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Analytical Study of Control Systems For Power Loss Minimization In 20 kV Medium Voltage Distribution Network at PT PLN (Persero) ULP Balige

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Article Info
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ABSTRACT

A Power losses in medium voltage distribution networks remain a significant concern for utility companies, particularly in developing regions. This study presents an analytical investigation into the role of control systems in minimizing power losses within the 20 kV medium voltage distribution network at PT PLN (Persero) ULP Balige. This paper research focuses on identifying key components contributing to energy losses, such as unbalanced loading, reactive power flow, and suboptimal voltage regulation. A control system approach is analysed through simulations and system performance evaluations, involving the implementation of automatic capacitor bank control, transformer tap changers, and load balancing strategies. Using simulation tools such as ETAP and actual operational data from the Balige, distribution network, the study evaluates system behaviour under various control scenarios. The results show that implementing a responsive and automated control system significantly reduces technical losses, improves power factor, and enhances voltage profile stability across the network. The study concludes that an integrated control strategy tailored to the characteristics of the local network can optimize distribution efficiency and reduce operational costs. This research provides practical recommendations for PT PLN and similar utilities seeking to modernize their distribution infrastructure through smarter control technologies and data-driven planning.

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INTRODUCTION

The efficiency and reliability of electrical power distribution systems are critical for meeting the increasing energy demands of modern society. In Indonesia, PT PLN (Persero) as the national electricity provider is responsible for ensuring optimal energy delivery across all regions, including rural and semi-urban areas such as Balige, North Sumatra. However, one of the persistent challenges in the distribution sector is the occurrence of technical power losses, particularly in medium voltage (MV) networks operating at 20 kV.

Power losses in MV distribution lines are often caused by several factors, including long transmission distances, unbalanced loads, poor power factor, and inefficient voltage regulation. These losses not only reduce the overall efficiency of the system but also lead to increased operational costs and reduced voltage quality for end-users. In this context, the

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implementation of effective control systems plays a pivotal role in optimizing power flow, reducing losses, and ensuring network stability.

Control systems in MV networks can involve automatic capacitor bank switching, transformer tap-changing mechanisms (OLTC), real-time monitoring through SCADA, and load balancing strategies. By deploying such systems, utilities can respond dynamically to load variations, compensate for reactive power, and maintain optimal voltage levels throughout the distribution lines. This research focuses on conducting an analytical study of control system applications in the 20 kV distribution network at PT PLN (Persero) ULP Balige. The objective is to evaluate how integrated control strategies—both conventional and modern—can minimize power losses and improve distribution performance. Simulation tools and field data are utilized to assess the effectiveness of these methods under various operational scenarios.

The outcome of this study is expected to contribute practical insights for PLN and other utilities aiming to modernize their medium voltage networks through automation and intelligent control mechanisms. Furthermore, it supports national efforts to enhance energy efficiency and reduce technical energy losses in line with Indonesia's sustainable energy goals.

Good efficiency can be achieved by minimizing energy losses as much as possible. Losses in the distribution network system are an important factor that must be considered both in planning and operational stages, as they affect investment costs (Bambang, 2001; Gonen, 1986; Sulasno, 2000). In calculating power losses, several limitations are applied. The calculation is conducted only based on resistance in a single overhead line and a single medium voltage cable line as an example. Power losses caused by inductance and capacitance are disregarded. Furthermore, power losses in distribution transformers are calculated, including core losses and copper losses. Meanwhile, voltage losses along the line—such as those caused by insulators or cable insulation—are not considered. The aim of this paper is to introduce a method for calculating power losses in primary distribution networks, taking into account load curves, load types, and distribution transformers. It is expected that the data on power losses can serve as a reference for improving existing network systems or for planning the development of new networks. (Waluyo, 2020).

Literature Review

Energy Loses

Good efficiency can be achieved by minimizing energy losses as much as possible. Losses in the distribution network system are an important factor that must be considered both in planning and operational stages, as they affect investment costs (Bambang, 2001; Gonen, 1986; Sulasno, 2000). In calculating power losses, several limitations are applied. The calculation is conducted only based on resistance in a single overhead line and a single medium voltage cable line as an example. Power losses caused by inductance and capacitance are disregarded. Furthermore, power losses in distribution transformers are calculated, including core losses and copper losses. Meanwhile, voltage losses along the line—such as those caused by insulators or cable insulation—are not considered. The aim of this paper is to introduce a method for calculating power losses in primary distribution

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networks, taking into account load curves, load types, and distribution transformers. It is expected that the data on power losses can serve as a reference for improving existing network systems or for planning the development of new networks. (Waluyo, 2020)

Electric Power System Schematic.

In general, a system is defined as a unit consisting of several components or elements connected to facilitate flow information, materials or energy to achieve a goal. Thus, A system must consist of several components that are connected. in such a way that they can work according to their respective roles achieve certain goals. When associated with electrical power, then what will happen flowing in the system is electrical energy.

An electric power system is a system that consists of several components, including generation units, transmission lines, substations and distribution networks that are connected in such a way and work together to serve the electricity needs of customers according to their needs (Slamet Suripto.2017). In general, the electric power system can be described by a scheme figure 1.

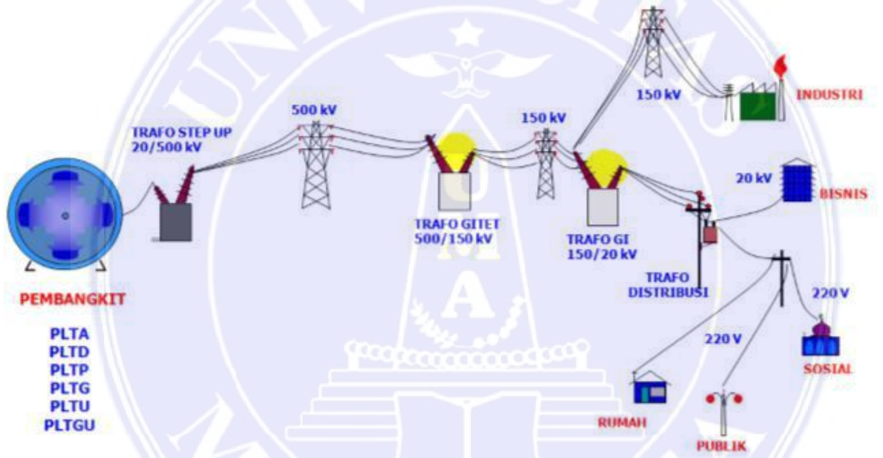

Figure 1. Schematic of electric power system

The electrical energy generated at the power plant will be distributed through the transmission channel then through the distribution channel it will reach consumers. A power plant is a part of an electric power system that tasked with producing electrical energy by converting various energy sources into electrical energy. The energy source can be water energy, fuel oil, coal, wind, solar, and others. To produce electrical energy,

a generating tool is needed which is usually called a generator. A generator can only produces electrical energy if the shaft rotates, and to rotate the generator, mechanical energy is needed which is generally produced by a turbine. Turbine functions to convert energy from primary energy sources into kinetic energy or mechanics. Each power generating unit is usually named according to its type. its primary energy source. For example, hydroelectric power plants (PLTA) utilize the power of water in reservoirs or rivers to rotate turbine or water wheel. Another type of power plant is a hydroelectric power plant. steam (PLTU), where the turbine is driven by the hot steam power produced from heating water to become high pressure steam. This water heating can using coal, oil, or natural gas

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as fuel. For power generation with small capacity, the use of diesel engines (PLTD) is often more economical even though the fuel is quite expensive.

Power generation based on renewable energy sources Recently, more and more have been developed to reduce global warming. global and air pollution. In this type of power plant, there is no longer any combustion fossil fuels that can cause global warming and air pollution. Geothermal power plants (PLTP), wind power plants (PLTB), and solar power plants (PLTS) are included in this category. PLTB uses wind power to turn windmills, PLTP using hot steam from within the earth to turn a turbine or heats the water, while the PLTS uses solar cells to convert solar heat energy into electrical energy. Each type of generator has different characteristics and properties, so that the construction of the power plant adapted to local conditions and needs.

Electric Power Transmission

Based on its construction, transmission channels are divided into channels overhead lines and underground cables. Air flows electrical energy through conductors suspended on towers or transmission poles with the help of insulators, while the underpass The ground transmits electrical energy through cables buried underground. ground surface. Both types of transmission lines have their advantages and 3their respective shortcomings.

Underground channels, compared to overhead channels, do not affected by adverse weather conditions such as typhoons, heavy rain, strong winds, lightning, or other natural disturbances. In addition, underground channels are more aesthetic because it does not interfere with the view, providing a neater appearance. Therefore, underground channels are preferred in densely populated areas, such as urban areas. However, in terms of investment costs, underground channels.Land requires greater costs compared to air ducts. In addition, repairs are also more difficult if there is a problem such as a short circuit. short, broken cables, and other problems. (Ramadoni Syahputra. 2021).

In an electric power system, the voltage used at each components can vary according to their function. In other words, each components in an electric power system operate at a voltage level that These adjustments are made to achieve greater efficiency good and make the system more economical.

In the generation system, the voltage level is adjusted according to the specifications and the capacity of the generator used, which generally ranges between 4.5 up to 20 kV. For generators with larger capacities, usually higher voltage levels are used. This is intended to reduce the magnitude of the current flowing, because at a certain generator power capacity, the magnitude of the current is inversely proportional to the voltage. This means that the higher the voltage, the smaller the current that flows. With a smaller current, the The cross-sectional area of the coil wire required is also smaller, so the size generators can be more compact and lower in cost. In addition, the current smaller also reduces power losses in the windings, making it more economical.

However, the voltage level at the generator is usually not very high, because the higher the generator voltage, the number of turns on the generator must be plus, that would make the generator bigger and heavier, so less efficient. The large size and weight of the generator will also make it difficult transportation and installation process. Conversely, for

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generators with smaller capacity, lower output voltage level is preferred to be more economical. If the generating unit will be connected to a transmission line whichas a higher voltage level, voltage boosting equipment is required, namely a step-up transformer.

Transmission Line Voltage

Transmission line systems generally use voltage levels that higher than the voltage at the generating unit. This is caused by the main function of the transmission line which is to transmit power or electrical energy, so that what is prioritized is the system's ability to transmit power with high efficiency or low power loss. One of the the way to achieve this is to increase the voltage level, so that the current flowing in the transmission line becomes smaller. When the current that flowing on the transmission line conductor becomes smaller, the power loss that occurs on the network is also getting smaller, so that the transmission channel becomes smaller efficient. In addition, with the reduction in current, the voltage drop that occurs on the channel is also smaller, so the voltage at the receiving end will not be too low.

However, the higher the voltage on the transmission line, the higher also the level of insulation required on the equipment, which has consequences on increased costs. In addition, for environmental safety and security, Higher support towers are required. Transmission line voltage usually ranges from 70 kV to 1000 kV. Transmission lines with A voltage of 500 kV or more will be more economical if used for transmit large power over long delivery distances. On the other hand, for short distance and not too much power, more economical to use lower voltage so that the construction costs are cheaper.

Distribution network voltage

Distribution networks generally use higher voltage levels. low compared to transmission lines. This is because the power that distributed are usually smaller, and the distribution network locations are generally located around customer settlements, so that safety factors become very important. Distribution network is part of the electric power system which is directly connected to the consumer, so that the voltage level adjusted to the needs of electrical energy users.

There are two voltage levels that are often used in distribution networks, namely the 20 kV medium voltage network (JTM) and the low voltage network (JTR) 220 V. Therefore, a distribution transformer is needed to reduce the voltage. voltage from JTM 20 kV to JTR 220 V according to needs customers. Medium voltage networks (MVNets) are usually used for connecting the substation to loads that require relatively large power, such as industry, hospitals, malls, or campuses, which usually subscribe with a medium voltage of 20 kV. Meanwhile, household loads with smaller power is usually connected to a low voltage network of 220 V.

METHOD

This study utilizes an analytical approach based on simulation modeling and real operational data to evaluate the impact of control systems on power loss minimization in a 20 kV medium voltage distribution network. Technical data were collected from PT PLN (Persero) ULP Balige, including:

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a. Load profiles
b. Transformer specifications
c. Conductor types and lengths (overhead and underground)
d. Power factor records and capacitor bank configurations

These data were used as the basis for the development of the simulation model. A representative model of the 20 kV distribution network was created using ETAP 19.0. The model included:

a. Main feeders
b. Distribution transformers
c. Load points and variations
d. Reactive compensation components (capacitor banks)

The simulation was run under various operating conditions: light, medium, and peak load scenarios. Power losses were analyzed under two main conditions:

a. Without control system (baseline)
b. With control system, which included:
    1. Automatic capacitor bank switching
    2. Load balancing
    3. Voltage regulation using transformer tap changers (OLTC)

The impact of these control systems was assessed based on:

a. Total active power loss (kW)
b. Voltage drop across feeders
c. System power factor

Performance Evaluation Simulation results were compared and visualized using tabular and graphical analysis to quantify:

a. Reduction in total losses
b. Improvement in voltage stability
c. Enhancement in power factor performance

The findings were used to recommend an optimal control configuration for PLN's existing distribution system. In this study, the author collected data at PT. PLN (Persero) ULP Balige, Data collection is carried out by requesting data which already exists at PT. PLN (Persero) ULP Balige, Data was obtained by follow the procedures in place at the agency, namely by send a letter of permission to collect data and the University. Next waiting for a reply from PLN, after the reply letter is received, then Data collection is carried out according to the needs for research. Data that is needed. The research tools needed by the author in Data retrieval is a device or object that is used or help us do something like write, draw, or measuring in this study the tools used in data collection are as follows :

a. Stationery
   Stationery functions as a recording medium in the data collection process. data, where the data will be used as calculation material.
b. Ampere Clamp

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Ampere clamp is one of several electrical measuring tools, clamp This meter or ampere clamp is a tool used to measure electric current without breaking the current path in this tool research used to measure incoming and outgoing current.

Data obtained from direct observation of objects research. One of the methods used to obtain primary data is an interview while in the field. Data collection was carried out directly at PT. PLN (Persero) ULP BALIGE. The purpose of this data collection is to obtain data that related to the final assignment research which will analyze power loss in medium voltage distribution system of overhead lines and cables on feeders BLG 01 PT. PLN (Persero) ULP BALIGE.

In a distribution network system, power loss occurs in the overhead lines. or cables and on transformers. Power loss on the line is caused by by the resistance present in the line itself, while in a transformer, power loss occurs due to transformer winding resistance and loss at the core. Power loss in this network is highly dependent on the conditions the load is constantly changing, so the calculations must be done based on every existing load condition. Specifically in this thesis, power loss is discussed in medium voltage distribution network and distribution transformers, so that written as.

RESULT

Analysis

The network used in this power loss calculation is a network medium voltage September 2023 BLG 01 feeder PT. PLN (Persero) ULP BALIGE as a sample of power loss calculations with the data obtained in the field, namely:

Table 1. Medium Voltage Current and Low Voltage Side Load Data BLG 01 PT. PLN (Persero) ULP BALIGE

Name Substation	WHEN SITE	TM FLOW (A)			TR CURRENT (V)			TR VOLTAGE (V)		
		IR	IS	IT	IR	IS	IT	VR-n	VS-n	VR-n
BL01	200	1.6	1.2	1.2	165	124	120	222	220	214
BL02	160	1.5	1.1	0.9	144	103	92	220	218	216
BL09	200	1.2	0.5	1	120	58	104	221	228	227
BL15	100	0.9	0.8	0.8	95	79	85	219	217	218
BL17	50	1.3	1.3	0.9	129	134	92	224	223	222
BL18	50	1	0.7	0.9	100	75	96	222	219	218
BL26	100	0.9	0.8	0.5	90	89	55	216	222	220
BL27	100	1.3	1.2	0.9	129	116	94	214	220	218
BL28	50	1.2	0.9	1.1	119	94	113	220	218	216
BL38	100	1.2	1.1	1.1	123	113	113	218	216	215
BL39	250	1.5	1.3	0.9	146	133	95	221	216	223
BL42	50	0.9	0.7	0.8	90	75	80	220	218	216
BL43	250	1.7	1.2	1.2	175	124	120	230	234	234
BL48	250	1.6	1.5	1.3	160	155	132	228	227	227

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Name Substation	WHEN SITE	TM FLOW (A) IR	IS	IT	TR CURRENT (V) IR	IS	IT	TR VOLTAGE (V) VR-n	VS-n	VR-n
BL55	100	1.1	1	1.1	111	97	112	231	229	234
BL67	250	1.3	1.2	1.1	132	124	111	228	226	227
BL71	50	1.1	1	0.9	111	98	90	224	218	220
BL75	50	1.1	0.7	1.1	113	75	111	222	228	216
BL76	250	1.4	1	1	145	103	95	222	219	223
BL80	250	1.3	1	1.2	135	104	121	220	218	218
BL83	160	1.3	1.3	0.9	129	134	92	219	216	218
BL86	100	1	1.2	1	94	103	92	222	218	220
BL87	100	1.4	1.1	1	141	109	97	220	222	222
BL90	160	1.4	1.1	1	134	113	95	218	220	220
BL93	50	1.2	1	1.1	121	103	112	218	215	216
BL94	100	1.1	2	1.2	113	103	110	215	213	212

Table 2. Distribution Transformer Data BLG 01 Feeder PT. PLN (Persero) ULP BALIGE.

Name Substation	Capacity (kVA)	Type Transformer	Shrinkage Iron Fe	Shrinkage Copper Cu
BL01	200	United Nations	480	2500
BL02	160	United Nations	400	2000
BL09	200	United Nations	480	2500
BL15	100	United Nations	300	1600
BL17	50	United Nations	150	800
BL18	50	United Nations	150	800
BL26	100	United Nations	300	1600
BL27	100	United Nations	300	1600
BL28	50	United Nations	150	800
BL38	100	United Nations	300	1600
BL39	250	United Nations	600	3000
BL42	50	United Nations	150	800
BL43	250	Starlite	600	3000
BL48	250	Starlite	600	3000
BL55	100	United Nations	300	1600
BL67	250	United Nations	600	3000
BL71	50	United Nations	150	800
BL75	50	United Nations	150	800
BL76	250	United Nations	600	3000
BL80	250	United Nations	600	3000
BL83	160	United Nations	400	2000

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Name Substation	Capacity (kVA)	Type Transformer	Shrinkage Iron Fe	Shrinkage Copper Cu
BL86	100	United Nations	300	1600
BL87	100	United Nations	300	1600
BL90	160	United Nations	400	2000
BL93	50	United Nations	150	800
BL94	100	United Nations	300	1600
BL95	100	United Nations	300	1600
BL111	160	Starlite	400	2000
BL112	50	Starlite	150	800
BL113	160	United Nations	400	2000
BL115	100	United Nations	300	1600
BL118	100	United Nations	300	1600
BL125	100	United Nations	300	1600

Low voltage side load data was obtained from measurements on each distribution substation and measured for each phase, namely load current (ITR), load voltage (VTR), and sometimes load power (STR) or calculated. explained in Table 4.1 Calculation of Load Current (ITM'), Load Voltage (VTM'), Load Power (STM'), is carried out at each distribution substation. The conductor used in this power loss calculation is conductor with a cross-sectional area of 240 mm² for air ducts and ducts cable is missing. The data of the conductor is listed in the table

Table 3. Data on Overhead Line Conductors and PLN Feeder Cables (Persero) ULP BALIGE.

NO	SUBSTATION BEGINNING	SUBSTATION END	TYPE CHANNEL	LONG (m)	R (ohm/km)
1	GI	BL01	SUTM	250	0.438
2	BL01	BL02	SUTM	167	0.438
3	BL02	BL09	SUTM	213	0.438
4	BL09	BL15	SUTM	217	0.438
5	BL15	BL17	SUTM	198	0.438
6	BL17	BL18	SUTM	323	0.438
7	BL18	BL26	SUTM	221	0.438
8	BL26	BL27	SUTM	213	0.438
9	BL27	BL28	SUTM	55	0.438
10	BL28	BL38	SUTM	75	0.438
11	BL38	BL39	SUTM	145	0.438
12	BL39	BL42	SUTM	177	0.438
13	BL42	BL43	SUTM	176	0.438
14	BL43	BL48	SUTM	218	0.438
15	BL48	BL55	SUTM	88	0.438
16	BL55	BL67	SUTM	231	0.438
17	BL67	BL71	SUTM	214	0.438

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NO	SUBSTATION BEGINNING	SUBSTATION END	TYPE CHANNEL	LONG (m)	R (ohm/km)
18	BL71	BL75	SUTM	228	0.438
19	BL75	BL76	SUTM	301	0.438
20	BL76	BL80	SUTM	145	0.438
21	BL80	BL83	SUTM	177	0.438
22	BL83	BL86	SUTM	176	0.438
23	BL86	BL87	SUTM	250	0.438
24	BL87	BL90	SUTM	167	0.438
25	BL90	BL93	SUTM	213	0.438
26	BL93	BL94	SUTM	217	0.438

Calculation Results

From the results of the analysis carried out, the results were obtained from the BL 01 feeder which is in PT.PLN (Persero) ULP Balige is as follows:

Table 4. Power Loss in Transformer BLG 01 PT. PLN (Persero) ULP BALIGE

NO	SUBSTATION	POWER DECLINE TRANSFORMER(W)
1	BL01	295.68
2	BL02	266.45
3	BL09	227.09
4	BL15	233.44
5	BL17	585.05
6	BL18	343.70
7	BL26	208.54
8	BL27	351.56
9	BL28	491.83
10	BL38	346.46
11	BL39	290.98
12	BL42	297.73
13	BL43	310.52
14	BL48	324.50
15	BL55	318.36
16	BL67	283.13
17	BL71	435.65
18	BL75	421.60
19	BL76	275.85
20	BL80	279.11
21	BL83	263.96
22	BL86	319.64
23	BL87	366.25
24	BL90	263.33

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NO	SUBSTATION	POWER DECLINE TRANSFORMER(W)
25	BL93	516.09
26	BL94	524.59
27	BL95	367.53

Table 5. Power Loss on BLG 01 Channel PT. PLN (Persero) ULP BALIGE.

NO	SUBSTATION BEGINNING	SUBSTATION END	TYPE CHANNEL	SHRINKAGE POWER CHANNEL(W)
1	GI	BL01	SUTM	0.17
2	BL01	BL02	SUTM	0.09
3	BL02	BL09	SUTM	0.10
4	BL09	BL15	SUTM	0.09
5	BL15	BL17	SUTM	0.12
6	BL17	BL18	SUTM	0.14
7	BL18	BL26	SUTM	0.08
8	BL26	BL27	SUTM	0.12
9	BL27	BL28	SUTM	0.03
10	BL28	BL38	SUTM	0.04
11	BL38	BL39	SUTM	0.09
12	BL39	BL42	SUTM	0.07
13	BL42	BL43	SUTM	0.13
14	BL43	BL48	SUTM	0.16
15	BL48	BL55	SUTM	0.05
16	BL55	BL67	SUTM	0.14
17	BL67	BL71	SUTM	0.11
18	BL71	BL75	SUTM	0.11
19	BL75	BL76	SUTM	0.17
20	BL76	BL80	SUTM	0.08
21	BL80	BL83	SUTM	0.10
22	BL83	BL86	SUTM	0.08
23	BL86	BL87	SUTM	0.14
24	BL87	BL90	SUTM	0.09
25	BL90	BL93	SUTM	0.12
26	BL93	BL94	SUTM	0.11
27	BL94	BL95	SUTM	0.09
28	BL95	BL111	SUTM	0.05
29	BL111	BL112	SUTM	0.06
30	BL112	BL113	SUTM	0.13
31	BL113	BL115	SUTM	0.12
32	BL115	BL118	SUTM	0.12

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NO	SUBSTATION BEGINNING	END	TYPE CHANNEL	SHRINKAGE POWER CHANNEL(W)
33	BL118	BL125	SUTM	0.06

From the table above it can be seen that the overall calculation of total shrinkage is: 11159.80 W.

CONCLUSION

This study has demonstrated that the implementation of control systems within the 20 kV medium voltage distribution network at PT PLN (Persero) ULP Balige can significantly minimize technical power losses. Based on simulation results using real operational data, it was found that: The integration of automatic capacitor bank control, load balancing, and transformer tap changer mechanisms contributed to a substantial reduction in active power losses across various load conditions. The application of control strategies also improved voltage profiles along the feeders, reducing the potential for undervoltage or overvoltage at end-user points. Power factor correction through reactive power compensation proved effective in lowering losses and optimizing overall system efficiency. The most significant loss reduction was observed under peak load conditions, where the presence of an adaptive control system helped stabilize power flow and minimize energy waste. These findings suggest that investing in intelligent and automated control technologies can provide practical benefits in improving operational performance and energy efficiency in distribution networks. It is recommended that PLN considers a phased implementation of such systems, supported by continuous monitoring and evaluation for optimal performance.

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