Reliability-Based Optimization of a PV-Hybrid Microgrid for Island Electrification: A Case Study of Palue, Indonesia

Gilang Rausan Fikri Noor [1,2,*] and Bambang Arip Dwiyantoro [2]

[1] Department of Planning, PT PLN (Persero) Unit Induk Wilayah NTT, 85228 Indonesia
[2] Department of Mechanical Engineering, Sepuluh Nopember Institute of Technology (ITS), Surabaya, 60111 Indonesia
* `gilang.fikri@pln.co.id`

Abstract. Reliable electricity access in remote archipelagic regions is a fundamental challenge to increasing the electrification ratio in Indonesia. This study evaluates the performance and reliability of a 760 kWp off-grid Photovoltaic (PV) Power Plant on Palue Island, which faces operational failure due to severe load growth. The research methodology integrates three approaches: Monte Carlo simulation to project system reliability from historical data, a simulation tool to validate the PV array's technical performance, and an optimization platform for the techno-economic analysis of a hybrid PV-BESS-Diesel system. The analysis confirms the existing system's inadequacy, with a projected Loss of Load Probability (LoLP) of 84.81% by 2025. To achieve 100% reliability, the optimal solution involves retaining the 760 kWp PV array, expanding the Battery Energy Storage System (BESS) to 2,800 kWh, and adding a 190-kW diesel generator for backup. This optimized architecture successfully meets all loads with a high renewable fraction of 99.5% and a competitive Levelized Cost of Energy (LCOE) of \$0.282/kWh. This research provides a robust, data-driven retrofit framework for failing renewable energy systems, offering a replicable model for enhancing electrification in other remote regions.

Keywords: EAF, Microgrid, Monte Carlo, Solar PV, Unmet Load.

1 Introduction

The Indonesian government is targeting an acceleration in the utilization of renewable energy to support its commitment to reducing emissions and increasing the national electrification ratio. However, the main challenge in remote, frontier, and outermost (3T) archipelagic regions is not only availability but also the reliability of the electricity supply, which is the primary foundation for equitable development.

This national challenge is clearly reflected in the operational failure observed in Palue Island, where the centralized PV plant has failed to operate as designed due to unanticipated demand spikes. The Palue PV Plant, operational since December 2021 in Sikka Regency, NTT, serves as a highly relevant case study. As the sole source of

M. A. Muflikhun et al. (eds.), *Proceedings of the 8th Mechanical and Industrial Engineering Symposium (MIE 2025)*, Atlantis Highlights in Engineering 42,
https://doi.org/10.2991/978-94-6239-687-6_7

electricity on the island, the system was designed as a Communal PV Plant (PV + Battery) with a capacity of 760 kWp PV and 1,680 kWh of batteries, without an initial backup diesel generator. Since its commissioning, the system has failed to provide a 24-hour electricity supply due to unpredicted load growth and component performance degradation. A drastic surge in demand occurred within the first six months, with the nighttime peak load increasing by more than 600%, as shown in Figure 1.

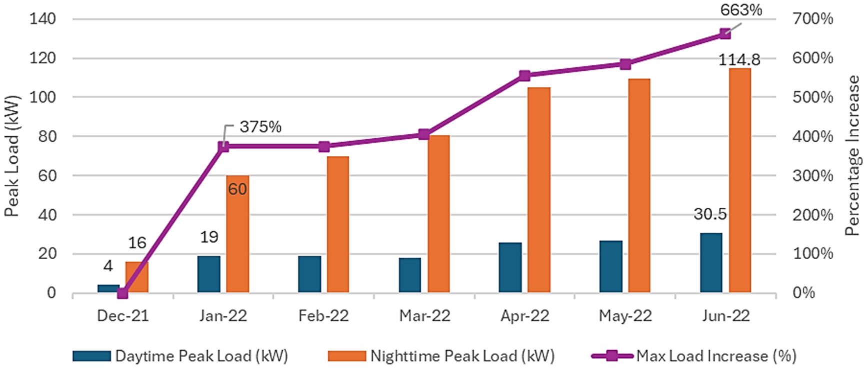


Fig. 1. Significant Peak Load Increase at PLTS Palue within the first six months of operation, highlighting the drastic surge in nighttime demand [1].

This load surge reflects a pent-up demand from a community that has lacked adequate electricity access for years. This operational pattern forces the battery to work with a deeper Depth of Discharge (DoD), which exponentially accelerates its degradation. This critical situation, compounded by a waiting list of ~400 new customers, demands a thorough evaluation and a fundamental system redesign.

These challenges, particularly the uncertainty in load patterns and component degradation, necessitate the use of probabilistic approaches. This shift in methodology is essential to bridge the gap between theoretical design and real-world operation, particularly in high-risk, data-scarce environments like Palue Island. To address these issues, this study builds upon a framework of established research in reliability analysis and hybrid system optimization. The literature highlights the necessity of using stochastic methods to account for the high variability of renewable energy resources and consumer demand.

This study builds upon a framework of established research in reliability analysis and hybrid system optimization. The literature highlights the necessity of using probabilistic methods over deterministic ones to account for the high variability of renewable resources and load demand. The study by Ayaz et al. [2] demonstrates that a stochastic approach provides a more realistic assessment of system performance. This is reinforced by Saad et al. [3], who successfully modeled solar irradiance uncertainty using a Monte Carlo-Beta PDF. In terms of system reliability evaluation, the work by Khatib & Elmenreich [4] shows the direct trade-off between reliability targets (measured by LoLP and EENS) and system cost, while Sandelic et al. [5] emphasizes that the reliability of power electronic components is a critical factor that is often overlooked.

For system design and optimization, specialized software is indispensable. The combination of HOMER Pro for techno-economic optimization and PVsyst for detailed technical validation is a well-documented and robust approach, as shown in studies by Kpomonè & Damipi and Baidya et al., and supported by recent reviews comparing PV simulation tools for research applications [6,7,8]. Table 1 summarizes these key references that form the foundation for this paper's methodology.

Table 1. Summary of Key Literature Review.

Author & Year	*Title (Short)*	*Category*	*Insight*
Ayaz et al. (2024)	Probabilistic PV Generation & Load Uncertainties	Uncertainty & Reliability	Supports a probabilistic approach in modeling load growth and supply uncertainty in microgrids.
Sandelic et al. (2022)	Reliability Aspects in Microgrid Planning		Reference for reliability indicators (LoLP and EENS) to evaluate off grid & microgrid PV systems.
Saad et al. (2019)	Irradiance Uncertainty using Monte Carlo-Beta		Highlights the importance of climatic variables in system reliability; inspires Monte Carlo-based probabilistic modeling.
Khatib & Elmenreich (2014)	Optimum Availability of Standalone PV	Reliability & HOMER	Applies actual load, HOMER software, and availability metrics such as LoLP and EENS. Connects reliability to system cost.
Kpomonè & Damipi (2024)	HOMER & PVsyst for Rural Electrification	PV Setup (HOMER + PVsyst) and Optimization	Demonstrates PVsyst-HOMER workflow in actual rural electrification projects.
Baidya et al. (2025)	Hybrid System Optimization for Remote Area		Reference for optimizing PV-diesel-BESS hybrid capacities using HOMER.
Islam et al. (2025)	Evaluation of PV Simulation Software	Review Software	Supports the validation of PVsyst & HOMER selection in research.

While these studies provide powerful tools and frameworks, a gap remains in applying an integrated methodology to diagnose and redesign a real-world, underperforming renewable energy system based on actual operational data. This research fills that gap by combining probabilistic failure analysis with techno-economic optimization and technical validation to offer a practical and data-driven retrofit solution.

These reliability issues are particularly prominent in the case of Palue Island, where the PV-BESS system commissioned in 2021 failed to meet growing demand and provide 24-hour electricity. The root cause lies in the high degree of uncertainty characterizing system operation and demand patterns. First, the actual load growth on the island significantly exceeds conventional projection standards, such as the 8.79% [9] annual estimate used in national planning documents, and similar demand-escalation behavior has also been reported in other Indonesian PV electrification projects [10]. Second, the behavioral characteristics of users—many of whom bypass load limiters—result in erratic consumption, further complicating accurate demand forecasting, as also noted in local demand-side studies in Indonesia [11]. Lastly, incomplete and inconsistent historical data due to system outages limits the reliability of conventional modelling approaches. These interrelated uncertainties underscore the need for a probabilistic reliability evaluation rather than a purely deterministic design approach.

The solution lies in a reliable hybrid microgrid. Such a system integrates various generation sources—in this case, PV, a Battery Energy Storage System (BESS), and a diesel generator—to enhance supply reliability. A critical metric for these systems is battery autonomy; the duration the BESS can supply the load without input from the PV array. As shown in Equation (1), autonomy is determined by the usable battery capacity relative to the average load it must serve.

$$Autonomy\ (hr) = \frac{Batt.\ Cap.\ (kWh)\ x\ \eta_{batt}\ x\ DoD_{max}}{Av.\ night\ load\ (kW)} \tag{1}$$

With an average night load already exceeding 100 kW, the existing 1,680 kWh battery capacity is theoretically unable to last through the night, quantitatively proving the need for capacity redesign. To evaluate this, this study uses two key reliability indicators: the Equivalent Availability Factor (EAF), which measures the plant's operational readiness, and the Loss of Load Probability (LoLP), the probability of the system failing to meet demand [12].

$$EAF\ (\%) = \frac{PH - \sum Derating\ Hours}{PH} \tag{2}$$

$$LOLP = \frac{\sum_{i=1}^{n} T_{loss,i}}{T_{total}} \tag{3}$$

Therefore, this study aims to: (i) evaluate the reliability and energy deficit of the existing PV-BESS system on Palue Island using historical data and probabilistic simulation; (ii) validate the PV array's technical performance through simulation; and (iii) design the most reliable and cost-effective hybrid configuration. The key contribution lies in offering a replicable framework for retrofitting underperforming renewable energy systems in remote areas.

The main contribution of this study is to provide a real-data-driven framework for evaluation and optimization that can be replicated for other rural electrification and de-dieselization projects in Indonesia, thereby supporting an accelerated, reliable, and sustainable energy transition.

2 Research Methodology

This research employs an integrated three-stage methodology to accurately diagnose the system's issues and design a reliable solution. The research workflow, as outlined in Fig. 2, is specifically designed to address the challenges of data uncertainty and unpredictable load growth identified in the introduction.

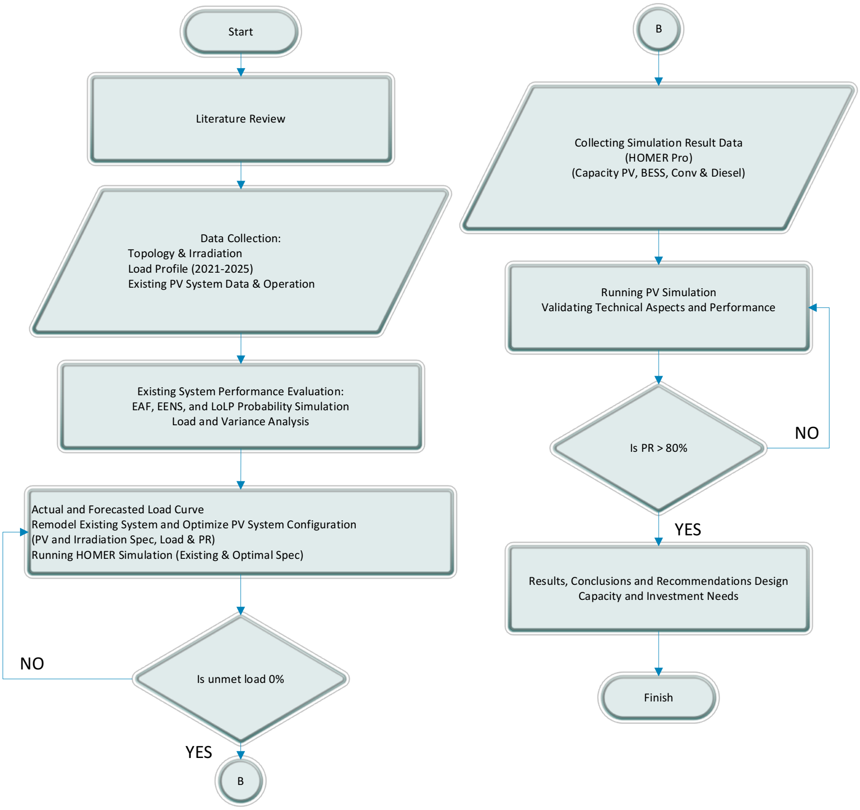


Fig. 2. The research methodology flowchart consists of three main stages: technical validation, reliability evaluation, and hybrid system optimization.

2.1 Data Collection and Preparation

The foundational stage of this research involved the collection and preparation of accurate data. Historical operational data (December 2021 – April 2025) in the form of daily log sheets were obtained from the utility, PLN UPK Flores. This dataset included hourly load records, energy production, and system operational status. However, the raw data suffered from very low completeness, with only 26.22% of the data being valid and usable due to frequent system failures and manual recording errors.

To address the issue of missing and unrepresentative data, a typical daily load profile was constructed. This was achieved by calculating the median hourly load from the entire set of valid data points. The median, rather than the mean, was deliberately chosen to minimize distortion from outliers and to produce a more robust representation of the load pattern. This daily profile was then projected for the year 2025, incorporating the estimated load increase from new perspective customers, to serve as the basis for the simulation.

Solar resource data, including Global Horizontal Irradiance (GHI) and ambient temperature, were obtained from the Global Solar Atlas (GSA) satellite database for the specific coordinates of the power plant.

2.2 Stage 1: PV Array Performance Validation

This initial stage aims to answer the question: Does the currently installed PV array perform well technically? This validation is crucial to confirm that the primary problem does not lie with the solar energy generation itself. The analysis was performed using PVsyst software, the industry standard for detailed photovoltaic system simulation [13].

A model of the existing PV system, including module specifications, inverter configurations, and string design, was built within PVsyst. Using the GHI and temperature data from the GSA, a year-long simulation was executed. The system's performance was evaluated based on the key metric of Performance Ratio (PR), which compares the actual energy output to the theoretical energy output under ideal conditions, as commonly used in PV engineering practice [14,15].

2.3 Stage 2: Probabilistic Reliability Evaluation

The second stage focuses on quantifying the failure rate of the existing system (PV + Battery). Given the uncertainties in component degradation rates and future load growth, a deterministic approach is insufficient. Therefore, a Monte Carlo simulation with 10,000 iterations was used to model the system's reliability probabilistically.

Monte Carlo simulation is a statistical method that uses random sampling to model uncertainty and project probabilistic outcomes [16]. It is widely used to evaluate reliability under variable inputs [12]. This simulation, conducted with Crystal Ball software, with 10,000 iterations, was employed to probabilistically forecast the system's reliability, specifically focusing on the Equivalent Availability Factor (EAF) and Loss of Load Probability (LoLP) over its technical lifespan.

Equivalent Availability Factor (EAF) measures the percentage of time the system can provide electricity at its rated capacity. While Loss of Load Probability (LoLP) measures the probability that the system will fail to meet the load demand at any given time.

The results from this stage provide strong quantitative evidence for the urgency of a system overhaul.

2.4 Stage 3: Hybrid System Optimization

The final stage is to design the most optimal technical solution. This process was carried out using HOMER Pro software, which is specifically designed for the techno-economic optimization of hybrid energy systems [17,18].

Within HOMER Pro, various system configurations consisting of the existing 760 kWp PV array, different sizes of BESS, and different sizes of diesel generators were simulated. The primary objective of the optimization was to find the configuration with the lowest lifecycle cost (Net Present Cost - NPC) that could meet 100% of the load demand (a zero unmet load constraint). The output of this optimization provides not only the most reliable and economical system architecture but also its normalized cost of energy, the Levelized Cost of Energy (LCOE).

2.5 Simulation Parameters and Assumptions

Several key parameters were carefully defined for the HOMER Pro simulation to ensure realistic outcomes. The PV derating factor was set to 81.53%, a direct, data-driven value obtained from the PVsyst validation, accounting for real-world losses like temperature and wiring. The diesel fuel price was set at \$0.69/L, based on the subsidized industrial fuel price in the East Nusa Tenggara region as of Q2 2024, ensuring the economic analysis reflects local conditions. A nominal discount rate of 7.4% was used, consistent with the standard rate applied for power infrastructure projects by the national utility.

Table 2. Table captions should be placed above the tables.

Parameter	***Value***
Location	Palue Island, Indonesia (-8.32°, 121.70°)
Avg. Solar GHI	2,238 kWh/m²/yr
Avg. Temperature	25.4 °C
PV Module Technology	Monocrystalline Trina TSM-550Wp
Total Capacity (DC)	760 kWp
Performance Ratio (PR)	81.53 % (Result from PVsyt)
BESS Technology	Lead-Acid
BESS Capacity (Optimal)	2,800 kWh
Diesel Capacity (Optimal)	190 kW
Project Lifetime	25 years
Nominal Discount Rate	7.4 %

Parameter	***Value***
Diesel Fuel Price	$0.69 / L

Solar resource data, including Global Horizontal Irradiance (GHI) and ambient temperature, were obtained from the Global Solar Atlas (GSA) satellite database for the specific coordinates of the power plant.

3 Results and Discussion

This section presents the results from each stage of the methodology, starting with the technical validation of the existing PV array, followed by the reliability diagnosis of the current system, and concluding with the proposed optimal hybrid solution.

3.1 PV Array Performance Validation

A detailed simulation of the existing 760 kWp PV array was first conducted using PVsyst to obtain a realistic Performance Ratio (PR) for use in the main system optimization. The simulation, based on local meteorological data from GSA, confirms that the PV array itself is well-designed and performs efficiently.

The system is projected to achieve an annual Performance Ratio (PR) of 81.53%, which is above the industry benchmark of 80% for high-quality systems. The energy loss diagram generated by the simulation (summarized in Fig. 3) indicates that the primary source of energy loss is the high module temperature (-11.99%), a typical characteristic for systems operating in a tropical climate. This result validates that the PV array is not the source of the system's failure and provides a reliable PR value (as a derating factor) for the subsequent HOMER Pro simulations.

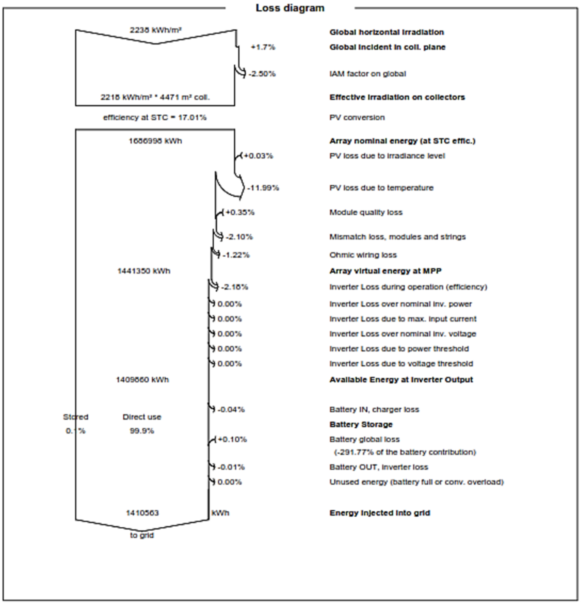


Fig. 3. Energy loss diagram from PVsyst, showing temperature as the main loss factor and a final PR of 81.53%.

A deeper look into the loss diagram (Fig. 3) reveals other contributing factors to the total 18.47% system loss. Beyond the primary thermal losses (-11.99%), significant losses also occur from module mismatch and wiring (-2.10% and -1.22% respectively). These ohmic and mismatch losses, although smaller, are critical for understanding the overall system efficiency and are essential inputs for accurate energy yield predictions.

The monthly PR analysis on Fig. 4 provides deeper insight, showing stable performance throughout the year, mostly above 75%. This consistency confirms the reliability of the PV generation component, and the final annual PR value was used as a realistic Derating Factor in the main HOMER Pro simulation.

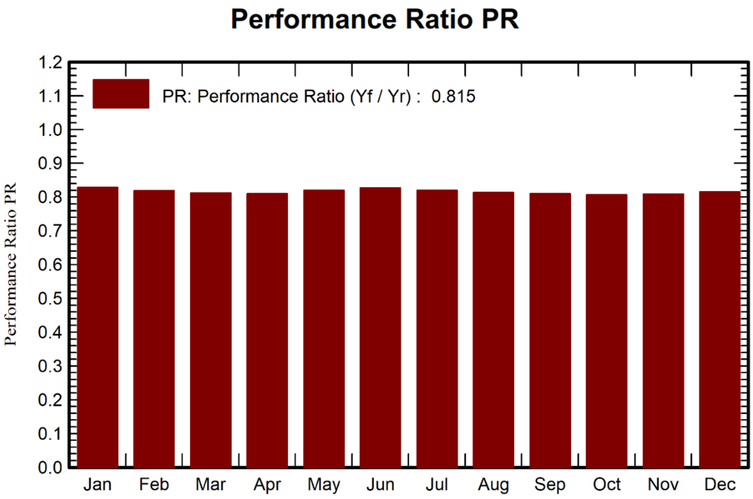


Fig. 4. Monthly Performance Ratio (PR) graph of the PV System.

3.2 Reliability Analysis of the Existing System

With a validated PR value, the existing system (760 kWp PV + 1,680 kWh BESS) was simulated in HOMER Pro and analyzed using Monte Carlo methods to quantify its failure. The results, summarized in Table 3, reveal a critical state of unreliability.

Table 3. Key Failure Metrics of the Existing System.

Metric	***Value***	***Unit***
Unmet Electric Load	123,458	kWh/year
Unmet Load Percentage	15.69	%
Excess Electricity	981,203	kWh/year
Mean EAF (Forecast)	54.02	%
LoLP (Base Case Forecast)	84.81	%

Furthermore, the analysis reveals a critical paradox. While the community suffers from nightly blackouts, the system simultaneously wastes over 981,000 kWh of clean energy per year (Table 3). This massive amount of excess electricity, generated during peak sun hours but unable to be stored by the undersized BESS, powerfully illustrates the fundamental design mismatch and inefficiency of the existing configuration. The problem is not a lack of energy potential, but a failure in energy management and storage capacity.

The system fails to serve 15.7% of the annual energy demand. The root cause is a fundamental design mismatch: the BESS is too small to absorb the massive surplus energy from the PV array during the day, leading to over 980,000 kWh of wasted energy per year, while being insufficient to cover the nightly load. This operational failure is visualized in Fig. 5, which shows the system's service duration progressively shortening each year.

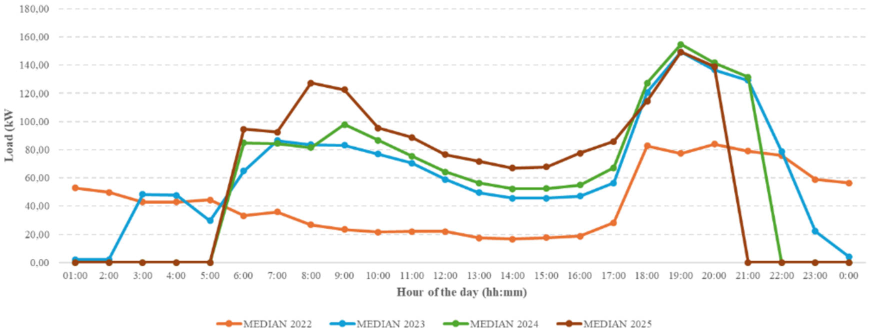
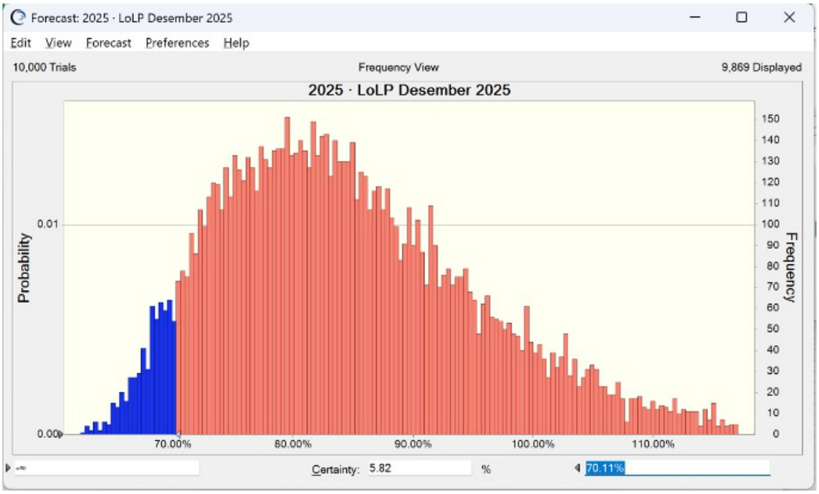


Fig. 5. Comparison of daily median load curves (2022-2025), showing the progressive shortening of nightly service duration

The probabilistic simulation, shown in Fig. 6, confirms this high risk, predicting a Loss of Load Probability (LoLP) of over 80%. This means the system is almost certain to fail to meet demand on any given day.



10,000 Trials

9,869 Displayed

Certainty: 5.82 %

70.11%

Fig. 6. Monte Carlo simulation for the LoLP of the existing system, showing a high probability of failure.

To complement this forward-looking probabilistic analysis, Fig. 7 provides a historical diagnosis through a monthly LoLP heatmap derived from operational data. This visual powerfully demonstrates that the system's failure is not random but chronic and systematic. The dark red cells, dominating the grid from 2023 onwards, indicate months where power outages were a consistent, near-daily occurrence, confirming that the high LoLP is a persistent operational reality.

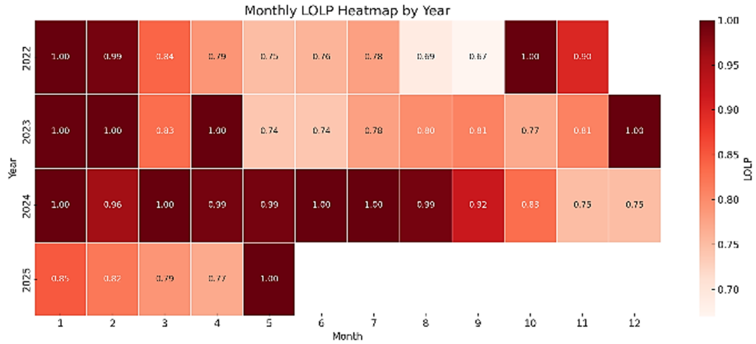
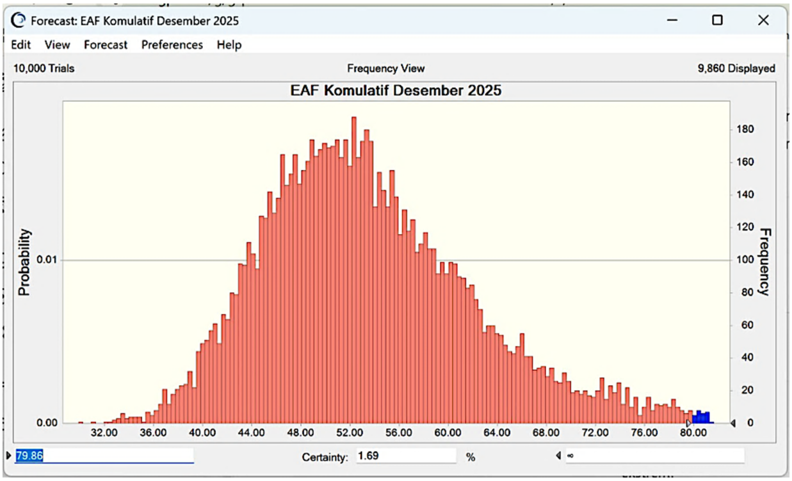


Fig. 7. Monthly LoLP heatmap (2022-2025), illustrating the chronic and escalating system failure.

In addition to the probability of failure, the system's availability was also projected. Fig. 8 shows the probability distribution of the cumulative Equivalent Availability Factor (EAF) for the end of 2025. The simulation, after 10,000 trials, indicates that the probability of the system meeting the standard reliability target of 86% is less than 1.70%, with the mean EAF value hovering around 52-54%.


Forecast: EAF Komulatif Desember 2025

10,000 Trials

Frequency View

9,860 Displayed

EAF Komulatif Desember 2025

79.86

Certainty: 1.69 %

∞

Fig. 8. Probability Distribution of the Cumulative EAF in December 2025.

To identify the dominant factors contributing to this low reliability, a sensitivity analysis was performed on the EAF projection. Fig. 9 shows the resulting tornado diagram. The analysis confirms that Outage Hours have the most significant negative impact on system availability, followed by Maintenance Hours. This indicates that the primary driver of system failure is the frequency of component outages and downtime, rather than other operational factors, consistent with recent assessments of reliability drivers in hybrid microgrids [19].

Outage hours in this study refer not only to periods of complete system failure but also include intervals when the generation unit operates under derated conditions, resulting in insufficient capacity to meet the actual load demand. This broader definition captures both forced outages and partial performance losses due to component degradation or capacity limitations.

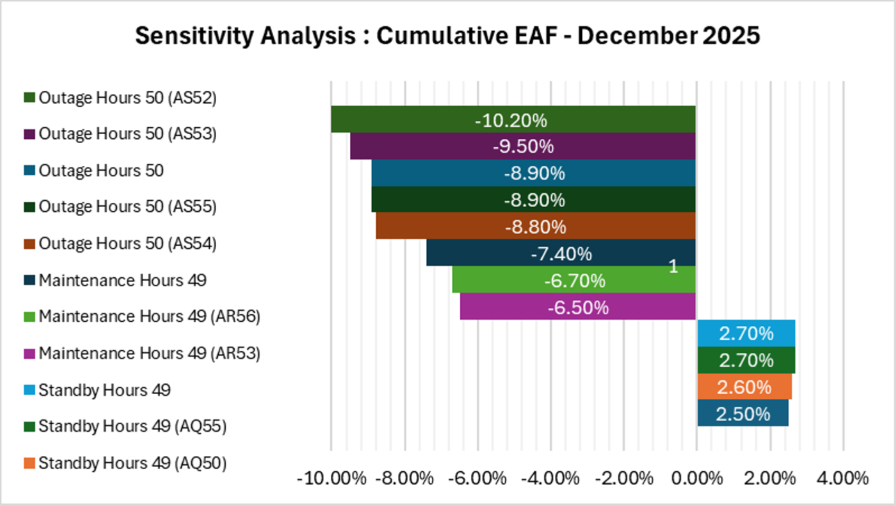


Fig. 9. Sensitivity analysis shows that outage and maintenance hours are the most significant factors reducing the system's EAF.

3.3 Hybrid System Optimization and Proposed Solution

Given the confirmed failure of the existing system, an optimization was performed in HOMER Pro to find the most cost-effective configuration that could meet 100% of the projected load (zero unmet load). The optimization retained the existing 760 kWp PV array and searched for the optimal BESS and diesel generator capacities.

The optimal solution (Scheme 3) recommends expanding the BESS to 2,800 kWh and adding a 190-kW diesel generator for backup. A comparison with other potential schemes is shown in Table 4.

Table 4. Techno-economic comparison of key optimized configurations.

Scheme	*NPC (M.USD)*	*LCOE ($/kWh)*	*Unmet Load (%)*	*RE Frac. (%)*	*Fuel (L/yr)*
1	$2.61	$0.25	0%	38.7	157,660
2	$2.79	$0.27	0.44%	100	0
3	$2.89	$0.28	0%	99.5	1,269
4	$3.27	$0.32	0%	0	179,009

Scheme 1 is 760kWp PV and 190kW diesel; Scheme 2 is 100% renewable with 760kWp PV and 2.815 kWh BESS; Scheme 3 is optimal hybrid with 760kWp PV, 2.815 kWh BESS and 190 kW diesel; and Scheme 4 are 190kW diesel only. The optimal hybrid system achieves 100% reliability with a minimal cost increase compared to a non-dispatchable diesel-only system, while maintaining a very high renewable fraction of 99.5%. The LCOE of $0.282/kWh is competitive for a fully reliable off-grid system in a remote location.

A critical trade-off analysis between Scheme 2 (100% renewable PV+BESS) and Scheme 3 (Optimal Solution) justifies the inclusion of the 190-kW diesel generator. While Scheme 3 is fully renewable, it still has a small but significant unmet load of 0.44%. The addition of the small diesel generator in Scheme 3 effectively ‘buys’ 100% reliability by covering this deficit. For a slight increase in LCOE (from $0.273 to $0.282/kWh), the system gains absolute certainty in power supply, a crucial factor for isolated island grids.

From an implementation standpoint, the optimized solution is highly feasible. While the full Net Present Cost (NPC) is $2.89 million, this figure assumes all components are new. A brownfield approach can be taken by reusing the existing 760 kWp PV array and 1,680 kWh of the BESS. This strategy significantly reduces the initial capital expenditure, making the upgraded project more financially viable and sustainable by minimizing waste and leveraging existing assets, consistent with recent retrofit-oriented hybrid microgrid studies [20].

The recommended optimal architecture, which integrates the existing PV array with the expanded BESS and the new backup diesel generator, is depicted schematically in Fig. 10.

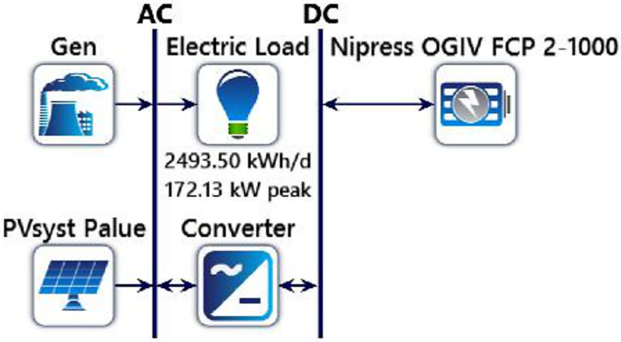


Fig. 10. Schematic of the optimal hybrid system architecture as determined by HOMER Pro

The operational strategy of this new architecture is shown in the merit order chart on Fig. 11. The BESS acts as the primary "energy shifter," absorbing surplus solar energy during the day and dispatching it at night. The small 190 kW diesel generator functions purely as a reliability insurer, operating only for a few hours in the early morning to cover the final portion of the load before sunrise, thus ensuring an uninterrupted 24-hour supply.

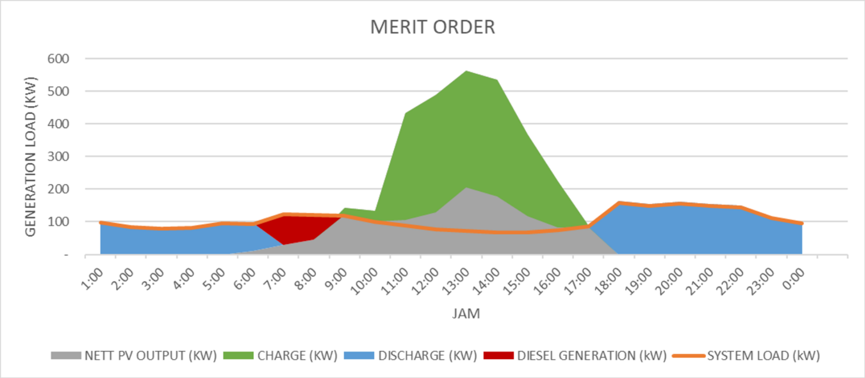


Fig. 11. Daily dispatch strategy (merit order) of the optimized hybrid system

This strategy ensures the battery operates in a healthy State of Charge (SoC) range, preventing the deep discharges that degraded the old system.

The effectiveness of this new operational strategy is best illustrated by the battery's performance. Fig. 12 shows the daily charge and discharge cycle of the new 2,800 kWh BESS. The battery is charged with surplus solar energy during the day and acts as the primary power source throughout the night.

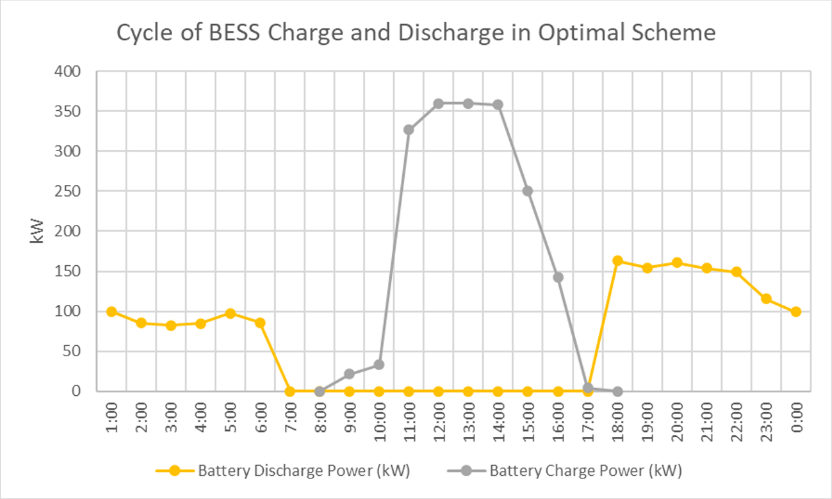


Fig. 12. Daily charge (grey line) and discharge (yellow line) cycle of the 2,800 kWh BESS in the optimal scheme, illustrating its role as the primary energy shifter.

This operational pattern allows the battery to always maintain a healthy State of Charge (SoC), as shown on Fig. 13. The SoC cycles smoothly between a peak charge during the day and a safe minimum level before sunrise, avoiding the deep discharge cycles that plagued the original system. This ensures not only reliability but also a longer operational lifetime for the battery asset.

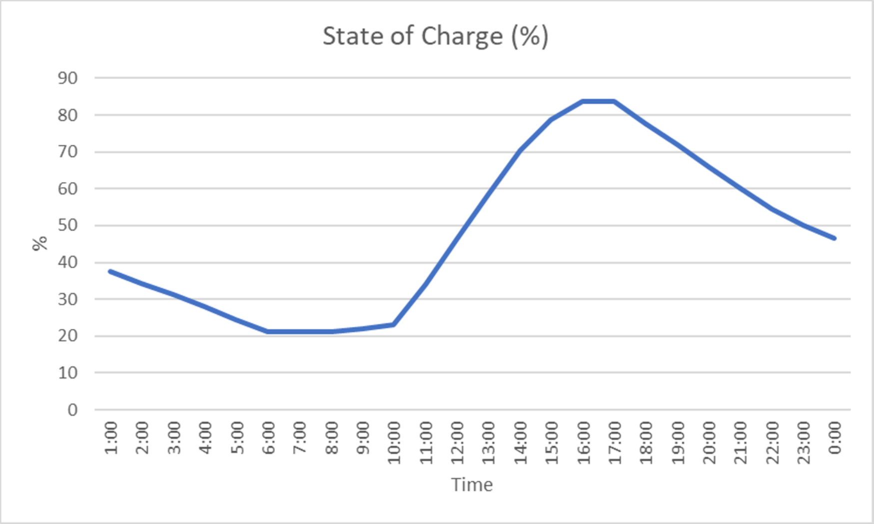


Fig. 13. Daily State of Charge (SoC) profiles the optimized system.

The economic analysis assumes battery replacement every 4,5 years, based on total throughput energy and charging-discharging cycle. This is reflected in the lifecycle cost estimation at HOMER Pro. The HOMER Pro simulation implicitly incorporated the cost of replacing the Battery Energy Storage System (BESS) multiple times over the 25-year project lifetime. This ensures a comprehensive representation of the system's total lifecycle cost.

4 Conclusion

This study successfully diagnosed the critical reliability issues of the Palue Island PV plant and proposed a validated, optimized solution. The research quantitatively proves that the existing system is no longer capable of meeting the community's electricity needs, primarily due to a fundamental design mismatch between its generation and storage capacities. The probabilistic analysis confirms a high risk of failure, with a projected Loss of Load Probability (LoLP) of 84.81% and an Equivalent Availability Factor (EAF) forecasted to be below 54% by 2025.

The optimal solution, derived from techno-economic optimization, involves retaining the existing 760 kWp PV array while making crucial upgrades: expanding the Battery Energy Storage System (BESS) to 2,800 kWh and adding a 190-kW diesel generator for backup. This reconfigured hybrid system is proven to achieve 100% supply reliability (zero unmet load) with a high renewable fraction of 99.5% and a competitive Levelized Cost of Energy (LCOE) of $0.282/kWh. The technical viability of the PV system component was also validated with a calculated Performance Ratio (PR) of 81.53%.

This paper presents a replicable method for upgrading underperforming renewable systems. The hybrid configuration ensures full reliability while maintaining a high share of renewables.

For future research, several avenues can be explored. First, a comparative study on alternative battery technologies (e.g., Lithium-ion vs. Lead-acid) could assess the long-term impact on the system's LCOE and environmental footprint. Second, developing a demand-side management strategy could help reduce peak loads and potentially lower the required BESS capacity. Finally, a more in-depth socio-economic analysis of the impact of improved electricity reliability on the local community in Palue would provide valuable insights for future rural electrification policies.

References

1. PLN UPK Flores, Laporan Pengusahaan (PT PLN Persero, Sikka, 2025).
2. M.S. Ayaz, M. Malekpour, R. Azizipanah-Abarghooee, M. Karimi, V. Terzija, Int. J. Elec. Power 159, 110016 (2024).
3. N.M. Saad, M.Z. Sujod, M.I.M. Ridzuan, M.F. Abas, M.S. Jadin, M.S. Bakar, A.Z. Ahmad, Bull. Electr. Eng. Inform. 8, 1135 (2019).
4. T. Khatib, W. Elmenreich, Int. J. Photoenergy 2014, 475080 (2014).
5. M. Sandelic, S. Peyghami, A. Sangwongwanich, F. Blaabjerg, Renew. Sust. Energ. Rev. 159, 112127 (2022).
6. A.B.K. Kpomonè, K. Damipi, Int. J. Res. Rev. 11, 318 (2024).
7. H. Baidya, M.T. Rahman Zisan, A.Z. Alif, A. Ahmed, M. Hasan, N.U.R. Chowdhury, Energy Convers. Manage. X 26, 101004 (2025).
8. M.A. Islam, et al., Energy Strat. Rev. 58, 101663 (2025).
9. PLN, Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) 2021-2030 (PT PLN Persero, Jakarta, 2021).
10. M. Ali, H.S. Wibowo, J. Tek. Bahan. Barang. Tek. 9, 55 (2019).
11. W.N. Cahyo, Jurnal Teknik Industri 13, 11 (2008).
12. R. Billinton, R.N. Allan, *Reliability Evaluation of Power Systems* (Springer US, 1996).
13. PVsyst SA, PVsyst SA Grid Connected Systems-User's manual (PVsyst SA, n.d.).
14. M. Boxwell, *Solar Electricity Handbook 2021 Edition* (Greenstream Publishing, Birmingham, 2021).
15. J.A. Duffie, W.A. Beckman, *Solar Engineering of Thermal Processes* (Wiley, 2013).
16. N. Metropolis, S. Ulam, J. Am. Stat. Assoc. 44, 335 (1949).
17. HOMER, *HOMER Help Manual* (HOMER Energy, 2015).
18. Yunanto, M.E. Susetyo, D. Ellis, A.D. Pranadi, B. Mudiantoro, *Modul Pelatihan HOMER Pro untuk PLN* (Crown, 2021).
19. N. Sakthivelnathan, A. Arefi, C. Lund, A. Mehrizi-Sani, S.M. Muyeen, Energy 311, 133426 (2024).
20. I. Kurniawati, R. Bagus, M.A. Batutah, A. Santoso, CYCLOTRON 7, 37 (2024).