ENHANCING VOLTAGE STABILITY AND ENERGY OUTPUT OF PLTM SALIDO IN THE PLN DISTRIBUTION NETWORK

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Abstract

Distributed generation (DG) integration in PLN's extended distribution network often encounters voltage instability issues due to high voltage drops. These challenges restrict power delivery and can lead to disconnection, particularly during peak load conditions. This study investigates methods to enhance voltage stability and optimize the energy output of PLTM Salido. Using ETAP Power Station software, various operational schemes were simulated to address the problem of low terminal voltage. The study focused on the impact of reactive power injection and governor settings optimization to maintain generator performance under high demand. Results indicate that reactive power injection significantly improves terminal voltage, ensuring continuous power delivery. Adding a third generator unit further increased energy supply capacity, leveraging the full potential of available hydropower. The optimized operation of PLTM Salido with two generators increased daily energy output by 32.2%, while introducing a third generator boosted energy delivery by 107%. This research highlights the critical role of reactive power management and system configuration in enhancing the performance of small-scale hydropower plants in rural distribution networks.

Keywords: *Voltage Stability, Hydropower Optimization, Reactive Power, Distributed Generation, Renewable Energy*

Abstrak

Integrasi Distributed Generation (DG) pada jaringan distribusi luas PLN sering kali mengalami permasalahan ketidakstabilan tegangan akibat jatuh tegangan yang tinggi. Tantangan-tantangan ini membatasi penyaluran daya dan dapat mengakibatkan terputusnya sambungan, terutama pada kondisi beban puncak. Penelitian ini menyelidiki metode untuk meningkatkan stabilitas tegangan dan mengoptimalkan keluaran energi PLTM Salido. Dengan menggunakan perangkat lunak ETAP Power Station, berbagai skema operasional disimulasikan untuk mengatasi masalah tegangan terminal rendah. Studi ini berfokus pada dampak injeksi daya reaktif dan optimalisasi pengaturan gubernur untuk menjaga kinerja generator di bawah permintaan tinggi. Hasil menunjukkan bahwa injeksi daya reaktif secara signifikan meningkatkan tegangan terminal, memastikan penyaluran daya berkelanjutan. Penambahan unit generator ketiga semakin meningkatkan kapasitas pasokan energi, memanfaatkan potensi penuh pembangkit listrik tenaga air yang tersedia. Pengoperasian PLTM Salido yang optimal dengan dua generator meningkatkan keluaran energi harian sebesar 32,2%, sementara penggunaan generator ketiga meningkatkan penyaluran energi sebesar 107%. Penelitian ini menyoroti peran penting manajemen daya reaktif dan konfigurasi sistem dalam meningkatkan kinerja pembangkit listrik tenaga air skala kecil di jaringan distribusi pedesaan.

Kata Kunci : *Stabilitas Tegangan, Optimasi Pembangkit Listrik Tenaga Air, Daya Reaktif, Pembangkitan Terdistribusi, Energi Terbarukan*

1. INTRODUCTION

1.1 Background

Small-scale distributed generation (DG) from renewable energy sources is expected to address the electricity crisis in Indonesia. West Sumatra has untapped small hydro potential of 461.1 MW, with only about 44.3 MW currently operational [1]. Studies indicate that integrating renewable energy sources, such as small hydroelectric power plants, can significantly improve grid reliability and

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reduce dependency on fossil fuels ([1]; [2]). Furthermore, distributed generation, when optimized, can mitigate voltage instability issues in rural distribution networks ([3]; [4]).
In Indonesia, hydropower is particularly promising due to its high potential for clean energy generation, as emphasized by recent studies on micro-hydro development ([5]; [6]). The PLTM Salido, located in South Pesisir, West Sumatra, utilizes two 400 kVA generators connected to PLN's 20 kV distribution network. Despite its potential, the plant faces challenges such as voltage drops and insufficient reactive power, which limit its efficiency during peak demand hours ([7]; [8]).

1.2 Problem Statement

PLTM Salido's connection to the 20 kV distribution network faces persistent low voltage issues due to high voltage drops and insufficient nearby reactive power support. While the PLTM can supply power during light load conditions, it fails to operate during peak load hours (typically between 17:00 and 22:00) as the terminal voltage drops below the generator's threshold. The synchronous generator's minimum terminal voltage is 80% of the nominal 400 V, or 320 V, with a stator current limit of 577 A ([9]; [10]). This results in significant energy losses during peak demand.

2. METHODOLOGY

This research addresses PLTM Salido's operational challenges through variations in active and reactive power injection simulated using the ETAP Power Station software. The software was chosen for its robust capabilities in modeling and simulating electrical networks, enabling accurate analysis of voltage profiles and power flows.
Initially, data was collected on the existing conditions of PLTM Salido, including load profiles, voltage levels, and power output. Simulations were then conducted to evaluate different operational scenarios. These scenarios included varying levels of reactive power injection and adjustments to the generator's governor settings to optimize performance. Furthermore, an additional simulation assessed the impact of introducing a third generator unit to fully utilize the hydropower potential.
Each simulation aimed to identify the optimal configuration that minimizes voltage drops and maximizes energy delivery to the PLN network. The results were compared to the existing operational performance to quantify the improvements in system stability and energy output.
This research employed the ETAP Power Station software to simulate and analyze the operational scenarios of PLTM Salido. The following assumptions were made during the simulations:

a) The load profile data was based on historical records of the South Pesisir distribution network.
b) Generator excitation was adjustable within safe operational limits to ensure stable reactive power injection.
c) The hydropower potential was assumed to remain constant throughout the simulations, reflecting typical water flow conditions.
d) The transmission line parameters, including impedance and capacity, were modeled according to standard PLN specifications.
e) All simulations considered peak load conditions as the critical testing scenario for voltage stability.

These assumptions ensured that the simulation results accurately represented the real-world operating environment of PLTM Salido, providing actionable insights for system optimization.

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3. RESULTS AND DISCUSSION

3.1 Initial Conditions of PLTM Salido Distribution System

Currently, PLTM Salido operates with two generators, each with a capacity of 400 kVA, connected to PLN’s 20 kV distribution network.

Table 1. Voltage Conditions

Load Condition	Terminal Voltage (%)	Action Required
Light Load	85.9	Operable
Heavy Load	76.7	Disconnect Generator

Power flow analysis revealed the following:

a) Light Load: The terminal voltage of units 1 and 2 is 85.9% of the nominal value (344 V), which is within the acceptable range for generator operation.
b) Heavy Load: The terminal voltage drops to 76.7% (307 V), below the minimum threshold of 80% (320 V), necessitating generator disconnection from the network.

These findings highlight significant voltage drops during peak load, preventing PLTM Salido from maintaining continuous power supply.

Figure 1. Conditions of PLTM Salido Distribution System

3.2 Optimization with Two Generators

3.2.1 Voltage Stability Analysis with Two Generators

By utilizing reactive power injection through increased generator excitation current, terminal voltage was improved:

a) Simulation Results: After optimization, the terminal voltage increased from 76.7% to 81.36%, enabling both generator units to continue operating under heavy load conditions.
b) Analysis: Increased excitation current allowed the generators to supply sufficient reactive power, stabilizing the network voltage and improving overall system performance.

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Table 2. Volatage Improvement

Load Condition	Terminal Voltage Before Optimization (%)	Terminal Voltage After Optimization (%)	Improvement (%)
Heavy Load	76.7	81.36	4.66

Figure 2. Optimization with Two Generators

3.2.2 Energy Output Improvement with Two Generators

In addition to voltage stability, the optimized operation of two generators also significantly increased energy output:

a) Daily Energy Output: Simulation results showed that daily energy production increased from 10.64 MWh (existing condition) to 14.06 MWh, representing a 32.2% improvement.
b) Operational Efficiency: The enhanced performance was achieved by maintaining optimal excitation levels, ensuring a balanced supply of active and reactive power to the grid.

Implications:

a) The increased energy output reduces dependency on other energy sources and enhances the reliability of power supply to the South Pesisir distribution network.
b) This improvement demonstrates the effectiveness of optimizing existing infrastructure before investing in additional generation capacity.

3.3 Adding a Third Generator

3.3.1 Voltage Stability Analysis with Three Generators

The addition of a third generator (unit 3) was simulated to maximize the available hydropower potential. Two operational scenarios were evaluated:

a) Scenario 1: All three generator units supply reactive power.
   1) Terminal voltage reached 84.29%.
   2) Total active power supplied was 0.906 MW.
b) Scenario 2: Two units supply reactive power, while one unit supplies active power only.
   1) Terminal voltage reached 82.94%.
   2) Total active power supplied was 0.917 MW.

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Tabel 3. Generation Scenarios

Scenario	Unit	Active Power (MW)	Reactive Power (MVAR)	Terminal Voltage (%)
1	1	0.302	0.146	84.29
1	2	0.302	0.146	84.29
1	3	0.302	0.146	84.29
1	Total	0.906	0.438	
2	1	0.297	0.143	82.94
2	2	0.297	0.143	82.94
2	3	0.323	0	81.28
2	Total	0.917	0.286	

Analysis:

a) Scenario 1 yielded better voltage profiles, enhancing network stability.

b) Scenario 2 provided higher active power output, which is more financially beneficial for PLTM operators due to increased energy sales.

Figure 3. Adding a Third Generator

3.3.2 Energy Production Enhancement with Three Generators

Adding a third generator substantially increased the energy production capacity of PLTM Salido:

a) Scenario 1: Total daily energy output reached 21.85 MWh, leveraging full reactive power supply from all three units.

b) Scenario 2: Total daily energy output slightly increased to 22.01 MWh due to prioritizing active power supply by one generator.

Comparison and Analysis:

a) Scenario 1: While offering better voltage profiles and system stability, this scenario produced slightly less energy compared to Scenario 2.

b) Scenario 2: By focusing more on active power output, this scenario maximized energy production, making it more financially viable for the operator.

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Implications:

a) The results highlight the trade-offs between system stability and energy production. Operators must balance these aspects based on operational priorities and economic considerations.

b) The increased energy capacity ensures the ability to meet growing energy demands while maintaining reliable grid performance.

3.4 Daily Energy Production

Daily energy production was calculated based on various operational scenarios:

a) Existing Condition: Total daily energy output was 10.64 MWh.

b) Optimized (Two Generators): Energy output increased to 14.06 MWh (a 32.2% improvement).

c) Three Generators (Scenario 1): Total daily energy output reached 21.85 MWh.

d) Three Generators (Scenario 2): Total daily energy output reached 22.01 MWh (a 107% increase compared to the existing condition).

Table 4. Energy Producrion

Scenario	Unit	Power (kW)	Energy per Day (kWh)	Total Energy per Day (MWh)
Existing Condition	1	260	4940	10.64
Existing Condition	2	300	5700	
Optimized 2 Units	1	293	7032	14.06
Optimized 2 Units	2	293	7032	
3 Units Scenario 1	1	302	7248	21.85
3 Units Scenario 1	2	302	7248	
3 Units Scenario 1	3	302	7248	
3 Units Scenario 2	1	297	7128	22.01
3 Units Scenario 2	2	297	7128	
3 Units Scenario 2	3	323	7752	

Figure 5. Daily Energy Production

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3.5 Discussion

Simulation results demonstrate that reactive power injection and the addition of generator units significantly enhance voltage stability and energy capacity. Optimizing the operation of two generators increased energy supply by 32.2%, while adding a third generator more than doubled daily energy output. From PLN's perspective, a scenario with higher reactive power supply offers better system stability. However, for PLTM operators, a scenario with higher active power output is more financially advantageous.

3.5.1 Broader Applications to Similar Regions

The success of PLTM Salido's optimization can serve as a model for improving rural distribution networks in areas with similar conditions. Key takeaways include:

a) Reactive Power Injection: Ensuring sufficient reactive power supply is essential for stabilizing voltage and preventing disconnections, especially during peak loads.
b) Scaling Up Infrastructure: Adding additional generation units, as demonstrated, can significantly increase energy output and utilize untapped renewable energy resources effectively.
c) Customizing Solutions: Adaptation of these methods to local conditions, such as hydropower potential, grid capacity, and typical load profiles, is crucial. Each region may require tailored adjustments to achieve optimal results.

For example, isolated grids in rural areas with micro-hydro potential can apply these strategies to reduce dependency on fossil fuels and improve grid reliability. Moreover, integrating real-time monitoring systems and advanced simulation tools, as used in this study, enables proactive adjustments and enhances system resilience.

3.5.2 Recommendations for Supporting Infrastructure and Training

To ensure sustainable implementation of these strategies, additional measures are recommended:

a) Operator Training: Regular training programs should be conducted for local operators to enhance their technical expertise in reactive power management, generator maintenance, and system monitoring. Skilled operators are critical for maintaining optimized system performance.
b) Investment in Monitoring Systems: Advanced monitoring and control systems should be installed to provide real-time data on voltage levels, power flow, and generator performance. This enables quick adjustments to maintain stability.
c) Improved Grid Infrastructure: Upgrading transmission lines and transformer capacities in rural areas will support increased energy output and minimize losses during power distribution.

These steps will enhance the long-term reliability and efficiency of the grid, ensuring that similar projects yield maximum benefits for rural electrification.

4. CONCLUSION

Optimization efforts at PLTM Salido successfully enhanced energy delivery to the South Pesisir distribution network. The implementation of reactive power injection increased voltage stability, enabling consistent power delivery under varying load conditions. Daily energy supply increased by 32.2% with two generators and by 107% with three generators. This demonstrates the effectiveness of leveraging existing hydropower potential through strategic system adjustments.

The findings suggest that the addition of a third generator is highly recommended to maximize hydropower utilization. This approach not only ensures voltage stability but also significantly increases energy output, making the system more resilient and economically beneficial. For future

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implementations, it is crucial to consider both operational efficiency and financial feasibility, ensuring optimal system performance while meeting the energy demands of the region.

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