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Exploration of Diodic Current-Voltage Convergence in Maximum Power Point Engineering within Single-Axis Solar Tracking Systems

Novita Asma Ilahi[1], Afrizal Abdi Musyafiq[2], Fadhillah Hazrina[3]

[1]Department of Elektronics Engineering, Politeknik Negeri Cilacap, Indonesia,
[2, 3]Departnement of Electrical Engineering, Politeknik Negeri Cilacap, Indonesia,

nasmailahi@pnc.ac.id

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Abstract

Indonesia, as a tropical country, has high solar irradiation potential, making it well suited for the development of photovoltaic (PV) energy. Along with the increasing demand for electrical energy driven by population growth and technological advancement, solar panels have become an important alternative energy source. However, static solar panel installations often result in suboptimal power absorption. This study focuses on evaluating the performance of a 20 Watt Peak (WP) PV system integrated with an automatic single-axis solar tracking mechanism to optimize solar radiation absorption. The system employs an Arduino Nano as the main controller, ACS712 current sensors, DC voltage sensors, and a NodeMCU ESP8266 module for real-time data communication. Experimental results indicate a significant performance improvement with the implementation of the single-axis tracking system. The average power output increased from 89.2 W without tracking to 93.70 W with tracking, while efficiency improved from 78.4% to 82%. Real-time monitoring of current, voltage, and power is displayed via the Blynk smartphone application, demonstrating the effectiveness of microcontroller-based solar tracking in tropical climates.

Keywords: Solar Tracker; Renewable Energy; Solar Cell; Current–Voltage Exploration

Abstrak

Indonesia sebagai negara tropis memiliki potensi iradiasi matahari yang tinggi sehingga sangat mendukung pengembangan energi fotovoltaik (PV). Seiring meningkatnya kebutuhan energi listrik akibat pertumbuhan penduduk dan teknologi, pemanfaatan panel surya menjadi solusi energi alternatif yang penting. Namun, sistem panel surya statis sering menghasilkan daya yang belum optimal. Penelitian ini bertujuan mengevaluasi kinerja sistem PV 20 Watt Peak (WP) yang dilengkapi pelacak matahari single-aksial otomatis untuk mengoptimalkan penyerapan radiasi matahari. Sistem dirancang menggunakan Arduino Nano sebagai pengendali utama, sensor arus ACS712, sensor tegangan DC, serta modul NodeMCU ESP8266 untuk komunikasi data secara real-time. Hasil pengujian menunjukkan bahwa penggunaan sistem pelacakan single-aksial mampu meningkatkan daya rata-rata dari 89,2 W menjadi 93,70 W. Efisiensi panel juga meningkat dari 78,4% menjadi 82%. Data arus, tegangan, dan daya dimonitor secara real-time melalui aplikasi Blynk. Penelitian ini membuktikan bahwa pelacakan matahari berbasis mikrokontroler efektif meningkatkan kinerja sistem PV di wilayah tropis.

Key word*: Solar Tracker; Energi Terbarukan; Sel Surya; Eksplorasi Arus Tegangan*

1. Introduction

The global energy transition toward renewable resources has emerged as a primary agenda in efforts to mitigate the impacts of climate change and ensure sustainable energy security. Within the spectrum of renewable energy technologies, photovoltaic (PV) systems predominate, offering modular, decentralized, and environmentally friendly solutions **[1-2].** Indonesia, an archipelagic nation situated on the equator, is endowed with optimal solar irradiation potential, allowing for high average annual sunlight exposure—an ideal condition for the widespread adoption of PV technology **[3-4].** This potential is increasingly urgent to exploit, given the surging domestic demand for electrical energy driven by population growth and rapid digitalization and industrialization. Despite Indonesia's high irradiation potential, the actual performance of PV modules remains highly sensitive to operational parameters and environmental conditions.

The efficiency of PV energy conversion is heavily dependent on two primary variables: solar irradiation intensity (W/m^2) and cell temperature, which collectively determine the location of the Maximum Power Point (MPP) on the current-voltage (I-V) and power-voltage (P-V) curves of the module **[5-6].** The majority of PV installations employing a static (fixed) mode are only capable of capturing power optimally during a brief period at midday, while substantial energy losses occur during morning and afternoon hours due to the non-orthogonal angle of incidence of sunlight. To address the power losses inherent in static installations, Solar Tracker technology has become an essential solution. These devices are mechatronically designed to automatically maintain the PV panel surface perpendicular (orthogonal) to the sun's rays, thereby maximizing photon absorption throughout the day. Various studies have confirmed that the use of trackers can increase daily energy output by 20% to 40% compared to static systems, depending on the tracking type (single-axis or dual-axis) and geographical location **[7-8].**

Among various tracking topologies, Single-Axis Tracker systems offer a highly competitive benefit-to-cost ratio. Single-axis systems provide significant power enhancement with lower mechanical complexity and more efficient internal power consumption compared to the more complex dual-axis systems; therefore, they are highly relevant for small-to-medium scale PV applications **[9-10].** At the core of tracking system optimization is the Maximum Power Point Tracking (MPPT) algorithm, which is responsible for ensuring that the inverter or power converter extracts power at the MPP accurately and rapidly **[11-12]**. Conventional MPPT algorithms face fundamental constraints, particularly under rapidly changing irradiation conditions (e.g., due to cloud cover) **[13-14].** The primary issues involve a slow convergence rate toward the new MPP and the presence of transient power oscillations around the MPP, which collectively result in unnecessary energy losses.

To address these inefficiencies, this study introduces and explores the concept of Diodic Current-Voltage Convergence. This approach hypothesizes that by utilizing or manipulating the mathematical characteristics of the single-diode equivalent model of a solar cell, it is possible to design MPPT control logic that is inherently faster and more stable in reaching the MPP. By engineering the I-V response around the MPP, the operating range that the MPPT algorithm must search can be narrowed, thereby substantially increasing the convergence rate **[15-16]**. This research is expected to provide a foundational framework for designing and implementing a robust and efficient automated Single-Axis Solar Tracker system using an Arduino Nano microcontroller as the primary control unit. Furthermore, it integrates an Internet-of-Things (IoT)-based real-time monitoring architecture, utilizing the NodeMCU ESP8266 module and the Blynk platform for the visualization of current, voltage, and power data, thus enabling remote performance monitoring. Finally, this study aims to quantitatively analyze and validate the effectiveness of the proposed system, specifically by comparing the power and efficiency of a 20 Watt Peak (WP) PV module between static and automated tracking modes.

2. Method

The system design was preceded by a comprehensive requirements analysis phase, encompassing hardware specifications and software programming logic. This analysis aimed to ensure the system operates optimally within the context of a photovoltaic (PV) system integrated with a Single-Axis Solar Tracker.

2.1 Solar Panel Requirements Analysis

The determination of the PV module capacity was based on the calculation of the daily energy required by the load. The designated load consists of a 3W 12V LED module with a daily operational duration of 10 hours. Assuming an average daily insolation of 4,5 kWh/m^2, the daily energy requirement is calculated as follows:

$$P_{modul} = \frac{Daily\ Energy\ Requirements}{Solar\ Insolation} \times 2$$

$$Daily\ Energy\ Requirements \quad = 3\ W\ \times 10\ hour$$

$$= \ 30Wh = 0{,}03\ KWh$$

$$P_{modul} = \frac{0{,}03\ KWh}{4{,}5\ KWh/m^2} \times 2$$

$$P_{modul} = 0{,}006\ KWp$$

$$P_{modul} = 6{,}6\ Wp$$

Based on the aforementioned calculations for a 3 W LED module operating 10 hours per day, a solar panel with a peak power of 20 Wp is employed. To ensure adequate power availability and system reliability, a single 20 Wp photovoltaic module is utilized.

2.2 Battery Capacity Analysis

The battery serves as the energy storage medium to store electricity generated by the solar panel and to sustain the operation of the 3 W LED load for 10 hours daily. The required Battery Capacity (Ah) is determined using the following formula:

$$AH = \frac{ET}{Vs}$$

$$AH = \frac{3\ W\ \times 10\ hour}{12\ V}$$

$$AH = 2{,}5$$

Based on the preceding calculations, a battery with a capacity of 7 Ah and a nominal voltage of 12 V was selected to guarantee stable load operation and system longevity.

2.3 Solar Charge Controller (SCC) Requirements Analysis

The capacity of the Solar Charge Controller (SCC) is determined by the short-circuit current (Isc) of the PV panel. Given that the Isc for a 20 Wp panel is 1.13 A, the minimum SCC current requirement is calculated. While initial projections considered a configuration of two 20 Wp panels, the implementation is optimized for a single-panel system as follows:

Pscc PV20 Wp = amount of solar panel x Isc
= 2 x 1,14
= 2.28 A

Pscc = Pscc PV20 W
= 2,28

2.4 System Configuration and Block Diagram

The Single-Axis Solar Tracking system is designed as a distributed mechatronic system governed by a microcontroller. The core architecture integrates several key components: the Photovoltaic (PV) panel (energy provider), an ACS712 current sensor, a DC voltage sensor, a potentiometer, and a Real-Time Clock (RTC). The current and voltage sensors, in conjunction with the potentiometer—utilized for resistance, voltage, and current adjustment—serve as the primary inputs to determine the Maximum Power Point (MPP).

The Arduino Nano functions as the central processing unit (CPU), interpreting data from the sensors and the RTC to ascertain the optimal tracking angle and to execute the proposed MPPT algorithm (hypothesized as Diodic Current-Voltage Convergence). Furthermore, a NodeMCU ESP8266 is employed as the Internet-of-Things (IoT) communication module to facilitate real-time data transmission.

A power window motor is actuated via a motor driver module to adjust the orientation of the solar panel for single-axis tracking. The monitored parameters, specifically current, voltage, and power, are transmitted to the Blynk platform for real-time visualization on a smartphone interface. Finally, the Solar Charge Controller (SCC) and the battery (lead-acid) constitute critical components that regulate the overall energy flow within the system.

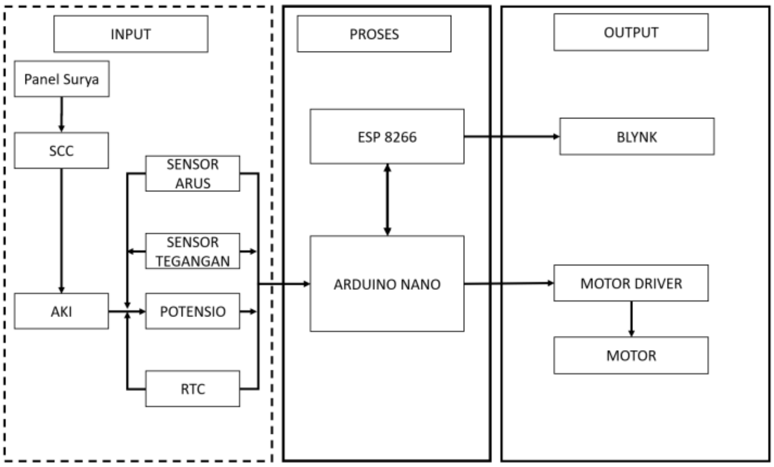


Figure 1. Block Diagram of the System Operational Process

2.5 Control Logic and Flowchart

The operational logic of the Solar Tracker utilizes a mapping mechanism between angular degrees and specific time intervals from 09:00 to 15:00 WIB (Western Indonesia Time), which corresponds to the period of peak solar radiation. The procedure is executed as follows:

a. The process commences with the initialization of the ACS712 current sensor, the DC voltage sensor, and the WiFi connection protocols.

b. The system performs sensor readings and verifies the WiFi status. In the event of a disconnection, the system automatically attempts to reconnect; otherwise, the acquired sensor data is transmitted to the Blynk cloud platform.

c. The system maps the hourly values (from 09:00 to 15:00) into corresponding target angular positions for the solar panel.

d. Tracking Logic: The actuation of the motor is governed by the comparison between the current tracking angle and the target angle. The motor rotates clockwise (to the right) if the current angle is less than the target, and counter-clockwise (to the left) if it exceeds the target. The motor ceases operation once the target angular degree is achieved.

e. Angular adjustments occur at hourly intervals until 15:00 WIB. Subsequently, the tracking system enters a standby state and resumes its operational cycle at 09:00 WIB the following day.

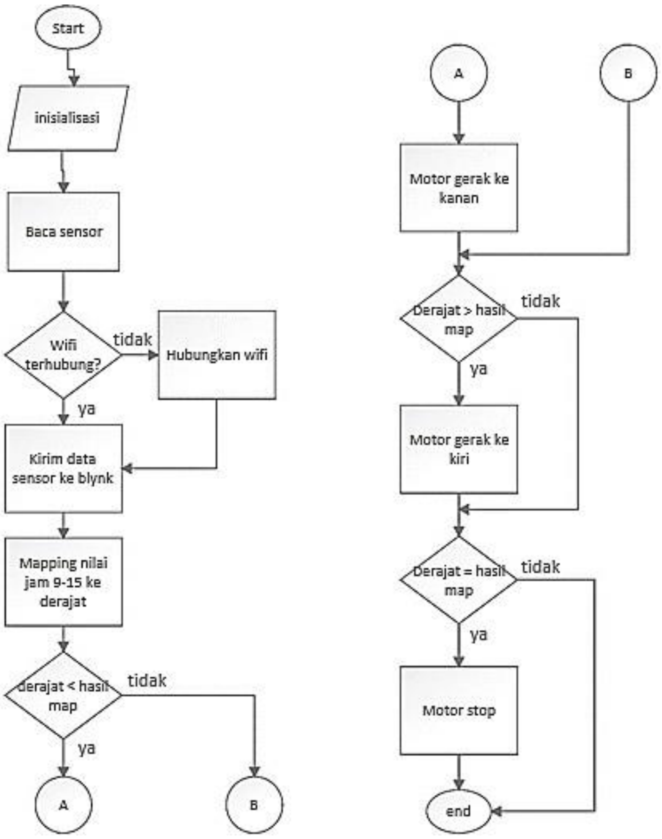


Figure 2. Flowchart of the Photovoltaic System and Real-Time Monitoring

3. Results and Discussion

The experimental evaluation of the system was conducted in the coastal region of Cilacap Regency, Central Java, between 09:00 and 15:00 WIB. The testing procedure involved a comparative analysis of the performance of a 20 Wp Photovoltaic (PV) module operating in two distinct modes: Automated Tracking (Tracker) and Static (Fixed). The discussion primarily focuses on validating the performance enhancement achieved by the tracking system and assessing the accuracy of the integrated real-time monitoring infrastructure.

Figure 3. Mechanical Design of the Automated Solar Tracking System

3.1 No-Load Voltage Testing (Open-Circuit Analysis)

The primary objective of measuring the photovoltaic (PV) panel voltage is to ascertain the electromotive force produced under no-load conditions. Furthermore, this test aims to determine the accuracy level and tolerance values of the integrated voltage sensor by comparing its readings against a calibrated measurement instrument. This evaluation was conducted under open-circuit conditions of the solar panel.

Table 1. Voltage Testing of the Solar Tracker System (Without Battery)

Time	Solar Tracker System (Without Battery)			
	Voltage (V)	Voltage sensor (V)	Weather Conditions	Error (%)
09.00 WIB	17,4	18,1	Overcast	4
10.00 WIB	18,6	19,2	Sunny	3,2
11.00 WIB	20,7	21,5	Sunny	3,8
12.00 WIB	22,2	22,8	Sunny	2,7
13.00 WIB	21,3	21,9	Sunny	2,8
14.00 WIB	19,9	20,4	Overcast	2
15.00 WIB`	18,3	19,3	Overcast	5,4

Table 2. Static Mode Voltage Testing

Waktu	Static Solar Panel System (Without Battery)			
	Voltage (V)	Voltage Sensor (V)	Weather Conditions	Error (%)
09.00 WIB	16,6	17,1	Overcast	3
10.00 WIB	17,9	18,2	Sunny	1,6
11.00 WIB	18,7	19,4	Sunny	3,7
12.00 WIB	21,2	21,5	Sunny	1,4
13.00 WIB	20,3	20,9	Sunny	2,9
14.00 WIB	18,1	19,3	Overcast	6,6
15.00 WIB`	17,3	18,1	Overcast	4,6

The open-circuit voltage (Voc) testing of the photovoltaic panels reveals that the Automated Tracking mode generates a significantly higher average voltage (19.77 V) compared to the Static mode (18.58 V). The average voltage differential between the two modes reached 1.19 V. This enhancement validates the capability of the solar tracker to maintain an orthogonal angle relative to the sun's rays, thereby maximizing the output voltage potential throughout the observation period.

3.2 Load Voltage Testing with Battery Integration

Subsequent voltage evaluations were performed on both the automated tracking and static solar panels under operational conditions. In this phase, the PV panels were integrated with a battery system to serve as an energy storage unit. This test aims to observe the voltage characteristics when the system is actively charging the battery.

Table 3. Voltage Testing of the Solar Tracker System with Battery Integration

Time	**Solar *Tracker* System (With Battery)**			
	Voltage (V)	**Voltage sensor (V)**	**Weather Conditions**	**Error (%)**
09.00 WIB	10,55	11,5	Overcast	**9**
10.00 WIB	11,62	11,70	Sunny	**0,6**
11.00 WIB	11,63	12,00	Sunny	**3**
12.00 WIB	12,56	12,83	Sunny	**2**
13.00 WIB	12,22	12,90	Sunny	**5**
14.00 WIB	12,12	12,80	Sunny	**5**
15.00 WIB`	11,75	12,60	Overcast	**7**

Table 4. Static Mode Voltage Testing with Battery Integration

Time	**Static Solar Panel Surya (With Battery)**			
	Voltage (V)	**Voltage Sensor (V)**	**Weather Conditions**	**Error (%)**
09.00 WIB	9,35	10,5	Overcast	**12**
10.00 WIB	10,22	11,70	Sunny	**14**
11.00 WIB	11,23	12,00	Sunny	**6**
12.00 WIB	11,48	12,50	Sunny	**8**
13.00 WIB	12,35	12,90	Sunny	**4**
14.00 WIB	11,12	12,80	Sunny	**15**
15.00 WIB`	10,75	12,60	Overcast	**17**

When integrated with the battery during the charging phase, the Tracker PV system produced an average voltage of 11.77 V, marginally higher than the Static mode, which yielded 10.92 V. The resulting average voltage differential was 0.78 V. Although the absolute voltage disparity diminished—as the operating voltage during charging is constrained by the battery's potential—the consistency with which the tracking system maintains a higher voltage level substantiates its efficacy under loaded conditions.

3.3 Current Output Testing (Non-Battery Configuration)

The current measurement analysis of the PV panels was conducted to determine the amperage generated during the charging process, as well as to evaluate the precision and tolerance levels of the current sensor relative to a calibrated measurement instrument. This evaluation took place between 09:00 and 15:00 WIB. To facilitate data collection, the current sensor was connected in series with the solar panel under both closed-circuit and open-circuit battery conditions. These tests were performed sequentially without the inclusion of the LED module load.

Table 5. Current Measurement of the Solar Tracker System (Without Battery)

Time	Solar Tracker System (Without Battery)			
	Current (A)	Current Sensor (A)	Weather Conditions	Error (%)
09.00 WIB	0,58	0,49	Overcast	**15**
10.00 WIB	0,65	0,58	Sunny	**10,7**
11.00 WIB	0,68	0,60	Sunny	**11,7**
12.00 WIB	0,78	0,79	Sunny	**1,2**
13.00 WIB	0,85	0,86	Sunny	**1,1**
14.00 WIB	0,63	0,78	Overcast	**23,8**
15.00 WIB	0,54	0,68	Overcast	**25,9**

The current output testing of the solar tracker system in a non-battery configuration, conducted using a digital clamp meter, yielded an average panel current of 0.65 A. Conversely, the measurements obtained via the integrated sensor produced an average reading of 0.68 A. Based on these data, the discrepancy between the measurements performed with the professional instrument and those recorded by the sensor was 1.49%. This marginal variance underscores the high reliability and accuracy of the implemented current sensing system.

Table 6. Current Measurement of the Static PV System (Without Battery)

Time	Static PV System (Without Battery)			
	Current (A)	Current Sensor (A)	Weather Conditions	Error (%)
09.00 WIB	0,56	0,51	Overcast	**8,9**
10.00 WIB	0,68	0,59	Sunny	**13,2**
11.00 WIB	0,71	0,74	Sunny	**4,2**
12.00 WIB	0,75	0,72	Sunny	**4**
13.00 WIB	0,81	0,83	Sunny	**2,4**
14.00 WIB	0,75	0,71	Overcast	**5,3**
15.00 WIB`	0,52	0,68	Overcast	**30**

The current measurement of the static PV system in a non-battery configuration yielded an average panel current of 0.68 A. In comparison, the integrated current sensor recorded an average reading of 0.69 A. These figures indicate a discrepancy of 1.47% between the measurements obtained via the professional instrument and the sensor-based data.

A comparative analysis between the solar tracker and the static system—both evaluated without battery integration—reveals an average current differential of 0.02 A. The resulting data substantiate that the PV panel equipped with a tracking system generates a higher current output compared to the static configuration.

3.4 Current Measurement with Battery Integration

Subsequent evaluations were conducted to measure the current output of both the tracker and static PV systems under battery-connected conditions. The tests were performed simultaneously over a six-hour duration under identical environmental conditions to ensure data consistency. The measurement results are presented in the following table:

Table 7. Current Measurement of the Solar Tracker System with Battery Integration

Time	Solar Tracker System with Battery Integration			
	Current (A)	**Current Sensor (A)**	**Weather Conditions**	**Error (%)**
09.00 WIB	0,48	0,52	Overcast	**8,3**
10.00 WIB	0,61	0,69	Sunny	**13,1**
11.00 WIB	0,72	0,63	Sunny	**4,1**
12.00 WIB	0,75	0,70	Sunny	**6,6**
13.00 WIB	0,74	0,89	Sunny	**20,2**
14.00 WIB	0,78	0,68	Overcast	**12,8**
15.00 WIB`	0,57	0,54	Overcast	**5,2**

The current output analysis of the solar tracker system while integrated with the battery shows an average panel current of 0.65 A. Meanwhile, the measurements recorded by the integrated sensor yielded an average reading of 0.66 A. Based on these results, the percentage discrepancy between the professional measurement instrument and the current sensor was calculated to be 1.53%. This low variance confirms the precision of the monitoring system even under active charging conditions.

Table 8. Current Measurement of the Static PV System with Battery Integration

Time	Static PV System with Battery Integration			
	Current (A)	**Current Sensor (A)**	**Weather Conditions**	**Error (%)**
09.00 WIB	0,43	0,51	Overcast	**18,6**
10.00 WIB	0,54	0,60	Sunny	**11,1**
11.00 WIB	0,62	0,66	Sunny	**6,4**
12.00 WIB	0,71	0,79	Sunny	**11,2**
13.00 WIB	0,81	0,85	Sunny	**4,9**
14.00 WIB	0,76	0,69	Overcast	**9.2**
15.00 WIB`	0,63	0,68	Overcast	**7,9**

The current measurement of the static PV system while integrated with the battery shows an average panel current of 0.64 A. Conversely, the integrated sensor recorded an average reading of 0.69 A. Based on these data, the percentage discrepancy between the professional measurement instrument and the current sensor was calculated to be 6.25%.

The current output evaluations demonstrate varying results between the Tracker and Static modes. In the non-battery configuration, the average current for the Tracker mode was 0.65 A, while the Static mode yielded 0.68 A. Although there is a marginal average differential of 0.02 A, the data substantiate that the Tracker system consistently generates a higher current output. Furthermore, under battery-connected conditions, the average current for the Tracker mode remained at 0.65 A, surpassing the Static mode's 0.64 A. The Tracker system exhibits a clear advantage with a higher average differential. These minor variances in current suggest that the performance enhancement provided by the tracker is more predominantly reflected in the voltage levels, which subsequently accumulates into an overall increase in total power output..

3.5 Photovoltaic Power Output Testing

Subsequent evaluations focused on the power output values of both the solar tracker and the static panels, conducted simultaneously under identical temporal and environmental conditions. The power values were derived through the mathematical product of the measured current and voltage. The following table presents a comparative analysis of the power output for both the tracker and static modes under battery-integrated conditions:

Table 9. Comparative Power Output Analysis with Battery Integration

No	Comparative Power Output Analysis with Battery Integration		
	20 wp *Tracker* (Watt)	**20 wp PV Static (Watt)**	**Time (WIB)**
1	5,0	4,0	09.00
2	7,0	5,5	10.00
3	8,4	6,9	11.00
4	9,4	8,1	12.00
5	9,0	10	13.00
6	9,4	8,4	14.00
7	6,6	6,8	15.00

The implementation of a solar tracking system enables the maximization of power extraction from solar energy. In this experimental evaluation, the harvested energy was highly contingent upon clear weather conditions. The data indicates that the average efficiency of the photovoltaic panels without a tracking system was 78.4%; however, with the integration of the tracking system, the efficiency increased to 82%. This enhancement underscores the effectiveness of the tracking mechanism in optimizing energy conversion.

Table 10. Comparative Power Output Analysis (Non-Battery Configuration)

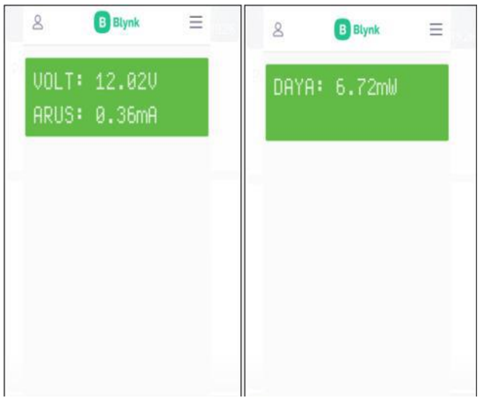
No	Comparative Power Output Analysis (Non-Battery Configuration)		
	20 wp *Tracker* (Watt)	**20 wp Statis (Watt)**	**Time (WIB)**
1	10,0	9,2	09.00
2	12,0	12,1	10.00
3	14,0	13,2	11.00
4	17,3	15,9	12.00
5	18,1	16,4	13.00
6	12,5	13,5	14.00
7	9,8	8,9	15.00

The photovoltaic power output was derived from the empirical measurements of current and voltage. A comparative analysis of these power values demonstrates a significant performance enhancement; the average power harvested by the solar panel in Static mode was 89.2 W, whereas the average power captured utilizing the Automated Tracking system increased to 93.70 W.

This power increment has a direct correlation with the overall system efficiency. The average efficiency of the PV panel in Static mode was 78.4%, which rose to 82% upon the implementation of the Automated Tracking mode. These results quantitatively validate that the single-axis tracking system—implemented based on temporal and angular mapping as part of a framework supporting the concept of Diodic Current-Voltage Convergence in Maximum Power Point Engineering—provides an efficient solution for power optimization within tropical climates.

3.6 Blynk Application and IoT Monitoring Evaluation

The evaluation of the Blynk application was conducted to assess the functional performance and reliability of the user interface. This phase encompassed the testing of the comprehensive monitoring system. The IoT-based real-time monitoring architecture was successfully implemented utilizing the NodeMCU ESP8266 module integrated with the Blynk platform. Consequently, measurements for voltage, current, and power were effectively visualized on a smartphone interface, thereby facilitating remote performance monitoring. Furthermore, the monitored data were cross-referenced with the previously presented experimental results to ensure the veracity and consistency of the telemetry data.



VOLT: 12.02V
ARUS: 0.36mA

DAYA: 6.72mW

Figure 4. Monitoring Interface on the Blynk Application

The experimental results illustrated in Figure 3 demonstrate the monitoring performance for voltage, power, and current via the Blynk application. The telemetry data displayed on the smartphone interface exhibits high precision, characterized by a marginal error discrepancy compared to manual measurements.

4. Conclusion

This research successfully executed the design and implementation of an automated Single-Axis Solar Tracker integrated with an Internet-of-Things (IoT)-based real-time monitoring system. The empirical findings consistently validate the primary hypothesis: that the utilization of a tracking mechanism significantly optimizes solar energy absorption, particularly under the specific irradiation conditions of Indonesia’s tropical climate. Quantitative validation indicates a substantial performance enhancement of the PV module. The average power harvested by the solar panel without a tracking system was 89.2 W, which increased to 93.70 W upon the implementation of the Single-Axis Solar Tracker. This resultant power increment is directly reflected in the system's efficiency, which surged from 78.4% in static mode to 82% using the tracking mode. This 3.6% efficiency gain substantiates that maintaining an orthogonal angle of incidence through RTC-based temporal control is an effective strategy for maximizing current and voltage output throughout the operational period of 09:00 to 15:00 WIB. Furthermore, the IoT monitoring architecture was successfully realized through the integration of the Arduino Nano microcontroller, ACS712 current sensor, DC voltage sensor, and the NodeMCU ESP8266 communication module. This system enables the real-time visualization of current, voltage, and power data via the Blynk smartphone application, providing essential diagnostic tools for remote performance monitoring. The successful implementation of this IoT framework establishes a robust platform for precision data acquisition, which constitutes an absolute prerequisite for the validation of more complex Maximum Power Point Tracking (MPPT) control algorithms.

References

[1] R. Alfita, A. F. Ibadillah, D. Rahmawati, M. K. H. Kusuma, A. Kuriawan, R. V. Nahari, dan M. Pramudia, "Perancangan Solar Tracker Four Axis Berbasis Internet of Things (IoT)," ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika, vol. 8, no. 2, hlm. 404, 2020.

[2] B. E. M. Salam, I. Kamil, dan N. Nadhiroh, "Sistem Monitoring Luaran Daya Panel Surya Solar Tracker Berbasis Internet of Things Dengan GOIOT," ELECTRICES, vol. 3, no. 2, hlm. 53-59, 2021.

[3] M. A. Prasetyo dan H. K. Wardana, "Rancang Bangun Monitoring Solar Tracking Sistem Menggunakan Arduino dan NodeMCU ESP8266 Berbasis IoT," RESISTOR (Elektronika Kendali Telekomunikasi Tenaga Listrik Komputer), vol. 4, no. 2, hlm. 163-168, 2021.

[4] M. A. Akbar, "Analisis Teknis Dan Ekonomis Pembangkit Listrik Tenaga Surya (Plts) Terintegrasi Vertical Indoor Farming," Disertasi Doktor, Universitas Islam Negeri Sultan Syarif Kasim Riau, 2022.

[5] Z. Fakhri, A. Daelami, dan A. Charisma, "Sistem Pengaturan Pendingin Ruangan dengan Menggunakan Thermoelectric dan Blower Motor Direct Current," Jurnal Teknik: Media Pengembangan Ilmu dan Aplikasi Teknik, vol. 21, no. 1, hlm. 84-94, 2022.

[6] T. Septyawan, "Rancang Bangun Keamanan Ruangan Pribadi Dengan Arduino Dan Sms Gateway," Jurnal Portal Data, vol. 2, no. 3, 2022.

[7] D. Setiawan dan A. Alhafiz, "Implementasi sensor TCS200 pada rancang bangun alat filter buah jeruk busuk menggunakan teknik counter berbasis microcontroller," Jurnal Cyber Tech, vol. 2, no. 6, 2022.

[8] M. S. Azam et al., "Performance enhancement of solar PV system introducing semi-continuous tracking algorithm based solar tracker," Energy, vol. 289, 2023, Art. no. 129989. doi: 10.1016/j.energy.2023.129989.

[9] S. Kumar et al., "Impact of liquid spectrum filter and solar tracker on the overall effectiveness of a photovoltaic thermal system: An experimental investigation," Renewable Energy, vol. 226, 2024, Art. no. 120390. doi: 10.1016/j.renene.2024.120390.

[10] I. Anshory et al., "Monitoring solar heat intensity of dual axis solar tracker control system: New approach," Case Studies in Thermal Engineering, vol. 53, 2023, Art. no. 103791. doi: 10.1016/j.csite.2023.103791.

[11] W. Liu et al., "All-day autonomous MPPT energy storage PV-TEG hybrid system based on dual axis solar tracker," Renewable Energy, vol. 256, no. E, 2025, Art. no. 124094. doi: 10.1016/j.renene.2025.124094.

[12] A. M. A. S. Azad et al., "Harnessing the sun: Framework for development and performance evaluation of AI-driven solar tracker for optimal energy harvesting," Energy Conversion and Management: X, vol. 26, 2025, Art. no. 100990. doi: 10.1016/j.ecmx.2025.100990.

[13] M. Mohamed-Abdulhussein dan R. Mohd Mokhtar, "A Review Of Solar Tracking Configuration And Optimization Algorithms For The Dual Axis Solar Tracker Systems," ASEAN Engineering Journal, vol. 14, no. 4, hlm. 49-60, 2024. doi: 10.11113/aej.v14.20986.

[14] R. Dandu dan T. S., "IoT Based Single Axis Solar Tracker," dalam Proc. 14th International

Conference on Computing Communication and Networking Technologies (ICCCNT), Delhi, India, 2023, hlm. 1-5. doi: 10.1109/ICCCNT56998.2023.10307807.

[15] X. Liu, Q. Tan, Y. Niu, dan R. Babaei, "Techno-economic analysis of solar tracker-based hybrid energy systems in a rural residential building: A case study in South Africa," International Journal of Green Energy, vol. 20, no. 2, hlm. 192–211, 2023. doi: 10.1080/15435075.2021.2024545.

[16] M. Engin, "Controller Design for Parallel Mechanism Solar Tracker," Machines, vol. 11, no. 3, Art. no. 372, 2023. doi: 10.3390/machines11030372.