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IoT-Based 100 WP Solar Power Plant for Ultraviolet Lighting in Dragon Fruit Cultivation: Design and Performance Comparison of Tracking and Non-Tracking Systems

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ABSTRACT: The use of solar energy for agricultural applications can reduce dependence on conventional electricity while enabling operation in locations where grid access is limited. This study aimed to design and evaluate a 100 Wp photovoltaic system integrated with an Internet of Things (IoT) monitoring and control system for lighting in a dragon fruit plantation. The system employed a 100 Wp monocrystalline solar panel, a solar charge controller, a battery storage unit, an inverter, an ESP32 microcontroller, voltage and current sensing, and Telegram as the remote monitoring interface. Electrical parameters were observed hourly from 09:00 to 17:00 WIB under two panel configurations: solar tracking and fixed non-tracking. Panel voltage, panel current, battery voltage, and calculated panel power were analyzed. For the tracking configuration, the average panel voltage and current were 19.64 V and 4.12 A, respectively, corresponding to an average calculated power of 81.47 W. The maximum calculated power was 100.94 W at 12:00. Under the non-tracking configuration, the average voltage and current were 18.69 V and 3.61 A, with an average calculated power of 68.08 W and a maximum of 91.65 W at 12:00. Thus, the tracking configuration produced approximately 19.7% higher average calculated panel power than the non-tracking configuration. The ESP32–Telegram system successfully transmitted operating information in real time when a stable Internet connection was available. The results demonstrate that combining solar tracking with IoT monitoring can improve the observed electrical performance and facilitate remote management of a small off-grid photovoltaic lighting system.

KEYWORDS: dragon fruit plantation, internet of Things, solar photovoltaic, ESP32, Telegram, solar tracking.

INTRODUCTION

Renewable-energy technologies are increasingly important as electricity demand grows and dependence on fossil fuels remains a concern. Photovoltaic solar power plants (PLTS) convert solar radiation into electrical energy and are suitable for decentralized applications. The final report supporting this study identifies solar power as a practical alternative for agricultural lighting, particularly where conventional grid electricity is limited. The report also notes the use of PLTS for additional night lighting in dragon fruit cultivation and the potential of Internet of Things (IoT) technology to support remote monitoring [1,2].

In an IoT-enabled photovoltaic system, operating information can be collected by sensors, processed by a microcontroller, and transmitted through the Internet to a remote user interface. This approach allows voltage, current, battery condition, and load status to be observed without requiring the operator to remain at the installation site. Previous work cited in the report describes IoT-based photovoltaic monitoring and battery monitoring as useful approaches for improving accessibility of system information [3,4].

Solar tracking is another approach used in photovoltaic applications to maintain a more favorable orientation of the panel relative to incoming sunlight. The final report specifically compares tracking and fixed non-tracking configurations to determine which arrangement provides more optimal electrical output. Based on this objective, the present study focuses on three aspects: development of a 100 Wp PLTS integrated with ESP32-based IoT monitoring, evaluation of real-time remote monitoring through Telegram, and comparison of the electrical output of tracking and non-tracking panel configurations.

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MATERIALS AND METHODS

The study was conducted as a design-and-build experimental study based on the final report. The installation was evaluated in the Padang Bulan area of Medan. The system was designed as a small off-grid photovoltaic supply for plantation lighting, with the ESP32 serving as the central monitoring and control unit. The principal system components reported in the study were a 100 Wp monocrystalline solar panel, solar charge controller, battery storage, 1000 W inverter, lighting load, ESP32 microcontroller, INA219 current/voltage/power sensing, a voltage-divider circuit for battery-voltage monitoring, and Telegram as the remote interface.

The system operating sequence consisted of photovoltaic energy generation, charge regulation and storage, data acquisition and processing, DC-to-AC conversion for the lighting load, and remote user monitoring. The solar panel supplied DC power to the charge controller and battery. The ESP32 acquired electrical measurements, processed the sensor readings, and transmitted the information through a Wi-Fi connection to Telegram. The report states that Telegram could also be used to issue simple remote commands, including switching the lighting load on or off.

Two experimental configurations were evaluated: (1) solar tracking, in which the panel orientation was adjusted to follow the apparent movement of the sun, and (2) non-tracking, in which the panel remained at a fixed position. Measurements were collected at hourly intervals from 09:00 to 17:00 WIB. The recorded variables were panel voltage, panel current, battery voltage, and system operating status. The data were tabulated and compared between the two configurations.

Panel output power was calculated from the measured voltage and current using $P = VI$, where P is electrical power in watts, V is panel voltage in volts, and I is panel current in amperes. Average voltage and current were calculated from the nine hourly observations for each configuration. The comparison focused on the average electrical output and the maximum observed output during the measurement period. The report also evaluated whether the monitoring data could be delivered to Telegram in real time when the Internet connection was stable.

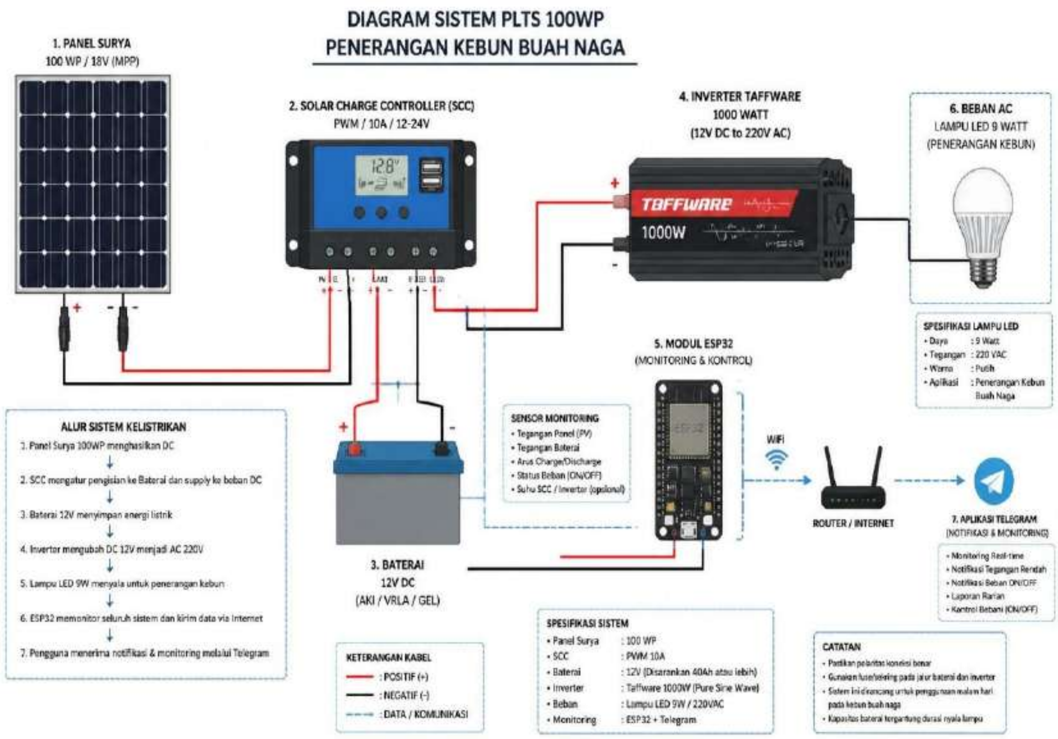

Figure 1. Wiring diagram of the 100 Wp PLTS and IoT monitoring system.

RESULTS

The developed system integrated the photovoltaic source, energy storage, inverter, sensors, ESP32 controller, and Telegram monitoring interface. During testing, the system was able to provide electrical parameter information remotely through Telegram

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when the ESP32 was connected to a stable Wi-Fi/Internet connection. The measured parameters changed with the solar resource and time of day, increasing toward midday and decreasing in the afternoon.

Table I. Electrical measurements for the solar-tracking configuration.

Time	Panel V (V)	Battery V (V)	Panel I (A)	P = VI (W)
09:00	18.7	12.48	3.85	72.00
10:00	19.5	12.65	4.32	84.24
11:00	20.1	12.90	4.70	94.47
12:00	20.6	13.18	4.90	100.94
13:00	20.5	13.42	4.82	98.81
14:00	20.2	13.58	4.48	90.50
15:00	19.8	13.60	4.12	81.58
16:00	19.1	13.55	3.42	65.32
17:00	18.3	13.46	2.48	45.38
Average	19.64	13.20	4.12	81.47

Table I shows that the tracking configuration reached its highest measured panel voltage of 20.6 V and current of 4.90 A at 12:00, giving a calculated instantaneous power of 100.94 W. The average panel voltage was 19.64 V and the average current was 4.12 A. Battery voltage increased from 12.48 V at 09:00 to 13.60 V at 15:00 before decreasing slightly toward the end of the test period.

Table II. Electrical measurements for the non-tracking configuration.

Time	Panel V (V)	Battery V (V)	Panel I (A)	P = VI (W)
09:00	18.3	12.40	3.10	56.73
10:00	18.8	12.55	3.90	73.32
11:00	19.2	12.72	4.40	84.48
12:00	19.5	12.89	4.70	91.65
13:00	19.3	13.05	4.50	86.85
14:00	19.0	13.18	4.10	77.90
15:00	18.6	13.30	3.50	65.10
16:00	18.1	13.42	2.70	48.87
17:00	17.4	13.45	1.60	27.84
Average	18.69	13.00	3.61	68.08

For the non-tracking configuration, the maximum measured panel voltage and current were 19.5 V and 4.70 A at 12:00, corresponding to 91.65 W calculated power. The average panel voltage and current were 18.69 V and 3.61 A, respectively. Battery voltage increased from 12.40 V at 09:00 to 13.45 V at 17:00. Compared with the tracking case, the fixed panel produced lower current and calculated power during most of the observation period.

Table III. Summary comparison of measured and calculated photovoltaic performance.

Configuration	Avg. V (V)	Avg. I (A)	Avg. P (W)	Max. P (W)
Solar tracking	19.64	4.12	81.47	100.94
Non-tracking	18.69	3.61	68.08	91.65
Tracking advantage	5.1%	14.1%	19.7%	10.1%

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The interpretation of the present results is supported by previous literature on photovoltaic monitoring, IoT-enabled energy systems, and solar tracking. Standardized PV monitoring practices emphasize consistent measurement, data acquisition, quality checking, and performance metrics [8]. Reviews of tracking technologies report that maintaining a more favorable module orientation can increase energy yield relative to fixed systems, although the benefit depends on location, weather, tracking strategy, and system complexity [9–14]. Recent work also demonstrates the feasibility of combining photovoltaic systems with IoT-based monitoring and remote control, including ESP32 and Telegram-based implementations [15–17].

Figure 2. Experimental installation and field testing of the photovoltaic system.

DISCUSSION

The experimental results indicate that the tracking configuration provided better observed photovoltaic performance than the fixed configuration. The calculated average power increased from 68.08 W for non-tracking to 81.47 W for tracking, an increase of approximately 19.7%. The maximum calculated power also increased from 91.65 W to 100.94 W. The difference is consistent with the objective of tracking: maintaining a more favorable panel orientation during the changing position of the sun. The final report similarly concludes that the tracking system provides more optimal and stable solar-energy absorption than the non-tracking arrangement.

The IoT monitoring function was also achieved. The ESP32 processed sensor measurements and transmitted panel voltage, battery voltage, current, calculated power, and system status to Telegram in real time. This provides a practical remote-monitoring mechanism for a plantation installation because the operator does not need to remain physically beside the PLTS. The result is aligned with the monitoring-oriented studies cited in the report, which emphasize remote acquisition of photovoltaic and battery information through IoT platforms [3,4].

The temporal pattern of the measurements is important. Both configurations produced their highest calculated power at approximately midday and showed declining current and power toward the afternoon. The fixed panel experienced a larger reduction at the end of the test period, reaching 27.84 W calculated power at 17:00 compared with 45.38 W for the tracking configuration. This suggests that maintaining panel orientation can be particularly useful when the sun moves away from the fixed panel's most favorable direction.

The study has several practical limitations. The comparison was based on hourly measurements from 09:00 to 17:00 for the tested configurations and did not report simultaneous solar-irradiance measurements, so the electrical differences cannot be normalized to irradiance. The final report also emphasizes real-time monitoring functionality rather than a formal sensor-accuracy or long-duration energy-yield assessment. Future work should therefore include irradiance measurement, longer-duration testing over different weather conditions, quantitative sensor-error analysis, and direct assessment of daily energy yield and lighting energy consumption.

CONCLUSION

A 100 Wp photovoltaic lighting system integrated with ESP32-based IoT monitoring was successfully designed and evaluated for a dragon fruit plantation application. The system combined photovoltaic generation, charge regulation and storage, inverter-based load supply, electrical sensing, ESP32 processing, and Telegram-based remote monitoring. The monitoring system was able to transmit operating information in real time when a stable Internet connection was available.

The tracking configuration showed better observed electrical performance than the non-tracking configuration. Based on the measured voltage and current, the calculated average panel power was 81.47 W for tracking and 68.08 W for non-tracking, representing an approximately 19.7% higher average output with tracking. The maximum calculated power was 100.94 W for tracking and 91.65 W for non-tracking. These results support the use of solar tracking where improved photovoltaic output and remote monitoring are desired for small off-grid agricultural lighting systems.

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