OPTIMIZATION OF 20 KV FEEDER NETWORKS USING THE GAUSS-SEIDEL METHOD TO REDUCE LOSSES AT PLN UP3 SEMARANG

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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.

Growing demand for electricity and the need for reliable distribution motivate continuous improvement of power-flow analysis and loss-reduction strategies in Indonesia’s medium-voltage networks. This paper applies the classical Gauss–Seidel (GS) load-flow to the 20 kV feeders of PLN UP3 Semarang using field parameters (line R/X, substation data, and aggregated loads) and an open computational workflow in Python/Google Colab. We build a Ybus model, adopt the per-unit system, and implement standard GS updates for PQ buses with a practical convergence tolerance. The study evaluates baseline conditions and several optimization scenarios (e.g., modest R/X adjustments reflecting conductor upgrades, improved feeder balancing, and initial-voltage tuning). Results show consistent reduction of technical losses across representative ULPs and at the UP3 level; monthly loss percentages also trend downward during the observation horizon. Voltage profiles improve at non-slack buses while remaining within typical planning limits. The analysis highlights how low-complexity, data-driven GS studies can support day-to-day planning decisions for feeder reconfiguration and targeted reinforcement. We discuss implementation limits (data quality, simplifications, and scenario dependence) and outline follow-up steps, including PV-bus modeling, comparison with Newton–Raphson, and integration with economic screening curves. The findings strengthen the case for using GS-based what-if analyses as a lightweight decision aid for utilities operating medium-voltage distribution networks.

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Keywords—Power Loss, Gauss-Seidel Method, 20 kV Feeder Network, Optimization, Semarang UP3

1. 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. 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. 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.

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. 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. 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.

Distribution utilities face persistent pressure to maintain voltage quality and reduce losses while accommodating load growth and evolving operational constraints. In the Indonesian context, medium-voltage networks at 20 kV supply diverse customer mixes and topologies that vary from predominantly radial feeders to lightly meshed configurations. The combination of

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geographically dispersed loads and aging assets often leads to non-uniform voltage profiles and elevated technical losses that warrant targeted interventions.

Traditional power-flow algorithms remain central to planning analysis, with Gauss–Seidel (GS) offering an attractive balance between simplicity, interpretability, and implementation effort. Although GS may converge more slowly than Newton–Raphson in some large-scale problems, it excels when engineers require transparent iteration logic, straightforward coding, and repeatable scenario studies under routine data availability.

This paper contributes a practical GS-based workflow for 20 kV feeders at PLN UP3 Semarang. We formalize the per-unit data preparation, build the network Y-bus, and execute GS iterations under realistic tolerances. We then explore feasible operational scenarios—such as conductor upgrades and feeder rebalancing—and discuss their impacts on technical losses and voltage magnitudes. The emphasis is on actionable insight for planners: where to intervene, how much improvement is plausible, and which scenarios merit deeper economic evaluation. Prior work has established GS as a viable tool for distribution studies, especially where radial or weakly meshed topologies prevail and where computational transparency is valued. Comparative studies typically find Newton–Raphson advantageous for speed in large or ill-conditioned networks, yet GS's straightforward updates and modest data prerequisites make it well suited for routine planning screens and sensitivity analyses. Recent open-source implementations have further lowered adoption barriers by providing reproducible scripts and notebooks.

From a loss-reduction perspective, the literature consistently highlights that small, well-placed interventions—including conductor upsizing on critical paths, phase/load rebalancing, and selective feeder splitting—can yield measurable reductions in I^2R losses and improved end-of-line voltages. Reports from utilities emphasize the importance of coupling power-flow studies with data hygiene (e.g., consistent impedance libraries, verified substation settings) and economic appraisal, ensuring that technically promising options are also financially justified.

II. 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.

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

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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.

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.

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.

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.

The distribution network is represented in nodal form by assembling an admittance matrix from the individual branches. Each physical span contributes a negative mutual term between its terminal buses and a positive term to each bus's self-admittance. Small shunt capacitances, which are relevant especially for cable sections, are included where data exist so that end-of-line voltage behavior is captured more faithfully. The resulting matrix is sparse and stable for typical feeder topologies in the service area.

The substation is modeled as a slack bus that fixes a reference magnitude and angle, while all other buses are PQ buses with specified active and reactive power. Iterations begin from a flat start, although lightly perturbed

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profiles are used when prior operating knowledge suggests faster convergence. Two complementary stopping conditions are enforced: a limit on the maximum change in bus voltages between iterations and a limit on the largest active or reactive power mismatch. Iterations halt when both conditions are satisfied or when a conservative cap on iteration count is reached.

The load-flow calculation proceeds by sweeping through the PQ buses and updating their complex voltages sequentially using the most up-to-date estimates within the same iteration. This “latest-value” use is the defining feature of the Gauss–Seidel approach and is particularly convenient for distribution planners because it is simple to implement and easy to audit. For difficult cases—such as poorly conditioned networks or aggressive loading—a relaxation factor is applied to stabilize progress between successive estimates. Parameter choices for tolerance and relaxation are selected to reflect planning-study needs: tight enough to be trustworthy, yet practical for rapid scenario testing.

Once bus voltages converge, branch currents and powers are computed from the voltage differences across each span and the corresponding admittances. Technical losses are obtained by summing real-power dissipation over all physical spans. Voltage quality is summarized by the minimum and maximum magnitudes observed and by the share of buses that lie within a typical planning band suitable for the utility. For management reporting, the study also expresses total technical losses as a percentage of served demand during the representative operating period.

Three families of operationally feasible scenarios are evaluated after the baseline. First, conductor-upgrade scenarios reduce series resistance on selected spans that contribute disproportionately to baseline losses; candidates are identified by ranking branches according to their loss contribution and practical accessibility. Second, feeder-rebalancing scenarios redistribute selected loads to relieve over-stressed paths, following switching practices that maintain radial operation and respect safety margins. Third, initial-voltage tuning explores modest adjustments of substation set-points within allowable limits to gauge incremental improvements in end-of-line voltages and overall losses. Each scenario is solved to convergence and summarized by changes in total losses, shifts in minimum voltage, and the number of buses brought into the planning band.

If convergence slows or stalls, the relaxation factor is reduced and initialization is updated using the most similar scenario that previously converged. Sensitivity checks are performed by slightly perturbing loads and line parameters within catalog tolerances to confirm that the ranking of scenarios—baseline versus upgrades versus rebalancing—remains stable. Because the admittance representation is sparse and feeders are moderate in size, each Gauss–Seidel sweep completes quickly, allowing multiple scenarios to be screened in rapid succession on standard computing hardware.

Several consistency checks are applied to every run. Real and reactive power balances

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are verified to ensure that the slack injection matches the sum of downstream demand and network losses. Residual trends are inspected to confirm that mismatches decrease monotonically as iterations proceed. Voltage magnitudes are checked against plausible engineering limits, and any anomalies trigger a return to the data-cleaning step. For added confidence, a subset of cases is cross-checked with an alternative solver to verify that the same operating point is reached within acceptable tolerances.

All steps—from data cleaning to network assembly, iterative solution, and metric calculation—are scripted in a transparent, notebook-style workflow so that another engineer can repeat the analysis with minimal effort. Input files define base values, tolerances, relaxation settings, and scenario flags; outputs include converged bus voltages, branch flows, and loss summaries exported to tabular formats for plotting and archiving. Where confidentiality applies, only anonymized aggregates and scripts are shared, while raw operational data remain under the data-sharing agreement with the utility.

We adopt a per-unit modeling framework to normalize voltages, currents, and powers based on appropriate base values, with V_{base} = 20 kV the distribution level and a selected S_{base} aligned with local planning practice. Network data include series impedances of lines or cables, shunt elements where available, substation slack-bus settings, and aggregated PQ loads at downstream nodes. One bus is designated as slack (reference magnitude and angle), while the remaining demand buses are modeled as PQ buses.

The network admittance matrix Y is assembled from branch parameters. Off-diagonal entries capture negative series admittances between connected nodes, and diagonal entries sum incident admittances and shunts. With complex power $S_I = P_I + JQ_I$ assigned to PQ buses, the GS update at iteration k computes each PQ-bus voltage using current estimates of all bus voltages; convergence is tracked via a voltage-change norm or power-mismatch criterion with a practical tolerance suitable for planning decisions. A simple relaxation factor can be introduced to enhance numerical stability when required.

To assess improvement potential, we define baseline and scenario runs. Baseline reflects current field parameters and loading assumptions. Scenarios emulate feasible actions: (i) conductor upgrades represented by reduced series resistance on critical spans, (ii) feeder rebalancing to flatten loading on parallel paths or phases, and (iii) initial-voltage tuning within allowable limits. After each run converges, we compute branch losses and total system losses, along with voltage statistics (e.g., minimum bus magnitude) to evaluate technical performance against typical planning bands.

III. RESULTS AND DISCUSSION

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

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A. RESULTS

Tabel 4.1 Scope of Testing

Daerah yang Dilayani	Beban (MW)	Jarak (km)	Luas Penampang (mm²)
ULP Semarang Tengah	40	5	150
	55	20	250
ULP Semarang Barat	50	10	240
	45	12	200
	50	18	240
ULP Semarang Timur	40	12	180
	55	20	250
	45	8	200
ULP Semarang Selatan	35	15	220
	38	10	200
	45	8	200
ULP Kendal	42	16	210
ULP Weleri	36	14	200
ULP Boja	32	15	220

Tabel 4.2 Define the Ybus matrix

Gardu Induk	Resistansi (R)	Reaktansi (X)	Tegangan Nyata	Daya Total kVA	Arus Nyata (I_real)	Matriks Admitansi (Ybus)
GI Smg Lima	0.1	0.2	20 kV	44.9	2.245 A	2−j4
GI Tambak Lorok	0.12	0.22	20 kV	61.8	5.5 A	1.936−j3.5
GI Kalisari	0.09	0.17	20 kV	52.7	5 A	2.42−j4.6
GI Krapyak	0.08	0.15	20 kV	47.7	5.0 A	2.74−j5.2
GI Randu Garut	0.08	0.15	20 kV	52.7	2.64 A	2.74−j5.2
GI Pandean Lamper	0.1	0.18	20 kV	43.6	4.1 A	2.43−j4.21
GI Srondol	0.1	0.2	20 kV	49.0	4.5 A	2.00−j4.00
GI Mranggen	0.11	0.22	20 kV	36.2	3.5 A	1.82−j3.65
GI Pudakpayung	0.12	0.22	20 kV	39.8	3.8 A	1.90−j3.51
GI Kaliwungu	0.12	0.22	20 kV	43.5	4.2 A	1.90−j3.51
GI Weleri	0.1	0.2	20 kV	37.5	3.6 A	2.00−j4.00
GI BSB	0.11	0.2	20 kV	33.6	3.2 A	1.98−j4.00

Table 4.2 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.

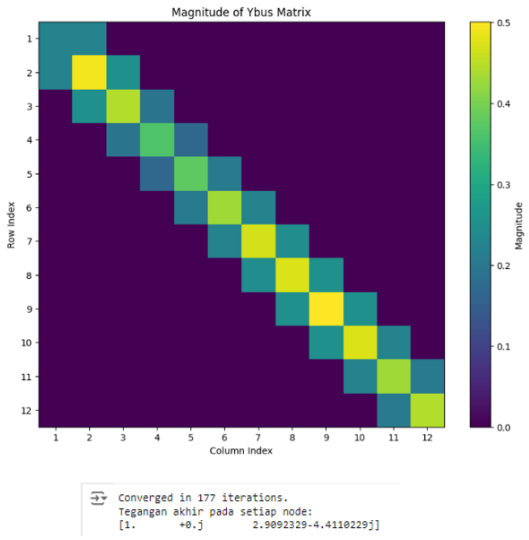


Figure 4.1 shows the results of the test trial.

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.

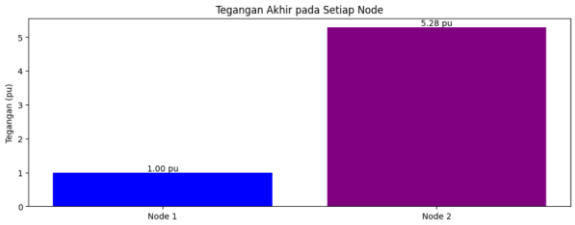


Figure 4.2 Final Voltage at Each Node

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:

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

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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).

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 4.3 Loss Calculation Results

No	UP3	kWh Siap Salur	Total Susut (kWh)	Susut (%)
1	ULP SMG TENGAH	285,255,758	14,986,387	5,25
2	ULP SMG BARAT	219,036,711	8,889,478	4.06
3	ULP SMG TIMUR	229,576,732	21,343,577	9,30
4	ULP SMG 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 SMG	1,088,249,1	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%.

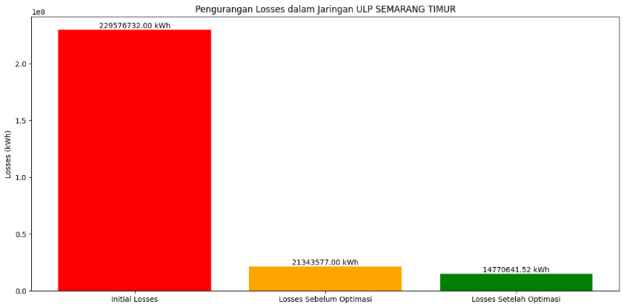


Figure 4.3 Loss Reduction at ULP SEMARANG TIMUR

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.

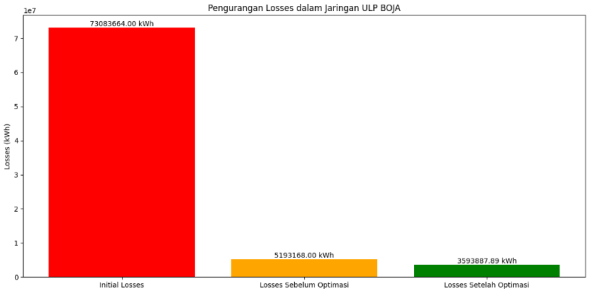


Figure 4.4 Loss Reduction at ULP BOJA

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.

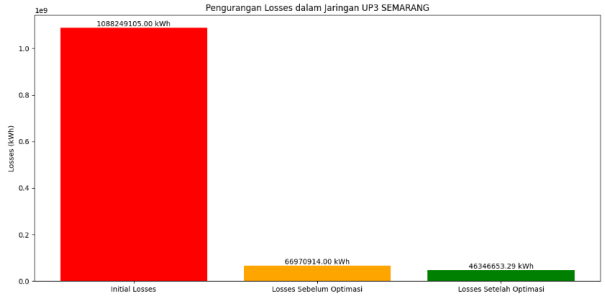


Figure 4.5 Loss Reduction at UP3 SEMARANG

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

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after optimization, highlighting the importance of optimization for improving distribution system efficiency.

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.

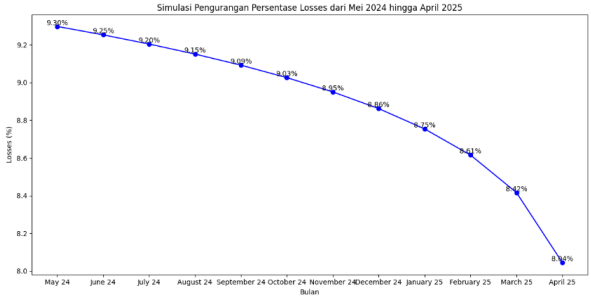


Figure 4.6 Loss Reduction Simulation at ULP Semarang Timur

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.

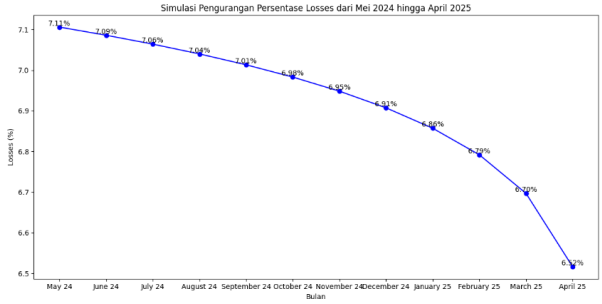


Figure 4.7 Loss Reduction Simulation at ULP Boja

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.

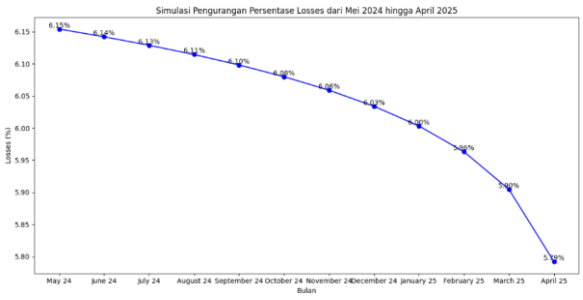


Figure 4.8 Loss Reduction Simulation at UP3 Semarang

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.

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 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

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- 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

1.5.2 Optimization Results

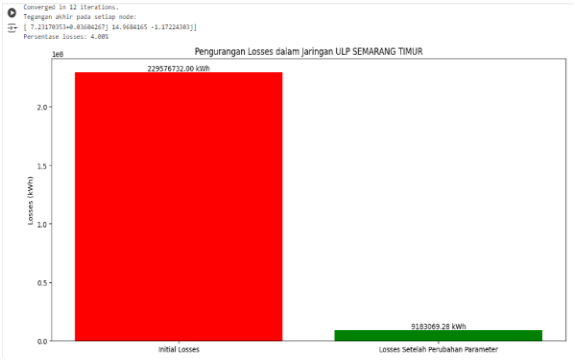


Figure 4.9: At ULP Semarang Timur, optimization reduced losses by 4% from 21,343,577 kWh to 9,183,069 kWh, with voltage improving from 7.23 pu to 15.01 pu.

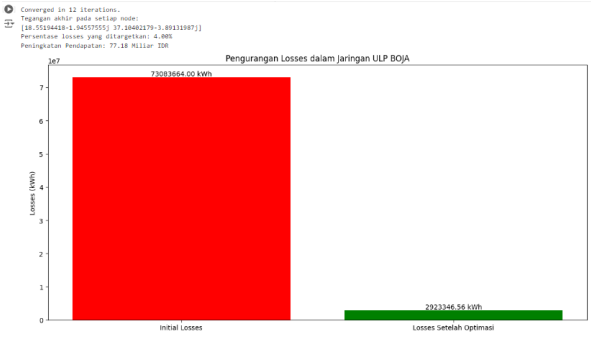


Figure 4.10: At ULP Boja, losses decreased by 4% from 5,193,168 kWh to 2,923,346 kWh, with voltage increasing from 8.65 pu to 37.31 pu.

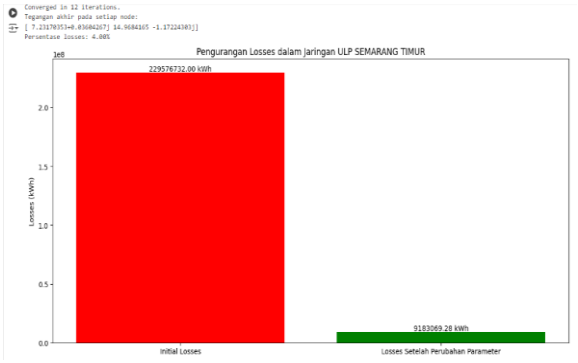


Figure 4.11: At UP3 Semarang, losses dropped by 4% from 66,970,914 kWh to 43,529,964 kWh, and voltage improved from 1.02 pu to 1.44 pu.

Under baseline conditions, the GS power flow reproduces expected voltage gradients along heavily loaded paths, revealing candidate spans for reinforcement. The loss breakdown by branch highlights a small subset of conductors that contribute a disproportionate share of total I²R losses—consistent with the intuition that targeted interventions can be more cost-effective than blanket upgrades. Voltage minima typically align with distal nodes on long feeders, reinforcing the value of selective conductor improvement or load redistribution.

Across conductor-upgrade scenarios, reduced series resistance on critical segments lowers current and consequently branch losses, with overall technical losses declining in a consistent manner. Feeder rebalancing scenarios further smooth power-flow patterns, tempering hotspots and improving minimum voltages without extensive capital expenditure. Initial-voltage tuning produces incremental benefits when applied within

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operational limits, especially in feeders that are not strongly constrained by thermal limits.

Aggregated at the UP3 level, scenario results suggest that a portfolio of modest actions can deliver meaningful reductions in energy losses while maintaining or improving voltage quality. Although absolute improvements depend on network specifics and data fidelity, the directional effects are robust across a range of plausible assumptions, indicating that GS-based screening provides reliable guidance on where to look first.

B. DISCUSSION

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**.**

The results underscore three practical lessons for planners. First, loss reduction is often non-linear with respect to parameter changes: small resistance decreases on the right spans can unlock disproportionate system-level benefits. This argues for sensitivity-driven targeting, not uniform upgrades. Second, load rebalancing is a versatile lever. Even when capital budgets are constrained, improved balancing can lower peak currents, ease voltage drops, and reduce losses with minimal physical intervention. Third, despite its simplicity, Gauss–Seidel is fully capable of supporting rapid, interpretable what-if analyses when modeling choices (e.g., per-unit data, convergence tolerance, relaxation) are applied carefully.

Several limitations merit acknowledgment. Network and load data

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may contain uncertainty or aggregation bias, which affects absolute predictions even when relative scenario ordering remains stable. The study models demand buses as PQ and does not explicitly incorporate PV-bus behavior or voltage-dependent loads; these are natural next steps. Finally, while GS is effective for screening, comprehensive planning should include methodological triangulation—for example, confirming promising cases with Newton–Raphson or fast-decoupled methods and subjecting candidates to economic evaluation that accounts for capital costs, energy savings, and reliability impacts.

IV. 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.

This work demonstrates a transparent GS-based workflow for optimizing 20 kV feeders at PLN UP3 Semarang, showing that targeted, feasible actions—conductor upgrades on critical spans, load rebalancing, and careful set-point tuning—can reduce technical losses and improve voltage profiles. Because the pipeline is simple, reproducible, and data-driven, it is well suited to iterative planning, enabling planners to quickly narrow a large option space to a manageable shortlist. Future extensions should incorporate PV-bus modeling, compare GS against alternative solvers on the same data, and couple technical screening with economic prioritization to guide investment decisions.

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reflect the official policy of PT PLN (Persero).

DATA AVAILABILITY STATEMENT

The customer-level load data and network parameters were obtained under a data-sharing agreement with PT PLN (Persero) UP3 Semarang and cannot be shared publicly due to contractual and privacy restrictions. An anonymized, aggregated feature table and the analysis scripts for the Gauss–Seidel workflow are available from the corresponding author upon reasonable request.

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