voltage transformer network distribution system Table of load and voltage data at the end of the low voltage distribution transformer network before the transformer was inserted, the results of measurements over three days.

Table 4. Load Measurement Data on Transformer Distribution System

No	**Titik Jaringan Tegangan Rendah**	**Arus (A)**		
		R	**S**	**T**
1	A-C	20	16	18
2	C-E	18	18	18
3	E-H	20	20	19
4	H-J	18	18	16
5	J-L	21	20	19
6	L-O	25	20	20
7	O-Q	19	16	18

3.2 Distribution Network Simulation Design Using ETAP

The ETAP Power Station single-line diagram consists of several components that assist us in designing complex and numerous circuits. The single-line diagram allows us to place various safety devices between the circuit branches and a bus. The following is a screenshot of ETAP Power Station version 12.6.0.

Results

Voltage Drop Measurement Results Before Adding an Insertion Transformer Based on the voltage measurement data on the transformer Using Etap, the voltage drop at each point in the network can be calculated before adding an insertion transformer.

$\Delta VAC = (Vs) - (Vr) = 389{,}7V - 358{,}9V = 30{,}8\ V$
$\Delta VCE = (Vs) - (Vr) = 358{,}9V - 342{,}2V = 16{,}7\ V$
$\Delta VEH = (Vs) - (Vr) = 342{,}2V - 321{,}8V = 20{,}4\ V$
$\Delta VHJ = (Vs) - (Vr) = 321{,}8V - 310{,}6V = 11{,}2\ V$
$\Delta VJL = (Vs) - (Vr) = 310{,}6V - 302{,}1V = 8{,}5\ V$
$\Delta VLO = (Vs) - (Vr) = 302{,}1V - 293{,}5V = 8{,}6\ V$
$\Delta VOQ = (V) - (Vr) = 293{,}5V - 290{,}9V = 2{,}6\ V$

Based on the results of the calculation, the total voltage drop from the distribution transformer substation to the end of the network, point Q, is:

Total $\Delta V = \Delta VAC + \Delta VCE + \Delta VEH + \Delta VHJ + \Delta VJL + \Delta VLO + \Delta VOQ$
$= 30{,}8V + 16{,}7V + 20{,}4V + 11{,}2V + 8{,}5V + 8{,}6V + 2{,}6V = 98{,}8V$

Based on the voltage measurement data on the PR 072 transformer using direct measurements, the voltage drop from the base to the end of the network can be calculated.

$\Delta VAC = (\ Vs\ ) - (Vr\ ) = 392{,}2\text{V} - 363{,}5\text{V} = 28{,}7\text{V}$
$\Delta VCE = (\ Vs\ ) - (Vr\ ) = 363{,}5\text{V} - 346{,}6\text{V} = 16{,}9\text{V}$
$\Delta VEH = (\ Vs\ ) - (Vr\ ) = 346{,}6\text{V} - 326{,}9\text{V} = 19{,}7\text{V}$
$\Delta VHJ = (\ Vs\ ) - (Vr\ ) = 326{,}9\text{V} - 315{,}5\text{V} = 11{,}4\text{V}$
$\Delta VJL = (\ Vs\ ) - (Vr\ ) = 315{,}5\text{V} - 306{,}6\text{V} = 8{,}9\text{V}$
$\Delta VLO = (\ Vs\ ) - (Vr\ ) = 306{,}6\text{V} - 298\text{V} = 8{,}6\text{V}$
$\Delta VOQ = (\ Vs\ ) - (Vr\ ) = 298\text{V} - 295{,}2\text{V} = 2{,}8\text{V}$

Based on the results of the calculation, the total voltage drop from the distribution transformer substation to the end of the network, point Q, is:

Table 5. Comparison of Voltage Drop Results of ETAP Simulation Before Insertion of Transformer

NO	Dasar Data	ETAP	Drop Voltage (V)	Pengukuran	Drop Voltage (V)
1	VINC	389,7V	-	392,2V	-
2	VAC	358,9V	30,8V	363,5V	28,7V
3	VCE	342,2V	16,7V	346,6V	16,9V
4	VEH	321,8V	20,4V	326,9V	19,7V
5	VHJ	310,6V	11,2V	315,5V	11,4V
6	VJL	302,1V	8,5V	306,6V	8,9V
7	VLO	293,5V	8,6V	298V	8,6V
8	VOQ	290,9V	2,6V	295,2V	2,8V

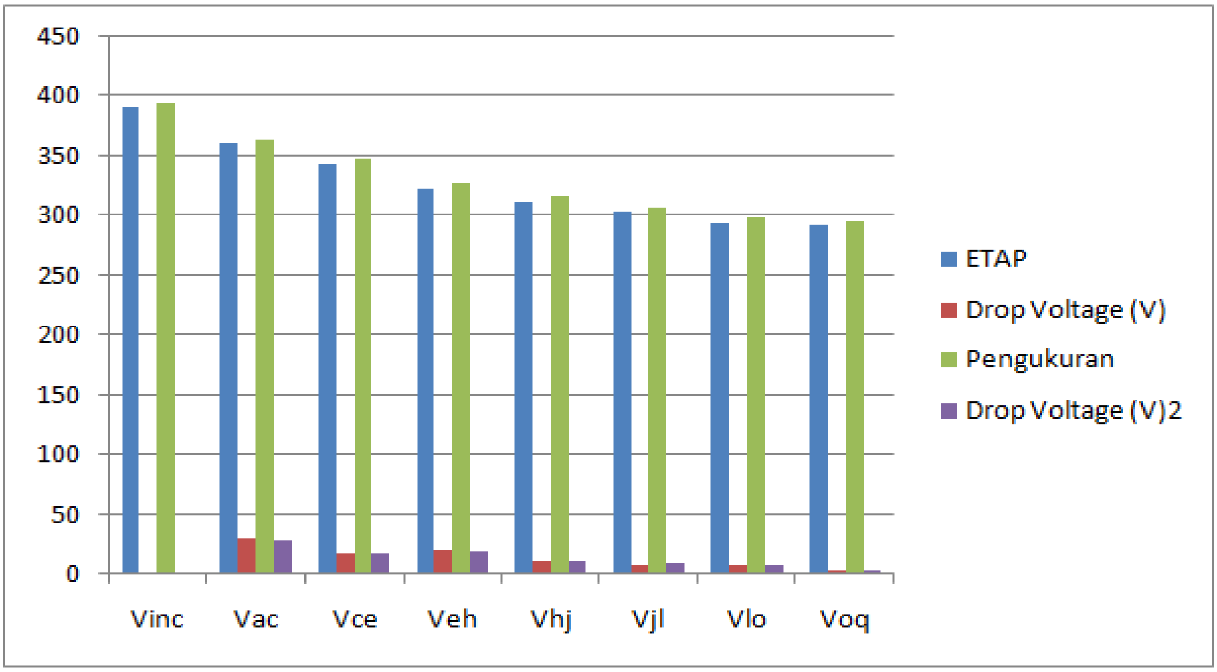


Figure 7. Voltage Drop Comparison Diagram Before Adding an Insertion Transformer

Based on the calculation results using the formula via PHBTR to the end network at point Q before adding the insertion transformer, the end voltage drop value can also be calculated as:

$(Vr) =$ (√3 x ρ x L x I x Cos phi) : A

= (1,732 x 0,0000000275 x 788 x 196 x 0,8) : 0,000035 = 168,14 V

Method for Calculating the Percentage of End-to-End Voltage Drop Before Transformer Insertion The calculation of the percentage of end-to-end voltage drop using direct measurements is as follows:

$$\Delta V\ (\%) = \frac{V_s - V_r}{V_r}\ x\ 100\%$$

$$\Delta V\ (\%) = \frac{392{,}7V - 295{,}2V}{295{,}2V}\ x\ 100\% = 32{,}8\%$$

The calculation of the percentage of end voltage drop using ETAP simulation is as follows:

$$\Delta V\ (\%) = \frac{V_s - V_r}{V_r}\ x\ 100\%$$

$$\Delta V\ (\%) = \frac{389{,}7V - 290{,}9V}{290{,}9V}\ x\ 100\% = 33{,}9\%$$

So, the calculation of the percentage of voltage drop by measuring and ETAP simulation has shown that the voltage at this end of the network is already does not comply with the provisions of the PLN standard voltage regulations stipulated in SPLN 1:1995 which states that the maximum and minimum limits of standard voltage are in the range of +5% or -10%. The following table compares the results of the end voltage drop calculations between the measurement results and the ETAP simulation.

Table 6. Comparison Results of ETAP Measurements and Simulations Before the Insertion Transformer

NO	Dasar Data	Presentase Drop Tegangan (%)
1	Pengukuran	32,8
2	Simulasi ETAP	33,9

Based on the results of current and voltage measurements at the PR 072 distribution transformer substation, the total average current in each phase can be calculated as seen from the measurement data as follows.

$$I\ rata - rata = \frac{Ir + Is + It}{3}$$

$$I\ rata - rata = \frac{199\ A + 188\ A + 200A}{3} = 196\text{A}$$

Thus, the results of the percentage of loading

$$\%\ \text{Load} = \frac{400\ x\ 196\ x\ \sqrt{3}}{160} : 1000\ x\ 100\% = 84{,}8\% = 135{,}7\ KVA)$$

Table 7. Comparison of Voltage Drop Results of ETAP Simulation After Transformer Insertion

NO	Dasar Data	ETAP	Drop Voltage (V)	Pengukuran	Drop Voltage (V)
1	VINC	393,3V	-	395,2V	-
2	VAC	387,4V	5,9V	390,6V	4,6V
3	VCE	385,1V	2,3V	387,4V	3,2V
4	VEH	383,6V	1,5V	385,2V	2,2V
5	VHJ	388,8V	4,5V	391,5V	3,7V
6	VJL	385,6V	3,2V	388,7V	2,8V
7	VLO	381,7V	3,9V	385V	3,7V
8	VOQ	380,5V	1,2V	383,2V	1,8V

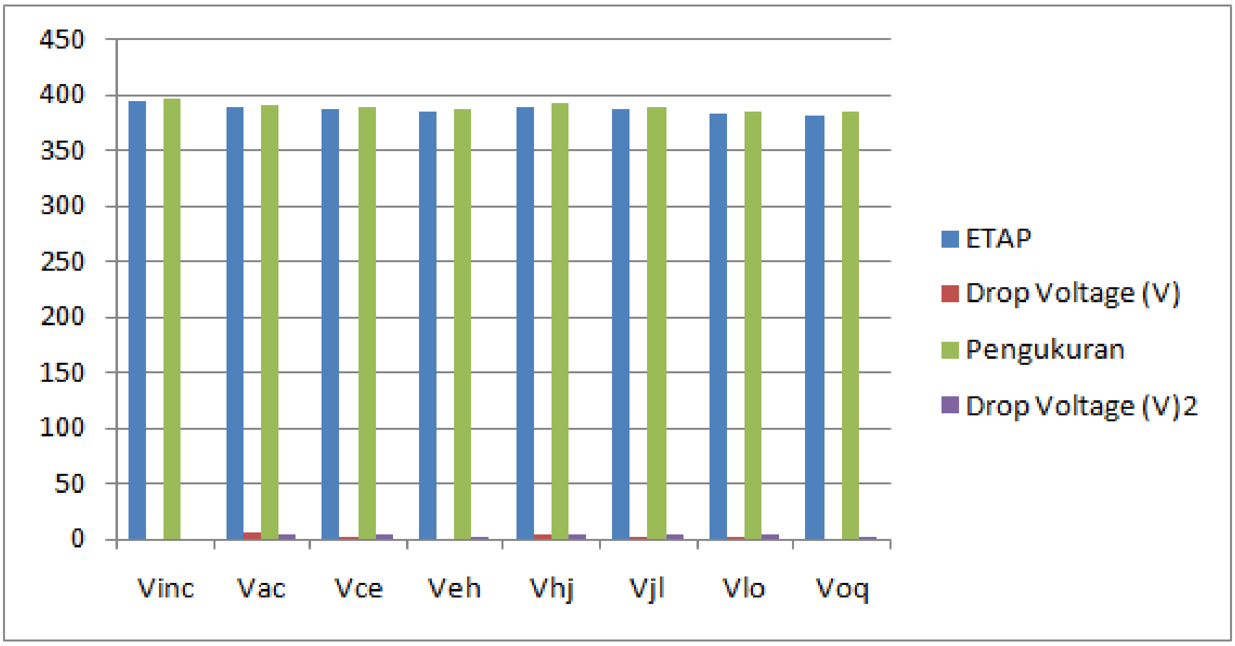
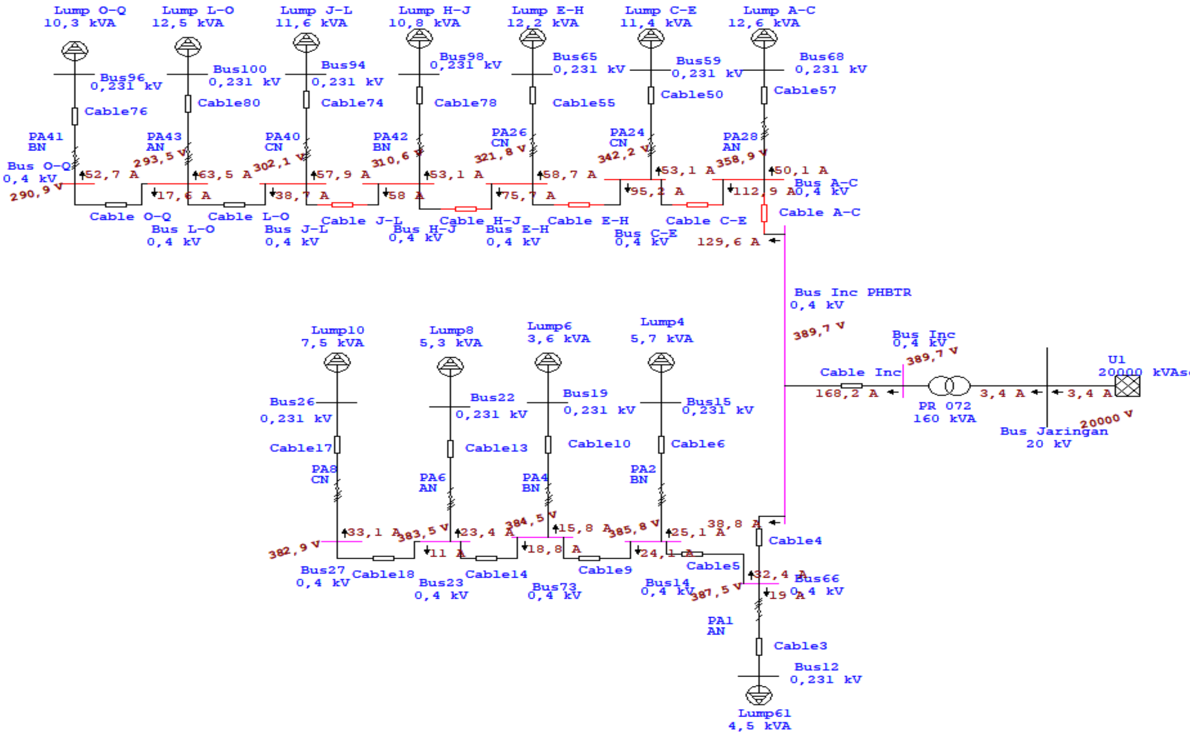
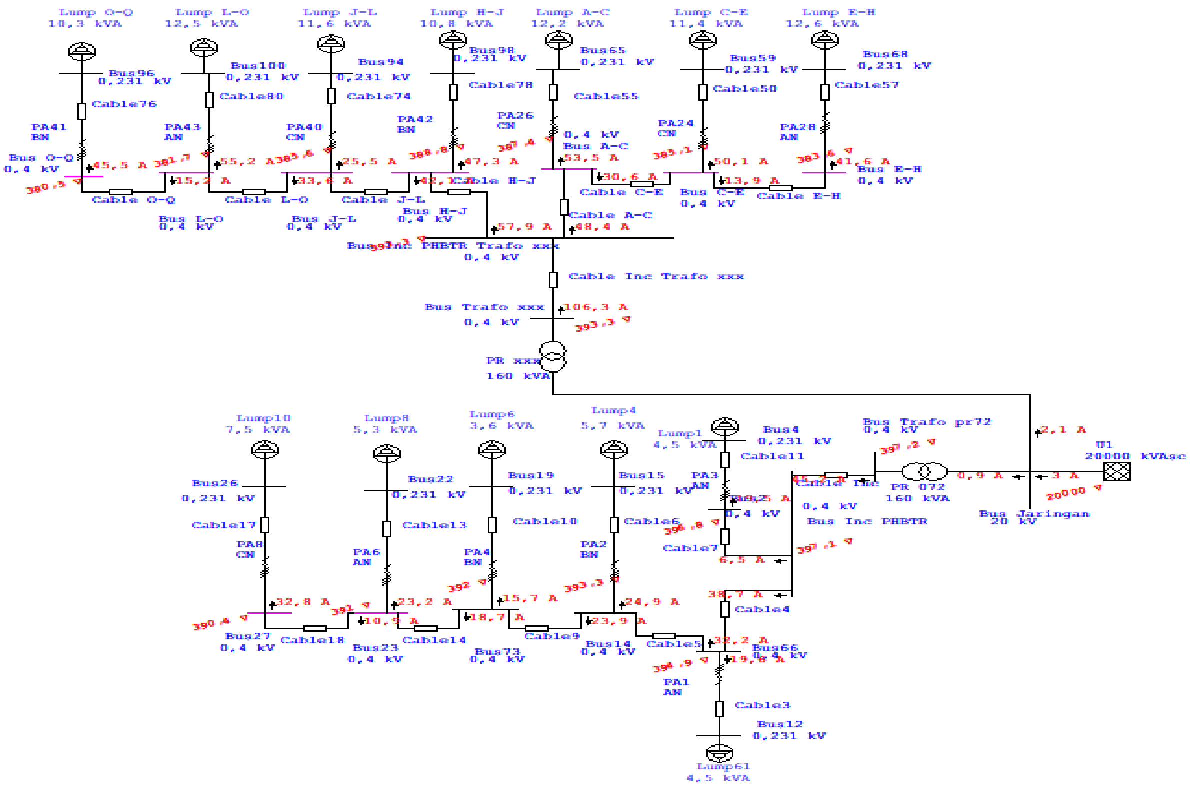


Figure 8. Voltage Drop Comparison Diagram After Transformer Addition Insert

ETAP Simulation of PR 072 Substation Before Adding Insert Transformer



Base and end voltage before adding insertion transformer through direct measurement



The calculation of the percentage of end voltage drop using ETAP simulation is as follows:

$$Vr\ (\%) = \frac{V_s - V_r}{V_r}\ x\ 100\%$$

$$Vr\ (\%) = \frac{392{,}7V - 295{,}2V}{295{,}2V}\ x\ 100\% = 32{,}8\%$$

Base and end voltage after adding an insertion transformer through ETAP simulation

$$Vr\ (\%) = \frac{V_s - V_r}{V_r}\ x\ 100\%$$

$$Vr\ (\%) = \frac{393{,}9V - 380{,}5V}{380,V}\ x\ 100\% = 3{,}3\%$$

Table 8. Comparison of Voltage Drop After Adding an Insertion Transformer

No	Dasar Data	Luas Penampang	Presentase Drop Tegangan (%)
1	Sebelum Penambahan Trafo Sisip	$3x35mm^2+1x25mm^2$	32,8
2	Sesudah Penambahan Trafo Sisip	$3x70mm^2+1x50mm^2$	3,3

For comparison of the percentage of voltage drop after adding insert transformers and uprating HUTR on the distribution network, it cannot be displayed yet because it is still in the implementation process, so the comparison taken is from the results of the ETAP simulation.

Conclusion

Based on the analysis of the voltage drop calculations for the 380/220 V low-voltage network, the following conclusions can be drawn: Transformer load conditions

1. Distribution transformers exhibit a relatively high load, exceeding 80% of the maximum load, amounting to 84.8% (135.7 kVA).
2. Voltage drop occurs at the end of the distribution system network, with the lowest voltage at the O-Q pole, measured directly at 295.2 V, or a voltage drop of 32.8%, and measured using the ETAP simulation, at 33.5%.
3. To address the voltage drop problem in the transformer, an insert transformer was added and an uprating of the HUTR TIC (3x70mm2 + 1x50mm2) with a length of 788 m with a capacity of 160 kVA was proposed to improve the quality of the electrical energy distribution.
4. The end voltage drop percentage after the insert transformer addition, based on the ETAP simulation, was 3.3%.

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