International Journal of Education, Information Technology and Others (IJEIT), Agustus 2025, 8(3.B), 329-338
DOI: https://jurnal.peneliti.net/index.php/IJEIT/article/view/12829
p-ISSN: 2654-2528 e-ISSN: 2623-2324
Accredited by Directorate General of Strengthening for Research and Development
Available online at https://jurnal.peneliti.net/index.php/IJEIT

Design and Construction of an Off-Grid Solar Power Plant (PLTS) Prototype as an Electrical Energy Supply for Booster Pumps in Fish Pond Filtration Systems

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		Abstract
Received: Revised: Accepted:	07 July 2025 16 July 2025 23 July 2025	*This study aims to design and construct a prototype of an off-grid Solar Power Plant (PLTS) as an electrical energy source for booster pumps used in fish pond filtration systems. The system is engineered to continuously supply a 12 Watt load for 24 hours. Testing was conducted under two weather conditions: clear and rainy. The results indicate that solar radiation intensity significantly influences the solar panel output. Under clear weather, the output was more optimal compared to rainy conditions. The battery, used for energy storage, was utilized up to approximately 60% of its total capacity. The system has demonstrated its potential as an alternative power supply solution for fish pond filtration systems.*
Keywords:		*Solar Panel, PLTS, Off-Grid, Battery, Booster Pump*
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How to Cite:		Kadhafi, M., & Khaeri, A. (2025). Design and Construction of an Off-Grid Solar Power Plant (PLTS) Prototype as an Electrical Energy Supply for Booster Pumps in Fish Pond Filtration Systems. *International Journal of Education, Information Technology, and Others*, *8*(3.B), 329-338. Retrieved from https://jurnal.peneliti.net/index.php/IJEIT/article/view/12829

INTRODUCTION

Indonesia's economic growth and increasing population have led to a steady rise in electricity demand annually (Mulyani, D., & Hartono, 2018). According to the Ministry of Energy and Mineral Resources (ESDM), national electricity consumption in 2023 reached 1,337 kWh per capita, marking a 14% increase from the previous year's 1,173 kWh per capita.This surge reflects society's heavy reliance on conventional energy sources, raising concerns about the sustainability of the national energy supply (Gunaldi, G, 2025). Moreover, extensive fossil fuel usage exacerbates environmental impacts, such as elevated carbon emissions (Layela, 2023). Addressing this challenge requires targeted policies and appropriate technologies. One increasingly adopted approach is the utilization of renewable energy, derived from natural, replenishable sources. Transitioning towards cleaner energy sources is imperative (Adrian, M. A, 2023).

Renewable energy stands as the primary solution to reduce fossil fuel dependency (Arutyunov, & Lisichkin, 2017). It is not only sustainable but also environmentally friendly and economically viable in the long term (Figge & Hahn, 2012). Solar energy is particularly promising in Indonesia, situated on the equator, ensuring high solar irradiance year-round (Al Hakim, 2020). Solar energy can be harnessed through photovoltaic power generation systems (PLTS), which convert solar radiation into electricity via photovoltaic cells (Prasetyo, Regannanta, et all 2023). This process generates direct current (DC), which can then be converted to alternating current (AC). Practically, PLTS can be implemented in two configurations: grid-connected (on-grid) and stand-alone (off-grid). The off-grid system is ideal for remote locations beyond the reach of the national electrical grid, serving small to medium-scale electricity demands independently (Odetoye, Olulope, et all 2023).

The off-grid PLTS system offers numerous advantages, especially for alternative energy utilization in remote areas. It requires no connection to the national grid, making it suitable for rural and suburban applications (Rahman et al., 2015). This technology also serves as an emergency power solution during outages (Khan et al., 2018). One applicable sector is freshwater aquaculture, which demands stable energy supply for operating critical equipment such as water pumps, aerators, and filtration systems (Sahu et al., 2017). Booster pumps play a crucial role in maintaining water quality. Any power disruption could compromise filtration efficiency and, consequently, fish growth (Azhar et al., 2020). Hence, a reliable and sustainable power generation system is essential. The off-grid PLTS system presents an appropriate solution for this requirement (Nasution et al., 2021).

Nile tilapia farming exemplifies a microenterprise requiring high energy efficiency. The operation involves continuous use of electrical equipment, including booster pumps critical for water circulation and filtration. Optimal pump performance greatly impacts fish productivity and health (Putri & Nugraha, 2022). However, continuous reliance on grid electricity elevates operational costs. Therefore, renewable alternatives such as PLTS offer a strategic, cost-effective, and environmentally sound solution (Yudha et al., 2019). With a properly designed system, the PLTS can autonomously meet booster pump energy needs and be adjusted to match energy demands. Designing an efficient and practical PLTS system is vital to achieve both functionality and economy (Latif et al., 2020).

One challenge in off-grid PLTS development is ensuring sufficient energy supply for a continuous 24-hour load. This necessitates energy storage components such as batteries to store daytime solar energy for nighttime use (Ibrahim et al., 2016). The system requires integrated design of key components: solar panels, solar charge controllers, inverters, and batteries. Each must have appropriate capacity and efficiency relative to the load (Karthick et al., 2020). This study's system is designed to supply a constant 12 Watt load, operating continuously without voltage drops or power interruptions. Detailed calculations and field testing are conducted to confirm system performance. External factors like solar irradiance intensity and weather conditions significantly affect PLTS operation; therefore, testing occurs under two distinct weather scenarios: clear and rainy (Sopian et al., 2018).

Designing an efficient PLTS system requires practical and experimental approaches. Particularly in technical education, students benefit from direct engagement with renewable energy systems. Designing and implementing a small-scale PLTS, as conducted in this study, enables real-time technical parameter measurement and environmental impact observation (Widodo & Harahap, 2021). This hands-on experience enhances understanding beyond theoretical learning and identifies design weaknesses. Consequently, such projects serve educational purposes and contribute to clean energy development in microenterprise sectors (Setiawan et al., 2017). The research findings aim to guide similar projects and promote environmentally friendly technologies in the community (Prasetyo et al., 2022).

The off-grid PLTS design in this study prioritizes energy efficiency and supply continuity. The system must operate during daylight and at night using stored battery energy. Selecting an appropriately sized battery is a key design focus, alongside solar panel efficiency and effective sunlight exposure (Nurhadi et al., 2019). Inverter and solar charge controller specifications are chosen based on load power requirements and system efficiency. All components must synergistically fulfill the system’s primary objective: sustainable power supply for the booster pump. The 12 Watt load serves as the baseline for daily energy needs calculations. The design is tested under different weather conditions to evaluate system responsiveness to environmental variables (Wicaksono et al., 2016). Testing results provide the basis for assessing system performance and efficiency.

This research concentrates on the design and performance testing of an off-grid PLTS supplying power to a fish pond booster pump. The main objective is a standalone electrical system capable of 24-hour operation. The constant load is a 12 Watt pump representing the minimum energy requirement for small-scale aquaculture. The system uses a 100 WP monocrystalline solar panel and a 12V 25Ah battery. Testing occurred at a Nile tilapia farm in Pulogebang, East Jakarta, over two days featuring clear and mixed weather conditions. Measured parameters include voltage, current, power, and solar radiation intensity. Results illustrate system stability and effectiveness in meeting load demands. The study hopes to inform further small-scale PLTS applications in agriculture and aquaculture sectors.

RESEARCH METHOD

Research Variables

Independent Variable: Solar Radiation Intensity (W/m^2)

The independent variable is solar radiation intensity, measured in Watts per square meter (W/m^2). This factor predominantly influences the electrical output of the solar panel. Higher radiation intensity results in greater electrical power generation. Data collection occurred periodically from 09:00 to 16:00. The effect of varying radiation intensity on panel performance was observed under clear and rainy weather conditions.

Dependent Variables: Voltage (V), Current (A), and Power (W)

The dependent variables are the system’s responses to changes in solar radiation intensity. Voltage (Volts), current (Amperes), and power (Watts) were measured to evaluate photovoltaic system efficiency. Measurements were taken hourly to provide real-time performance insights, enabling comparison of energy conversion effectiveness under differing weather.

Control Variables: Location, Panel Type, Panel Angle, Testing Time, Fixed Load

Control variables were maintained constant to isolate the relationship between independent and dependent variables. The test location remained at the Pulogebang fish pond to avoid geographical variation. A monocrystalline solar panel, chosen for its superior efficiency, was used. The panel tilt angle was fixed at 15° without sun-tracking. The pump load was constant at 12 Watts to ensure objective comparisons across time and weather.

Research Procedure

The initial stage involved preparing the PLTS system. Activities included calculating power requirements, designing the off-grid PLTS circuit, and selecting main components such as the solar panel, solar charge controller (SCC), inverter, and battery. After design completion, the system was assembled according to the specified configuration. Measurement tools including multimeters and luxmeters were prepared to record technical parameters such as voltage, current, and solar radiation intensity. The PLTS system was then permanently installed at the Nile tilapia farm in Pulogebang, East Jakarta.

Following installation, the system was tested under two weather conditions across two consecutive days. The first day featured clear weather from 09:00 to 16:00, while the second day began clear but transitioned to rain in the afternoon and evening. The objective was to evaluate the effects of solar radiation fluctuations on panel output and battery performance during low irradiance periods.

Key parameters monitored during testing included solar radiation intensity (W/m^2), voltage (V), current (A), and power (W) generated by the PLTS system. Battery voltage was also tracked to assess its efficacy in storing and supplying reserve energy over 24-hour operation. Data was collected hourly from 09:00 to 16:00 for the solar panel and continuously for 23 hours during battery testing. Recorded data was then analyzed comparatively based on weather conditions, providing a comprehensive view of the off-grid PLTS system's stability and performance in powering the fish pond booster pump.

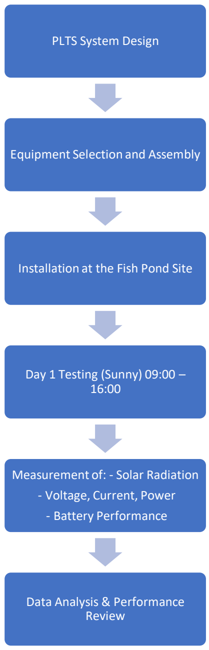

Figure 1. Research Procedure Flowchart

Main Components

Table 1 System Components and Specifications

Component	Specification
Solar Panel	100 WP, Monocrystalline
Inverter	500 Watt
Battery	12V 25 AH
Solar Charge Controller	10.00 AM
Load	Booster pump 12 Watt

The main components of the off-grid PLTS system include a 100 WP monocrystalline solar panel, which serves as the primary energy converter from sunlight to electricity. A 500-watt inverter is used to convert the direct current (DC) from the panel and battery into alternating current (AC) to match the load requirement. The system also uses a 12V 25AH battery to store electrical energy for continuous operation during periods without sunlight. A 10A solar charge controller (SCC) is integrated to regulate the charging process and protect the battery from overcharging or deep discharging. The load in this study is a 12-watt booster pump used for the fish pond filtration system.

Design Calculations

Daily Energy Requirement

The electrical load in this system is a 12-watt booster pump, which is required to operate continuously over a 24-hour period to maintain water circulation and filtration in the fish pond. The total energy demand for one day is determined by multiplying the power of the load by its operational duration:

Energy Demand = 12 W × 24 h = 288 Wh/day.

However, in practical off-grid photovoltaic (PV) systems, energy losses due to inefficiencies in energy conversion, storage, and transmission must be considered. These losses typically occur within the solar panel, charge controller, battery, and inverter, and are estimated at approximately 40%, resulting in an overall system efficiency of around 60%. Therefore, to reliably supply the required 288 Wh to the load, the photovoltaic system must generate a total of:

Required Solar Energy Input = 288 Wh / 0.60 = 480 Wh/day.

This adjusted energy target ensures that the system can compensate for operational losses and maintain consistent performance, especially under varying solar irradiance conditions.

Solar Panel Power Requirement

To meet the adjusted daily energy demand of 480 Wh, the required power capacity of the solar panel must be calculated based on the average effective sun hours per day. In Indonesia, particularly in urban areas such as Jakarta, the optimal solar irradiation period is approximately 5 peak sun hours per day. Therefore, the required panel output is computed as follows:

Panel Power = 480 Wh / 5 h = 96 Watts

Given this calculation, a solar panel rated at 100 WP (Watt-peak) is selected to ensure adequate energy generation. The additional margin above the minimum 96 W accounts for potential losses due to environmental factors such as dust accumulation, panel aging, and suboptimal orientation. This selection ensures the system's reliability and energy sufficiency under typical operating conditions.

Battery Capacity

To ensure the booster pump can operate continuously for 24 hours, a battery must be sized to store the total required daily energy. The nominal system voltage is 12V, and the total energy demand is 480 Wh. Therefore, the theoretical battery capacity is calculated as:

Battery Capacity = 480 Wh / 12 V = 40 Ah.

However, considering practical usage and the need to avoid deep discharge, only 60% of the battery's capacity is typically usable in off-grid systems. Based on this, a 12V 25Ah battery is selected, as it allows up to 60% of its capacity to be utilized, effectively delivering 300 Wh, which is sufficient when supported by daytime solar generation. This approach balances cost, weight, and system reliability.

Inverter and Solar Charge Controller (SCC)

The inverter is responsible for converting DC power from the battery or solar panel into AC power to run the pump. Since the load requires only 12 Watts, the inverter must be sized higher to accommodate startup surges and system efficiency. Thus, a 500 Watt inverter is selected to ensure stable operation and future scalability.

For the solar charge controller (SCC), the sizing is based on the short circuit current (ISC) of the solar panel. A safety margin of 25% is added to account for peak solar conditions and system protection. Assuming the ISC of the 100 WP panel is within standard range (around 8 A), the final requirement becomes:

$$\text{SCC Rating} = \text{ISC} + 25\% \approx 8\text{ A} + 2\text{ A} = 10\text{ A}$$

Hence, a 10 A SCC is used to regulate charging and protect the battery from overcharging or deep discharging.

RESEARCH RESULTS AND DISCUSSION

Solar Radiation Intensity (Daily Average)

Table 2: Average Solar Radiation Intensity by Weather Condition

weather conditions	average intensity (W/m²)
sunny	855
sunny and rainy	531

The average solar radiation intensity was measured under two weather conditions to assess its impact on photovoltaic performance. Under clear weather, the average intensity was recorded at 855 W/m², while in mixed weather conditions (sunny and rainy), it dropped significantly to 531 W/m². This reduction illustrates the substantial influence of cloud cover and rainfall on the system's solar energy input. Lower solar irradiance directly affects the efficiency and energy output of the solar panels. These findings are essential in evaluating system reliability under varying environmental conditions.

Daily Output of the PLTS (Clear Weather)

Table 3: Daily Power Output of the Photovoltaic System

Time	voltage (V)	current (A)	Power output (W)
12.00	13,71	3,71	50,86

At peak solar conditions (12:00 PM), the photovoltaic system produced a voltage of 13.71 V, current of 3.71 A, and power output of 50.86 W. These values demonstrate the system's capability to exceed the load requirement of 12 W during optimal sunlight exposure. The excess energy during this period contributes to charging the battery, ensuring energy availability for night-time operation. The result confirms that the system performs efficiently under high solar irradiance. It also validates the selection of the 100 WP panel for reliable daytime operation.

Daily Output of the PLTS (Clear and Rainy Weather)

Table 4: Daily Power Output of the Photovoltaic System

Time	Voltage (V)	Current (A)	Power (W)
12.00	0,59097222	0,17430556	50.86

During the same peak period on a day with mixed weather, the system output at 12:00 PM was slightly lower with 12.87 V, 3.6 A, and 46.33 W of power. However, at 14:00 when heavy rain occurred, the output dropped significantly to 11.66 V, 1.28 A, and 14.92 W. This data clearly shows the decline in photovoltaic performance due to reduced solar irradiance during rain. Although the output still managed to support the load, the surplus energy for charging the battery was substantially reduced. Such variability emphasizes the importance of adequate energy storage to ensure system continuity.

Actual Power Consumption of the Pump

Table 5: Actual Power Consumption of the Booster Pump

Time	Current (A)	Power (W)
09.00	01.01	13.01
10:00–16:00	01.00	12

Measurements of the booster pump's actual energy consumption showed that at 09:00 AM, the pump consumed 1.1 Aand 13.1 W of power. From 10:00 AM to 16:00 PM, it operated steadily at 1.0 A and 12 W. The slight surge in current during startup is attributed to the inrush current phenomenon common in electric motors. After initial startup, the system stabilizes at its nominal operating level. This data confirms the pump's average demand aligns with the system's design target of 12 W.

Battery Performance

The minimum operational voltage of the battery was recorded at 9.7 V, below which the system automatically shuts down to prevent damage. The battery becomes active again once the voltage returns to 9.94 V. This hysteresis behavior ensures protective cycling and prolongs battery lifespan. The battery was found to utilize approximately 60% of its rated capacity, confirming prior estimations made during system design. This validates that the selected 25Ah battery is appropriate for daily load requirements when paired with adequate solar input.

CONCLUSION

The prototype of the off-grid solar power system successfully supplied continuous energy to a 12 Watt booster pump for fish pond filtration. The system's performance was highly influenced by solar radiation intensity, showing better output during clear weather compared to rainy conditions. The battery storage was effective but could only utilize up to 60% of its total capacity, indicating room for improvement in energy storage efficiency. The off-grid solar system proved to be a reliable alternative energy source, especially in remote or off-grid locations. This solution supports sustainable and eco-friendly aquaculture practices by reducing dependence on conventional electricity. The use of monocrystalline solar panels contributed to higher efficiency in energy conversion. Integrating solar charge controllers and inverters ensured stable and continuous power supply throughout the testing period. The design can be scaled or modified to suit different power requirements in similar applications. Weather variability remains a key challenge in maintaining consistent energy output. Overall, the study demonstrates the feasibility and benefits of using off-grid solar power for small-scale aquaculture systems.

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