



Analysis of End Voltage Quality Improvement through Transformer Tap Adjustment and Grounding System Optimization at the Distribution Substation of PT PLN (Persero) ULP Alas

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Abstract: Reducing distribution losses in low-voltage networks remains a key operational priority for PT PLN (Persero) ULP Alas. This study investigates the effectiveness of distribution transformer tap optimization and grounding system reinforcement as a combined approach to improving voltage quality and reducing technical losses. The transformer tap was adjusted at Distribution Substation AL114 from position 5 (19.0 kV) to position 3 (20.0 kV) to align secondary voltages with the nominal 400/230 V standard, thereby decreasing conductor current and mitigating energy losses. In addition, a grounding system installation was implemented to enhance system stability and reduce voltage fluctuations. Following these improvements, the end-voltage on the Low Voltage Network (LVN) increased from 202 V to 217 V, resulting in an energy-loss reduction of 2.973 kW, equivalent to IDR 2,990,505 in cost savings. The results confirm that transformer tap adjustment combined with proper grounding implementation provides a practical and effective method for improving voltage regulation and overall distribution system performance.

Article History

Received: 06.03.2026

Accepted: 20.04.2026

Published: 25.05.2026

Keywords: Distribution losses, Grounding system, Voltage regulation, System stability.

Cite this article:

Sukadana, I.W., Krisna, I.G.E.W., Sutama, I.W., Ariawan, P., Arnaya, P.B., (2026). Analysis of End Voltage Quality Improvement through Transformer Tap Adjustment and Grounding System Optimization at the Distribution Substation of PT PLN (Persero) ULP Alas. *ISAR Journal of Science and Technology*, 4(5), 70-74.

Introduction

PT PLN (Persero) is a state-owned electricity utility responsible for the generation, transmission, and distribution of electrical power to customers across Indonesia. By implementing the principles of Good Corporate Governance (GCG), PLN aims to enhance corporate performance, operational efficiency, and service quality to ensure customer satisfaction and maintain healthy financial performance [1].

The Following the COVID-19 pandemic, the need for improved distribution efficiency has become increasingly critical. One of PLN's key strategies is to reduce energy losses, defined as the difference between the amount of energy generated and the portion successfully delivered to customers. These losses are typically categorized into technical and non-technical losses [2].

Within PT PLN (Persero) UP3 Sumbawa, ULP Alas has implemented transformer tap adjustments on low-voltage networks (LVNs) to improve customer voltage quality. The targeted voltage levels are 230 V for phase-to-neutral and 400 V for phase-to-phase, with an allowable voltage drop tolerance of +5% to -10% according to established standards [3]. Adjusting the transformer tap is expected to improve voltage profiles, reduce excessive current flow, and lower technical losses in the LVN [4].

Prior to the tap adjustment, the end-voltage at Distribution Substation AL114 was recorded at below 200 V, resulting in customer complaints and potential equipment malfunction. In addition to tap optimization, grounding installation was carried out at the terminal pole of the low-voltage feeder to further reduce losses, enhance system stability, and improve overall network safety.



This study aims to analyze the improvement of end-voltage conditions on the LVN before and after the implementation of transformer tap adjustment and grounding installation at PT PLN (Persero) ULP Alas. Furthermore, the study estimates the potential energy and cost savings generated from the improved voltage performance at Substation AL114. The scope of this research focuses on technical losses within the low-voltage network, utilizing data obtained from field measurements and the Substation Management Application. The findings are expected to provide insights into voltage quality enhancement, loss reduction, and contributions to improved network safety, while supporting PLN's position as a reliable electricity service provider.

Methods

This study refers to several relevant previous works. In the journal "Optimization of Load Balancing with Feeder Network Reconfiguration Using ETAP Simulation," technical losses were reported to occur due to overload conditions, particularly when currents exceeded 150 A on the Tangeb Feeder. The study employed ETAP software to simulate feeder network reconfiguration by adding a new feeder from the Pamaron Munggu Load Break Switch (LBS) to the Dukuh Sengguan LBS. The results demonstrated the effectiveness of this method in reducing technical losses, as indicated by an increase in system voltage from 19 kV to 19.238 kV [5].

Moreover, I Made Edy Suriawan, in his research titled "Analysis of Distribution Transformer Tap Adjustment at PT PLN (Persero) ULP Samawa Rea for Improving Distribution Energy Losses," explained that transformer tap readjustment aims to optimize secondary voltage to the nominal level of 400/230 V. The study successfully reduced distribution losses from 3,128,639.3101 watts to 2,828,168.4660 watts, yielding an energy saving of 300,470.8441 watts [6].

The distinct contribution of the present study lies in the combination of methods applied, namely transformer tap adjustment, grounding installation at the terminal pole of the Low-Voltage Network (LVN), and load balancing at Distribution Substation AL114. In addition, this research utilizes the Substation Management Application (AMG) to support data collection and analysis, providing a more integrated and data-driven approach compared to previous studies. This study was conducted at PT PLN (Persero) UP3 Sumbawa on the Tambak Sari Feeder within the operational area of ULP Alas. The research location is illustrated in Figure 2.1, which shows the position of Substation AL114 based on Google Maps mapping.



Figure 2.1. AL114 Substation on the Tambak Sari Feeder (Source: Google Maps)

The research began with a literature review and the collection of substation-related data, including the 20 kV system single-line diagram, load data, distribution substation management data, and end-voltage measurements. Voltage and load measurements were conducted from June to July 2024 to obtain baseline data prior to load balancing. If the current imbalance exceeded 20%, a load balancing process was carried out. Following the balancing process, additional measurements were taken to ensure that the current imbalance had been reduced to below 20%.

Subsequently, energy loss calculations were performed by comparing voltage conditions before and after the load balancing. An increase in voltage results in a reduction of current, thereby decreasing losses in the low-voltage distribution network (JTR). Based on these calculations, the amount of energy savings expressed in kWh and monetary value was determined.

Results and Discussions

The implementation of end voltage improvement and maintenance at the distribution transformer substation of PT PLN (Persero) ULP Alas is carried out through the Tambak Sari feeder, originating from the outgoing panel of the Alas Substation (GI Alas). This feeder plays a critical role in delivering electrical energy from the substation to the distribution transformer before it is supplied to customers. In this process, transformer tap adjustments and grounding installations are essential measures to ensure voltage stability and distribution reliability.

The network structure of the Tambak Sari feeder is illustrated in Figure 3.1, which presents the 20 kV Single Line Diagram of the Tambak Sari Feeder at GI Alas, while the configuration of the external-mounted pole-mounted transformer substation is shown in Figure 3.2.

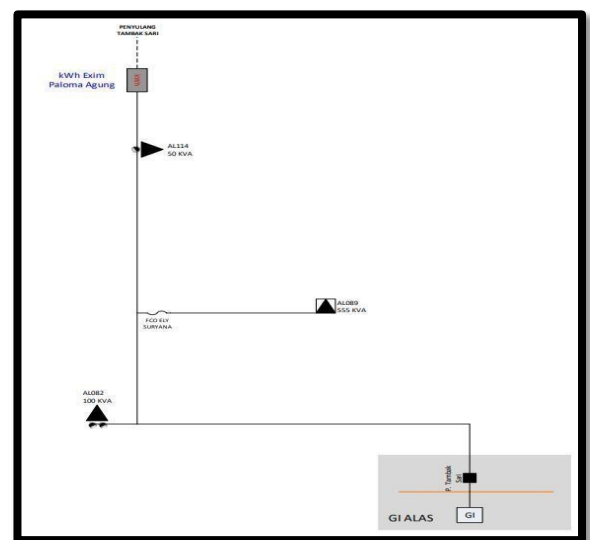


Figure 3.1. Single-Line Diagram of the 20 kV Tambak Sari Feeder at Alas Substation

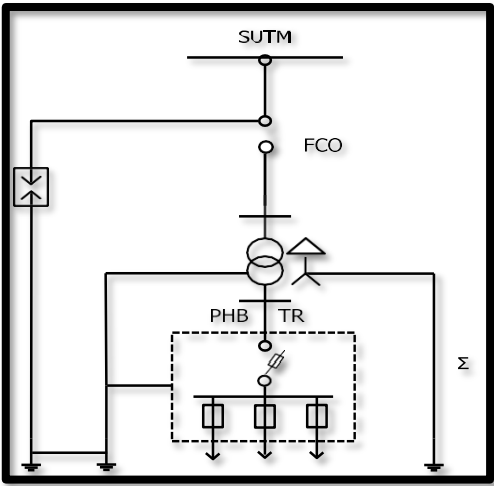


Figure 3.2. Single-Line Diagram of the External Mounted Cantol Distribution Transformer

The AL114 Distribution Substation consists of several key components that support the reliable and continuous delivery of electrical power. The Fused Cut Out (FCO) functions as an external distribution transformer protection device and is equipped with three types of fuse links—Type-K (fast), Type-T (slow), and Type-H (high-surge)—each selected based on load characteristics and protection requirements. In addition, the Lightning Arrester (LA) protects the distribution transformer from overvoltage surges caused by lightning strikes or switching events, thereby preventing potential damage to critical substation components.

Another essential component is the AL114 Distribution Transformer, which steps down medium voltage (20 kV) from the Medium Voltage Overhead Line (SUTM) to low voltage (400 V) before it is supplied to customers. The transformer has a rated capacity of 50 kVA, a primary rated current of 2.89 A, a secondary rated current of 72.17 A, and contains 112 liters of mineral-naphthenic insulating oil.

The Low Voltage Distribution Panel (PHB-TR) is also a critical element of the AL114 Substation. This panel serves as the central low-voltage distribution point, integrating switching equipment, metering, protection, and control devices. The PHB-TR at AL114 uses a 630 A main switch, is connected through NYY 95 mm² inlet and outlet cables, and complies with the D3.002-1:2020 standard.

Furthermore, the Low Voltage Network (LVN) acts as the final distribution pathway delivering electricity to end-users. This network uses NFA2Y conductors installed on 9-meter concrete poles, with conductor specifications of 3×50 + N, and a total network length of 1.15 km.

Prior to conducting the grounding installation at the end pole and the transformer tap adjustment at Substation AL114, several preparatory steps were carried out to ensure operational safety and workflow efficiency. The process began with the development of a Job Safety Analysis (JSA), completed at least four days before field execution, to identify and mitigate potential electrical work hazards under the supervision of project and HSE personnel.

Following JSA approval, a detailed work schedule and work permit were issued to organize each task in accordance with operational standards. The final preparation stage involved verifying the readiness and functionality of all required equipment. Key tools included a ground rod, 30 meters of NYAF cable, an earth tester for grounding resistance measurement, and an AVO meter for voltage and current inspection, supported by additional equipment such as a full-body harness, ladder, crimping tools, wire strippers, and screwdrivers.

The grounding installation and transformer tap adjustment at Substation AL114 began with a pre-work analysis to assess the initial operating condition of the substation. Data collection included measurements of the sending-end voltage, the active tap position, the receiving-end voltage on the Low Voltage Network (LVN), and the neutral current. These parameters were obtained through the Substation Monitoring Application (AMG) and subsequently documented, as presented in Tables 1, 2, and 3.

Table 1 Secondary Substation Data Before Work Execution

Secondary Transformer Data				
NO	Conductor	Current	Line-to-Line Voltage	Line-to-Neutral Voltage
1	R Phase	32.2 A	R-S 416.1 V	R-N 221 V
2	S Phase	15.5 A	S-T 416.3 V	S-N 220 V
3	T Phase	17.6 A	R-T 415.2 V	T-N 219 V
4	Neutral	26.1 A		
5	Unbalanced Current	31.96 %		

Table 2 Feeder B Substation Data Before Work Execution

Feeder B Substation Data		
Conductor	Current	End Voltage
R Phase	3.5 A	R-N 202 V
S Phase	6.7 A	S-N 202 V
T Phase	5.1 A	T-N 204 V
Neutral	10.1 A	

Table 3. Feeder D Substation Data Before Work Execution

Feeder B Substation Data		
Conductor	Current	End Voltage
R Phase	28.9 A	R-N 201.5 V
S Phase	8.7 A	S-N 202.3 V
T Phase	12 A	T-N 200.2 V
Neutral	16.1 A	

After data collection was conducted using the AMG application (Transformer Monitoring Application), the subsequent stage involved further analysis, including the calculation of the percentage increase in end voltage, the calculation of the neutral current difference at the distribution transformer after maintenance activities, the conversion of the observed current variation into the corresponding power value, and finally, the calculation of cost savings in terms of rupiah per kWh at Transformer AL114 following the implemented corrective actions.

Table 4. Comparison of End Voltage Rise on Feeder B at the Distribution Transformer

Distribution Transformer Data for Feeder B		
Phase-Neutral Voltage	Terminal Voltage Before Maintenance	End Voltage After Maintenance
R-N	202 V	216 V
S-N	202 V	217 V
T-N	204 V	217.5 V

Table 5. Comparison of End-of-Feeder Voltage Increase on Feeder D

Distribution Transformer Data for Feeder D		
Phase-Neutral Voltage	Terminal Voltage Before Maintenance	End Voltage After Maintenance
R-N	201.5 V	218 V
S-N	202.3 V	217 V
T-N	200.2 V	218.5 V

Tables 4 and 5 present the end of feeder voltage values before and after maintenance activities. The subsequent stage of this study involves calculating the percentage increase in the end-of-feeder voltage. The following equation is used to determine the percentage increase in the end-of-feeder voltage:

$$\begin{aligned}
 \text{Percentage Change (\%)} &= ((V_2 - V_1) / V_1) \times 100\% \\
 &= ((216 - 202) / 202) \times 100\% \\
 &= (14 / 202) \times 100\% \\
 &= 6.93\%
 \end{aligned}$$

where:

V2 = voltage after maintenance

V1 = Tegangan Sebelum dilakukan perbaikan

The analysis results indicate that energy losses prior to corrective actions reached 5.96 kW, whereas after the improvements, the losses decreased to 2.987 kW. Consequently, an energy saving of 2.973 kW was achieved, which, when converted into monetary value, is equivalent to IDR 2,990,505.00. This demonstrates that the implemented improvements not only enhanced service quality but also improved operational efficiency.

These findings confirm that the application of transformer tap adjustment methods and the installation of grounding systems constitute efficient and effective measures for reducing distribution losses. Furthermore, these improvements have a positive impact on the quality of customer service in the AL114 distribution transformer area.

Conclusions

Based on the discussion, it can be concluded that the installation of grounding systems and the readjustment of transformer tap settings at the AL114 distribution transformer resulted in significant improvements to the electrical distribution system. The analysis indicates that the average end-of-feeder voltage per phase increased by 7.59%, reflecting an enhancement in power quality delivered to customers. Furthermore, the readjustment of the transformer tap from tap 5 (19,000 V) to tap 3 (20,000 V) successfully reduced the neutral current from 26.1 A to 10.1 A, yielding a difference of 16.1 A. This reduction improved power distribution efficiency and decreased the load on the neutral system.

The conversion of current into power revealed that the power loss due to imbalance reached 2.973 kW, which can be utilized more efficiently after the corrective actions. The maintenance activities resulted in a monthly cost saving of IDR 2,990,505.00 for PLN, demonstrating tangible economic benefits for both the utility company and its customers.

It is recommended that transformer maintenance activities be carried out in accordance with proper procedures and established Standard Operating Procedures (SOPs), ensuring that both personnel and supervisors possess adequate technical knowledge. Regular training programs are essential to enhance competency, improve work efficiency, and minimize technical errors. Occupational health and safety (OHS) should be prioritized by strictly adhering to safety procedures and utilizing appropriate personal protective equipment to prevent workplace accidents. Periodic post-maintenance monitoring is also crucial to mitigate potential disturbances or hazards.

Additionally, PLN is encouraged to develop more advanced transformer monitoring systems to obtain accurate and real-time data, facilitate effective supervision, and enable faster problem resolution. Finally, transformer improvement and maintenance activities should be planned more routinely, taking into account the potential energy and cost savings achievable through a more efficient electrical distribution system.

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