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Technical, Financial, and Environmental Feasibility Analysis of a Hybrid Diesel-Solar Power-BESS System in the Isolated Merasa Grid

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Abstract

The reliance on diesel power plants (PLTD) in isolated electrical systems results in high fuel consumption, increased operational costs, and substantial greenhouse gas emissions. This study aims to evaluate the technical, financial, and environmental feasibility of integrating solar photovoltaic (PV) systems and battery energy storage into the existing PLTD-based Merasa grid in Berau Regency, East Kalimantan. Four alternative hybrid configurations—varying PV capacities from 300 to 700 kWp and battery storage capacities from 1,200 to 1,500 kWh—were modeled and simulated using HOMER Pro based on the 2025 load profile, solar radiation data, component specifications, and cost parameters. The performance of each scenario was assessed in terms of fuel consumption, renewable fraction, capacity shortage, net present cost (NPC), levelized cost of energy (LCOE), net present value (NPV), internal rate of return (IRR), payback period, and greenhouse gas (GHG) emission reductions. The results indicate that the optimal configuration consists of a 600 kWp solar PV system and a 1,500 kWh battery storage system (utilizing Gen. 1 and Gen. 5 generators), achieving annual fuel consumption of 4,847 L/year, a renewable fraction of 96.7%, zero capacity shortage, an NPC of IDR 26.64 billion, an LCOE of IDR 2,852.97/kWh, an NPV of IDR 21.34 billion, an IRR of 15.3%, a payback period of 6.17 years, and a 96.51% reduction in GHG emissions compared with the existing PLTD-only system. This configuration is recommended as the most feasible alternative based on its combined technical, financial, and environmental performance; however, final implementation should consider land availability for solar PV installation.

INTRODUCTION

An isolated electrical system is a system that operates without support from an interconnected network. In remote areas, Pembangkit Listrik Tenaga Diesel (PLTD) remains widely used because it can operate independently and offers high operational flexibility. However, dependence on diesel fuel results in relatively high operating costs and generation-related emissions. The integration of renewable energy is one approach to reducing this dependence and supporting the dedieselization program (The Electricity Supply Business Plan (RUPTL) PT PLN (Persero) 2021-2030, 2021).

Solar power (Bhandari, 2018) plants are suitable for application in isolated systems with adequate solar radiation potential (Mahfud et al., 2025). However, their variable generation characteristics, which depend on solar radiation conditions, require proper operational management and energy storage systems to maintain a balance between power generation and load demand. Modeling using HOMER Pro has been widely applied to compare hybrid power system (Rehman, 2021) configurations based on technical (Sumbyarti et al., 2025) and economic considerations (Samodrawati & Sukasri, 2024).

The Sistem Kelistrikan Merasa in Berau Regency, East Kalimantan, is currently supplied by PLTD. This study aims to analyze the existing conditions, determine the appropriate hybrid system configuration (Ma et al., 2014), compare its technical performance (Vatankhah Ghadim et al., 2025), and assess the financial feasibility (Arif et al., 2025) and environmental impacts of several alternative solar power plant configurations. The evaluation was conducted based on fuel consumption, generator operating hours, renewable fraction, capacity shortage, net present cost (NPC), levelized cost of energy (LCOE), net present value (NPV), internal rate of return (IRR), payback period, and greenhouse gas (GHG) emissions ((Persero), 2019).

Numerous studies have demonstrated the effectiveness of hybrid renewable energy systems in improving the performance of isolated grids. For instance, (Maulana, 2024) and (Karnanto et al., 2023) employed HOMER Pro to optimize PV-diesel-battery configurations in rural areas of Maluku and the Riau Islands, respectively, achieving significant reductions in fuel consumption and levelized cost of energy (LCOE). Samodrawati and Sukasri (2024) and (Rianto & Adi, 2024) similarly applied HOMER-based modeling to evaluate hybrid systems in Nusa Penida and Sebesi Island, highlighting the importance of balancing PV capacity with battery storage capacity to maximize economic benefits. However, most existing studies focus on regions with relatively low diesel fuel prices or subsidized fuel, while few have addressed systems with exceptionally high fuel logistics and operational costs, such as those in Berau. Furthermore, limited research has systematically compared multiple PV-storage configurations within a single isolated system while incorporating comprehensive financial indicators, including net present value (NPV), internal rate of return (IRR), and payback period, alongside technical and environmental performance metrics (Maleki & Askarzadeh, 2014).

Given this research gap, the present study aims to comprehensively analyze the feasibility of integrating solar photovoltaic (Lekbir et al., 2025) (PV) systems and battery energy storage into the existing PLTD-based Sistem Kelistrikan Merasa. The specific objectives are to model and simulate four alternative hybrid configurations—with PV capacities ranging from 300 to 700 kWp and battery storage capacities from 1,200 to 1,500 kWh—using HOMER Pro based on the 2025 load profile, solar resource data, and component costs; evaluate the technical performance of each configuration in terms of fuel consumption, generator operating hours, renewable fraction, and capacity shortage; assess the financial viability of each scenario using net present cost (NPC), LCOE, NPV, IRR, and payback period, with the existing PLTD-only system serving as the baseline; and quantify the environmental benefits in terms of GHG emission reductions. This research is expected to contribute to the growing body of knowledge on hybrid system optimization (Sari et al., 2022) for isolated Indonesian grids and provide actionable recommendations for PLN's dedieselization strategy. The findings may also serve as a reference for policymakers and project developers in designing cost-effective and sustainable off-grid electrification solutions.

This study is limited to a pre-feasibility analysis, assuming the availability of sufficient land for solar PV installation and excluding battery degradation effects beyond HOMER Pro's built-in lifetime model. The analysis considers a project lifetime of 25 years with a discount rate of 10% per year, in accordance with PLN's standard economic evaluation framework.

METHOD

The research was conducted using primary and secondary data. Primary data were obtained through observations of plant conditions and system operations, while secondary data included load profiles, generator specifications, solar energy potential, component characteristics, and cost parameters. The actual load profile from October to December 2025 was used as the basis for developing the annual load profile, while the January–September profile was derived from the hourly average of these three months.

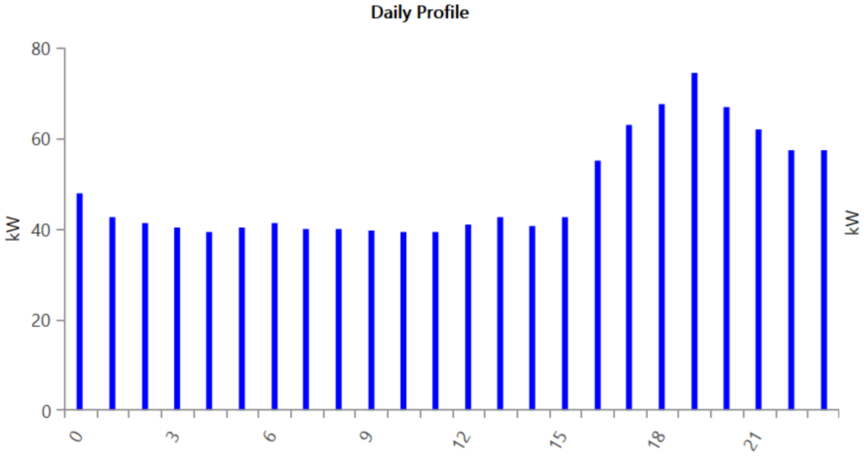

Figure 1. Daily load profile of the Feel electrical system.
Source: PLN Berau load data, 2025 (processed in HOMER Pro)

Figure 2. The condition of the location of PLTD is felt.
Source: Field documentation, PLN Berau, 2025

The modeling was performed using HOMER Pro. The generator and load were configured on the AC bus, while the solar PV system and battery energy storage system were configured on the DC bus and connected through a bidirectional converter. Four hybrid configurations were evaluated: Gen. 1 + Hybrid 700 kWp/1,200 kWh, Gen. 5 + Hybrid 700 kWp/1,500 kWh, Gen. 1 and Gen. 5 + Hybrid 600 kWp/1,500 kWh, and Gen. 1 and Gen. 5 + Hybrid 300 kWp/1,200 kWh. The HOMER-based hybrid system modeling and optimization approach followed methods applied in previous studies on isolated power systems (Maulana, 2024; Karnanto et al., 2023).

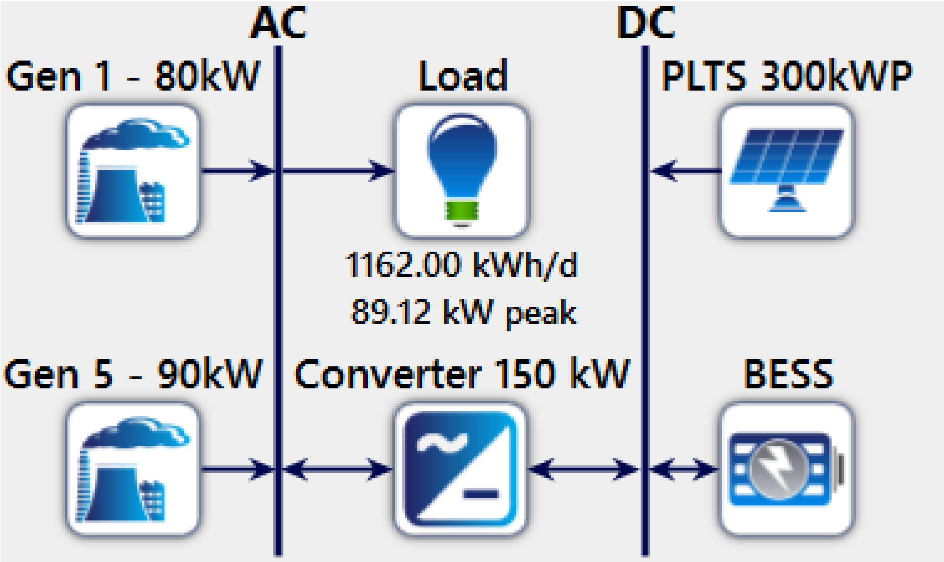

Figure 3. Hybrid system modeling configuration on HOMER Pro.
Source: HOMER Pro modeling output, 2025

Financial analysis was conducted over a 25-year project lifetime using economic indicators commonly applied in solar power plant and hybrid system assessments, including NPC, LCOE, NPV, IRR, and payback (Hidayat et al., 2019) (Rahmawati & Dalimi, 2023). NPC and LCOE were obtained from the HOMER Pro simulation results, while NPV, IRR, and payback period were calculated based on incremental cash flows using the existing PLTD system as the baseline. Cost adjustments from the base year were performed using the future value approach in engineering economics.

RESULTS AND DISCUSSION

The simulation results show that there is a considerable difference between the four configurations. The addition of solar PV capacity does not automatically result in the most economical configuration because investment costs, storage capacity, diesel consumption, and the use of renewable energy affect each other. Therefore, the configuration selection is carried out by considering technical and economic parameters simultaneously, as with the hybrid optimization approach used in previous research (Kusuma & Dalimi, 2025).

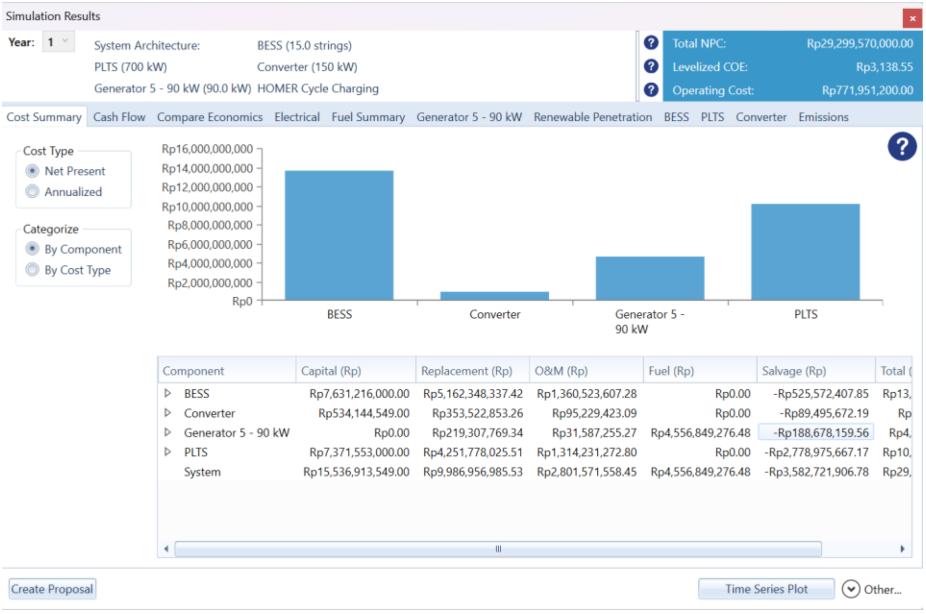

Figure 4. Example of system configuration optimization results in HOMER Pro.
Source: HOMER Pro simulation results, 2025

Table 1. Comparison of hybrid system optimization results.

Scenario	PLTS (kWp)	Storage (kWh)	NPC (IDR billion)	LCOE (Rp/kWh)	Fuel (L/year)	RF (%)
Gen. 1 + Hybrid	700	1.200	34,10	3.652,63	8.809	93,3
Gen. 5 + Hybrid	700	1.500	29,30	3.138,55	6.958	94,7
Gen. 1 & 5+ Hybrid	600	1.500	26,64	2.852,97	4.847	96,7
Gen. 1 & 5+ Hybrid	300	1.200	38,35	4.108,16	36.671	71,9

Source: HOMER Pro simulation results (processed), 2025

The Gen. 1 and Gen. 5 configurations with 600 kWp solar power and 1,500 kWh storage provide the lowest NPC and LCOE. Fuel consumption in this configuration decreased to 4,847 L/year with a renewable fraction of 96.7% and a capacity shortage of 0%. These results show that a capacity of 600 kWp provides a better balance between investment and utilization of renewable energy than the capacity of 700 kWp and 300 kWp.

Table 2. Comparison of investment eligibility.

Scenario	NPV (Rp)	IRR (%)	PBP (year)	Remarks
Gen. 1 + Hybrid	12.868.154.991	13,5	6,18	Worthy
Gen. 5 + Hybrid	18.389.249.389	13,7	6,77	Worthy
Gen. 1 & 5 + Hybrid 600 kWp	21.339.496.548	15,3	6,17	Worthy
Gen. 1 & 5 + Hybrid 300 kWp	10.414.716.998	18,1	5,15	Worthy

Source: Financial analysis results (processed), 2025

All configurations result in positive NPVs and IRRs that meet the investment eligibility criteria. The largest NPV value, which is IDR 21.34 billion was obtained in the 600 kWp configuration. Thus, such configurations not only provide better technical performance, but also provide the greatest economic benefits over the life of the project.

Table 3. Comparison of GHG emissions.

Scenario	GHG emissions (kg CO_2/year)	Decrease (%)
Existing PLTD	372.581	–
Gen. 1 + Hybrid	23.604	93,66
Gen. 5 + Hybrid	18.645	95,00
Gen. 1 & 5 + Hybrid 600 kWp	12.988	96,51
Gen. 1 & 5 + Hybrid 300 kWp	98.263	73,63

Source: HOMER Pro simulation results (processed), 2025

From an environmental aspect, the 600 kWp configuration also resulted in the largest reduction in emissions. GHG emissions decreased from 372,581 kg CO_2/year under existing conditions to 12,988 kg CO_2/year or reduced by 96.51%. This decline mainly stems from reduced generator fuel consumption after most of the energy needs are met by renewable energy sources.

CONCLUSION

The results of the study showed that the integration of solar PV systems and energy storage in isolated power systems could reduce dependence on PLTD. Among the four evaluated scenarios, the configuration consisting of Gen. 1 and Gen. 5 generators with a 600 kWp solar PV system and 1,500 kWh battery storage provided the best performance, with fuel consumption of 4,847 L/year, a renewable fraction of 96.7%, zero capacity shortage, an NPC of IDR 26.64 billion, an LCOE of IDR 2,852.97/kWh, an NPV of IDR 21.34 billion, an IRR of 15.3%, and a payback period of 6.17 years. GHG emissions in this configuration decreased by 96.51% compared with the existing PLTD-only system. Overall, this configuration was identified as the most feasible alternative based on the combined technical, financial, and environmental performance, although final implementation (Saputra & Prabowo, 2024) should consider the availability and suitability of land for solar PV installation. Future studies are recommended to incorporate sensitivity analyses of fuel price fluctuations and battery degradation rates, as well as conduct detailed land suitability assessments for PV deployment. In addition, pilot project implementation is suggested to validate the simulation results under actual operating conditions before large-scale deployment.

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