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OPTIMIZING 20 KV FEEDER NETWORKS WITH GAUSS-SEIDEL TO MINIMIZE LOSSES AT PLN UP3 SEMARANG

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Abstrak: Meningkatnya permintaan energi listrik, yang didorong oleh pertumbuhan penduduk dan kemajuan teknologi, menghadirkan tantangan bagi PT PLN (Persero), penyedia listrik utama di Indonesia. Salah satu isu utamanya adalah mengurangi kehilangan daya pada jaringan distribusi, yang berdampak pada efisiensi sistem dan pendapatan perusahaan. Penelitian ini mengeksplorasi penggunaan metode Gauss-Seidel untuk analisis aliran daya pada jaringan distribusi 20 kV di PLN UP3 Semarang, yang bertujuan untuk mengurangi rugi-rugi dan meningkatkan pendapatan. Menggunakan data impedansi dan beban online dari PLN UP3 Semarang, metode Gauss-Seidel diterapkan melalui skrip Python di Google Colab. Temuan menunjukkan bahwa metode ini efektif mengurangi kerugian jaringan, dengan potensi keuntungan finansial bagi PLN UP3 Semarang. Penelitian ini juga meletakkan dasar bagi strategi optimasi jaringan di masa depan dan berkontribusi pada bidang analisis aliran daya. Kajian difokuskan pada jaringan 20 kV dan tidak membandingkan metode Gauss-Seidel dengan pendekatan lainnya.
Kata Kunci: Rugi Daya Metode Gauss-Seidel, Jaringan Penyulang 20 kV, UP3 Semarang.

Abstract: *The rising demand for electrical energy, driven by population growth and technological advancements, presents challenges for PT PLN (Persero), Indonesia's main electricity provider. One key issue is reducing power losses in the distribution network, which affects both system efficiency and company revenue. This study explores the use of the Gauss-Seidel method for power flow analysis on the 20 kV distribution network at PLN UP3 Semarang, aiming to decrease losses and improve revenue. Using data on line impedance and load from PLN UP3 Semarang, the Gauss-Seidel method is applied via a Python script in Google Colab. The findings show that this method effectively reduces network losses, with potential financial benefits for PLN UP3 Semarang. This research also lays the groundwork for future network optimization strategies and contributes to the field of power flow analysis. The study is focused on the 20 kV network and does not compare the Gauss-Seidel method with other approaches.*
Keywords: *Power Loss, Gauss-Seidel Method, 20 kV Feeder Network, Semarang UP3.*

INTRODUCTION

Load flow analysis is a critical component in the study of power systems, providing essential insights into the distribution of electrical power across a network. By determining the current and voltage at each bus within the system, load flow analysis facilitates the effective planning and optimization of electricity distribution, particularly within 20 kV feeder networks. These networks play a pivotal role in transmitting electricity from substations to end consumers. Reducing losses, both technical and non-technical, within these distribution networks is essential for enhancing system efficiency and reliability [1]. Technical losses are primarily due to factors like cable resistance, connections, and other components, while non-technical losses often arise from electricity theft and measurement errors. One of the effective methods for optimizing distribution networks is the Gauss-Seidel method, which employs a simple iterative approach to solve power flow equations. Although this method is valued for its simplicity and ease of implementation, it has limitations, such as slow convergence under certain conditions. This study focuses on the application of the Gauss-Seidel method in optimizing the distribution network of PLN UP3 Semarang, aiming to identify and reduce losses. By implementing this method, the distribution network in the region is expected to operate more efficiently and reliably [2]-[5]. Literature suggests that the Gauss-Seidel method has been successfully applied in various contexts for optimizing distribution networks, though the outcomes vary depending on specific network conditions. This research seeks to contribute significantly to reducing losses in PLN UP3 Semarang's distribution network while expanding the understanding of the Gauss-Seidel method's application in broader contexts [6].

Previous studies have explored various aspects of optimizing and analyzing power distribution networks. One study focused on the 20 kV primary distribution network in Lhokseumawe, utilizing the Power World Simulator and the Gauss-Seidel method to identify and quantify network losses [7]-[10]. Another research analyzed load reconfiguration on a 20 kV distribution line at the University of Riau, aiming to find an optimal configuration that reduces power losses [11]. Additionally, a study from the University of Bangka Belitung assessed the impact of operational patterns of the Ceko feeder on voltage levels in Sebagin Village, investigating how these patterns affect end voltage and power losses. Finally, research conducted by the State University of Jakarta used ETAP 12 software to simulate load flow in a 20 kV distribution network, employing Newton-Raphson and Gauss-Seidel methods to evaluate voltage quality and losses across various feeders [12]-[15].

RESEARCH METHOD

This study focuses on the 20 kV primary distribution system at UP3 Semarang. Data for this research was obtained from PT. PLN (Persero) UP3 Semarang, specifically related to the primary distribution network in the Semarang area. The research employs Python programming and the Gauss-Seidel method for power flow simulations. The results of these simulations provide insights into the losses within the 20 kV primary distribution network at UP3 Semarang.

Data Collection

The initial step of the study involved gathering essential data for the analysis. This included collecting load data, which provided information on the demand across various sectors within the 20 kV distribution network. Additionally, distance data were obtained, detailing the distances between substations and distribution transformers, as well as the lengths of the distribution lines connecting different nodes. Cable specifications were also recorded, encompassing details on the types of cables used and their cross-sectional areas for each distribution line. Finally, substation data were collected to understand the characteristics and capacities of the substations supplying power to the distribution network.

Parameter Initialization

After collecting the necessary data, the next step was to initialize the parameters for the power flow simulation using the Gauss-Seidel method. This process began with setting up the Admittance Matrix (Ybus), which represents the admittance of transmission lines in a complex format, effectively modeling the impedance between the network nodes. Additionally, load data, including both active (real) and reactive (complex) power values at each node, were integrated into the simulation. Initial voltage values at each node were also established to provide starting conditions for the iterative process. These initializations were crucial for ensuring the accuracy and effectiveness of the power flow analysis.

Power Flow Simulation and Loss Calculation

The core of the study involved simulating power flow using the Gauss-Seidel method, renowned for its iterative efficiency in managing distribution networks. This simulation process began with iterative updates to the voltage values at each node, based on power flow relationships defined by the admittance matrix and the existing load conditions. Each iteration refines the voltage estimates until convergence is achieved, ensuring that the solution is accurate within predefined tolerance limits. Following the simulation, power loss calculations were conducted to identify inefficiencies in the power distribution. These losses were computed using the admittance matrix (Ybus) and node voltages (V), with losses determined by the product of squared voltage differences between nodes and the real part of the corresponding Ybus elements. The total losses, expressed in kilowatts (kW), provided a measure of the energy lost during distribution.

Visualization of Results

The results of the simulation and loss calculations were presented through several key visualizations. A bar chart was used to compare initial, pre-optimization, and post-optimization losses, highlighting the improvements achieved. Additionally, a monthly percentage losses simulation was displayed to illustrate the reduction in losses from May 2024 to April 2025. Finally, a node voltage comparison chart was created to show the final voltage magnitudes at each node before and after optimization, providing a clear view of the changes in voltage distribution

RESULTS AND DISCUSSION

This section presents the outcomes of the optimization process for each area within the Semarang UP3.

Data Description

Table 1. Scope of Testing

Daerah yang Dilayani	Gardu Induk	Beban (MW)	Jarak (km)	Jenis Penghantar	Luas Penampang (mm²)
ULP Semarang Tengah	GI Simpang Lima	40	5	ACSR	150
	GI Tambak Lorok	55	20	ACSR	250

	GI Kalisari	50	10	ACSR	240
ULP Semarang Barat	GI Krapyak	45	12	ACSR	200
	GI Randu Garut	50	18	ACSR	240
ULP Semarang Timur	GI Pandean Lamper	40	12	ACSR	180
	GI Tambak Lorok	55	20	ACSR	250
	GI Srondol	45	8	ACSR	200
	GI Mranggen	35	15	ACSR	220
ULP Semarang Selatan	GI Pudakpayung	38	10	ACSR	200
	GI Srondol	45	8	ACSR	200
ULP Kendal	GI Kaliwungu	42	16	ACSR	210
ULP Weleri	GI Weleri	36	14	ACSR	200
ULP Boja	GI BSB	32	15	ACSR	220

Table 2. Define the Ybus matrix

Gardu Induk	**Resistansi (R)**	**Reaktansi (X)**	**Tegangan Nyata (V_real)**	**Daya Total (S)**	**Arus Nyata (I_real)**	**Matriks Admitansi (Ybus)**
GI Simpang Lima	0.1	0.2	20 kV	44.9 kVA	2.245 A	2−j4
GI Tambak Lorok	0.12	0.22	20 kV	61.8 kVA	5.5 A	1.936−j3.5
GI Kalisari	0.09	0.17	20 kV	52.7 kVA	5 A	2.42−j4.6
GI Krapyak	0.08	0.15	20 kV	47.7 kVA	5.0 A	2.74−j5.2

GI Randu Garut	0.08	0.15	20 kV	52.7 kVA	2.64 A	2.74−j5.2
GI Pandean Lamper	0.1	0.18	20 kV	43.6 kVA	4.1 A	2.43−j4.21
GI Srondol	0.1	0.2	20 kV	49.0 kVA	4.5 A	2.00−j4.00
GI Mranggen	0.11	0.22	20 kV	36.2 kVA	3.5 A	1.82−j3.65
GI Pudakpayung	0.12	0.22	20 kV	39.8 kVA	3.8 A	1.90−j3.51
GI Kaliwungu	0.12	0.22	20 kV	43.5 kVA	4.2 A	1.90−j3.51
GI Weleri	0.1	0.2	20 kV	37.5 kVA	3.6 A	2.00−j4.00
GI BSB	0.11	0.2	20 kV	33.6 kVA	3.2 A	1.98−j4.00

Table 2 shows that the Gauss-Seidel method achieved convergence after iterations ranging from 95 to 177. The iterative process was repeated to approach the desired results.

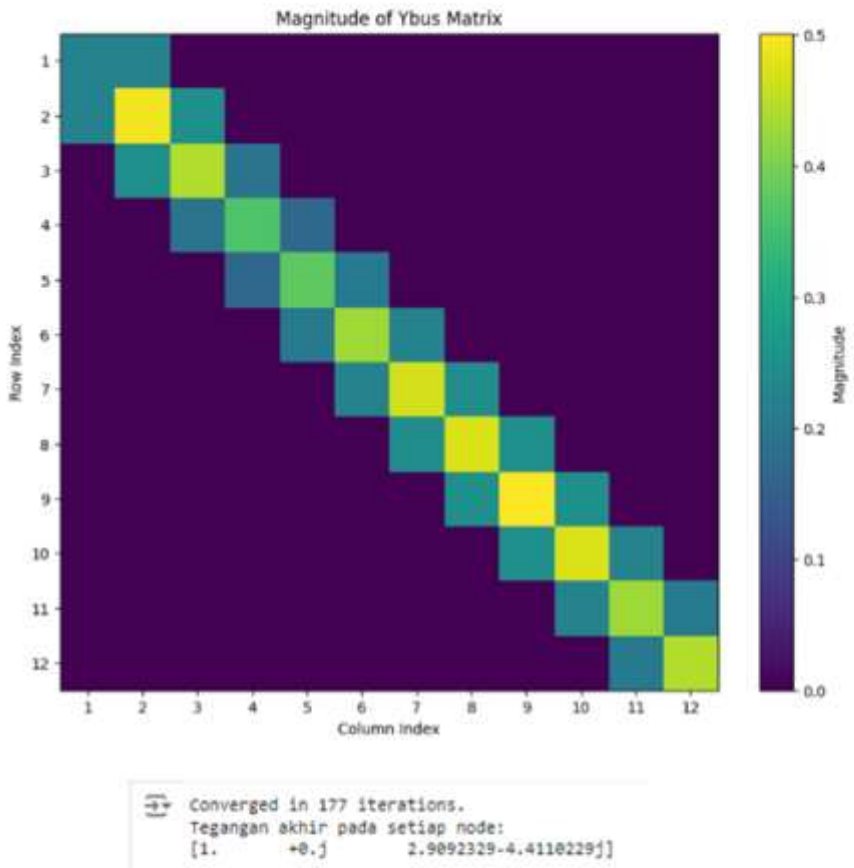

Figure 1. Shows the results of the test trial

This shows that the voltage at node 1 has a real component of 2.9092329 and an imaginary component of -4.4110229. These components can be used to calculate the magnitude and phase of the voltage at that node.

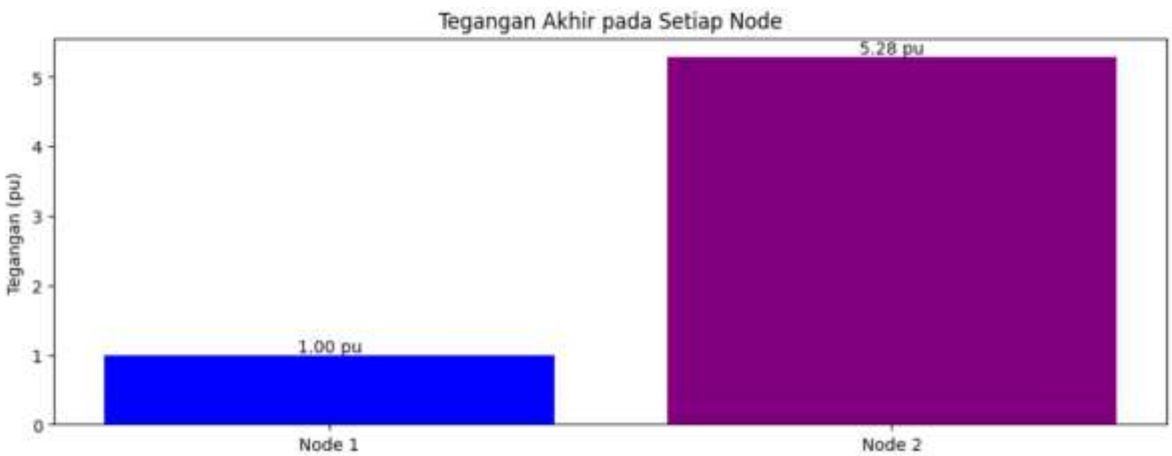

Figure 2. Final Voltage at Each Node

In the figure, the voltage at node 0 remains at its initial condition, 1.0 + 0.0j (or 1 per unit), usually the reference or voltage bus. The voltage at node 1 changes significantly from its initial state, reflecting the effects of applied active and reactive loads. The magnitude of the voltage at node 1 is calculated as:

$$|V_1| = \sqrt{(2.9092329)^2 + (4.4110229)^2} \approx 5.31\, p.u \quad (1)$$

This indicates that the voltage at node 1 increases from 1 per unit to approximately 5.31 per unit after iteration, due to factors such as load effects, network configuration, and impedance parameters in the admittance matrix (Ybus). Detailed voltage calculations are provided in Appendices A.1 (UP3 Semarang), A.2 (ULP Boja), and A.3 (ULP Semarang Timur).

Power Loss Calculation in the Network

Calculating power losses in electrical networks is crucial for evaluating system performance. Losses arise from the resistance and reactance of transmission lines, leading to energy dissipation as heat. To minimize these losses, various analysis and optimization methods, including the Gauss-Seidel method, are employed. This section details the power loss calculation using final voltage data from the Gauss-Seidel method and analyzes the results.

Table 3. Loss Calculation Results

No	UP3	kWh Siap Salur	Total Susut (kWh)	Presentase Susut (%)
1	ULP SEMARANG TENGAH	285,255,758	14,986,387	5,25
2	ULP SEMARANG BARAT	219,036,711	8,889,478	4.06
3	ULP SEMARANG TIMUR	229,576,732	21,343,577	9,30
4	ULP SEMARANG SELATAN	114,313,880	6,275,763	5,49

5	ULP KENDAL	188,867,240	8,063,589	4,27
6	ULP WELERI	77,890,844	2,218,954	2,85
7	ULP BOJA	73,083,664	5,193,168	7,11
8	UP3 SEMARANG	1,088,249,105	66,970,914	6,5

Power losses result in wasted energy and additional costs for the company. Thus, optimization methods like Gauss-Seidel are used to reduce these losses. Analysis shows varying loss levels across ULPs, with some exceeding PLN's target of 5%.

Figure 3. Loss Reduction at ULP SEMARANG TIMUR

ULP SEMARANG TIMUR: Initial loss of 21,343,577 kWh reduced to 14,770,641 kWh after optimization, indicating a high need for effective optimization methods.

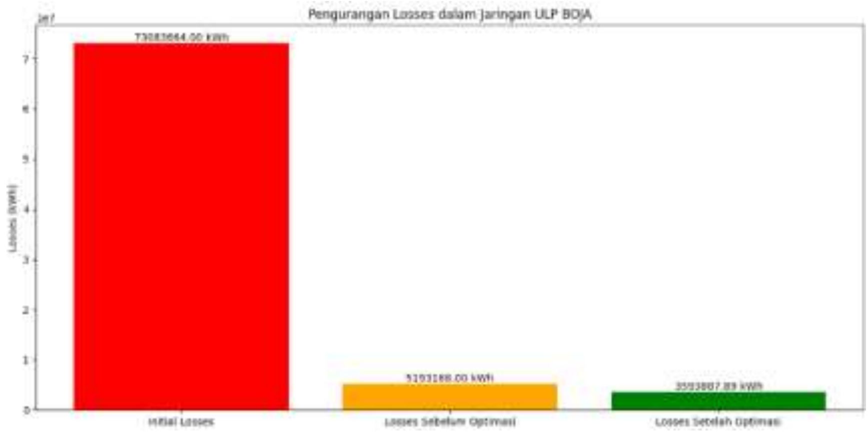

Figure 4. Loss Reduction at ULP BOJA

ULP BOJA: Initial loss of 5,193,168 kWh reduced to 3,593,887 kWh after optimization, demonstrating successful application of the Gauss-Seidel method.

Figure 5. Loss Reduction at UP3 SEMARANG

UP3 SEMARANG: Total kWh delivered of 1,088,249,105 kWh with initial losses of 66,970,914 kWh reduced to 46,346,653 kWh after optimization, highlighting the importance of optimization for improving distribution system efficiency.

Simulation of Loss Percentage Reduction with Gauss-Seidel Method

This simulation explores the reduction of loss percentages in various customer service units (ULPs) within UP3 Semarang using the Gauss-Seidel method. It demonstrates how optimizing power flow in the distribution system can significantly reduce energy losses caused by resistance and reactance in transmission lines.

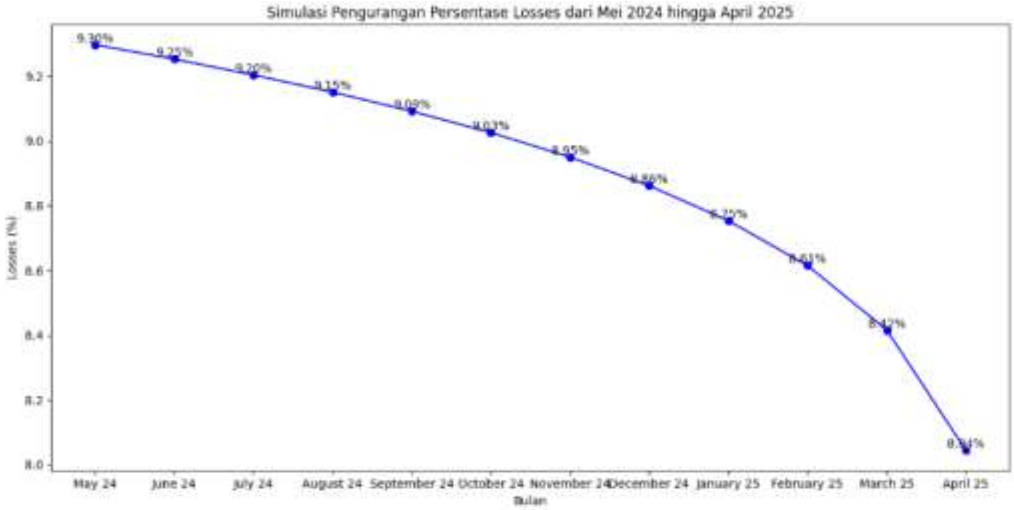

Figure 6. Loss Reduction Simulation at ULP Semarang Timur

This graph shows the percentage of losses at ULP Semarang Timur from May to December. Losses decreased from 9.30% in May 2024 to 8.04% in April 2025, due to optimized power flow using the Gauss-Seidel method.

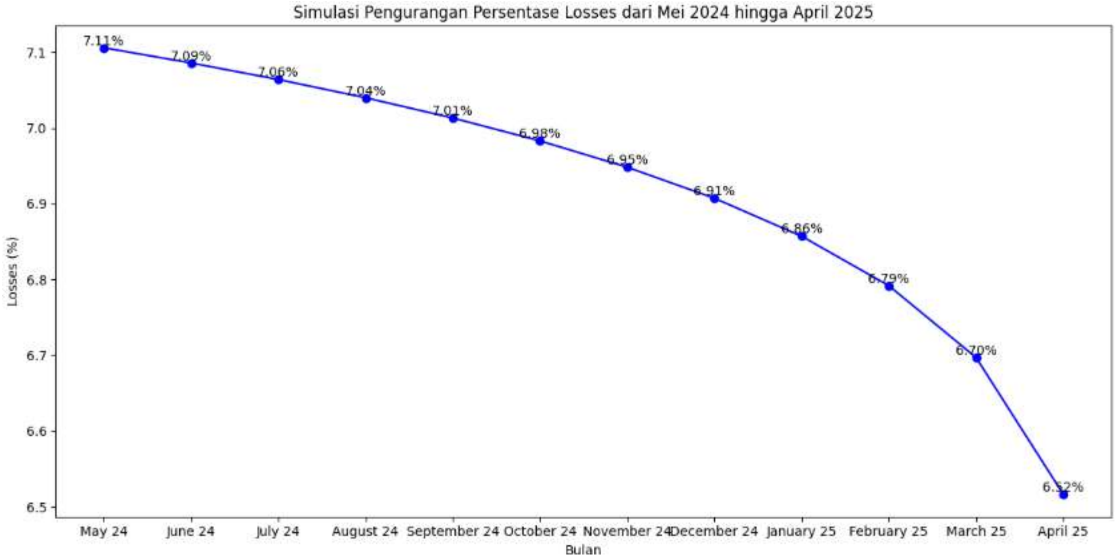

Figure 7. Loss Reduction Simulation at ULP Boja

The graph for ULP Boja indicates a reduction in losses from 7.11% in May 2024 to 6.52% in April 2025, attributed to Gauss-Seidel method optimization.

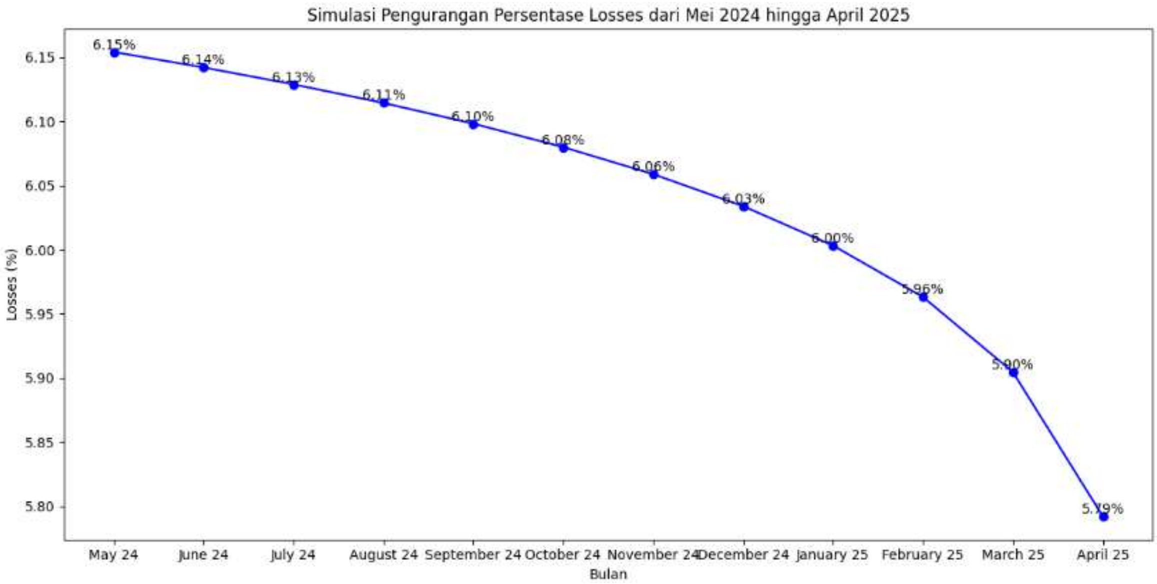

Figure 8. Loss Reduction Simulation at UP3 Semarang

The graph shows a decrease in loss percentage at UP3 Semarang from 6.15% in May 2024 to 5.79% in April 2025, reflecting the effectiveness of the Gauss-Seidel method in optimizing power flow.

Parameter Adjustments for Target Loss Reduction

Despite optimization using the Gauss-Seidel method, some areas have not yet met the target loss reduction. Further adjustments to parameters are necessary to achieve the desired targets.

Parameter Changes

Parameter changes include adjusting line impedance, load, and initial voltage. The adjustments are as follows:

Parameter Changes at ULP Semarang Timur

- **Impedance:** Reduced from complex(15, -8) to complex(10, -5)
- **Load (P_load):** Reduced from 120 kW to 80 kW
- **Load (Q_load):** Reduced from 60 kVAR to 40 kVAR
- **Initial Voltage (V):** Increased from complex(0.97, 0.03) to complex(0.98, 0.01)
- **Conductor Cross-Section:** Increased from 120 mm² to 150 mm²
- **Feeder Split:** Improved load distribution, reducing total load to 67.08 kVA per feeder

Parameter Changes at ULP Boja

- **Impedance:** Updated values for better simulation accuracy
- **Load:** Reduced from 150 kW to 75 kW, and reactive load from 75 kVAR to 37.5 kVAR
- **Initial Voltage:** Adjusted to complex(1, 0) and complex(0.98, 0.02)
- **Conductor Cross-Section:** Increased from 50 mm² to 150 mm²

Parameter Changes at UP3 Semarang

- **Load:** Reduced from 180 kW to 80 kW
- **Reactive Load:** Reduced from 90 kVAR to 45 kVAR
- **Conductor Cross-Section:** Increased from 100 mm² to 150 mm²

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Optimization Results

Figure 9. Losses reduction in the ULP Semarang Timur network

Figure 9 At ULP Semarang Timur, optimization reduced losses by 4% from 21,343,577 kWh to 9,183,069 kWh, with voltage improving from 7.23 pu to 15.01 pu.

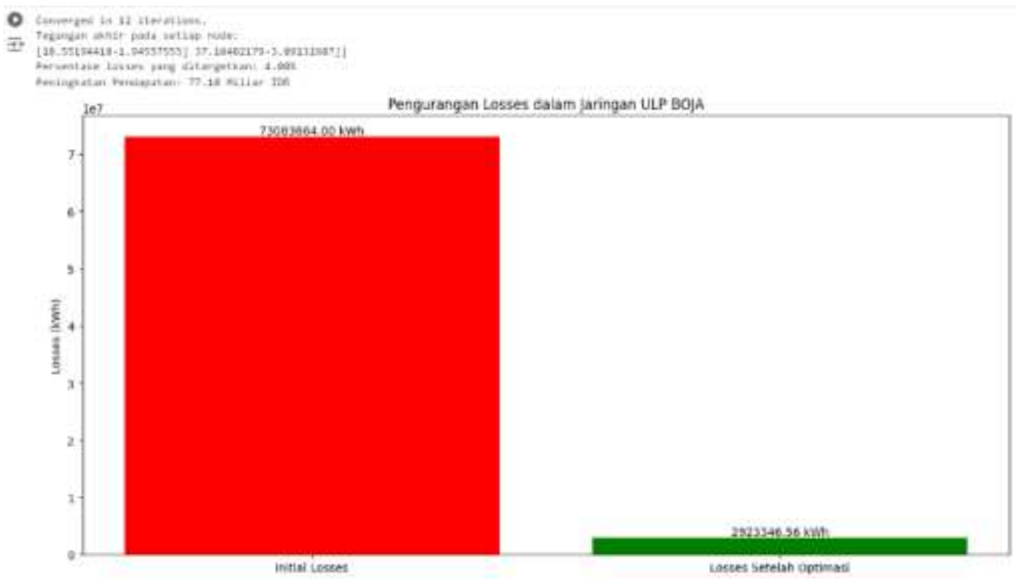

Figure 10. Losses reduction in the ULP Boja network

Figure 10 At ULP Boja, losses decreased by 4% from 5,193,168 kWh to 2,923,346 kWh, with voltage increasing from 8.65 pu to 37.31 pu.

Figure 11. Losses reduction in the ULP Semarang network

Figure 11 At UP3 Semarang, losses dropped by 4% from 66,970,914 kWh to 43,529,964 kWh, and voltage improved from 1.02 pu to 1.44 pu.

The application of the Gauss-Seidel method for optimizing power flow in the 20 kV distribution network has demonstrated notable improvements in performance. By reducing line impedance and adjusting both active and reactive loads, significant reductions in network losses were achieved. The enhancements in voltage stability across various nodes indicate the method’s effectiveness in managing power distribution and minimizing inefficiencies. These findings are consistent with the theoretical benefits of the Gauss-Seidel method, which is designed to iteratively solve power flow equations and optimize network parameters.

The study highlights that systematic changes, such as increasing the initial voltage and enhancing conductor cross-sections, can have a substantial impact on network efficiency. Reducing line impedance directly decreases power losses due to lower resistive heating, while optimizing load distributions and feeder configurations further improves the system's overall stability. The significant decrease in losses across ULP Semarang Timur, ULP Boja, and UP3 Semarang underscores the method’s ability to effectively manage and optimize power flow in real-world applications.

Moreover, the application of these optimization techniques provides actionable insights for PLN UP3 Semarang. The improvements in operational efficiency and reduction in costs achieved through these methods could lead to more effective loss management and enhanced system performance. The study suggests that continued application and refinement of the Gauss-Seidel method, along with adjustments to network parameters, can offer further benefits in terms of operational efficiency and cost-effectiveness in power distribution systems

CONCLUSION

The implementation of the Gauss-Seidel method has proven effective in optimizing power flow within the 20 kV distribution network. The study observed a significant reduction in network losses and an improvement in voltage levels at each node. This optimization not only minimized losses but also enhanced the overall stability and efficiency of the electrical network. The findings indicate that changes such as reduced line impedance, adjusted active and reactive loads, and increased initial voltage have effectively contributed to these improvements.

The results offer valuable insights into the application of the Gauss-Seidel method in distribution networks and underscore its potential for enhancing operational efficiency. By applying these optimization techniques, PLN UP3 Semarang can achieve more effective loss management, leading to reduced operational costs and better network performance. The study's outcomes highlight the benefits of increased conductor cross-sections and feeder splitting, which further support the efficient distribution of power and reduced losses

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