International Journal of Technology and Education Research

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E-ISSN: 2986-0733

Optimizing Solar Energy For Realizing Sustainable Energy Security In Sedalit, North Kalimantan

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Abstract

Energy resilience, defined as the ability of a region to meet its energy needs independently and sustainably, has become a strategic issue, particularly in remote areas that are not yet optimally served by conventional electricity networks. Sedalit Village in North Kalimantan represents one of the regions with significant potential for the development of renewable energy to strengthen local energy independence and resilience. With an estimated 147 buildings and a population of approximately 400 people, the village hosts several essential public facilities, including three schools, two places of worship, three community halls, three government offices, one sports facility, two health posts (posyandu), and several other supporting infrastructures. A 52.8 kWp Solar Power Plant (PLTS) in Sedalit serves as a strategic solution for providing reliable, efficient, and environmentally friendly electricity supply. This study employs a quantitative method with an experimental approach to evaluate the performance of the off-grid solar power system in the area. The results show that the grounding system operates effectively, achieving the lowest resistance values ranging from 0.63 to 0.83 ohms. The inverter output remains stable at 219–220 V with a frequency of 50 Hz. Meanwhile, the DC input voltage varies between 456–502 V with a current of 0.60–0.84 A, indicating a slight decrease in performance across several solar module strings. Overall, the PLTS system in Sedalit demonstrates good operational performance and effectively supports sustainable energy supply.

Keyword: Energy Resilience; Remote Areas; Solar Power Plant (PLTS).

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INTRODUCTION

Energy is a fundamental human need that plays a significant role in supporting social and economic activities, as well as driving development across various sectors (Fandi & Latif, 2024). Energy security, defined as a region's ability to meet its energy demands independently and sustainably, has become a critical issue particularly in remote areas that are not yet fully reached by the conventional power grid (Indriyani, 2022). Sedalit Village in North Kalimantan possesses great potential for renewable energy development to strengthen local energy security (Mochamad, 2020). Home to approximately 400 residents across 147 buildings including schools, houses of worship, government offices, sports facilities, and integrated health posts (posyandu) the high demand for electricity to support community activities and public services in this area remains unfulfilled due to the limitations of the conventional grid. This condition poses a distinct challenge in the effort to achieve energy equity and improve community welfare (Pratama, 2023).

As a solution to these electricity limitations, a solar photovoltaic (PV) system is a precise and sustainable choice (Alim, 2023). A solar PV system with a capacity of 52.8 kWp, utilizing an off-grid scheme or a standalone system without connection to the state electricity company (PLN) grid, can provide a stable and efficient energy supply for all buildings in the Sedalit region. This technology is highly suited for remote areas lacking reliable electricity access and supports the acceleration of the clean energy transition toward achieving national new and renewable energy targets (Sidik, 2023). Through the implementation of this solar PV system, Sedalit Village is expected to strengthen its local energy security, enhance community productivity, drive efficiency in public services across various community facilities, and reduce dependence on fossil energy sources (Salsabila, 2023). This study examines the extent to which the implementation of the solar PV system in Sedalit contributes to energy security and sustainable development in the remote regions of North Kalimantan.

METHOD

This study employs a quantitative method with an experimental approach to evaluate the performance of the off-grid solar photovoltaic (PV) system implemented in Sedalit Village, North Kalimantan. This approach was selected because it can generate objective, measurable, and statistically analyzable data to assess the efficiency and effectiveness of the system in supporting local energy security (Putung, 2021).

The research object encompasses all major components of the solar PV system, including the grounding system, solar PV modules, inverter, energy storage battery, and electrical load

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devices used in public facilities and community buildings in Sedalit (Cahyadi et al., 2020). Testing on the solar panels was conducted to measure power output, solar energy conversion efficiency, and power production stability under various weather conditions in tropical regions. The inverter was tested to assess its DC-to-AC conversion efficiency, output voltage stability, and system frequency in accordance with operational standards (Yuwono et al., 2021). Meanwhile, the battery was evaluated to determine its energy storage capacity, charging and discharging efficiency, and performance degradation based on the number of duty cycles (Kharisma et al., 2024).

Data collection was conducted directly through automated monitoring devices installed on each system component over a specific observation period, spanning 30 consecutive days in March 2025, with a recording interval of every 30 minutes. The collected data included voltage (V), current (A), power (W), and system efficiency. In addition, environmental conditions such as solar radiation intensity, temperature, and humidity were recorded to strengthen the analysis of the relationship between weather conditions and solar PV system performance (Noval et al., 2024). The obtained data were then analyzed using descriptive and inferential statistical methods, alongside a comparative analysis mapping the actual system performance against design specifications and the community's energy demands. The results of this analysis are expected to provide a comprehensive overview of the performance and contribution of the solar PV system to energy security in Sedalit Village, as well as serve as a reference model for community-based renewable energy development in remote regions of North Kalimantan and other similar areas.

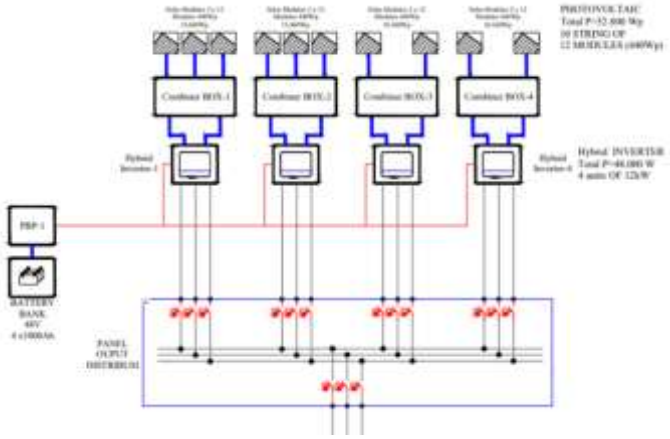


Figure 1. Solar PV System Components

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RESULTS AND DISCUSSION

Earthing Measurement Results

Grounding system measurement determines the soil resistance value within a grounding system to ensure that electrical fault currents dissipate safely into the earth. This measurement is essential to protect both equipment and personnel from potential electric shocks, lightning damage, and other electrical disturbances.

Table 1. Grounding Measurement Results

No	Component/Test	Criterion	Measured Value
1.	Grounding Pit	≤5 ohm	
2.	Inverter 1		2,15
3.	Inverter 2		1,61
4.	Inverter 3		1,22
5.	Inverter 4		0,80
6.	Combiner Panel #1		0,61
7.	Combiner Panel #2		0,65
8.	Combiner Panel #3		0,71
9.	Combiner Panel #4		0,83
10.	Battery Panel		1,04
11.	Battery Bank #1		1,72
12.	Battery Bank #2		1,81
13.	Battery Bank #3		1,85
14.	Battery Bank #4		1,75
15.	Solar Module Mounting #1		0,60
16.	Solar Module Mounting #2		0,60
17.	Solar Module Mounting #3		0,71
18.	Solar Module Mounting #4		0,82
19.	Lightning Rod / Lightning Arrester		1,11

All test points showed resistance values below 5 ohm, confirming the proper functionality of the grounding system. The resistance ranged from a minimum of 0.63–0.83 ohm, at the combiner panels and mountings to a maximum of 2.17 ohm at Inverter 1, all remaining

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within safe limits. Overall, these findings demonstrate that every system component has a reliable grounding path to provide robust fault current protection and ensure installation safety.

Solar Module Testing

PV module testing assesses solar panel performance, including the measurement of maximum generated voltage. This testing primarily aims to verify that the modules operate according to technical specifications and deliver optimal performance under field conditions.

Table 2. Solar Measurement Results

No. STP / No. String	Testing Results
	Vmax (V)
1.	480
1	485
2	485
3	485
4	457
5	461
6	
2.	505
1	505
2	505
3	505
4	506
5	506
6	
3.	490
1	490
2	500
3	486
4	486
5	485
6	
4	502
1	

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	2	502
	3	501
	4	501
	5	502
	6	502

The test results indicate that the maximum voltage values (Vmax) all strings generally function well and remain stable. In STP 1, a relatively large voltage variation was observed, ranging from 458 V to 488 V, with the 5th and 6th strings exhibiting the lowest values. This condition indicates potential disturbances, such as shading, sub-optimal connections, or module degradation. Conversely, STP 2 demonstrated highly stable performance, with all strings ranging between 505 V and 506 V, signifying optimal and uniform system operation. STP 3 showed voltages ranging from 484 V to 500 V, with minor drops in several strings, which remain within acceptable tolerance limits. Meanwhile, STP 4 displayed excellent stability with voltages within the 500–502 V range. Overall, these test results indicate that the solar modules operate under good conditions and are feasible for continuation.

PV Inverter Testing

Photovoltaic (PV) inverter testing is a process to assess the inverter's performance in converting direct current (DC) generated by solar panels into alternating current (AC). This testing encompasses evaluations of power conversion efficiency, output voltage and frequency stability, and the inverter's response to load variations. The primary objective of this testing is to ensure that the inverter operates optimally, efficiently, and safely within the photovoltaic power system.

Table 3. PV Inverter Testing

No. Inverter	**1**	**2**	**3**	**4**
Measurement Time	15.30	15.35	15.37	15.40
Solar Irradiation (Watt/m²)	612	612	612	612
Measured DC Input (V)	S1: 493 S2: 492	S1: 497 S2: 496	S1: 502 S2: 480	S1: 456 S2: 496
Measured DC Input (A)	S1: 0,84 S2: 0,75	S1: 0,72 S2: 0,83	S1: 0,75 S2: 0,78	S1: 0,78 S2: 0,60

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***Measured AC Output* (V)**	R: 220 S: 220 T: 219	R: 220 S: 220 T: 220	R: 220 S: 219 T: 220	R: 220 S: 220 T: 220
Measured AC Output (A)	R: 0,8 S: 0,5 T: 0,5	R: 0,5 S: 0,5 T: 0,6	R: 0,5 S: 0,4 T: 0,4	R: 0,4 S: 0,5 T: 0,5
AC Output Frequency (Hz)	50	50	50	50

CONCLUSION

The utilization of a 52.8 kWp off-grid Solar Power Plant (PLTS) in Sedalit Village, North Kalimantan, has proven effective in strengthening local energy security. This system is capable of providing a reliable and sustainable electricity supply to meet community needs and support the operations of various public facilities. Based on the testing results, all major components including the grounding system, solar panels, inverters, and batteries demonstrated stable performance within safe parameter limits. The grounding resistance values remained below the specified threshold, while the voltage and current of both the panels and inverters were monitored to be consistent, alongside a well-distributed battery voltage. With optimal technical performance, this solar power plant not only expands access to clean energy for rural communities but also has the potential to serve as a model for renewable energy implementation that can be replicated in other regions to support the national energy transition agenda toward net-zero emissions by 2060.

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