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Optimizing Solar Panel Output with an IoT-Based Solar Tracker: UNIPMA Integrated Lab Case Study

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Abstract

The development and development of new renewable energy has become increasingly widespread recently, one of the most widely used is solar panels. The biggest disadvantage of installing solar panels is that they are not able to follow the movement of the sun so that the power output produced is less than optimal. A solar tracker is a device used to optimize the absorption of sunlight by solar panels by following the movement of the sun. However, the use of sensors on solar trackers often requires quite complicated manufacturing. Therefore, this research aims to design a solar tracker without sensors in photovoltaic (PV) systems. The method in this research is to compare the power produced by solar panels with and without solar trackers based on IoT (Internet of Things) case studies at the UNIPMA Integrated Lab. Data collection was carried out in real time over a period of 3 days starting at 09.00 WIB with a solar panel tilt of 45° until 15.00 WIB with a solar panel tilt of 135°. The results of measurements using a solar tracker on photovoltaic (PV) showed an average current of 0.74 amperes (A), an average voltage of 18.7 volts (V), and an average power output of 14.4 watts. (W). Meanwhile, measurement results without a solar tracker showed an average current of 0.6 amperes (A), an average voltage of 17.9 volts and an average power output of 11.04 watts (W). So, the power produced with a solar tracker is more optimal than without a solar tracker.

Keywords: Solar Energy, Photovoltaic (PV), Solar Tracker.

1. Introduction

One of the visions of Indonesia Zero Carbon is to increase the use of new renewable energy (NRE) and reduce fossil energy. One of the most widely developed currently is the Solar Power Plant (SPP). Solar panels are a tool used to produce renewable energy from sunlight into electrical energy [1]. Usually, solar panels are placed outdoors to obtain sunlight in free space. The amount of energy produced by solar panels is influenced by a number of variables, one of which is the length of sunlight.
The potential of the sun which is used as a solar power generator is the reason for testing to determine the current, voltage and power produced by solar panels in the city of Madiun [2]. The city of Madiun is located on land at a height of 63 meters above sea level, which means that light reception in the city of Madiun is quite good for using solar panel energy sources. Therefore, in order to optimize the power produced by solar panels, it is necessary to move the solar panels so that they can follow the movement of the sun. The movement of the solar panels is designed by adjusting the tilt angle at certain hours.

Previous studies have also discussed how to use IoT technology as a method for monitoring systems at Solar Power Plant, as in research [2]–[5]. The classification of tracking systems is explained in research [6]. The aim of this research is to design a monitoring tool to monitor current and voltage values and their performance on a 50 wp polycrystalline solar panel using Arduino, NodeMCU, IoT-based INA219 sensors using the Blynk platform where the solar panel does not move and compare it with current and voltage measurements. move following the sun's rays (solar tracker). In previous research, IoT was used with the Blynk platform only and compared with manual measurements. The novelty in this research is the measurement of solar panel current and voltage from a timer-based solar

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tracker and compared with voltage and current measurements with an IoT-based solar tracker with the Blynk platform.

2. Research Methods

The stages of this research are as follows:

2.1 Literacy Study

Researchers carry out observations and data analysis by reading and analyzing previous research related to monitoring systems on solar panels to find innovations so that the equipment can run well and efficiently

2.2 Tool Planning

Next is planning the design of the tools that will be used and what materials are needed to design a monitoring system for solar panels to get the desired design results. Research Tools and Materials include, among others: Solar Panels, Actuator motor, Arduino Uno, Motorbike drivers, Real Time Clock (RTC), SensorINA219, NodeMCU ESP8266, I2C IIC 4 Channel (stepdown), Solar Charge Control, Battery, and Watt Meters

2.2.1 Photovoltaic/Solar Panels

Photovoltaic (PV) is a technology that can produce DC (Direct Current) electricity using semiconductor materials. Photovoltaics can produce electrical energy when a surface is exposed to light, if the surface is not exposed to light then the photovoltaic stops producing electrical energy [7].

2.2.2 Actuator

An actuator is a mechanical device that can move or control a mechanism or system. Actuators work by using electrical energy which is converted into motion and can then move the object where the actuator is installed (Figure 1). This tool is used to move the solar panel to obtain a specified position [8].

Figure 1. Motor Actuator

2.2.3 Solar Charge Controller (SCC)

The Solar Charge Controller (SCC) is an electronic component in PLTS to regulate battery charging using photovoltaic modules to be more optimal (Figure 2). The Solar Charge Controller (SCC) works by regulating the charging voltage and current based on the power available from the photovoltaic module and the battery charge status [9], [10].

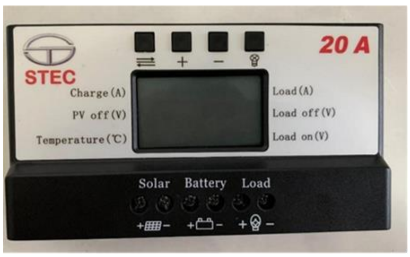

Figure 2. SCC (Solar Charge Controller)

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2.2.4 Motor Driver

A motor driver is an electronic component that controls a DC motor (Figure 3). The motor driver is the part responsible for converting the signal received by the microcontroller into an output signal that has the ability to drive a DC motor. This DC motor driver has a PWM function and can output current up to 43A. The DC source voltage can be between 5.5V27VDC, and the input voltage level can be between 3.3V-%VDC [11].

Figure 3. Motor Draiver BTS7960

2.2.5 Arduino Uno [12]

Arduino UNO has its own advantages compared to other microcontroller boards [7]. Arduino UNO Atmega 328 is an 8-bit microcontroller chip based on the AVR-RISC architecture produced by Atmel. This chip is equipped with 32 KB of ISP flash memory that can be read/written, 1 KB of EEPROM, and 2 KB of SRAM [4]. To operate it, you only need to connect the Arduino UNO module to a PC using a USB cable or DC adapter [5]. Arduino UNO has a total of 14 input/output pins, of which 6 pins can be used as PWM outputs, and 6 analog inputs. Additionally, the Arduino UNO is equipped with a 16 MHz crystal oscillator, USB connection, power jack, ICSP head, and reset button.

2.3 Tool Design

After determining the design that will be carried out, and preparing the tools and materials needed, the next stage is to design the tools. This design contains hardware and software

2.3.1 Hardware Design

The hardware planning image is shown in Figure 4.

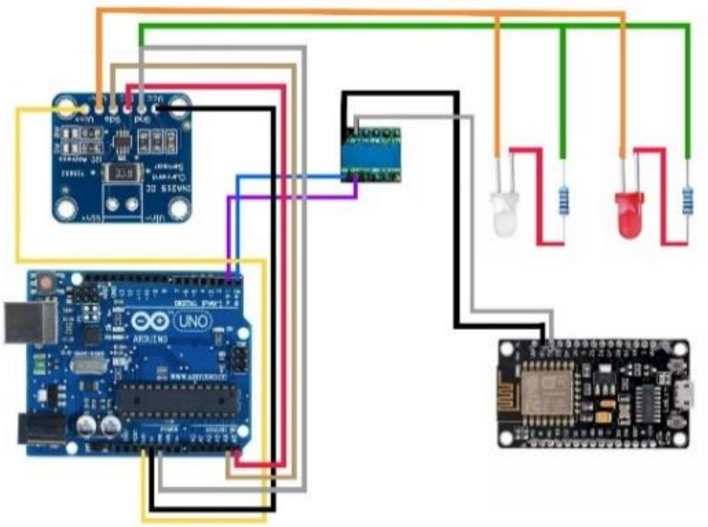

Figure 4. Hardware Design

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2.3.2 Software Design

Figure 5 show when the solar panel receives light and produces electrical energy, then it enters the SCC (Solar Charge Control) to regulate the power that enters the battery and then enters the battery. Then, Arduino Uno sends a command to the INA219 sensor to read the voltage and current obtained by the solar panel. The next step, the NodeMCU microcontroller sends voltage and current data from the INA219 sensor readings to the Blynk platform by connecting to the internet network.

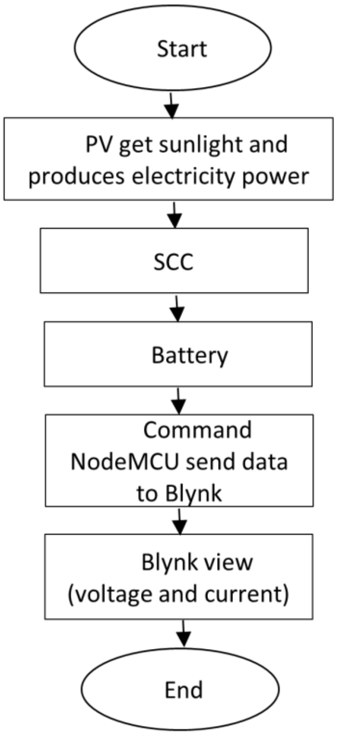

Figure 5. Flowchart Software Design

2.4 Tool Testing

The next step is to test the tool that has been assembled and carry out an evaluation to determine the performance of the tool and complete the program or component if there are deficiencies in the tool.

2.5 Data Collection

After testing and evaluating the tool, the next step is to collect data on the solar panel to obtain data on the voltage, current and power obtained by the solar panel

3. Result and Discussion

3.1 RTC (Real Time Clock) Testing

The Arduino is set to set the RTC to turn on for 9 seconds every 30 minutes to turn on the actuator, and it will move for 9 seconds. RTC test results data are presented in the following Table 1:

Table 1. RTC Testing

Start	End	Explanation
09:30:00	09:30:09	√
10:00:00	10:00:09	√
10:30:00	10:00:09	√
11:00:00	11:00:09	√
11:30:00	11:30:09	√

Explanation: √ (Success)

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3.2 Actuator Movement Testing

Based on the journal reference [13], the angle data required to change the tilt of the solar panel every 30 minutes is 7.50. So, the actuator was tested when it moved with an angle difference of 7.50 for a time of 9 seconds. Table 2 shows the time required for the actuator to move 7.5 degrees.

Table 2. Actuator Testing

Time (Seconds)	Angle Difference (degree)
6	5.0^0
8	6.5^0
9	7.5^0
10	10.0^0

Figure 6 shows the time display from the stopwatch for the actuator moving 7.5 degrees.

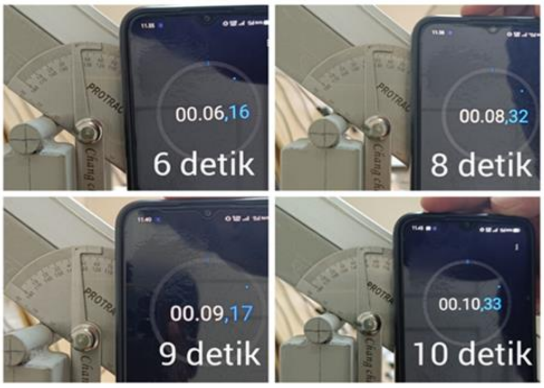
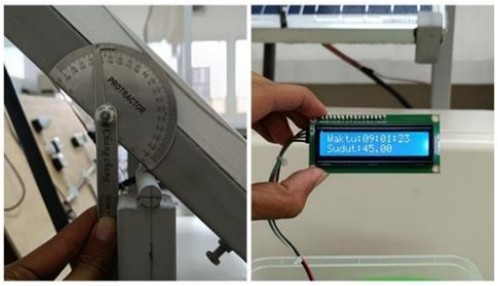
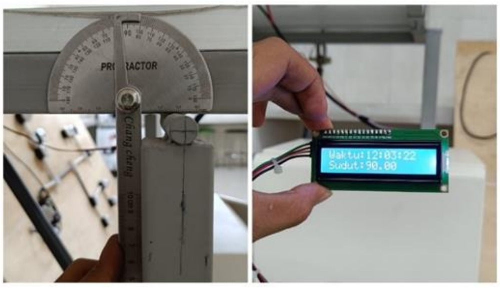


Figure 6. Testing the Actuator with a Stopwatch Solar Tracker Testing

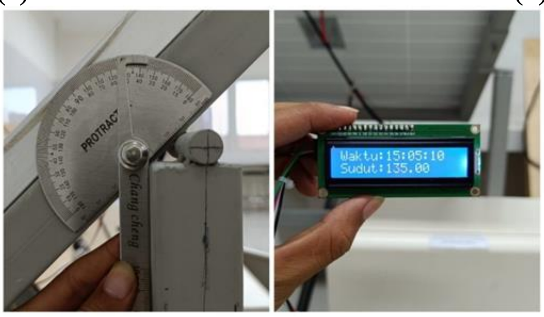
After getting 8 seconds to move the actuator, the solar panel was tested starting from 09.00 WIB to 15.00 WIB as shown in Figure 7.



(a)



(b)



(c)

Figure 7. a) Starting Position (09.00 am), b) Middle Position (12.00 pm), c) Final Position (03.00 pm)

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Table 3 shows the angle test at 09.00 WIB to 15.00 WIB using a solar tracker. The resulting angle difference is 45 degrees every 3 hours.

Table 3. Solar Panel Testing Based on Measured Angles

Time	Solar Panel Angle
09.00	45°
12.00	90°
15.00	135°

3.3 Solar Panel Testing Based on Measured Angles

After testing the angle with a solar tracker, the next step is to test the IoT-based solar tracker using the Blynk application as shown in the design in Figure 1. The tool test is shown in Figure 7, while Table 4 shows the angles measured from 09.00 WIB to 15.00 WIB according to the reference [11].

Table 4. Solar Tracker Testing Angle Every 30 Minutes

Time	Solar Panel Angle
09.00	45.0°
09.30	52.5°
10.00	60.0°
10.30	67.5°
11.00	75.5°
11.30	82.5°
12.00	90.0°
12.30	97.5°
13.00	104.5°
13.30	113.5°
14.00	120.0°
14.30	127.5°
15.00	136.0°

Figure 8 shows the testing of the tool, namely solar panels using an IoT-based solar tracker with the blynk platform. The tool was tested in the UNIPMA integrated laboratory building.

Figure 8. Assembling Equipment and Testing Solar Tracker

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3.4 Result of Current, Voltage and Power

Data collection is carried out by measuring current, voltage and power at each tilt angle reached by the solar panel. Testing is carried out for 7 hours and is tested every 30 minutes, starting from 09.00 WIB to 15.00 WIB. The test was carried out at that hour because sunlight is efficient for only 7 hours [8]. The following is the current, voltage and power data obtained (Table 5).

Table 5. Test Current, Voltage and Power with a Solar Tracker Every 30 Minutes

Time	Angle (°)	Current (A)	Voltage (V)	Power (W)
09.00	45.0°	0.34	16.68	5.7
09.30	52.5°	0.33	17.18	5.6
10.00	60.0°	0.34	18.14	6.1
10.30	67.5°	0.34	17.66	6.1
11.00	75.0°	0.81	17.96	14.5
11.30	82.5°	1.87	20.60	38.6
12.00	90.0°	1.65	19.84	32.8
12.30	97.5°	1.04	20.11	21.0
13.00	105.0°	0.82	19.88	16.4
13.30	112.5°	0.28	20.05	5.7
14.00	120.0°	0.92	18.55	17.1
14.30	127.5°	0.67	18.81	12.6
15.00	135.0°	0.31	17.64	5.4
Average		0.74	18.70	14.4
Minimum		0.28	16.68	5.4
Maximum		1.87	20.60	38.6

Researchers tested the entire tool to find out the output results obtained by a 50wp solar panel using the INA219 sensor and watt meter as a comparison. The test was carried out for 7 days with 7 measurements, namely from 09.00 WIB to 15.00 WIB, this was done to determine the difference in voltage and current produced by the solar panels as shown in Table 5 and Table 6.

Table 6. Voltage and Current Measurement without a Solar Tracker with the INA219 Sensor Every Day

Day	Voltage (volt)	Current (Ampere)
1	17.77	0.54
2	17.79	0.48
3	16.46	0.44
4	19.10	0.71
5	18.31	0.67
6	18.22	0.83
7	18.04	0.61
Average	17.90	0.61

The results of current, voltage and power measurements for each hour are shown in Table 7 to Table 13.

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Table 7. Day 1 Measurements Measured Current, Voltage and Power Every Hour

Time	Watt Meter			Sensor INA219		
	Voltage (Volt)	Current (Ampere)	Power (Watt)	Voltage (Volt)	Current (Ampere)	Power (Watt)
9.00	16.72	0.51	8.53	15.92	0.43	6.85
10.00	17.27	0,46	7.94	17.01	0.41	6.97
11.00	18.30	0.49	8.97	17.98	0.39	7.01
12.00	19.86	1.02	20.26	19.12	0.63	12.05
13.00	18.47	0.46	8.50	17.97	0.42	7.55
14.00	17.12	0.43	7.36	16.49	0.38	6.27
15.00	16.67	0.44	7.33	16.14	0.40	6.46

Table 8. Day 2 Measurements Measured Current, Voltage and Power Every Hour

Time	Watt Meter			Sensor INA219		
	Voltage (Volt)	Current (Ampere)	Power (Watt)	Voltage (Volt)	Current (Ampere)	Power (Watt)
9.00	17.78	0.51	9.07	16.92	0.42	7.11
10.00	17.76	0.51	9.06	16.89	0.42	7.09
11.00	18.04	0.41	7.40	17.14	0.38	6.51
12.00	19.62	0.62	12.16	19.02	0.45	8.56
13.00	17.06	0.34	5.80	16.76	0.41	6.87
14.00	17.41	0.45	7.83	16.64	0.41	6.82
15.00	16.84	0.52	8.76	16.24	0.40	6.50

Table 9. Day 3 Measurements Measured Current, Voltage and Power Every Hour

Time	Watt Meter			Sensor INA219		
	Voltage (Volt)	Current (Ampere)	Power (Watt)	Voltage (Volt)	Current (Ampere)	Power (Watt)
9.00	15.11	0.48	7.25	14.51	0.41	5.95
10.00	17.12	0.49	8.39	16.91	0.41	6.93
11.00	17.91	0.41	7.34	17.24	0.41	7.07
12.00	16.71	0.45	7.52	16.35	0.42	6.87
13.00	16.94	0.41	6.95	16.57	0.41	6.79
14.00	15.18	0.44	6.68	14.52	0.42	6.10
15.00	16.23	0.41	6.65	16.12	0.41	6.61

Table 10. Day 4 Measurements Measured Current, Voltage and Power Every Hour

Time	Watt Meter			Sensor INA219		
	Voltage (Volt)	Current (Ampere)	Power (Watt)	Voltage (Volt)	Current (Ampere)	Power (Watt)
9.00	18.91	0.44	8.32	18.21	0.41	7.47
10.00	19.02	0.44	8.37	18.56	0.33	6.12

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11.00	19.12	0.59	11.28	18.61	0.51	9.49
12.00	19.47	1.10	21.42	18.78	0.61	11.46
13.00	19.36	0.99	19.17	18.67	0.51	9.52
14.00	18.95	0.87	16.49	18.08	0.51	9.22
15.00	18.90	0.51	9.64	18.55	0.51	9.46

Table 11. Day 5 Measurements Measured Current, Voltage and Power Every Hour

	Watt Meter			Sensor INA219		
Time	Voltage (Volt)	Current (Ampere)	Power (Watt)	Voltage (Volt)	Current (Ampere)	Power (Watt)
9.00	19.02	0.54	10.27	18.54	0.41	7.60
10.00	19.38	0.56	10.85	18.76	0.41	7.69
11.00	19.75	0.68	13.43	19.20	0.42	8.06
12.00	19.30	1.04	20.07	19.01	0.42	7.98
13.00	18.95	0.99	18.76	18.07	0.42	7.59
14.00	16.12	0.44	7.09	15.52	0.41	6.36
15.00	15.65	0.45	7.04	15.18	0.41	6.22

Table 12. Day 6 Measurements Measured Current, Voltage and Power Every Hour

	Watt Meter			Sensor INA219		
Time	Voltage (Volt)	Current (Ampere)	Power (Watt)	Voltage (Volt)	Current (Ampere)	Power (Watt)
9.00	18.15	0.82	14.88	17.02	0.52	8.85
10.00	17.98	0.82	14.74	17.14	0.52	8.91
11.00	17.71	0.84	14.88	17.07	0.53	9.05
12.00	17.99	0.82	14.75	17.27	0.52	8.98
13.00	19.88	0.98	19.48	19.17	0.52	9.97
14.00	19.01	0.99	18.82	18.22	0.65	11.84
15.00	16.81	0.52	8.74	16.14	0.51	8.23

Table 13. Day 7 Measurements Measured Current, Voltage and Power Every Hour

	Watt meter			Sensor INA219		
Time	Voltage (Volt)	Current (Ampere)	Power (Watt)	Voltage (Volt)	Current (Ampere)	Power (Watt)
9.00	18.75	0.65	12.19	18.03	0.42	7.57
10.00	19.22	0.98	18.84	18.62	0.42	7.82
11.00	18.15	0.55	9.98	17.89	0.42	7.51
12.00	18.85	0.55	10.37	18.19	0.45	8.19
13.00	16.94	0.51	8.64	16.18	0.45	7.28
14.00	17.86	0.51	9.11	17.12	0.41	7.02
15.00	16.48	0.51	8.40	15.78	0.41	6.47

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Tables 7 to Table 13 show the measurement results for 7 days and you can see the differences in current, voltage and power each day. The results obtained are quite stable. This is influenced by the intensity of light from the sun which is relatively stable due to the climate. The average power results produced by the sensor during the 7 days of measurement are shown in Table 14.

Table 14. Average Power Everyday without Solar Tracker

Time	Power (Watt)
Day 1	9.84
Day 2	8.58
Day 3	7.25
Day 4	13.53
Day 5	12.50
Day 6	15.19
Day 7	11.08
Average Power	11.04

The results of a comparison of the power produced by solar panels using a solar tracker and without a solar tracker are shown in Figure 9. The most significant difference is on the first to third day, this is because the sun's heat is optimal without any cloudiness.

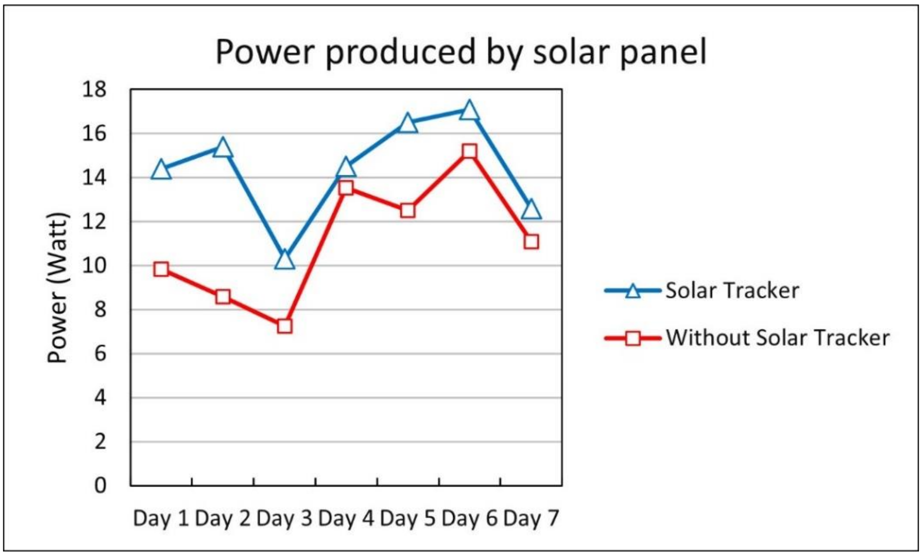

Figure 9. Comparison of the Power Produced by Solar Panels

4. Conclusion

Based on the results of the analysis of testing the design of an IoT-based solar panel monitoring system tool using Blynk with a solar tracker and without a solar tracker, the results of the discussion are as follows:

- Tests on a 50 wp solar panel using a solar tracker obtained an average current of 0.74 A, an average voltage of 18.7 Volts and an average power of 14.4 Watts. These results were obtained from testing during 09.00 WIB to 15.00 WIB.
- Testing the INA219 sensor is known to be able to read the output results from the power supply for comparison. The test was carried out 11 times with an accuracy difference of less than 5%.
- For overall testing, solar panel measurements without a solar tracker were carried out for 7 days with a time interval of 7 hours. Testing uses the INA219 sensor. The test results show that the average daily power results obtained in Table 14 are 11.04 watts.

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- The test results in Table 4 and Table 14 can be seen that the test results show that the average output power produced using a solar tracker is 14.4 Watts and the power output without a solar tracker is 11.04 Watts. So, using a solar tracker makes the power output more optimal.

This research on IoT-based solar trackers has positive implications, namely that using IoT makes it easier to monitor output power so that it is easy to control. With this convenience, it is hoped that more solar panels will be built in various places, especially on the UNIPMA campus. By continuing to conduct research and development, solar panels can become an increasingly effective and sustainable solution for a cleaner and more sustainable future.

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