

PANELIZED ELECTRICAL POWER OUTPUT MONITORING SYSTEM INTEGRATED SOLAR WEB SERVER

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DevOps

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Abstract

In Indonesia, the duration of sunlight energy harvesting is around 7-8 hours per day. It is considered capable of generating electricity with photovoltaics (PV). Proper monitoring of solar panels can help identify and fix problems with solar panels. To overcome these problems, this research will develop a solar panel electrical power output monitoring system integrated with a Web Server using the Internet of Things that allows users to perform remote monitoring via smartphones and PCs. The method used in this research is the DevOps method. The results showed that the monitoring system of solar panel electrical power output integrated with Web Server runs well and can display data in real-time with a delay time of ± 0.50 ms. Furthermore, overall system testing was carried out from 08.00 to 16.00 with the maximum voltage and current generated of 5.13V and 0.176A. The efficiency value produced by the 10Wp solar panel is 94.16%.

1. Introduction

1.1. Introduction

In Indonesia, the duration of solar energy harvesting ranges from 7 to 8 hours, starting at 08:00 and ending at 16:00 each day, due to Indonesia's location on the equator, which provides ample sunlight year-round with a relatively high light intensity of around 4.8 kWh/m² daily (Suryanto & Asnil, 2021). In terms of benefits, using solar panels to generate electricity requires regular maintenance and monitoring efforts to improve efficiency and ensure optimal performance. This monitoring can help identify and fix issues with solar panels, such as damage to electrical systems or photovoltaic cells. Proper supervision also helps optimize and maximize energy-to-electricity conversion by the solar panels. Poor monitoring can lead to partial loss of generated electrical energy or undetected damage. Therefore, a monitoring system is necessary to track solar panel electrical power output in real time, prevent further damage, assess system performance, determine appropriate maintenance intervals, and ensure solar panels operate at peak efficiency. This research aims to develop a monitoring system for the electrical power output from solar panels integrated with a Web Server using the Internet of Things, enabling users to monitor remotely via smartphones and PCs. With this system, users can optimize electrical energy use from solar panels in real time remotely, calculate the efficiency of the panels, and detect problems early faster.

2. Methods

This research utilizes the DevOps method, which emphasizes collaboration and communication between development and operation teams to enhance effectiveness and efficiency. The DevOps approach is also chosen because it can accelerate data delivery and help detect problems when errors occur. There are eight stages in the DevOps process: planning, coding,

development, testing, release, deployment, operation, and monitoring (Alnafessah et al., 2021). This study involves both hardware and software components, making the DevOps methodology suitable for optimizing system development and operation toward greater effectiveness and efficiency, in line with the research objectives, namely, producing and testing a monitoring system for the output of converted electrical power from solar panels. The tools and materials used in this research are designated for data collection, transmission, and processing within the system. The primary components include 10 Wp polycrystalline silicon solar panels, a Wemos D1 Mini ESP8266 microcontroller, an INA219 sensor, a BH1750 sensor, and a DHT22 sensor. Table 1 presents the specifications of the solar panels panel.

Table I. 10Wp solar panel specification

Category	Information
Power Rating (1000W/ 25°C)	$P_{mp} = 10$ Watt
Voltage At Maximum Power	$V_{mp} = 17.4$ Volt
Current at Maximum Power	$I_{mp} = 0.65$ Ampere
Open Circuit Voltage	$V_{oc} = 21.6$ Volt
Short Circuit Current	$I_{sc} = 0.61A$
Maximum System Voltage	1000 Volt
Temperature Coefficient at Maximum Power	-0.47°C
Operating Temperature	-40°C – 85°C
Maximum Series Fuse Rating	15A
Solar Cell Dimensions	380 x 310 x 17 mm

The hardware design includes a series of components connected and integrated to form a monitoring system that aims to ensure the system operates as intended. Figure 1 shows the system block diagram with solar panels and sensors as system inputs. In the process stage, a Wemos D1 Mini ESP8266 microcontroller is used to process data from sensors and also functions as a Wi-Fi module to transmit and receive data wirelessly, allowing it to be sent to the database server, specifically the Ubidots cloud database. Data stored in the database will be displayed on the Web Server as part of the system output.

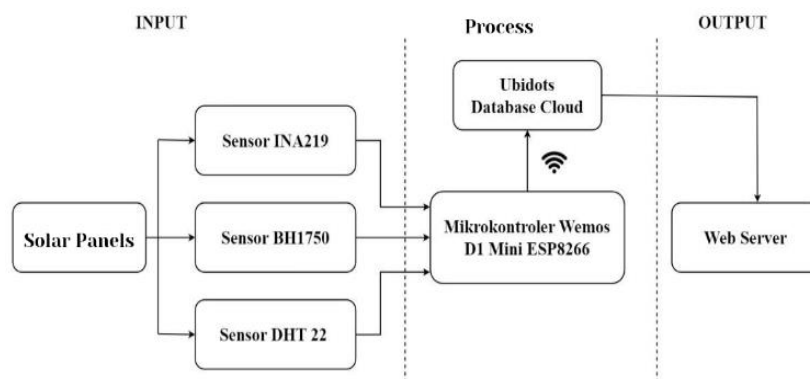


Figure 1. System block diagram

3. Results and Discussion

In the initial test, a calibration is performed on each sensor to improve the accuracy of the sensor readings used in system testing. Afterward, system testing is conducted to evaluate the system's reliability and the accuracy of each reading sensor.

3.1. Voltage Sensor Testing

This test compares the voltage reading from the INA219 sensor in the Arduino IDE with that from a digital multimeter. The testing phase begins with connecting a DC power supply and applying voltage variations from low to high, ranging from 9V to 13V.

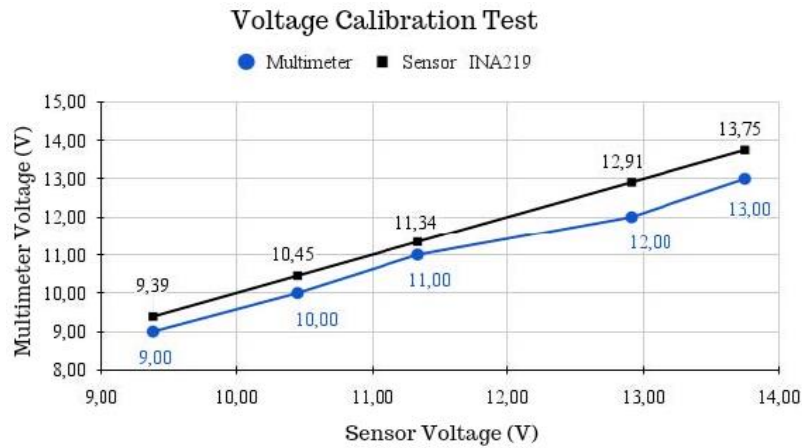


Figure 2. Comparison chart of voltage sensor testing

The test results shown in Figure 2 show that there are still differences in voltage values between the INA219 sensor and a digital multimeter caused by environmental temperature factors, noise in the microcontroller, and differences in sensitivity in voltage sensor readings with an average difference value of 0.56 and an average error value of 5% with an accuracy level of 95%.

3.2. Current Sensor Testing

This test is done by comparing the measurement results of the system device connected to the microcontroller with a digital multimeter by connecting a DC power supply and providing a voltage that is varied between 9V to 13V with a fixed difference. The maximum current that can be detected by the INA219 sensor is 3.2A.

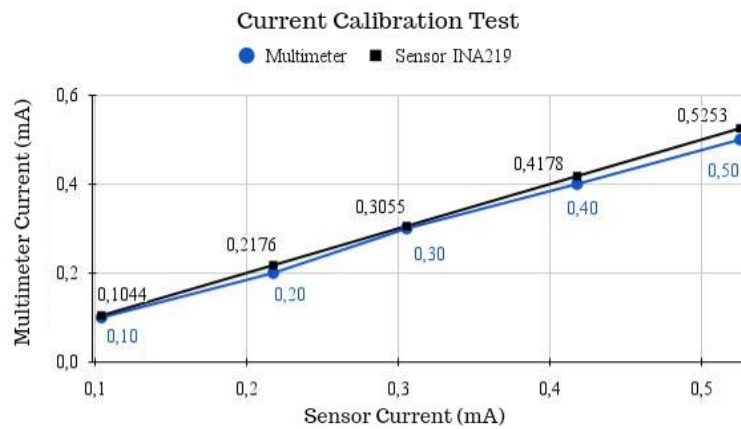


Figure 3. Comparison chart of current sensor testing.

The test results in Figure 3 show a difference in the measurement of the INA219 sensor's current value compared to a digital multimeter, with an average difference of 0.01 and an average error of 4.8%, resulting in an accuracy level of 95.12%. The graph indicates that the measurements overlap, meaning the sensor readings are close to the multimeter readings, but some reading errors still occur at specific points.

3.3. Light Intensity Sensor Testing

Testing is done by comparing the value measured by the BH1750 sensor with the lux meter instrument. From the test results shown in Figure 4, it is known that the test is conducted every hour from 08:00 to 16:00 to observe the difference in light intensity as the sun rises and shines brightly until it begins to dim in the afternoon. The average difference value is 108.65, and the average error is 6.3%, with an accuracy level of 92.9%. The BH1750 sensor can measure up to 55,000 Lux. If the light intensity exceeds this value, the data cannot be read (Perdana & Rosma, 2020).

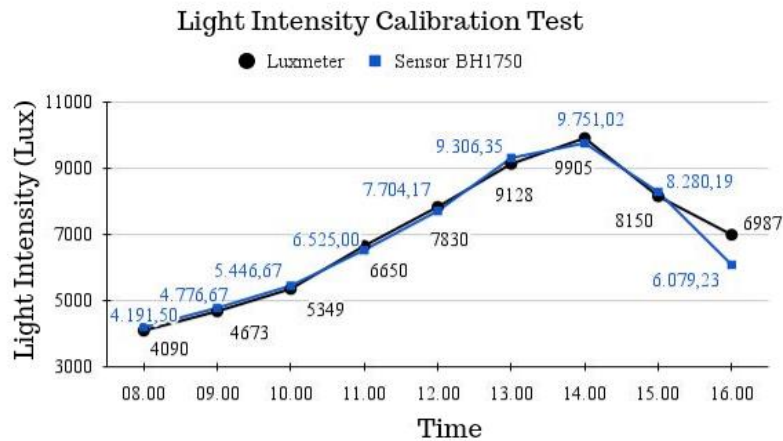


Figure 4. Comparison chart of light intensity sensors

3.4. Temperature Sensor Testing

In this test, the temperature measured is the ambient temperature around the solar panel. The temperature sensor uses the DHT22 module, which compares sensor readings with a digital thermometer.

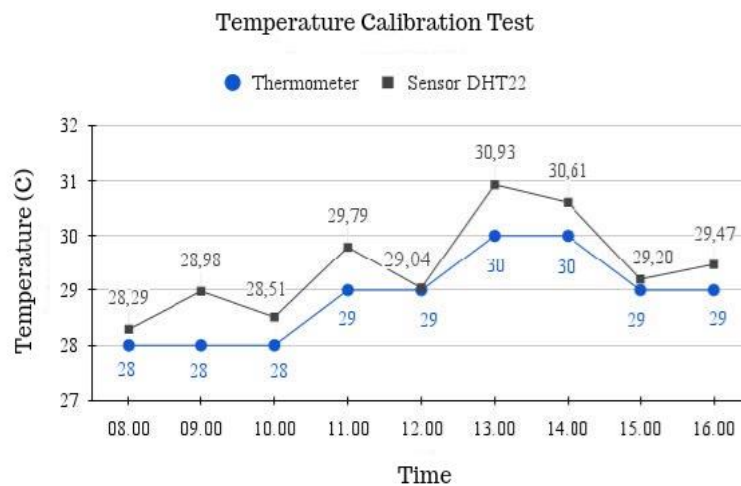


Figure 5. Comparison chart of temperature sensor testing.

Temperature sensor testing is conducted every hour with 9 trials from 08:00 to 16:00. Based on testing the current sensor, the average difference is 0.53, the average error is 1.8%, and the accuracy is 98%. Therefore, the DHT22 sensor is considered capable of operating properly for data collection during system-wide testing. Figure 5 is a graph of the temperature sensor results comparison.

3.5. No-Load System Testing

After testing each sensor's calibration, the next step is to evaluate the entire system to determine if the microcontroller can effectively receive data from each parameter, transmit it to the Web Server, and observe its impact on the solar power output panel.

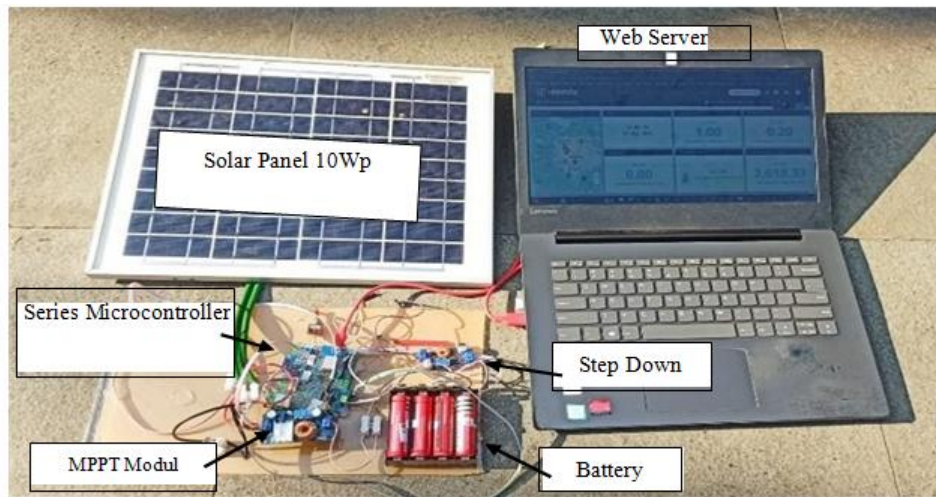


Figure 6. Monitoring data collection table 2.

Table 2. System testing result voltage, current, and power (no load)

Time	Voltage (V)	Current (A)	Power (mW)	Light Intensity (Lux)	Solar Radiation (Watt/m ²)	Temperature (°C)
08.00	5,01	0,059	0,296	4.011,89	38,07	28,17
08.30	5,12	0,069	0,353	4.509,23	38,97	28,34
09.00	5,03	0,076	0,382	4.951,34	40,29	28,92
09.30	5,05	0,085	0,429	5.386,61	41,54	29,03
10.00	5,09	0,100	0,509	5.899,55	45,36	29,19
10.30	5,11	0,111	0,567	6.245,90	52,28	29,56
11.00	5,06	0,110	0,557	6.474,38	59,95	29,65
11.30	5,13	0,113	0,580	6.968,97	64,53	29,93
12.00	5,09	0,126	0,641	7.198,96	66,66	30,17
12.30	5,08	0,143	0,726	7.723,54	71,51	30,21
13.00	5,04	0,157	0,790	8.092,00	74,92	30,46
13.30	5,13	0,170	0,872	9.218,65	85,36	30,21
14.00	5,01	0,176	0,882	9.590,56	88,74	29,98
14.30	5,11	0,170	0,869	9.377,68	86,83	29,81
15.00	4,99	0,146	0,729	8.245,89	76,35	29,78
15.30	4,98	0,127	0,632	7.137,23	66,08	29,45
16.00	5,00	0,120	0,600	6.091,86	56,36	29,14

Testing of the entire system was conducted on Saturday, May 20, 2023, over an 8-hour period from 8:00 p.m. to 4:00 p.m., in the courtyard of Building B11, Faculty of Engineering, State University of Malang, as shown in Figure 2. The test results are summarized by collecting data samples every 30 minutes. Table 2 displays the overall system test results. The test conducted in sunny weather indicates that the voltage remains stable, ranging from 4.98V to 5.13V. The highest measured current is 0.176A, while the lowest is 0.059A. The data show that the maximum power output is 0.882W at 2:00 p.m., with a light intensity of 9,590.56 Lux and a temperature of 29.98°C. The results are affected by the solar panel temperature, sunlight intensity, and the panel's orientation relative to the sunlight (Fachri *et al.*, 2015). The output power of solar panels depends on how much sunlight the photovoltaic cells absorb, as more photons increase the release of electrons, producing electric current. As shown in the graph in Figure 3, the highest light intensity occurred at 2:00 p.m., reaching 9,590.56 Lux, generating 0.88W of power. Starting at 2:30 p.m., the light intensity decreased as sunlight declined, and the power output decreased, illustrating that light intensity and energy produced are directly proportional. The more sunlight the solar panels absorb, the more electricity they generate. Typically, about 15-20% of the solar energy absorbed is converted into electricity, while the rest becomes heat, raising the surface temperature of the solar panel (Gomaa *et al.*, 2020).

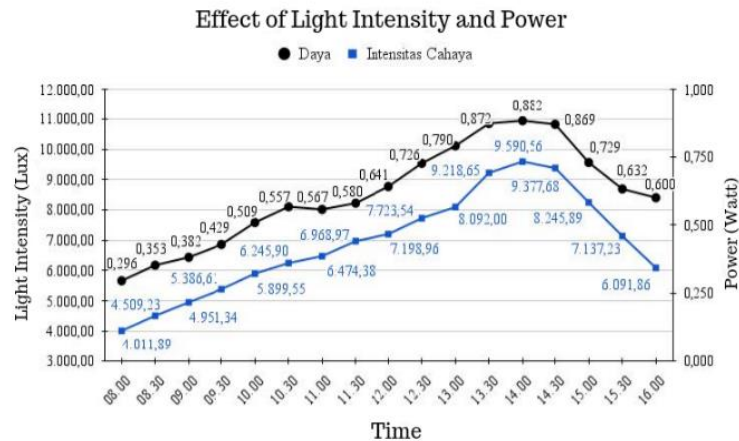


Figure 7. Graph of the effect of light intensity and power.

3.6. Load System Testing

Load system testing is conducted using a resistor load, with resistors of 56Ω, 39Ω, and 22Ω. According to the current measurement rules, the power source and load are measured in series. However, when measuring voltage, it is taken in parallel between the power source and the load. When testing the current sensor, measurements are made based on the load values resistor.

Table 3. Comparison of power values

Parameter	Resistor 56Ω	Resistor 39Ω	Resistor 22Ω
Calculation	0,4W	0,6W	1,1W
Multimeter Digital	0,4W	0,60W	1,10W
Sensor INA219	0,447W	0,641W	1,136W

The resistor's value influences the amount of current it allows to flow. A smaller resistor results in a higher current, while a larger resistor results in less current. This impacts the measurement range of the INA219 sensor, which is designed to measure current within a specific range, namely 0-26V and 0-3.2A. If the current exceeds this range, the measurements will become inaccurate, or the sensor may even be damaged.

3.7. Solar Panel Output Calculation

The calculation of solar panel output involves determining the input power (P_{in}), which is the power received by solar panels from sunlight; the fill factor (FF), which describes the power conversion efficiency of solar panels; and the output power (P_{out}) to find out what efficiency value ($\frac{P_{out}}{P_{in}}$) is produced by 10Wp solar panels in converting solar energy into electrical energy. When calculating the input power of solar panels, the calculations are based on the results of system testing under maximum sunlight intensity conditions. The surface area of the solar panels is obtained from their specifications, allowing for calculation as follows.

$$P_{in} = I_r \times A$$

$$P_{in} = 10,45 \text{ Watt}$$

Next, calculate the fill factor since V_{mp} , I_{mp} , V_{oc} , and I_{sc} are taken from the specifications of the solar panel module used. The fill factor is calculated as follows.

$$FF = \frac{(V_{pm}) \cdot (I_{pm})}{(V_{oc}) \cdot (I_{sc})}$$

$$FF = 0,74$$

In calculating the output power of a solar panel, the power (P_{out}) is determined by multiplying the open circuit voltage by the short circuit current (I_{sc}), and the fill factor (FF) produced by the photovoltaic cell is calculated as follows.

$$P_{out} = Voc \times I_{sc} \times FF$$

$$P_{out} = 9,84 \text{ Watt}$$

After obtaining the solar panel's input and output power values, the efficiency calculation can be done as follows.

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = 94,16\%$$

3.8. Display of the Monitoring System on the Web Server

The results of the monitoring system are displayed on the Web Server via the Ubidots platform. The main page of the Web Server dashboard is shown in Figure 4 and includes a research location card, a time and date card, and a card with five measurement parameters. It also features a tabular display of monitoring results data that users can download, as shown in Figure 8.

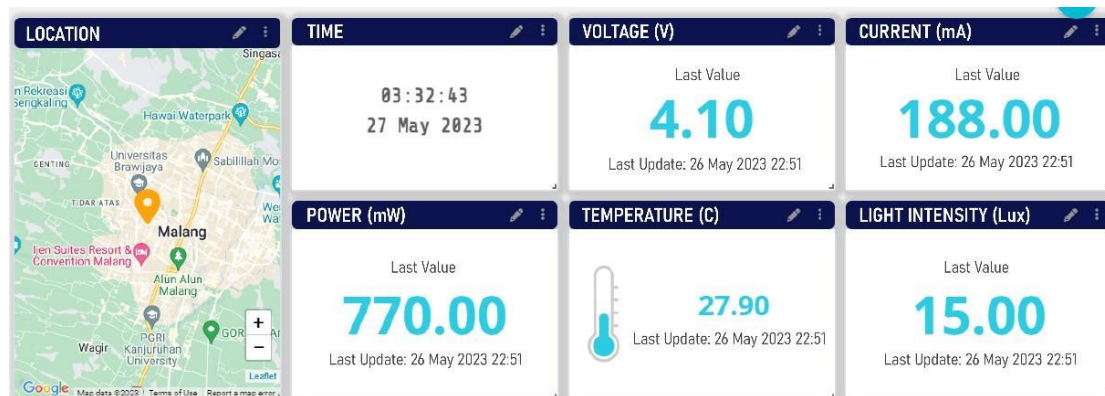


Figure 8. Main menu display of monitoring on web server.

Monitoring Data					
Time	Voltage (V)	Current (mA)	Power (mW)	Light Intensity (Lux)	Temperature (C)
2023/05/26 10:51:39	4.10	188.00	770.00	15.00	27.90
2023/05/26 10:51:28	4.10	188.50	766.00	20.83	27.90
2023/05/26 10:51:18	4.10	187.60	766.00	88.33	27.90
2023/05/26 10:51:07	4.10	187.90	766.00	186.67	27.90
2023/05/26 10:50:57	4.10	187.70	766.00	1433.33	28.00
2023/05/26 10:49:45	4.09	187.70	766.00	6.67	28.00

Figure 9. Display of monitoring results data on the web server.

4. Conclusion

Based on the research conducted, several conclusions can be drawn as follows: (1) The Web Server integrated solar panel electrical power output monitoring system operates well and can display data in real time with a delay of approximately ± 0.50 ms, which is affected by the stability of the internet network. Reading errors may also occur due to signal instability captured by the Wemos D1 Mini ESP8266 microcontroller. (2) To verify the system's proper operation, a sensor calibration test was performed. The results showed that the INA219 sensor had an error of 5% for

voltage and 4.8% for current, the BH1750 sensor had an error of 6.3%, and the DHT22 sensor had an error of 1.8%. Subsequently, the entire system was tested from 08:00 to 16:00, with maximum voltage and current readings of 5.13V and 0.176A. Additional testing involved load resistors of 56 Ω , 39 Ω , and 22 Ω to assess how load affects the measurement range of the INA219 sensor. (3) The efficiency of a 10Wp solar panel was found to be 94.16%. System testing results indicated that sunlight intensity increased steadily from 08:00 to 16:00, reaching a maximum of 9,590.56 Lux at 14:00, when the sun was shining brightly, enabling it to produce 0.882W of power.

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