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ADVANCES IN SOCIAL HUMANITIES RESEARCH

Analysis of Solar Photovoltaic Output Characteristics Based on Solar Irradiance, Temperature, and Humidity Using an IoT Monitoring System

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Solar Panel; ESP32; Internet of Things; Light Intensity; Real-Time Monitoring.

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Abstract

Solar photovoltaic (PV) power plants (Pembangkit Listrik Tenaga Surya, PLTS) represent a renewable energy technology with significant development potential in Indonesia. The performance of solar PV panels is influenced by solar irradiance, temperature, and humidity, highlighting the need for a real-time monitoring system. This study aimed to analyze the electrical output characteristics of a 100 Wp monocrystalline solar PV panel using an Internet of Things (IoT)-based monitoring system. The system incorporated an ESP32 microcontroller, an INA226 sensor for measuring voltage and current and calculating electrical power, a DHT22 sensor for measuring ambient temperature and relative humidity, and a BH1750 sensor for measuring illuminance. Data were transmitted via Wi-Fi and monitored through the Blynk Console platform. Testing was conducted over three days, from 08:00 to 17:00 Eastern Indonesia Time (WIT), at BPVP Sorong. The results showed a maximum voltage of 20.7 V, a maximum current of 6.9 A, and a maximum power output of 109.7 W. The highest recorded temperature was 48.7°C, while relative humidity reached 84.2%. Reduced light intensity caused by cloud cover and rainfall was associated with decreased electrical output from the solar PV panel. The IoT-based monitoring system successfully collected, transmitted, and displayed measurement data in real time, demonstrating its capability to monitor solar PV output characteristics under varying environmental conditions.

INTRODUCTION

The adoption of renewable energy, particularly solar energy, has increased rapidly across residential and industrial sectors worldwide (Jabbar et al., 2022). Electricity demand continues to grow due to technological advancements, population growth, and expanding industrial activities (Amoako et al., 2023). Meanwhile, continued dependence on fossil fuels presents significant challenges, including resource depletion and increased greenhouse gas emissions that contribute to environmental degradation. Consequently, the transition toward environmentally sustainable renewable energy sources has become increasingly important. Solar energy is among the most promising renewable energy resources in Indonesia due to its geographical location and abundant sunlight (Kurniawan et al., 2022; Silalahi et al., 2021). However, one of the major limitations of photovoltaic (PV) technology is its relatively low energy conversion efficiency, with conventional commercial PV modules reported to have efficiencies ranging from 15% to 18% (Radia et al., 2023).

Solar energy originates from solar radiation and can be converted into electricity using photovoltaic systems, commonly referred to in Indonesia as Pembangkit Listrik Tenaga Surya (PLTS). Solar PV systems offer several advantages, including installation flexibility and relatively low environmental impacts during operation (Widyastuti et al., 2021). These systems generate electricity through the photovoltaic effect, in which solar cells convert incident sunlight directly into electrical energy. Indonesia's equatorial location provides substantial solar energy potential, with relatively consistent solar radiation availability throughout the year. The country's average daily solar irradiation has been reported at approximately 4.8 kWh/m²/day (Suwarti, 2019). Sorong City, located in Southwest Papua Province, also has considerable potential for solar energy utilization due to its tropical climate and year-round solar radiation availability. Solar cells constitute the fundamental components of PV modules, enabling the direct conversion of solar radiation into electrical energy (Anhar et al., 2017).

Although photovoltaic technology has advanced considerably, challenges remain in optimizing, monitoring, and managing PV system performance. Inadequate monitoring and maintenance can contribute to reduced energy conversion efficiency and undetected operational problems. Monitoring photovoltaic system parameters is therefore essential for optimizing performance and improving on-site operational efficiency (Alombah et al., 2025; He et al., 2024; Ilori et al., 2024). Real-time monitoring is particularly important because PV system performance is strongly influenced by incident solar irradiance, operating temperature, and the physical condition of the modules (Pambudi et al., 2018).

Solar radiation availability varies according to geographical location, atmospheric conditions, cloud cover, rainfall, and daily weather patterns. In coastal tropical regions such as Sorong, high relative humidity and variable cloud cover may coincide with substantial fluctuations in incident solar radiation. Changes in solar irradiance directly affect the electrical characteristics of photovoltaic modules, particularly their output current and power generation. Under clear-sky conditions, higher solar irradiance generally increases electrical output, whereas cloud cover and rainfall reduce incident radiation and consequently decrease power generation. PV output is primarily determined by the amount of global solar irradiance incident on the module surface, which varies throughout the day and under changing atmospheric conditions (Raduan & Islam, 2022). Temperature also influences PV performance, as increasing cell temperature generally reduces output voltage and conversion efficiency, and field measurements in humid tropical environments have shown that relative humidity also affects monocrystalline PV output (Njok & Kamgba, 2023). Therefore, continuous monitoring of environmental and electrical parameters is necessary to characterize PV performance under actual operating conditions.

Advancements in Internet of Things (IoT) technology have enabled the development of automated monitoring systems capable of collecting, transmitting, and displaying data remotely (Al-Fuqaha et al., 2015). IoT-based monitoring can reduce the operational limitations and potential risks associated with conventional manual measurement methods (Boubakr et al., 2022). Several microcontroller platforms, including Arduino Uno, Arduino Nano, ESP8266, and ESP32, have been used in IoT applications. Among these platforms, the ESP32 offers integrated Wi-Fi and Bluetooth connectivity, sufficient processing capability, relatively large memory capacity, and cost-effective implementation, making it suitable for wireless

monitoring applications (Deyi et al., 2024; Pozi et al., 2022). The ESP32 is a microcontroller-based system-on-chip (SoC) that supports wireless communication and can be programmed using C/C++ through the Arduino Integrated Development Environment (IDE). Its integrated communication capabilities enable sensor data acquisition and transmission to remote servers without requiring continuous on-site monitoring. Previous research has demonstrated the applicability of ESP32-based platforms to IoT monitoring and data communication systems (Hermansyah et al., 2020). Furthermore, the Blynk IoT platform provides a graphical interface for monitoring and controlling connected devices through web-based dashboards and mobile applications. Its configurable widgets, including graphs, indicators, and control elements, facilitate real-time visualization of sensor measurements (Inayah et al., 2023).

Previous studies have also examined temporal variations in solar radiation. Mustajab et al. (2019) reported solar irradiance measurements collected on May 26, 27, and 28, 2019, showing a gradual increase from approximately 08:00 to 12:30, followed by a decrease beginning around 13:00. These findings demonstrated the influence of daily solar radiation patterns on the availability of solar energy. However, conventional PV monitoring practices often rely on manual measurements and direct data recording, which can limit measurement frequency, data continuity, and operational efficiency. Automated IoT-based monitoring offers an alternative by enabling continuous data acquisition, remote access, and more systematic observation of PV performance under changing environmental conditions.

Based on these considerations, this study aimed to analyze the electrical output characteristics of a monocrystalline solar PV panel in Sorong City under varying environmental conditions using an ESP32-based IoT monitoring system. The system integrated sensors for illuminance, ambient temperature, relative humidity, voltage, and current to acquire environmental and electrical measurements. The collected data were analyzed to examine the relationships between measured light intensity, temperature, relative humidity, and PV electrical output. The findings were expected to support the development of affordable IoT-based solar PV monitoring systems and provide empirical information on PV performance under the local environmental conditions of Sorong City.

Although numerous studies have investigated IoT-based photovoltaic monitoring systems, evidence from coastal tropical locations with limited ground-based environmental monitoring infrastructure remains relatively limited. In particular, studies integrating illuminance, ambient temperature, relative humidity, and electrical output measurements within a single ESP32-based real-time monitoring system in Sorong City have not been extensively reported. This research gap is relevant because Sorong's coastal tropical environment, characterized by high humidity, variable cloud cover, and frequent rainfall, may produce PV operating conditions that differ from those observed in temperate or extensively monitored regions. Furthermore, illuminance measurements obtained using a BH1750 sensor provide information on incident visible light intensity but do not directly measure broadband solar irradiance in W/m^2. Accordingly, this study focused on evaluating the relationships between measured illuminance, environmental conditions, and PV electrical output rather than directly quantifying solar irradiance. The contribution of this study lies in the development and application of a low-cost, ESP32-based IoT monitoring system that integrates environmental

and electrical measurements to characterize solar PV performance under the local climatic conditions of Sorong City.

METHOD

This study employed an experimental approach to investigate the effects of light intensity, ambient temperature, and relative humidity on the electrical output characteristics of a 100 Wp monocrystalline solar photovoltaic (PV) panel in Sorong City. An Internet of Things (IoT)-based monitoring system was developed to collect environmental and electrical data in real time and transmit them to the Blynk Console platform via Wi-Fi.

Research Location and Time

The research was carried out at the Electrical Vocational Workshop, Sorong Vocational and Productivity Training Center (BPVP), which is located at the geographical coordinates of 0°53'14.8" S 131°18'34.6" E. The selection of this location is based on the potential for high solar radiation intensity in the Sorong area and the availability of supporting facilities for solar panel testing. Data collection was carried out for three days, namely on June 24, 25, and 26, 2026, with a recording time range from 08.00 to 17.00 WIT and data collection intervals every 30 minutes.

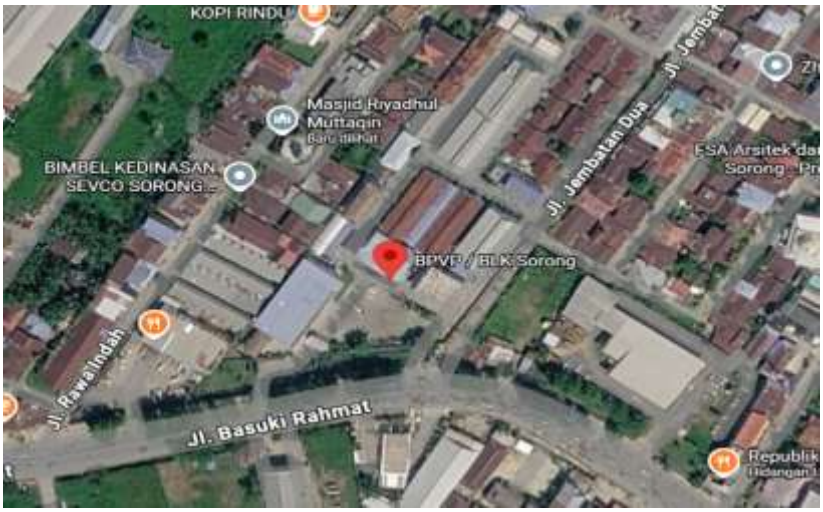


Figure 1. Research Location Plan, BPVP Sorong Electricity Workshop

Monitoring System Design

The monitoring system developed uses a layered architecture consisting of four main blocks, namely the sensor block, the processing block, the communication block, and the user application block. The monitoring system architecture is shown in Figure 2.

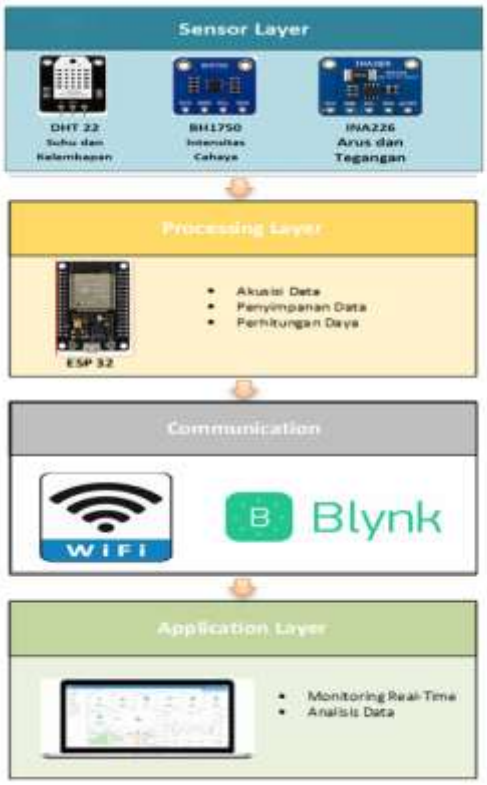


Figure 2. Diagram of the Monitoring System

1. Sensor Block (Sensor Layer) This block serves as a unit of ambient environmental data acquisition. The INA226 sensor is used to measure the power, voltage and output current of the solar panel. The DHT22 sensor is used to monitor the temperature and humidity of the air around the solar panel. The BH1750 sensor is used to measure the intensity of sunlight received by the solar panel in lux units.
2. The Processing Layer uses the ESP32 microcontroller as the main control unit. The ESP32 is in charge of reading data from the INA226, DHT22, and BH1750 sensors, then processing the data to calculate the solar panel's output power based on the voltage and current values obtained.
3. The Communication Block sends the data that has been processed by the ESP32 over a Wi-Fi connection to the Blynk Console platform. This platform serves as a cloud-based data storage medium that supports real-time data synchronization between the user's hardware and applications.
4. The Application Layer uses the Blynk application as a user interface for real-time and remote visualization of sensor data. The data displayed on the Blynk dashboard includes voltage, current, power, temperature, humidity, and light intensity values in numerical form and real-time graphs.

Hardware Components

The hardware used includes;

1. ESP32 as the main microcontroller and Wi Fi communication module.
2. DHT22 as a sensor for temperature (°C) and air humidity (%RH) measurement.
3. BH1750 as a light intensity (lux) measurement sensor.

4. INA226 as a sensor for the measurement of the voltage (V), current (A), and power (W) output of solar panels.
5. Adapter as power supply for ESP32 and sensor
6. Board as sensor component holder and ESP32
7. 100 Wp monocrystalline solar panel as the test object.

The wiring circuit between the components is shown in Figure 3.

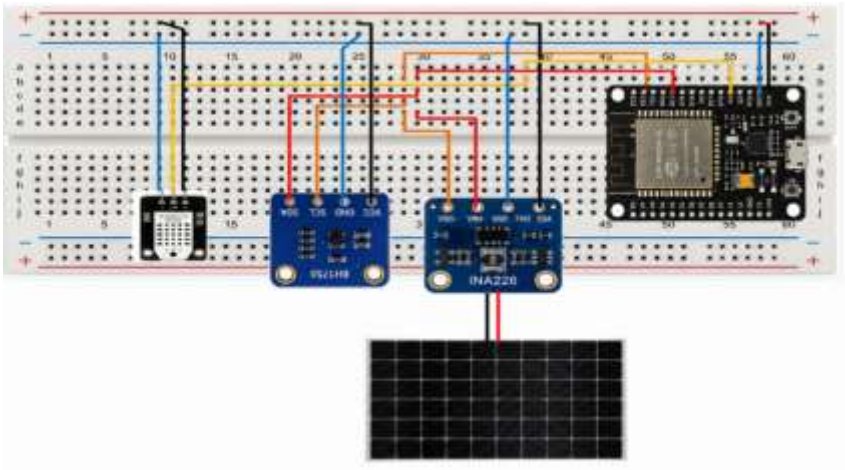


Figure 3. Wiring Components in the Network

Sensor Calibration

Validation and calibration of the sensor is carried out before the data collection process to ensure the accuracy of the measurement results. The DHT22 sensor is calibrated against a digital thermometer and hygrometer, the BH1750 sensor is compared to a standard lux meter, while the INA226 sensor is compared to a Solar MPPT Meter. The calibration results show that the measurement difference between the sensor used and the standard measuring instrument is still within the tolerance limit of the sensor specification, so that all sensors are declared suitable for research data collection. The calibration process of comparing the INA226 sensor with the Solar MPPT Meter is shown in Figure 4.



Figure 4. Comparative Calibration of INA226 and Solar MPPT Meter

Mobile Software and Applications

The software on the ESP32 was developed using the Arduino IDE to read the sensor and send it to the Blynk Console platform via a Wi-Fi network. (Rahayu et al., 2026). The Arduino IDE is used to write, compile, and upload programs to the ESP32, while the Blynk Console is used to display the sensor measurement data in real-time in the form of dashboard monitoring.

The workflow of the monitoring system is illustrated in the form of a flowchart in Figure 5. In general, the system works in the following stages:



Figure 5. Monitoring System Workflow Flowchart

In Figure 5 is the workflow of the tools used in this study,

1. Start: The initial stage when the system is activated. The ESP32 gets the power source and starts running the pre-uploaded program.
2. System Initialization: The ESP32 configures all devices used in the system, including DHT22, INA226, BH1750 sensors, as well as Wi-Fi and Blynk communication parameters. At this stage, the input/output pin and communication address are also set.
3. Wi-Fi and Blynk connections: ESP32 tries to connect to a predefined Wi-Fi network. Once the connection is successful, ESP32 connects to Blynk Cloud's servers in order to send and receive data online.
4. Read DHT22: Air temperature (°C) and air humidity (%RH) sensor readings that are data to find out the weather conditions around the solar panel
5. Read BH1750 : Reading of the sunlight intensity sensor received by the solar panel in lux.
6. Read INA226 :p sensor readings for measurement of panel solar output voltage (Volt) and panel solar output current (Ampere).
7. Calculate Power: ESP32 processes voltage and current data obtained from INA226 to calculate solar panel output power (W)

8. Send Data to Blynk : Data Transmission to Blynk Cloud by ESP32 transmits temperature, humidity, light intensity, voltage, current, and power data over the internet network to Blynk Cloud servers using IoT communication protocols.
9. Display Data: Display Data on the Blynk Dashboard according to the data that has been received by Blynk displayed on the dashboard of the smartphone or web application in the form of numerical values, real-time graphs and monitoring indicators. Measurement data
10. can be stored on Blynk's servers as historical data that can be used for analysis of the performance of solar panels over a given period.
11. Repeat the Process: Repeating the process is carried out after the entire process is completed, the ESP32 again reads the sensor and repeats all stages continuously.
12. continuously in a certain time interval so that monitoring can take place in real-time.

The working principle of this system begins with the ESP32 which initializes the DHT22, BH1750, and INA226 sensors and connects the device to the Wi-Fi and Blynk networks. The DHT22 sensor measures the temperature and humidity of the air, the BH1750 measures the intensity of sunlight, while the INA226 measures the voltage and current of the solar panel's output. The data obtained is then processed by ESP32 to calculate the solar panel's output power, which is then sent to the Blynk platform via the internet and displayed in real-time on the monitoring dashboard. This process takes place iteratively so that the environmental conditions and performance of the solar panels can be continuously monitored.

Testing

The test was carried out by installing a 100 Wp monocrystalline solar panel on a stable iron frame with an angle of inclination of 12° to the horizontal plane. Observation data was taken for three days with a recording time range from 08.00 to 17.00 WIT and data transmission intervals every 30 minutes. During the test, the parameters of voltage, current, power, light intensity, temperature, and humidity were stored on the Blynk Console server to be processed and analyzed.

RESULTS AND DISCUSSION

Power Measurement Results Data

The test on the 100 Wp solar panel aims to obtain data on voltage, current, power, light intensity, temperature, and humidity at real weather conditions at the research site. Data collection was carried out for three days on June 24, 25, and 26, 2026, with a time range of 08.00–17.00 WIT and an interval of 30 minutes, so that 19 data points per day were obtained for each parameter. The data from the measurement results for three days are presented in Table 1, Table 2, and Table 3.

Table 1. Data on the First Day of Measurement (June 24, 2026)

Yes	Time	Voltage	Current	Power	Temperature	Humidity	Lux
1	08.00	20,1	1,1	22,1	32,1	64,2	8860
2	08.30	19	1,7	32,3	34,3	56,9	14255,8
3	09.00	19	2,3	43,7	38,4	46,1	17725,8
4	09.30	16,7	3,1	51,7	40,8	39,5	23900,8
5	10.00	17,4	3,9	67,8	39,9	39,7	28961,7
6	10.30	17,1	1,3	22,2	39,6	40,9	11185

7	11.00	16,1	4,4	70,8	45	30,8	47097,5
8	11.30	16,3	4,7	76,6	45,6	29,2	54612,5
9	12.00	17,4	2	34,8	48,6	25,7	18610,8
10	12.30	16,5	5,7	94	45,6	29,2	54612,5
11	13.00	15,6	6,1	95,1	48,7	24,5	54612,5
12	13.30	19,8	0,6	11,8	36,6	48,8	11595,8
13	14.00	19,1	1,2	22,9	40,8	39	10498,3
14	14.30	15,3	0,4	6,1	35,5	50,2	3846,7
15	15.00	17,9	2,9	51,9	35,9	51,4	38310,8
16	15.30	19	0,5	9,5	36,1	49,4	3822,5
17	16.00	19,6	1,6	31,3	41,3	38,6	49344,2
18	16.30	20,7	1,2	24,8	40,1	40,7	6935
19	17.00	19,2	1,80	34,5	39,1	43,5	8430,8

Table 2. Data on the Results of Measurement on the Second Day (June 25, 2026)

Yes	Time	Voltage	Current	Power	Temperature	Humidity	Lux
1	08.00	16,9	0,8	13,5	29,3	72,6	6876,7
2	08.30	20	1,4	28	33,7	59,6	15699,2
3	09.00	19,5	1	20,4	36,6	50,8	11362,5
4	09.30	16,8	2,2	36,9	40,8	40,4	20474,2
5	10.00	16,9	4,4	74,3	42,1	37,8	35670,8
6	10.30	19,4	1,3	25,2	36,5	49,5	10543,3
7	11.00	15,5	4,9	75,9	45,1	31,4	47130
8	11.30	16,7	5,7	95,1	42,6	35,3	54612,5
9	12.00	17,1	1,8	30,7	45,5	30,8	14674,2
10	12.30	16,3	6,2	101	42,9	35	54612,5
11	13.00	15,6	5,5	85,8	48,1	27,3	54612,5
12	13.30	15,5	2	31	48,1	26,6	20281,7
13	14.00	15,8	5,8	91,6	45,2	31,2	54612,5
14	14.30	17,7	1,9	33,6	46,4	28,9	54612,5
15	15.00	15,5	5,1	79	47,5	27,8	54612,5
16	15.30	18	0,7	12,6	40,1	39,1	5541,7
17	16.00	19	0,9	13,3	39,7	40,8	6211,7
18	16.30	15,1	0,7	17,1	36,8	46,3	7991,7
19	17.00	18,3	1,6	29,2	38,5	45,6	4854,2

Table 3. Data on the Third Day of Measurement (June 26, 2026)

Yes	Time	Voltage	Current	Power	Temperature	Humidity	Lux
1	08.00	18,7	0,2	3,7	27,6	83,1	3775
2	08.30	20,1	1,3	26,1	31	69,2	10284,2
3	09.00	16,8	1,7	28,5	35,3	55	14352,5
4	09.30	19,9	1,5	29,8	34,1	56,3	13542,5
5	10.00	16,4	2,5	41	37,2	47,9	21977,5
6	10.30	17,5	3,1	54,2	38,6	44,2	29308,3
7	11.00	17	2,6	44,2	35,6	54	21393,3
8	11.30	16,1	2,8	45	45,8	32,3	27244,2
9	12.00	19,9	1,3	25,8	33,9	60,6	11375
10	12.30	17,5	2,8	49	39,3	45,4	26279,2
11	13.00	18,5	3,4	62,9	43x	35,5	34401,7
12	13.30	17,5	3,7	64,7	43,7	34,5	42422,5
13	14.00	16,2	3,2	51,8	44,1	33,8	37966,7
14	14.30	15,9	6,9	109,7	39	43,6	54612,5
15	15.00	17,4	2,9	50,4	42,9	36,1	37278,3
16	15.30	16	3,2	51,2	41,8	38,6	30323,3
17	16.00	18,5	0,2	3,7	28,8	76,8	1632,5

18	16.30	13,3	0,2	2,6	28,3	83,4	1255,8
19	17.00	18,3	0,2	3,6	26,6	84,2	1625

Analysis of measurement results based on table data

Based on the data in Table 1–3, the output characteristics of a 100 Wp monocrystalline solar panel can be analyzed through patterns of changes in voltage, current, power, light intensity, temperature, and humidity during the three days of testing.

1. Characteristics of Solar Panel Output Voltage

The voltage data on the three days of the test showed fluctuations that were closely related to changes in the intensity of sunlight. On the first day (June 24), the highest voltage was recorded at 20.7 V at 16.30 WIT, while the lowest voltage was 15.3 V at 14.30 WIT. On the second and third days, the voltage values ranged from 13.3 V to 20.1 V, with a similar fluctuation pattern.

In general, the voltage tends to be higher in the morning (08.00–09.30) and afternoon (15.30–17.00), while during the day (11.00–14.30) there is a significant decrease in voltage. This decrease mainly occurs when the light intensity drops drastically due to cloudy or rainy weather conditions, as seen in the data at 12.00–13.30 on the first and second days, where the voltage drops to below 17 V even though the light intensity was relatively high before. This indicates that the output voltage of solar panels is not only affected by irradiance, but also by load dynamics and transient conditions due to sudden weather changes.

2. Characteristics of Current and Output Power

The current and output power show a pattern that is more sensitive to changes in light intensity than voltage. On the first day, the highest current was recorded at 6.1 A at 13.00 WIT, with a maximum power of 95.1 W at the same time. On the second day, the current and power reached higher values, namely 6.2 A and 101 W at 12.30 WIT. The highest values overall were obtained on the third day, which were 6.9 A and 109.7 W at 14.30 WIT.

The pattern of increasing current and power follows a pattern of increasing light intensity, with a common peak occurring in the time range of 11.30–15.30 WIT, which coincides with the period of highest irradiance (around 54,612.5 lux). When the light intensity drops below 15,000 lux, for example at 08.00 on the third day (3,775 lux) or at 16.30 on the third day (1,255.8 lux), the current drops drastically to 0.2 A and the power is only 2.6–3.7 W. This suggests that the current and power of the solar panel are highly dependent on the availability of irradiance, and the direct drop in light has implications for a decrease in electrical performance.

3. Sunlight Intensity (Lux)

The light intensity measured using the BH1750 sensor showed daily variations consistent with the local weather pattern of Sorong. The lowest lux value was recorded in the morning or during cloudy/rainy conditions, which was 1,255.8 lux on the third day at 16.30. The highest value measured by the sensor was 54,612.5 lux, which appeared repeatedly at 11.30–15.30 on all three days of testing.

It is important to note that the BH1750 sensor has a maximum reading limit of about 54,612.5 lux. In very bright irradiation conditions (e.g. midday with clear skies), the actual lux value is likely to be higher, but it cannot be accurately recorded by this sensor. This limitation

is evident from the data showing a "sticky" value at 54,612.5 lux for several consecutive hours, although visually the light conditions may still change. For advanced research that requires more precise irradiance measurements, it is recommended to use a special irradiance sensor or pyranometer.

4. Ambient Environment Temperature of Solar Panels

The ambient temperature measured using the DHT22 sensor ranged from 26.6°C to 48.7°C during the three days of testing. The highest temperature was recorded on the first day at 13.00 WIT at 48.7°C, which coincided with a period of high light intensity and high output power. The lowest temperature was recorded on the third day at 17.00 WIT at 26.6°C, which occurs when light intensity is very low and weather conditions tend to be cloudy or after rain.

In general, temperatures tend to increase as light intensity increases, with daily patterns showing low temperatures in the morning, increasing during the day, and decreasing again in the afternoon to evening. Although high temperatures can slightly decrease the conversion efficiency of solar panels, in this study the main influence on panel output remains dominated by changes in light intensity, not temperature.

5. Air Humidity

The measured air humidity ranged from 24.5% to 84.2% during the test period. The highest humidity was recorded on the third day at 17.00 WIT at 84.2%, which occurs when light intensity is very low (1,625 lux) and weather conditions tend to be humid or after rain. The lowest humidity was recorded on the first day at 12.00 WIT at 25.7%, which coincides with sunny weather conditions and high light intensity.

The humidity pattern showed an inverse relationship with light intensity: when the light was high, the humidity tended to be low, and vice versa. Although humidity did not directly affect the electrical characteristics of the solar panels in this study, this parameter is important as an indicator of environmental conditions that can affect the degradation of panel materials in the long term, especially in coastal areas such as Sorong which have high humidity.

Discussion and Comparison with Previous Research

The results of this study show that the output of 100 Wp monocrystalline solar panels in Sorong City is greatly influenced by changes in the intensity of sunlight, with voltage, current, and power fluctuating significantly as weather conditions change. The maximum power value obtained of 109.7 W exceeds the nominal rating of the panel (100 Wp), which indicates that the panel still has a good performance margin under high irradiance conditions.

This finding is in line with the research of Pambudi et al. (2018) who reported that the performance of solar power plants is greatly influenced by solar radiation and surrounding environmental conditions, with a significant decrease in power occurring during cloudy or rainy conditions. The research of Mustajab et al. (2019) in Sorong City also showed a pattern of solar radiation intensity that gradually increased from 08.00 to 12.30, then decreased after 13.00, which is consistent with the pattern obtained in this study.

The main difference between this study and previous research lies in the integration of an IoT-based monitoring system that allows real-time data acquisition and historical data storage on a cloud platform. Most of the previous studies, as reported by Pambudi et al. (2018), still use manual monitoring methods with direct measurements using measuring tools and

periodic data recording, so the data obtained is limited and cannot be monitored remotely. This study overcomes these limitations by implementing an ESP32-based automated monitoring system integrated with INA226, DHT22, and BH1750 sensors, as well as the Blynk Console platform for data visualization and storage.

In terms of measured parameters, this study is also more comprehensive than some similar studies that only focus on the output voltage and current of solar panels. By adding measurements of temperature, humidity, and light intensity, this study provides a more complete picture of the relationship between environmental conditions and solar panel performance in coastal tropical areas such as Sorong. This is an added value compared to the research of Hermansyah et al. (2020) which although using ESP32 for solar panel monitoring, focuses more on the control and data communication aspects without in-depth analysis of environmental characteristics.

However, this study also has limitations, especially related to the accuracy of light intensity measurements. The BH1750 sensor used has a maximum reading limit

approximately 54,612.5 lux, so that in very high irradiance conditions, the recorded values no longer represent the actual light intensity. This limitation has also been reported in several low-cost sensor-based solar PV monitoring studies, which suggest the use of a special irradiance sensor or pyranometer for more accurate measurements. For follow-up research, it is recommended to use a sensor with a higher measurement range or perform further calibration of the BH1750 sensor with reference to standard measuring instruments.

Overall, the results of this study reinforce the finding that the characteristics of solar irradiation in Sorong City have good potential for the utilization of solar PV, with optimal solar panel performance in sunny weather conditions and high irradiance. The IoT-based monitoring system developed in this study can be a reference for the development of solar PV performance monitoring systems in 3T (frontier, outermost, disadvantaged) areas such as Sorong, where access to formal meteorological data may be limited.

CONCLUSION

Based on the three-day experimental results, the ESP32-based monitoring system successfully measured voltage, current, power, illuminance, ambient temperature, and relative humidity in real time using INA226, BH1750, and DHT22 sensors. All measurement data were successfully transmitted to and displayed on the Blynk Console platform, enabling continuous monitoring of solar photovoltaic (PV) panel performance. The BH1750 sensor effectively detected variations in illuminance; however, under high solar irradiance conditions, its readings reached a maximum recorded value of approximately 54,612.5 lux, indicating measurement saturation and limiting its ability to represent actual illuminance levels. Therefore, future studies requiring accurate solar irradiance measurements should incorporate a calibrated solar irradiance sensor or pyranometer.

The experimental results indicated that the study site in Sorong City had promising potential for solar photovoltaic power generation. The 100 Wp monocrystalline solar PV panel recorded a maximum voltage of 20.7 V, a maximum current of 6.9 A, and a maximum power output of 109.7 W under high-illuminance conditions. Conversely, cloudy and rainy conditions reduced incident solar radiation, resulting in substantial decreases in output current and

electrical power. These findings demonstrated that solar PV output varied with environmental conditions and suggested that the study site had favorable daytime solar energy availability. However, a comprehensive assessment of long-term solar energy potential and system feasibility would require extended monitoring and calibrated solar irradiance measurements.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to the conduct of the research, preparation, or publication of this article.

AUTHOR CONTRIBUTIONS

All authors contributed to the preparation of this article. Joni, Yohanis Tangke Tosuli, Melania Yosefina Making, was responsible for the conceptualization of the study, data collection and analysis, interpretation of the results, and manuscript preparation. The other authors contributed to the review, editing, and final approval of the manuscript.

GENERATIVE ARTIFICIAL INTELLIGENCE USAGE STATEMENT

The authors declare that no generative artificial intelligence was used in the preparation of this article.

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