Feasibility and Technical Reliability Study of a Standalone Rooftop Solar Power Plant System Using Python Pvlib: A Case Study on Renewable Energy Engineering Laboratory Building of Universitas Malikussaleh

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Abstract

Article history:
Received: 19-12-2025
Accepted: 13-03-2026
Published: 06-04-2026

***Keywords**:*
loss of power supply probability (lpsp);
off-grid photovoltaic system;
python pvlib;
rooftop solar power plant;
solar energy reliability.

This study evaluates the technical feasibility and reliability limits of a standalone rooftop solar power plant system for the Renewable Energy Laboratory at Universitas Malikussaleh, North Aceh. Utilizing the pvlib Python library and NASA POWER meteorological data from 2022 to 2024, a high-resolution time series simulation was conducted to model energy yield, battery dynamics, and Loss of Power Supply Probability (LPSP). The results reveal a significant seasonal reliability gap, while the system achieves optimal performance in dry months with LPSP < 1%, it suffers critical power failures during the monsoon season, with LPSP peaking at 31.80% in December due to consecutive low irradiance days. Furthermore, the energy balance analysis highlights a system inefficiency where substantial energy curtailment occurs during high-irradiance periods despite severe deficits in wet months. Consequently, a pure off-grid configuration is deemed technically unfeasible for critical laboratory loads without unrealistic oversizing. The study concludes that transitioning to a PV-Hybrid topology with backup generation is essential to ensure operational continuity while complying with current non-export regulatory constraints.

1. Introduction

Global climate change has necessitated a fundamental transformation in the energy sector, shifting focus from fossil fuels to New and Renewable Energy (NRE). As a signatory to the Paris Agreement, Indonesia is committed to reducing carbon emissions and achieving an NRE mix of at least 23% by 2025, as mandated in the National Energy General Plan (RUEN)[1-3]. Solar energy, with a technical potential of 108.7 GWp, is a primary driver of this transition, particularly for educational facilities aiming for "Green Campus" status[4]. However, the implementation landscape has shifted significantly with the issuance of Minister of Energy and Mineral Resources Regulation Number 2 of 2024[5,6]. This regulation eliminates the export-import (net-metering) scheme for grid-connected systems, reducing the economic feasibility of conventional on-grid topologies and necessitating a design shift toward standalone systems that rely on battery storage to maximize self-consumption[7,8].

Implementing standalone solar systems in humid tropical climates, such as North Aceh, presents unique technical challenges due to high irradiance intermittency driven by dynamic cloud cover[9,10]. For critical facilities like the Renewable Energy Engineering Laboratory at Universitas Malikussaleh (5.20° N, 97.06° E), supply instability increases the risk of Loss of Power Supply (LPSP), potentially disrupting sensitive equipment[11,12]. Previous studies have indicated that battery performance in these tropical conditions is critical, yet often underestimated in standard sizing protocols[13,14]. Therefore, ensuring operational continuity without utility dependence requires precise capacity sizing and rigorous reliability analysis beyond simple daily averages[15,16].

Current feasibility studies often rely on commercial software like PVSyst or HOMER. While effective, these tools are often "black-box" in nature, limiting the flexibility to modify calculation algorithms for specific research needs[8, 17]. To address this limitation, this study utilizes an open-source computational approach using the Python pvlib library [17-19]. This method offers greater transparency and allows selection of radiation decomposition and cell-temperature models that best suit local microclimates, in accordance with IEC 61724 standards [9-11].

This study aims to analyze the annual energy production potential using pvlib and local satellite data, evaluate system reliability through LPSP analysis and battery cycle dynamics, and determine the technical feasibility limits of a standalone system for critical laboratory loads under the current non-export regulatory constraints. By using high-resolution time-series simulation, this approach provides a more accurate mapping of energy-deficit probability under extreme weather scenarios in the North Aceh region.

Global climate change, driven by greenhouse gas emissions, has driven a fundamental transformation in the energy sector worldwide, shifting from complete dependence on fossil fuels to consideration of New and Renewable Energy (NRE). Indonesia, as a country that ratified the Paris Agreement through Law Number 16 of 2016, is committed to reducing carbon emissions and increasing the share of NRE in its energy mix[1]. In the National Energy General Plan (RUEN), the government targets the NRE mix to reach at least 23% by 2025[2]. One of the NRE sources with the greatest potential in Indonesia, especially in most regions along the equator, is solar energy with a technical potential of up to 108.7 GWp[3].

The use of Solar Power Plants (PLTS) with installations on the roofs of educational facilities, especially campuses (Green Campus), is one of the targets in the strategy to accelerate the energy transition. However, the implementation landscape of PLTS in Indonesia has undergone significant regulatory changes with the issuance of Minister of Energy and Mineral Resources Regulation Number 2 of 2024, which concerns PLTS directly connected to the electricity grid provided by the holder of a business license for the provision of electricity for public interest or PLN[20]. This latest regulation eliminates the electricity export-import scheme (net-metering), so that excess energy generated by PLTS to the building's electricity grid is no longer counted as a reduction in customers' electricity bills. This condition reduces the economic feasibility of conventional on-grid systems and underscores the urgency of a design shift toward standalone or off-grid systems that rely on battery-based energy storage to maximize the building's independent energy consumption (self-consumption)[7, 8].

Implementing an independent solar power system in a humid tropical climate, such as North Aceh, poses technical challenges due to high solar irradiance intermittency driven by cloud dynamics and intensity. The research location is in the Renewable Energy Engineering Laboratory Building at Universitas Malikussaleh (5.2016216 N, 97.0650506 E), which experiences fluctuating weather conditions throughout the year. Instability in the energy supply from the solar power system can increase the risk of power supply failure (Loss of Power Supply) to critical laboratory equipment[10]. Therefore, a precise capacity design (sizing) and reliability analysis method is needed to ensure the continuity of system operations without relying on the main utility network.

Current feasibility studies of solar power plant systems mostly rely on commercial software such as PVSyst or HOMER, which are often "black-box" in nature, making their calculation algorithms difficult to modify flexibly to meet specific research needs[21]. This study uses an open-source computational simulation approach using the Python programming language with the pvlib library which offers higher transparency of mathematical models as an alternative solution to these limitations[22]. The pvlib library allows researchers to select and validate the radiation decomposition model and cell temperature model that best suits local microclimate conditions, as recommended in the International Electrotechnical Commission (IEC) 61724 standard[17, 18].

This study proposes a technical feasibility and reliability analysis of a standalone solar power system using Python's pvlib-based time-series simulation. This approach is expected to provide a more accurate picture of system performance than conventional methods, especially for mapping the probability of energy deficits under extreme weather scenarios in the North Aceh region. The objectives of this study include (i) analyzing the annual energy production potential of the solar power system using the Python pvlib computational approach with local satellite meteorological data, (ii) evaluating the reliability of the standalone solar power system through load loss probability (LPSP) analysis and battery charge-discharge cycle dynamics, and (iii) determining the technical feasibility limits of the standalone solar power system in serving critical laboratory loads in response to regulations without a power export scheme.

This study applies several limitations to ensure a more focused and in-depth discussion and to minimize uncertainty in formulating final conclusions. These limitations include:

i. The object of this study is the rooftop solar power system at the Renewable Energy Engineering Laboratory Building, Universitas Malikussaleh, with coordinates 5.2016216 N, 97.0650506 E.
ii. The meteorological data used is sourced from the NASA POWER (Prediction of Worldwide Energy Resources) database with an hourly temporal resolution for the period 2022 to 2024[19].
iii. Numerical simulations were performed using the Python 3.11.2 programming language with the main library pvlib version 0.13.1 or later[22].
iv. The radiation models used are the Perez transposition model[23] and the Sandia cell temperature model[24], which are considered to have good accuracy for satellite data conditions.
v. The analysis focuses on technical aspects such as energy production and reliability (power availability) of the solar PV system. In-depth economic analysis such as LCOE or NPV is beyond the scope of this study given the current volatile market prices of solar PV components.
vi. The modeled system is a stand-alone system with battery storage, without considering the reverse power flow or power export to the PLN grid, in accordance with Minister of Energy and Mineral Resources Regulation No. 2 of 2024[20].
vii. The load profile is modeled based on the estimated laboratory equipment load and the energy consumption intensity (IKE) standards for educational buildings according to SNI 03-6196-2000 [25].

2. Methods

Figure 1 presents the overall research methodology, outlining the sequential stages from location selection and meteorological data acquisition to load profiling, photovoltaic system configuration, and creating a Python-based simulation algorithm.

2.1 Location Selection

This research focuses on the Renewable Energy Engineering Laboratory Building, Universitas Malikussaleh, located in North Aceh Regency, Aceh Province. Geographically, the research location is at 5.2016216 N, 97.0650506 E. This location selection reflects the characteristics of a tropical climate in the equatorial region, or a tropical rainforest climate, with high relative humidity and dynamic cloud cover throughout the year.

The physical object that limits the installation area is the concrete roof of the laboratory building, with a total roof area of approximately 1,317 m^2. Based on an initial survey for the effective area free from building structure shadows (shading) and maintenance access, the roof area of the building that can be utilized for solar module installation is assumed to be a maximum of 50% of the total roof area, or approximately 658 m^2.

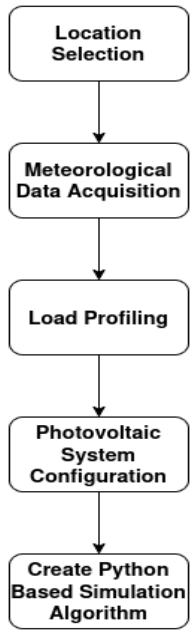

Figure 1. Research methodology

2.2 Meteorological Data Acquisition

Simulation of photovoltaic system performance requires time-series meteorological data with high temporal resolution. This study uses secondary data acquired through the NASA POWER (Prediction of Worldwide Energy Resources) Application Programming Interface (API). Parameters acquired through the NASA POWER API include solar irradiance consisting of Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), and Diffuse Horizontal Irradiance (DHI), as well as environmental data such as average ambient temperature and wind speed at a height of 10 meters[26].

The data period used in this study spans a full 3 years, from January 1, 2022, to December 31, 2024, with hourly resolution. Data acquisition is automated using pvlib.iotools module in the Python programming environment to ensure the integrity and consistency of the data format used[22]. Validation from previous studies shows that NASA POWER data has an acceptable level of accuracy for initial feasibility studies, with Root Mean Square Error (RMSE) for GHI ranging from 15-20% compared to ground station measurements in tropical regions[27].

2.3 Load Profiling

Due to the lack of historical hourly energy consumption data, the electrical load profile is modeled using a synthetic approach based on the operational patterns of an educational building, particularly a laboratory building. Energy consumption estimation is based on an audit of the use of laboratory equipment such as lights, air conditioners, computers, and test equipment, as well as the Energy Consumption Intensity (IKE) standard for educational buildings in Indonesia[25].

The load profiles are divided into two main categories i.e. peak load (8:00 AM - 4:00 PM), reflects the active activities of lectures and labs, with air conditioning, lighting, and laboratory equipment operating at maximum capacity and base load (4:00 PM - 8:00 AM), reflects standby loads such as security lighting, data servers, and sample storage refrigerators, which must be on 24/7, commonly referred to as critical loads.

This daily load profile is then multiplied by a random variability factor of ±10% using the normal distribution function via the NumPy library in Python for a more realistically daily energy usage fluctuation.

2.4 Photovoltaic System Configuration

The solar power system was designed using a standalone scenario to meet the energy needs of the laboratory building without being directly connected to the PLN electricity grid. Based on this scenario, several initial configurations were required, including photovoltaic modules and battery-based energy storage modules.

The photovoltaic module configuration in this simulation uses a Monocrystalline Silicon module model with a capacity of 500 Wp. The module's electrical parameters are taken from the California Energy Commission (CEC) database integrated through the pvlib library in Python[28]. The array configuration is designed with a fixed orientation (fixed tilt) at 10° and an azimuth angle of 180° (facing South). The selection of the 10° tilt angle is based on a compromise among optimizing irradiation capture, a self-cleaning mechanism when it rains, and minimizing wind loads due to air friction on the roof structure[29].

The energy storage system is modeled as a battery bank with Lithium Iron Phosphate (LiFePO4) technology, with a round-trip efficiency of 95% and a maximum Depth of Discharge (DoD) of 80%. Battery capacity is determined using the Days of Autonomy (DoA) method, in which the system is designed to support critical loads for a minimum of 1.5 days without significant solar energy input, such as during heavy cloud/rain.

2.5 Python-Based Simulation Algorithm

The simulation framework was built using Python 3.11.2. The system performance calculation flow to be simulated consists of three main stages: modeling solar irradiation on an inclined plane, modeling thermal factors and DC power from PV, and energy balance analysis.

Data obtained from the NASA POWER API generally provides solar irradiance components on a horizontal plane (GHI), so to obtain the effective solar irradiance value on a tilted module surface (GPOA), the author uses the Perez Model (Perez Transposition Model). This model was chosen for its superior ability to calculate the circumsolar diffuse radiation component and horizon brightness, which are common in cloudy areas such as Aceh[23].

Meanwhile, the temperature of the PV cell will be calculated using the Sandia Array Performance Model (SAPM), which takes into account the influence of solar irradiation, ambient temperature, wind speed, and the type of installation (mounting) applied[24]. The accuracy of temperature prediction for the PV cell is crucial because the power-temperature coefficient of the silicon module is negative, which can result in a decrease in PV efficiency at high operational temperatures typical of tropical climates. The DC output power from the PV will then be calculated by considering the total loss factor due to soiling, mismatch, and cable degradation, assumed to be 14% per the NREL conservative standard[30].

In the energy balance analysis, the author applies energy balance principles at each time step to simulate power flow between the PV, load, and battery. Furthermore, the power dispatch algorithm is configured with load-following priority logic, with the provision that if the PV-generated power exceeds the load requirement, the excess energy will charge the battery until it reaches the maximum State of Charge (SoCmax). If the battery is fully charged or in a fully charged state, the excess energy is recorded as dump energy. Conversely, if the PV-generated power is less than the load's power requirement, the shortfall will be supplied by the battery if the SoC is not below the minimum predetermined SoC (SoCmin). Furthermore, the system's reliability will be evaluated using the Loss of Power Supply Probability (LPSP), defined as the ratio of the total energy the system fails to supply to the total annual load demand[31].

3. Results and Discussion

Based on the research conducted in accordance with the described methodology, several findings were obtained.

3.1 Meteorological Characteristics and Resource Potential

The performance of a photovoltaic (PV) system is highly dependent on the microclimate conditions of the installation site. Based on data acquired from the NASA POWER API over 2022-2024 for the Renewable Energy Engineering Laboratory of Universitas Malikussaleh (5.2016° N, 97.0650° E), the meteorological profile shows significant seasonal variability, which is a major challenge for the implementation of a standalone solar PV system. The meteorological profile of the research site is shown in Table 1 and Figure 2.

As shown in Table 1 and the visualization in Figure 2, the research site experienced sharp fluctuations in average daily insolation or Global Horizontal Irradiance (GHI). Insolation values fluctuated from the lowest of 3.30 kWh/m^2/day in December 2022 to a peak of 5.80 kWh/m^2/day in February 2024.

A drastic decrease in solar irradiation consistently occurs at the end of the year, around November and December. Data shows a downward trend in average daily insolation from 4.66 kWh/m^2 in September 2022 to only 3.30 kWh/m^2 in December 2022. This pattern repeated itself the following year, indicating a strong seasonal cycle that could directly impact the decline in energy production (yield) from solar power plants. Meanwhile, the average ambient temperature was recorded as stable at around 23.1°C to 25.5°C, which is relatively conducive to the thermal efficiency of PV modules compared to hotter tropical regions.

Table 1. Meteorological profile data

Datetime (M/D/Y H:m)	Daily Insolation (kWh/m^2/day)	Avg Temp (°C)
1/31/2022 7:00	5.028	23.754
2/28/2022 7:00	4.148	23.876
3/31/2022 7:00	4.815	24.174
4/30/2022 7:00	4.930	24.672
5/31/2022 7:00	4.891	24.731
6/30/2022 7:00	4.768	24.147
7/31/2022 7:00	4.773	24.168
8/31/2022 7:00	4.702	24.397
9/30/2022 7:00	4.662	24.113
10/31/2022 7:00	3.961	23.820
11/30/2022 7:00	3.955	23.513
12/31/2022 7:00	3.296	23.213
1/31/2023 7:00	4.235	23.102
2/28/2023 7:00	4.742	23.651
3/31/2023 7:00	5.481	24.234
4/30/2023 7:00	5.016	25.198
5/31/2023 7:00	5.085	25.489
6/30/2023 7:00	5.061	24.904
7/31/2023 7:00	5.215	24.704
8/31/2023 7:00	4.612	24.985
9/30/2023 7:00	4.457	24.851
10/31/2023 7:00	4.456	24.465
11/30/2023 7:00	3.750	24.076
12/31/2023 7:00	3.957	24.204
1/31/2024 7:00	4.662	24.257
2/29/2024 7:00	5.798	24.815
3/31/2024 7:00	5.493	25.141
4/30/2024 7:00	5.414	26.091
5/31/2024 7:00	4.646	26.118
6/30/2024 7:00	5.052	25.317
7/31/2024 7:00	4.961	24.988
8/31/2024 7:00	4.369	24.697
9/30/2024 7:00	4.901	24.450
10/31/2024 7:00	4.790	24.603
11/30/2024 7:00	3.779	24.279
12/31/2024 7:00	3.655	23.882

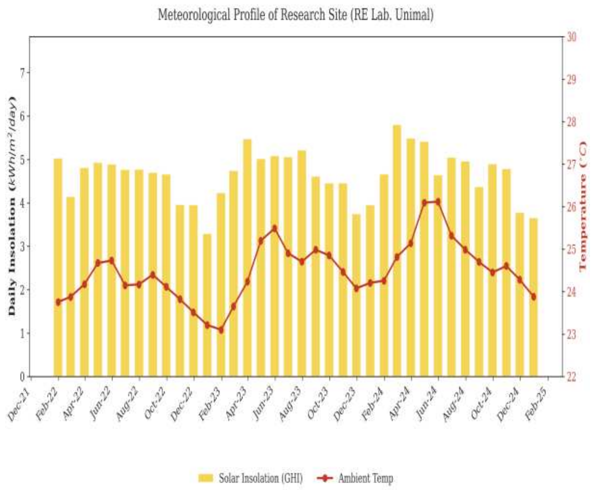

Figure 2. Visualization of meteorological profile

3.2 Energy Production Profile and Daily Load Dynamics

A standalone solar power system simulation was conducted by integrating the obtained meteorological data with a load profile model for a laboratory building. Annual simulation results revealed a mismatch between the building's energy production and consumption.

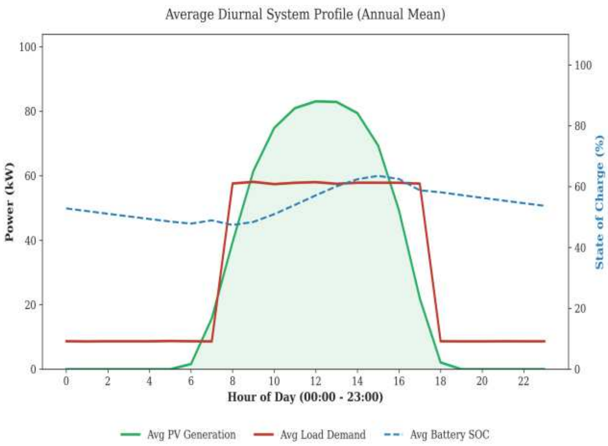

Figure 3. System daily average profile (diurnal profile)

Figure 3 illustrates the average daily system profile. Effective energy production from PV (green curve) is limited to 8:00 AM to 4:00 PM. In contrast, the energy consumption load from the laboratory (red curve) has a base load component that must be maintained at night. This forces the battery to work hard every night, as seen in the average State of Charge (SoC) curve (blue dashed line), which begins to decline drastically from 5:00 PM and reaches its lowest point near sunrise. This emergence of complete dependence on the battery at night is a critical point in analyzing system reliability.

3.3 Reliability Analysis

The main indicator of the technical feasibility of a solar PV system in this study is based on the Loss of Power Supply Probability (LPSP) value. Based on the simulation results for the solar PV system implementation over three years, presented in Table 2, the purely off-grid system is highly vulnerable to power supply failures during wet months or the rainy season.

Referring to Table 2, the monthly LPSP values show a significant disparity between the reliable and critical periods. The most prominent reliable period was seen in February 2024, when the system operated optimally. This is evident in the solar PV system's energy production, which reached 23.88 MWh, far exceeding the building's energy supply requirement of 20.56 MWh. During this period, the LPSP was only 0.58%, enabling the system to meet international reliability standards, which require an LPSP below 1%. A different phenomenon occurred during the system's critical period, for example, in December 2022, the solar PV system's energy production was only 17.54 MWh, while the building's energy supply requirement increased to 20.63 MWh. The energy deficit during this critical period led to an LPSP of 31.80%, indicating power outages occurred for nearly a third of the month. This critical condition was also seen in November in two different years with LPSP of 21.46% in 2023 and 23.08% in 2024.

Table 2. Simulation results of the PV system in 3 years

Datetime (M/D/Y H:m)	PV Gen (MWh)	Load (MWh)	LPSP (%)
1/31/2022 7:00	23.587	20.977	1.556
2/28/2022 7:00	16.909	19.660	17.209
3/31/2022 7:00	20.883	22.126	10.431
4/30/2022 7:00	20.316	20.667	12.351
5/31/2022 7:00	21.330	21.554	8.528
6/30/2022 7:00	20.258	21.300	8.585
7/31/2022 7:00	20.622	21.068	12.545
8/31/2022 7:00	20.139	22.040	11.149
9/30/2022 7:00	19.392	21.234	13.387
10/31/2022 7:00	17.662	21.140	17.086
11/30/2022 7:00	17.701	21.255	18.863
12/31/2022 7:00	15.433	21.474	31.796
1/31/2023 7:00	19.759	21.723	9.929
2/28/2023 7:00	19.252	19.595	8.530
3/31/2023 7:00	23.426	22.119	3.665
4/30/2023 7:00	20.785	20.420	8.894
5/31/2023 7:00	21.901	22.080	7.533
6/30/2023 7:00	21.073	21.230	7.383
7/31/2023 7:00	22.261	20.897	3.155
8/31/2023 7:00	19.836	22.116	13.181
9/30/2023 7:00	18.581	20.768	15.190
10/31/2023 7:00	20.046	21.713	11.459
11/30/2023 7:00	16.621	21.167	21.458
12/31/2023 7:00	18.793	20.975	14.941
1/31/2024 7:00	21.732	21.968	7.582
2/29/2024 7:00	23.881	20.556	0.576
3/31/2024 7:00	23.440	20.967	2.827
4/30/2024 7:00	22.591	21.414	0.745
5/31/2024 7:00	20.575	22.038	10.220
6/30/2024 7:00	20.889	20.471	5.698
7/31/2024 7:00	21.382	22.025	7.200
8/31/2024 7:00	18.966	21.393	12.892
9/30/2024 7:00	20.263	20.824	6.891
10/31/2024 7:00	21.443	22.062	9.903
11/30/2024 7:00	16.724	20.915	23.076
12/31/2024 7:00	17.012	21.689	23.535

Figure 4 shows a consistent spike in LPSP exceeding the 1% tolerance threshold (green line) at the end of each year. This demonstrates that the designed battery capacity is unable to bridge the consecutive periods of no-sun days in North Aceh.

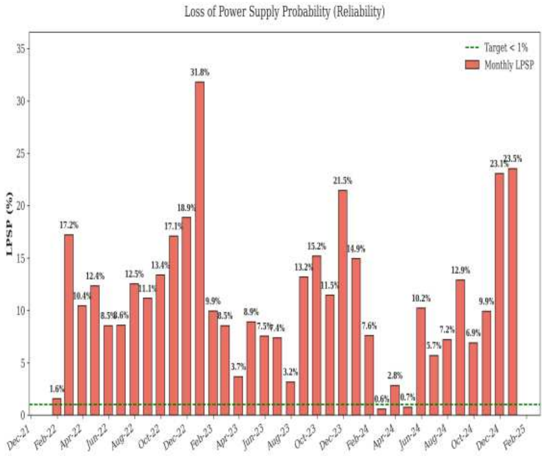

Figure 4. Monthly LPSP in 3 years

This failure condition is further clarified in Figure 5, which shows the system dynamics in December 2022, the most severe critical period. The graph shows a period where the battery SoC reached its minimum operational value and remained flat for several days, marked by the appearance of a blackout event (red area). The system failed to recover battery charging during the day because the solar intensity was too low to lift the SoC from its nadir.

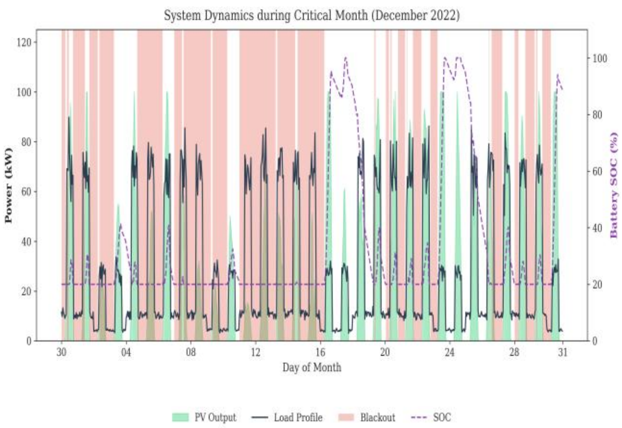

Figure 5. System dynamics on critical month

3.4 Evaluation of Storage and Energy Balance

Energy balance analysis reveals the phenomenon of inefficiency in pure off-grid systems, namely energy wastage in sunny months but still experiencing a deficit in wet months. Annual state of charge (SoC) heatmap in 3 years is shown in Figure 6.

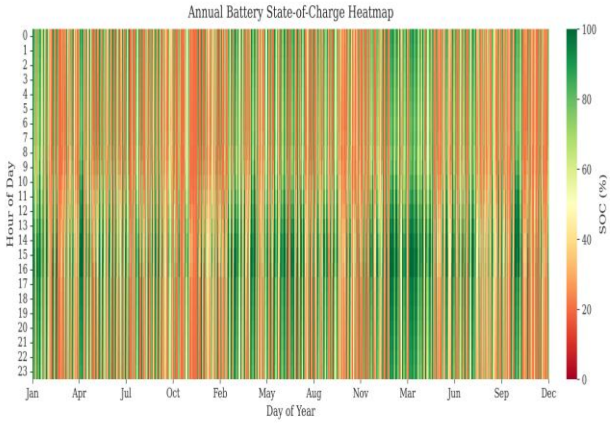

Figure 6. Annual state of charge (SoC) heatmap in 3 years

Based on Figure 6, a heatmap visualization of the annual battery SoC values over three years, the full battery condition (dark green area) predominantly occurs at the beginning of the year. However, critical battery conditions (red area) are widespread in the final quarter, which is generally the rainy season. The average monthly SoC during critical months falls below 50%, reaching 47.25% in February 2022 and even worse, reaching 43.30% in December of the same year. Frequent deep discharge conditions can potentially significantly shorten the battery's cycle life.

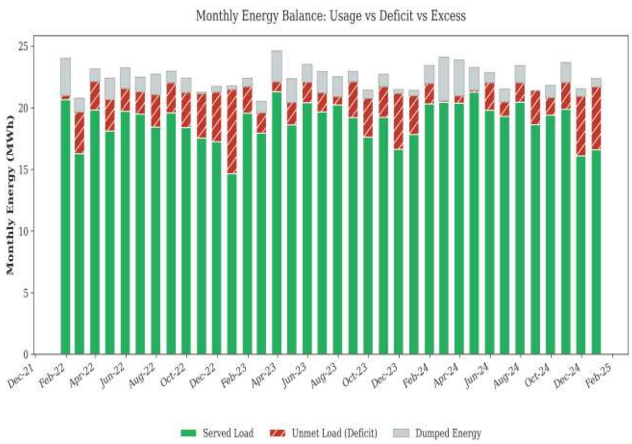

Figure 7. Monthly energy balance in 3 years

The paradox of system performance is clearly visible in Figure 7, where at some times, such as December 2022, the system experienced an energy deficit of 6.56 MWh, but the opposite condition occurred at other times, such as February 2024, where 3.55 MWh was wasted due to an energy surplus.

3.5 Technical Feasibility Discussion

Based on quantitative data from simulation results, the implementation of a pure standalone PV system in the Unimal Renewable Energy Engineering Laboratory Building is considered technically unfeasible for high reliability targets. This is because, although the system is capable of operating independently for 8-9 months a year, the risk of supply failure of 20-30% during the rainy season is intolerable for laboratory facilities that demand a 24-hour energy supply due to the presence of critical load equipment. Efforts to reduce LPSP to less than 1% with a pure off-grid scheme will require an unrealistic increase in system capacity (oversizing), given the limited physical roof area of the building.

As a solution, the authors recommend transitioning to a PV-Hybrid topology. The system requires a backup energy source, such as a backup generator or a limited grid, that only needs to be activated to cover a monthly energy deficit of 4-6 MWh during wet months like November and December, while the solar PV system can serve as an efficient primary support during other months.

4. Conclusion

Based on the results of numerical simulations and performance analysis of the standalone solar power system at the Renewable Energy Engineering Laboratory Building, Universitas Malikussaleh using the Python pvlib library, it is evident that seasonal variability is a dominant factor affecting the stability of the energy supply. The research location exhibits a fluctuating average daily insolation potential, ranging from a low of 3.30 kWh/m²/day during the peak rainy season to 5.80 kWh/m²/day during the dry season. Consequently, the implementation of a purely off-grid system demonstrates significant technical vulnerabilities. Although the system can operate with high reliability during dry months, which achieves a Loss of Power Supply Probability (LPSP) of less than 1%, such as the 0.58% recorded in February 2024, it experiences widespread supply failures at the end of the year. The LPSP value jumped drastically to 31.80% in December 2022 and 23.08% in November 2024, indicating the battery's inability to bridge consecutive no-sun days. Furthermore, an energy balance analysis reveals an operational paradox: in months with high irradiation, energy waste (dumped energy) reaches 3.55 MWh/month due to full battery capacity, whereas wet months suffer an energy deficit (unmet load) of up to 6.56 MWh/month. Overall, targeting 100% year-round power availability for critical laboratory loads using a pure standalone PV system design is considered technically unfeasible, as it would require an unrealistic oversizing of components relative to the available roof area

Acknowledgement

The authors gratefully acknowledge the support from the Department of Mechanical Engineering, Universitas Malikussaleh, the Department of Chemical Engineering, Politeknik Negeri Bandung, and the Department of Engineering Physics and Nuclear Engineering, Universitas Gadjah Mada, for the collaboration to complete this research. Special thanks are also extended to Sandia National Laboratories, PVLIB Python Development Team, and all of PVLIB Python Contributors for openly developing and sharing the powerful tools used in this research.

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