Utilization of Solar Power Plants (PLTS) as an Environmentally Friendly Energy Source in the Makhtab Park Area of Panca Budi Campus

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ABSTRACT
The utilization of Solar Power Plants (PLTS) is one of the environmentally friendly and sustainable renewable energy solutions. This study aims to evaluate the effectiveness of using PLTS as an alternative energy source in the Makhtab Building Park area of Panca Budi Campus. The PLTS system used consists of solar panels, a solar tracking system, and a battery charging system equipped with overcharge protection. Testing was conducted under two conditions: with the solar panel in motion and stationary as well as during the battery charging process. The test results show that solar panels with a tracking system can generate higher voltage and current compared to static panels, particularly during productive hours between 08:00–13:00. Additionally, the battery charging system functions optimally, with stable voltage increases and automatic cut-off by the relay when the maximum voltage is reached. Therefore, the implementation of PLTS on campus not only supports energy efficiency but also serves as a tangible step in supporting green campus initiatives and reducing carbon emissions.

Keywords: PLTS, Renewable Energy, Solar Tracker, Green Campus, Battery Charging.

Introduction

The utilization of renewable energy has become a primary focus in efforts to reduce dependence on fossil fuels and their negative environmental impacts. One rapidly growing form of renewable energy is solar energy, which can be harnessed through Solar Power Plant (PLTS) technology. This technology is considered environmentally friendly, sustainable, and holds significant potential for application across various sectors, including educational institutions (International Energy Agency, 2022). In the context of the Makhtab Building Park at Panca Budi Campus, the increasing demand for electricity—driven by the expansion of activities and facilities such as lecture halls, laboratories, and public spaces—necessitates innovation in providing efficient and eco-friendly energy sources.

The limitations of conventional energy supply and the high operational costs pose significant challenges for the campus (Ministry of Energy and Mineral Resources of the Republic of Indonesia, 2023). Therefore, installing a PLTS system as an alternative energy source in the Makhtab Building Park is a strategic choice. It not only reduces dependence on the main power grid but also supports a sustainable green campus program (Widodo & Sari, 2021). To ensure successful PLTS implementation, in-depth planning and analysis are required, covering various aspects such as energy needs, solar irradiance potential, system efficiency, and integration with existing electrical infrastructure (Mulyadi et al., 2020).

This study aims to design and analyze the installation of a PLTS system at the Makhtab Building Park of Panca Budi Campus. The main focus includes installation planning based on energy requirements, optimizing solar energy usage by considering weather variations and fluctuations in electricity demand, integrating the PLTS system with the existing electrical infrastructure, and measuring performance and its impact on energy efficiency and the environment. With this approach, the study is expected to make a meaningful contribution to the development of renewable energy systems on campus and serve as a model for the application of solar energy in other educational settings.

LITERATURE REVIEW

A. The Advantages of Solar Power Plants (PLTS) as an Environmentally Friendly Energy Source

Solar Power Plants (PLTS) are one of the most environmentally friendly sources of renewable energy, producing significantly lower carbon emissions compared to fossil fuel-based power plants. The use of PLTS can reduce CO_2 emissions by up to 79.69%, making a substantial contribution to a cleaner and healthier environment (Edwinanto et al., 2023; Rahman et al., 2022). In addition, PLTS does not produce air, water, or noise pollution, making it highly suitable for public areas such as campus parks (Rahman et al., 2022; Aloui & Geo, 2020).

B. Efficiency and Implementation of PLTS in Urban and Campus Areas

PLTS has proven capable of generating stable and reliable electricity for daily needs in residential, office, and public facility environments, including campus parks. Studies on rooftop PLTS systems show stable and efficient monthly energy production, with the potential for significant electricity cost savings (Edwinanto et al., 2023; Pawenary & Pradana, 2023). The implementation of PLTS can also be integrated with Internet of Things (IoT)-based systems to support vertical garden operations, improve water use efficiency, and automatically and sustainably maintain the garden ecosystem (Falah et al., 2024).

C. Challenges and Solutions in PLTS Management

Several challenges in implementing PLTS include the need for substantial initial investment, limited technical human resources, and external factors such as weather and ambient temperature that affect solar panel performance (Jamil et al., 2024; Pawenary & Pradana, 2023; Taryana et al., 2024). Solutions that can be applied include the development of technologies such as DC converters to extend solar energy utilization time, as well as routine solar panel maintenance to maintain optimal performance (Taryana et al., 2024; Pawenary & Pradana, 2023). Moreover, collaboration between the government, community, and private sector is crucial to support the sustainable operation of PLTS (Jamil et al., 2024).

D. Environmental Impact and Sustainability

PLTS has a positive impact on the environment by reducing dependence on fossil fuels, lowering greenhouse gas emissions, and supporting climate change mitigation efforts (Rahman et al., 2022; Jurnal, 2018). The use of PLTS in campus park areas can also serve as a tangible example of green energy application that is educational and inspiring for the academic community and surrounding society. PLTS is a highly relevant green energy solution to be implemented in campus park areas. With its advantages in efficiency, minimal pollution, and potential for technological integration, PLTS supports the creation of a green, healthy, and sustainable campus environment. Implementation challenges can be overcome through technological innovation and cross-sector collaboration.

E. Solar Cell

Solar cells are one of the most environmentally friendly renewable energy sources and hold great promise for the future. This technology does not produce pollution during the energy conversion process, as it does not involve burning fossil fuels. Furthermore, the primary energy source for solar cells—sunlight—is abundantly available in nature and free of cost. Indonesia's geographical position as a tropical country receiving sunlight year-round makes this technology highly promising for widespread development. The process of converting light energy into electrical energy in solar cells is enabled by the semiconductor materials that make them up. Solar cells typically consist of two layers of semiconductors—an N-type and a P-type. The N-type semiconductor is a material with excess electrons (negative charge), while the P-type has an excess of holes or electron vacancies (positive charge).

These two types of semiconductors are created through a process called doping, which involves adding certain elements to the base semiconductor material (such as silicon) to control its electrical characteristics. When sunlight hits the surface of a solar cell, the photon energy from the light release electrons from atomic bonds in the semiconductor material, creating electron-hole pairs. The charge difference between the N-type and P-type layers generates an internal electric field that drives electrons through an external circuit, producing direct current (DC) electricity. This process is the fundamental working principle of a solar cell, which, when combined in large numbers, form solar modules and then solar panels to generate electricity on a larger scale. With technological advancements, the energy conversion efficiency and the production cost of solar panels continue to improve and decrease, making this technology increasingly viable both economically and environmentally.

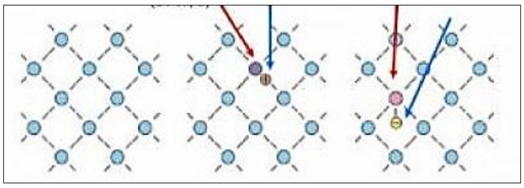

Figure 1. Photon Sun Energy.

1. Solar Panel
   A solar panel is a power-generating device capable of converting sunlight into direct current (DC) electricity. The electricity produced is used to supply power to automation systems, including charging batteries and serving as a power source for electronic components. In the design process of this final project, the solar panel is used as the primary source of electrical energy for the Arduino-based automated garden lighting system.

Figure 2. Solar Panel

2. Arduino Uno
   Arduino Uno is a microcontroller based on the ATmega328P, functioning as the brain of the automatic control system. In this final project, the Arduino Uno acts as the control center that processes data from sensors and automatically turns the garden lights ON/OFF based on environmental conditions. Arduino Uno is advantageous due to its ease of programming and flexibility in integrating with various sensors and actuators.

Figure 3. Arduino Uno

3. Arduino IDE
   The Arduino Integrated Development Environment (IDE) is a software tool used to write, compile, and upload programs to Arduino microcontroller boards. In this final project, the Arduino IDE is used to create the control system program, including solar panel movement control (if a light-tracking system is used), motion detection via sensors, and light intensity control of the garden lamps. Programs are written in the C/C++ programming language and uploaded to the microcontroller via a USB connection.

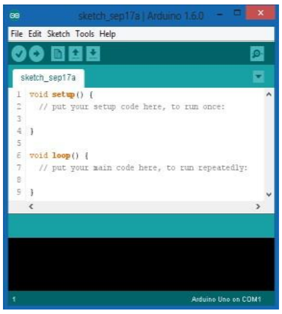

Figure 4. Interface Arduino IDE

Research Method

This research uses a quantitative descriptive approach with the stages of design, implementation, and evaluation of a Solar Power Plant (PLTS) system designed to meet the electricity needs in the Garden Area of the Makhtab Building at Panca Budi Campus. The research methodology steps are as follows:

a) Problem Identification

The initial stage involves identifying the electricity needs in the Makhtab Building garden area and the issues faced with conventional energy supply. Needs analysis is carried out by measuring the daily electrical load and observing the potential site for solar panel installation.

b) Literature Review

A literature review is conducted to understand the fundamental and technical concepts of Solar Power Plants, PLTS system configurations (on-grid and off-grid), power conversion using DC-DC converters, system control using microcontrollers (such as STM32), and energy efficiency and environmental aspects of solar energy utilization.

c) PLTS System Design

System design includes determining the solar panel capacity, calculating battery requirements (if used), selecting an inverter and power controller, and designing the control system using the STM32F103 microcontroller. Voltage regulation is managed using a Proportional-Integral (PI) control method to ensure stable power output according to demand.

d) Microcontroller Programming

The STM32F103 microcontroller is programmed to manage power conversion using PWM (Pulse Width Modulation) signals. The PI control algorithm is applied to maintain output voltage stability from a voltage doubler-type DC-DC Boost Converter, ensuring system responsiveness to load and light intensity variations.

e) Circuit Implementation and Solar Panel Installation

The PLTS system is assembled by integrating solar panels, power controllers, voltage converters, microcontrollers, and energy storage systems. Components are connected and tested to ensure the system integration functions as designed.

f) Testing and Measurement

The system is tested to measure output voltage, power efficiency, and output stability under various weather conditions. Measurements are taken by comparing the reference voltage to actual field results.

g) Data Analysis

Test results are quantitatively analyzed to evaluate the PLTS system performance in terms of energy efficiency, control response, voltage stability, and its contribution to reducing conventional energy consumption and environmental impact.

Results Discussion

1. Hardware Schematic Circuit
   The electronic design functions as the main control system for the automatic control of the solar panel and garden lighting.

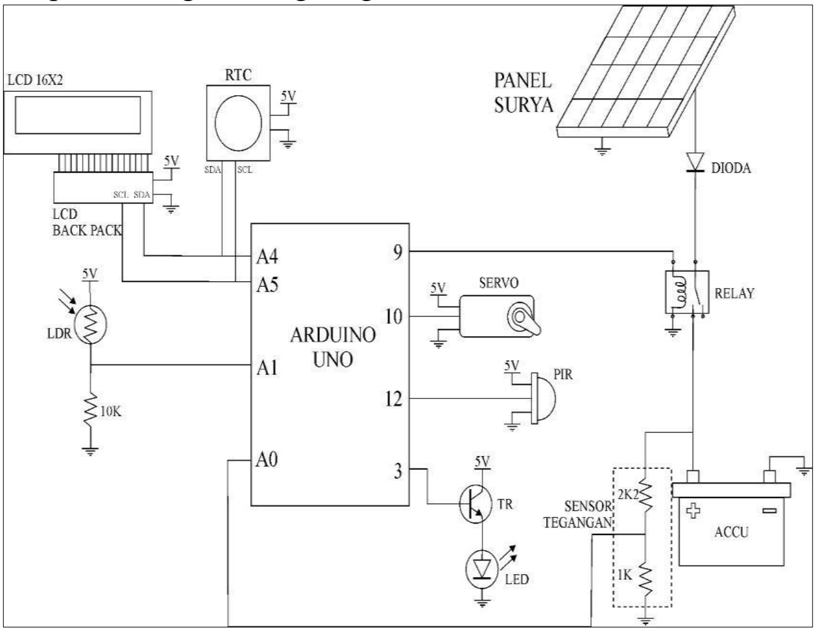

Figure 5. Hardware Schematic Circuit

Explanation of the PLTS Block Diagram Functions:

Based on the diagram above, each component in the Solar Power Plant (PLTS) system has the following functions:

Solar Panel: The main component that functions to convert sunlight energy into direct current (DC) electricity through the photovoltaic effect. Solar Charge Controller: Regulates the charging process to the battery to ensure stability and safety. It also controls the current flow from the battery to the load, preventing overcharging or overdischarging. Battery: Serves as the storage medium for the electrical energy generated by the solar panel. The stored energy is in the form of DC electricity and is used to supply power to the load when sunlight is unavailable, such as at night or during cloudy weather.

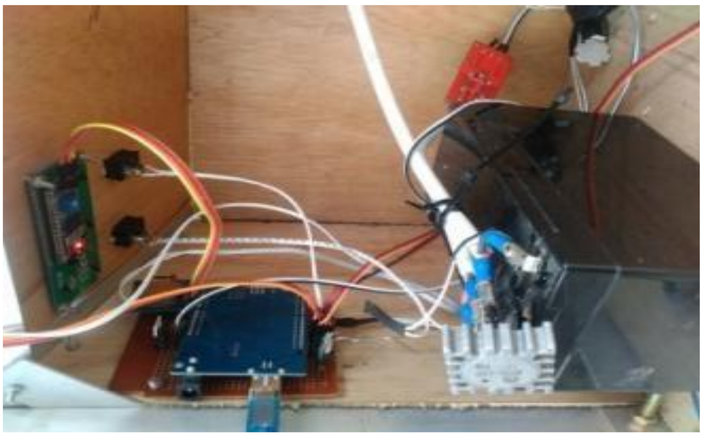

Figure 6. Electronic Components.

Testing

Once all parts (hardware and software) of the system have been fully developed, the next step is system testing to verify whether it aligns with the established design. Testing begins with the movement of the solar panel, followed by the PIR sensor test, and finally the charging test on the battery using both an adapter and electricity from the utility grid (PLN).

1. Solar Panel Testing
   a. Testing of Solar Panel in Moving Position

Table 1. Solar Panel Testing in Moving Position – May 1, 2025

No	Time	V PV (Volt)	V Battery	I PV	Weather Condition
1	06:00	18.07	5.02	11.7 mA	Cloudy
2	07:00	20.40	5.60	0.11 A	Sunny
3	08:00	21.00	6.80	0.17 A	Sunny
4	09:00	21.00	8.30	0.34 A	Sunny
5	10:00	19.70	9.30	0.32 A	Sunny
6	11:00	19.40	9.50	0.32 A	Sunny
7	12:00	20.10	10.50	0.34 A	Sunny
8	13:00	19.60	11.30	0.45 A	Sunny
9	14:00	18.55	10.80	0.37 A	Cloudy
10	15:00	17.70	10.87	0.37 A	Cloudy
11	16:00	10.00	9.39	41 mA	Rainy
12	17:00	9.98	9.30	70 mA	Rainy
13	18:00	7.82	7.30	68 mA	Rainy

Table 2. Solar Panel Testing in Moving Position – May 2, 2025

No	Time	V PV (Volt)	V Battery	I PV	Weather Condition
1	06:00	15.80	6.54	16 mA	Cloudy
2	07:00	17.20	6.25	48 mA	Cloudy
3	08:00	19.87	7.00	0.35 A	Sunny
4	09:00	20.00	7.70	0.60 A	Sunny
5	10:00	19.64	9.85	0.29 A	Sunny
6	11:00	20.06	9.86	0.63 A	Sunny
7	12:00	14.31	8.00	36 mA	Rainy
8	13:00	13.55	7.82	36 mA	Rainy
9	14:00	13.31	7.52	46 mA	Cloudy
10	15:00	12.25	7.46	40 mA	Cloudy
11	16:00	10.92	7.22	42 mA	Cloudy
12	17:00	7.76	7.00	40 mA	Cloudy
13	18:00	7.62	6.96	34 mA	Cloudy

b. Solar Panel Testing in a Fixed (Non-Moving) Position

Table 3. Solar Panel Testing in a Fixed Position – May 3, 2025

No	Time	V PV (Volt)	V Battery	I PV	Weather Condition
1	06:00	15.70	5.02	17 mA	Cloudy
2	07:00	17.40	5.10	34 mA	Cloudy
3	08:00	18.03	6.32	0.17 A	Sunny
4	09:00	18.23	7.81	0.21 A	Sunny
5	10:00	19.55	8.86	0.19 A	Sunny
6	11:00	20.40	9.56	0.20 A	Sunny
7	12:00	18.18	10.20	0.26 A	Sunny
8	13:00	19.34	11.00	0.29 A	Sunny
9	14:00	18.76	10.80	68 mA	Cloudy
10	15:00	17.70	10.87	63 mA	Cloudy
11	16:00	10.34	9.59	51 mA	Cloudy
12	17:00	8.78	9.40	47 mA	Cloudy
13	18:00	7.22	8.30	35 mA	Rainy

Table 4. Solar Panel Testing in a Fixed Position – May 4, 2025

No	**Time**	**V PV (Volt)**	**V Battery (Volt)**	**I PV**	**Weather Condition**
1	06:00	15.80	6.50	16 mA	Cloudy
2	07:00	17.00	6.10	40 mA	Cloudy
3	08:00	19.02	6.26	0.30 A	Cloudy
4	09:00	18.53	7.12	0.31 A	Sunny
5	10:00	19.67	8.55	0.35 A	Sunny
6	11:00	20.00	9.36	0.38 A	Sunny
7	12:00	18.30	9.87	0.36 A	Sunny
8	13:00	18.15	9.30	0.40 A	Sunny
9	14:00	10.40	8.52	43 mA	Cloudy
10	15:00	10.25	7.16	38 mA	Cloudy
11	16:00	9.92	6.32	35 mA	Cloudy
12	17:00	8.51	6.23	34 mA	Rainy
13	18:00	7.62	6.16	22 mA	Rainy

Solar panel testing was conducted to evaluate system performance under two conditions: with a movable panel (equipped with a sun-tracking system) and with a fixed (static) panel. The test results show that solar panels equipped with a tracking system are capable of generating higher and more stable voltage (V PV) and current (I PV) compared to static panels, especially during peak productive hours between 09:00 and 13:00. The maximum voltage for the tracking panel ranged between 19–21 V, with peak current reaching up to 0.6 A, while the static panel was only able to produce a maximum current of approximately 0.38 A during the same period. Furthermore, under cloudy or rainy weather conditions, the tracking panel still demonstrated better performance despite a decrease in current, maintaining a range between 16–70 mA, compared to the static panel which dropped to a range of 22–68 mA. From these results, it can be concluded that the sun-tracking system significantly improves solar energy absorption efficiency and accelerates the battery charging process, especially when sunlight intensity is at optimal levels.

Battery Charging Test

Table 5. Battery Charging Test

No	Time	Battery Voltage (V)	Relay
1	06:00	9.63	On
2	06:30	10.26	On
3	07:00	10.83	On
4	07:30	11.02	On
5	08:00	11.28	On
6	08:30	11.69	On
7	09:00	12.02	Off

The battery charging system test was conducted to evaluate the effectiveness and safety of the charging process performed by the solar panel. Based on the data in Table 5, the battery voltage shows a consistent increase, starting from 9.63 V at 06:00 and reaching 12.02 V by 09:00. The stable voltage rise—averaging around 0.5–0.6 V every 30 minutes—indicates that the power supplied by the solar panel is sufficiently optimal to support the charging process.

When the battery voltage reaches the threshold of 12 V, the system's relay automatically disconnects the charging current (relay OFF) as a form of protection against potential overcharging. This demonstrates that the charging system is equipped with an effective safety mechanism to prevent battery damage due to overcharging. With this automatic relay system in place, battery lifespan can be better preserved, and the risks of damage caused by overheating or excessive electrical pressure can be minimized. Overall, this test confirms that the charging system is well-designed and capable of operating efficiently and safely.

Implications

The solar-powered automatic garden light system was designed using solar panels, a microcontroller, relays, a battery, and LED lights. This system operates automatically based on the light intensity detected by the solar cell. During the day, when sunlight is sufficient, the solar cell generates a voltage that triggers the system to turn the light OFF. Conversely, at night when the light fades, the system automatically turns the light ON through microcontroller and relay control. Tests show that the 12V 7.2 Ah battery can supply energy for approximately ±20 hours, while the lamp only operates for around 3 hours per night, making the battery capacity more than adequate. During the day, the solar cell also efficiently recharges the battery, with a full charge time of about 13 hours under optimal sunlight. This system has proven to be efficient, environmentally friendly, and suitable for implementation in tropical regions such as Indonesia.

Conclusion

This study demonstrates that the Voltage Doubler-type DC-DC boost converter circuit functions as expected, both in computational simulations and hardware implementation. The system is capable of producing an accurate output voltage that is twice the input voltage, with stable performance even under input voltage variation and load changes. The PI (Proportional-Integral) control applied in the system has proven effective in correcting the difference between the actual voltage and the reference voltage, allowing the output voltage to follow the reference voltage waveform accurately.

Testing under varying loads and input voltages shows that this circuit can maintain a stable output voltage in accordance with the targeted value. The system also responds quickly to load changes or input voltage fluctuations. The successful performance is highly influenced by the appropriate selection of components such as inductors, capacitors, and resistors, as well as good implementation practices in the hardware setup.

The Voltage Doubler-type DC-DC boost converter circuit is reliable for applications that require stable and accurate output voltage, even under diverse operating conditions. The success of this study provides a significant contribution to the development of efficient power conversion systems that can be adapted for various applications requiring stable voltage boosting.

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