Journal of Experimental and Applied Physics
Journal Homepage: jeap.ppj.unp.ac.id
Vol. 2, No. 2, June 2024.
ISSN (Print): 2988-0378 ISSN (Online): 2987-9256

Comparison of Power Absorption Effectiveness of Dynamic Solar Panels and Static Solar Panels at an Angle of 15°

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Article History
Received : June, 11th 2024
Revised : June, 27th 2024
Accepted : June, 30th 2024
Published : June, 30th 2024

DOI:
https://doi.org/10.24036/jeap.v2i2.56

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Abstract: This study aims to determine the performance specifications and design of the measurement system so that it can measure the effectiveness of the two panel systems. The performance specifications of this system use 2 20Wp solar panels for both systems, namely static solar panels and dynamic systems, namely dual-axis solar trackers. Voltage and current measurements use INA219 sensors and are displayed and stored using a serial Bluetooth terminal as a data logger. Design specifications for The results of this linearity test show very satisfactory results in terms of measurements on voltage and current parameters, namely the R-Square value, which reaches 1 and 0.99. The accuracy of the INA219 sensor is 97.78% for voltage and 96.21% for current. The precision of the INA219 sensor for voltage is 100% and 91% for current. Based on these data, it can be said that this tool works well. The measurement results of the increase in solar panel power absorption are compared between the static solar panel system at an angle of 15 ° to the north and the dynamic solar panel system with the dua-axis solar tracker method. The power generated by the static solar panel system is 3229.81 watts, and the power generated by the dual-axis solar tracker system is 3865.92 watts, with a percentage increase in power of 19.7%. It can be concluded that the dual-axis solar tracker system is more efficient in generating power compared to static systems.

Keywords: Solar Cell; Dual-Axis Solar Tracker; Static Solar Panel.

1. Introduction

The sun is the main energy source that delivers a large amount of energy to the Earth's surface [1]. The potential of solar energy can be used to benefit the human living environment in various fields such as agriculture, plantations, fisheries, the growth of the solar cell industry as a substitute for fossil fuels, and many more [2]. The need for electrical energy is increasing in modern times, so to overcome the increase in the use of electrical energy, it is necessary to add energy from other sources. It is estimated that energy demand in Indonesia will grow by about 4.27% annually

How to cite:
W.A. Fauzi, Mairizwan, Yulkifli, 2024, Comparison of Power Absorption Effectiveness of Dynamic Solar Panels and Static Solar Panels at an Angle of 15°, *Journal of Experimental and Applied Physics,* Vol.2, No.2, page 37-50.
https://doi.org/10.24036/jeap.v2i2.56

between 2011 and 2030 [3]. Indonesia, with its location on the equator and tropical climate, where the Indonesian region will always be illuminated by the sun for 10–12 hours every day, has enormous solar energy potential [4]. Indonesia has a very high solar energy capacity of about 4.8 KWh/m2 per day [5].

Solar cells are a group of photovoltaic cells that convert solar energy directly into electrical energy in the form of direct current (DC). This semiconductor material has an interaction between electrons and holes when exposed to light with Eg > 1 eV. After that, there will be a flow of holes and electrons in the opposite direction, creating a current flow that, when connected to a load, will generate electricity. Each electron and hole will return to their initial concentration after the light source is turned off abruptly, when the electrons and holes are not exposed to light. Recombination is the process of returning the concentration of electrons and holes to their initial state. As a result, once the recombination process begins, energy is no longer stored in the solar cell and will instead be lost. In order for the free electrons and holes to escape through the external load and supply energy to the load, this obviously requires a long lifetime or a low recombination rate [6].

Optimal power extraction from photovoltaic (PV) systems is a major goal of researchers and businesses. Before the installation process, an appropriate and effective model is needed to improve the quality of energy delivered by the PV module [7]. The higher the efficiency level of the solar panel, the greater the amount of electrical energy produced [8]. A well-designed solar tracking system can increase production efficiency by about 40-50% [9]. There are several solar PV module models proposed, including static and dynamic PV models. Solar trackers are divided into two main categories, depending on the way they rotate including one-axis trackers and two-axis trackers [10]. Single-axis solar trackers are only able to follow the movement of sunlight by rotating about a horizontal or vertical axis [11]. A two-axis solar tracker is a tracking device that uses vertical and horizontal rotation axes to move the location of solar panels while following the path of the sun. Four light sensors are positioned on the east, west, south, and north axes of the two-axis solar tracker device, and two motors are mounted on each axis as drives. The solar panel is not perpendicular to the sunlight when one of the sensors gets more sunlight intensity than the others, so the controller will choose which of the two motors should be driven. In addition, it shows that the solar sail is perpendicular to the sun when all four light sensors measure the same amount of sunlight [12]. The closed-loop control system present in the servo motor is useful for regulating or controlling the movement and final position of the servo motor shaft. Broadly speaking, the brief explanation is that the input control will send a control signal so that the shaft position is exactly in the required position, and the shaft position will be sensorized to find out whether the shaft position is as desired or not [13].

In the research "Comparative Analysis of Static Solar Cell Energy with Dynamic Solar Cell Energy Using Arduino Uno R3-Based Data Logger" described by Wahidah [14]. Using an Arduino Uno-based data logger, this research compares the energy results of static solar cells installed horizontally (0° angle) with dynamic solar cells. A sensor that can measure the voltage and current coming from the solar panel is needed in the design of this tool. In addition to the current and voltage sensors, an SD card module is also required to act as a data logger and an RTC to act as a timer. The tool design is broken down into two phases: hardware and software. "Comparative Analysis of 55 Watt Solar Panel Efficiency with Tracking and Without Tracking," described by Rahman [15], tests solar panels with two types, namely solar panels without solar trackers and solar panels with solar trackers. This test of solar panels without solar trackers was done by pointing the solar cells upwards at an angle of 0°, not towards sunlight. "Comparative Analysis of Solar Panel Electric Power Results with Solar Tracker and Without Solar Tracker" is described by Prasetiyo et al., [16]. A solar tracker is a device that uses light sensors to monitor the position of the sun and adjust the solar panels so that they are 90° perpendicular to the sun. This technology guarantees maximum power output and energy capture. A light sensor (LDR) is included with the single-axis solar tracker to help it determine the direction of the sun.

Based on these studies, previous research only compared static solar cells mounted at an angle of 0°. When solar cells are placed flat and there is no tilt, dust, dirt, and rainwater will collect on the surface of the solar panel. As a result, the effectiveness of the solar panel may be hindered, which is referred to as energy loss. The amount of electricity generated by solar panels can also be affected by their tilt position. The latitude of the solar panel placement location can be used to determine the tilt of the solar panel. Indonesia's astronomical location is 6°N–11°N, and Indonesia's location is mostly on the south side of the earth. The installation position for solar panels is expected to tilt 15° to the north [17].

Previous research still uses dynamic solar cells with a single-axis solar tracker. Dual-axis solar trackers can follow the sun's movement along the horizontal and vertical axes simultaneously, while single-axis solar trackers can only follow the sun's movement along one of these two axes, so that the power comparison value obtained is less than optimal.

Therefore, further study is needed related to this problem by using static solar cell installation at a 15° tilt to the north and dynamic solar cells with the development of a dual-axis solar tracker to produce maximum electrical energy by solar panels so that the comparative value of static solar cell power and dynamic solar cell power is known to be maximized. The power comparison value obtained can be used to determine the effectiveness of solar panel systems.

Static solar cell installations are positioned at a fixed 15° tilt to the north, utilizing a traditional yet effective approach to capture sunlight throughout the day. In contrast, dynamic solar cells with dual-axis solar trackers are designed to adjust their orientation continuously, ensuring they remain perpendicular to incoming sunlight. This dynamic approach potentially enhances energy yield by optimizing the panels' alignment with the sun's position.

Comparing the outputs of static and dynamic solar cell configurations will provide valuable insights into their respective efficiencies. By quantifying and analyzing the electrical output under various conditions, researchers can assess which system configuration offers superior performance in terms of energy generation. This comparative analysis is essential for determining the effectiveness and viability of solar panel systems aimed at maximizing energy production.

2. Materials and Method

The research is engineering research. Engineering research is a design process that requires new input at each stage, either in the form of procedures or prototypes [18]. The procedures of this research include finding ideas and clarity of tasks, creating design concepts, determining geometry and function arrangements, making detailed designs, creating modeling tools, and conducting tests. Ideas and task clarity are the initial stages in the research process. Ideas and task clarity can be obtained through a literature study from a variety of relevant sources by understanding and studying these sources. The design concept refers to the design used by the researcher as the researcher's realization stage before forming the research system to be created.

The design concept will be developed when the ideas for the research have been found. In the geometry and function arrangement, all components of the designed system will be arranged geometrically based on their functions. The following geometry arrangement of the dual-axis solar tracker system block diagram can be seen in Figure 1.

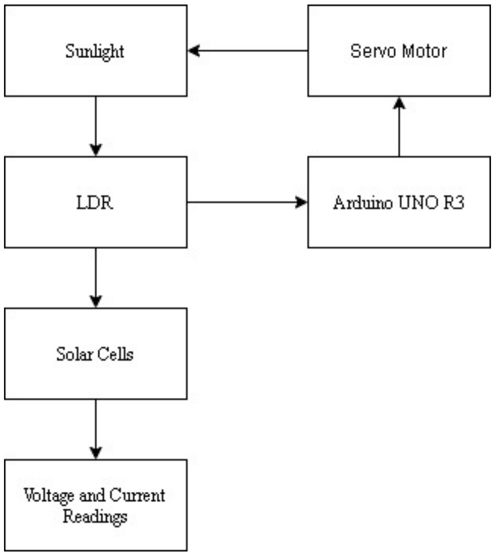


Figure 1. Solar tracker block diagram

The Arduino Uno commands the servo to follow the light source after the LDR sensor captures light from the sun. The Arduino Uno has a microprocessor with a 16 MHz oscillator that enables precise performance for time-based tasks [19]. The solar panel is not perpendicular to the sunlight when one of the sensors gets more sunlight intensity than the other, so the controller will choose which of the two motors should be driven to follow the sunlight. In addition, it shows that the solar panel is perpendicular to the sun when all four light sensors measure the same amount of sunlight. After that, the solar cell converts light energy into electrical energy, whose current and voltage are read by the current and voltage monitoring design as shown in Figure 2.

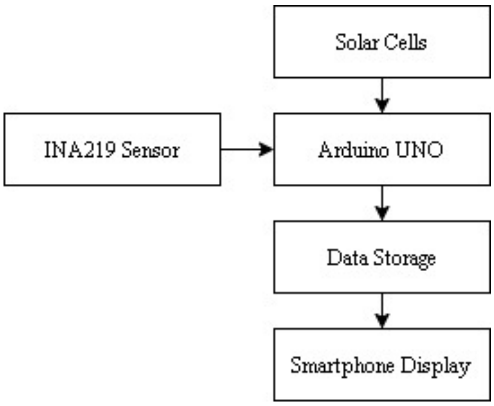


Figure 2. Block diagram of a measuring device

Solar cells will take solar energy and then convert it into electrical energy. The INA219 sensor will read the current and voltage values in real time, which are processed and programmed by the Arduino. After taking data from the INA219 sensor, the current data and voltage data will be stored, and then the data is sent to a smartphone using a Bluetooth module. Bluetooth is a wireless communication technology that works in the 2.4 GHz unlicensed ISM frequency band and uses frequency hopping tranceivers to provide real-time voice and data communication services between Bluetooth hosts with limited service coverage [20].

The detailed design of this research consists of hardware design and software design. This stage is the stage of combining the components used to form the prototype. The software functions as a command-giver by using a microcontroller to execute commands. The software is designed and made in such a way that the performance it produces meets the objectives to be achieved. The software design flowchart can be seen in Figure 3.

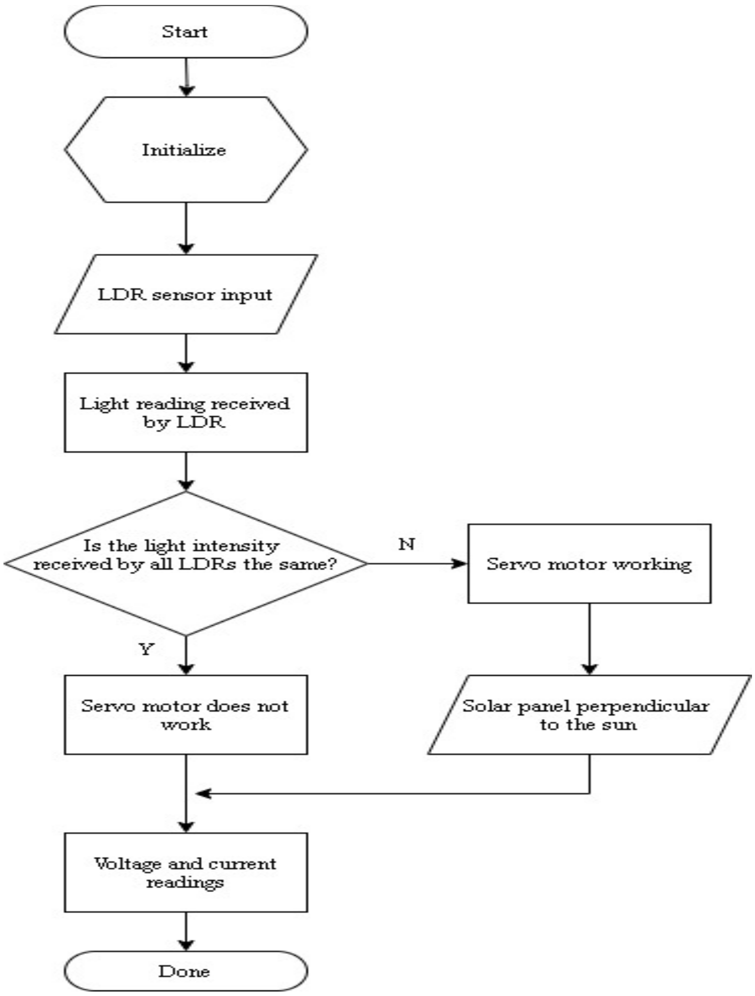


Figure 3. Software design flowchart

LDR detects the intensity of sunlight; when the four light sensors get the same intensity, then the servo motor will not work, but if not, then the servo motor will work so that the four LDRs get the same light intensity. The servo motor is operated by an Arduino, which functions to read the program from the light sensor (LDR). The servo motor will move according to the light intensity read by the LDR. Sunlight received by photovoltaic (PV) will be converted into voltage and current and will be read by the monitoring system.

The hardware design aims to make it easier to provide an overview of the shape of the system to be designed. The hardware design of the tool can be seen in Figure 4. The description of the numbers in the figure can be seen in Table 1.

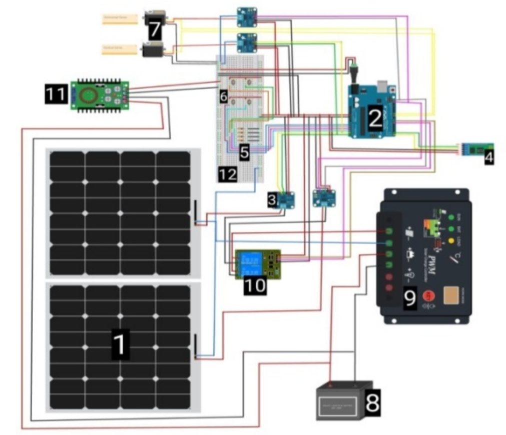


Figure 4. Hardware design

The sensor circuit is placed on a microcontroller, which in this case is an Arduino Uno. This microcontroller will be programmed to operate the sensor according to the planned function. In this arrangement, the Arduino Uno acts as the brain or central control that receives data from the connected sensors and then processes the data according to the logic or program that has been implemented. This programming process allows the sensors to interact and function in a coordinated manner according to the needs of the application or research being conducted. In this system, there is an INA219 sensor to measure the output power of the panel and a relay function for switching inputs on static and dynamic solar panels. Relays allow efficient and safe control of electrical devices that have high voltage [21]. The tools and materials used can be seen in Table 1.

Table 1. Tools and Materials

Number	Tools/Materials	Usage
1.	20 wp Solar Panel	Converts sunlight into electricity.
2.	Arduino UNO	Processing device to run the system
3.	INA219 Sensor	Knowing the power value
4.	HC-05 Bluetooth Module	Wireless serial communication
5.	Resistor	Limiting the current flow
6.	LDR	Sunlight intensity detector
7.	Servo Motor	Solar panel drive
8.	Battery	Storing energy
9.	Solar Charge Controller	Controlling the incoming current from the solar panel
10	Relay	Connecting or disconnecting electricity
11	Step Down Buck Converter	Lowering Voltage
12	Project Board	Media to unite the current connection
13	Arduino IDE	Software used to program Arduino

The device used in making the tool will be made in accordance with the design that has been described. Testing is carried out on the tool if the system has been completed. If testing has been carried out on the tool, it can conduct experiments in this study. Tool testing is the final stage of engineering research. This test is carried out to ensure the system can function properly. At this stage, there is data collection and analysis. Data analysis techniques are used to draw conclusions, assess the level of precision, and assess the accuracy of the measurement method [22]. The accuracy level of the sensor measurement results on the system is carried out by comparing the measurement results read in the application with the measurement results manually using standard measuring instruments so that the percentage error is obtained [23].

3. Results and Discussion

Specifications The results of the analysis that has been carried out, both through graphic methods and statistical analysis, reach conclusions that are in accordance with the research objectives. The findings of this research include the design specifications and performance specifications of the solar panel effectiveness measuring instrument, as well as the results of increasing the effectiveness of solar panels on stratic solar panels and dual-axis solar trackers. The performance specification and design specification of a solar panel system are two key aspects that must be considered when designing and installing a solar panel system. Performance specifications are obtained by identifying the role and performance of the components that make up the system. Meanwhile, design specifications are obtained through the process of collecting and analyzing data generated from the research that has been carried out.

Tool performance specifications refer to information that describes the capabilities and characteristics of a device or tool. These specifications are very important to understand the extent to which a tool can fulfill a given need or task. The initial result obtained is the performance specification of the sensor circuit used in this device. This system is divided into two parts, namely the tracker system and the solar panel output power monitoring system. In the tracker system, there are 4 LDRs connected to 4 resistors and then connected to the analog pin on the Arduino to detect the intensity of sunlight and provide information about the position of the sun in the sky, and there are two servo motors as panel drivers connected to the Arduino digital pin. In the monitoring system, there is an INA219 sensor as a measure of the output power of the panel and a relay that acts as a switching system that will alternately direct input from the solar panel output to the INA219 sensor. The microcontroller is in charge of controlling this switching system by regulating the alternation of inputs for static and dynamic solar panels, which are then displayed via a Bluetooth module. In addition, the system is also equipped with a solar charge controller (SCC) as a charging controller for the battery. Components such as the Arduino microcontroller, Bluetooth module, relay module, SCC, Step Down Buck Converter, and battery are arranged on an acrylic board that is placed under the dual-axis solar tracker. Based on the performance specifications on the serial Bluetooth terminal display, the process begins by downloading the serial Bluetooth terminal software and then connecting it to the Bluetooth module that has been installed on the Arduino Uno board. The results of the measurements and data displayed on the smartphone reflect what was previously only visible through the serial monitor in the Arduino IDE. The data display on the smartphone can be seen in Figure 5.

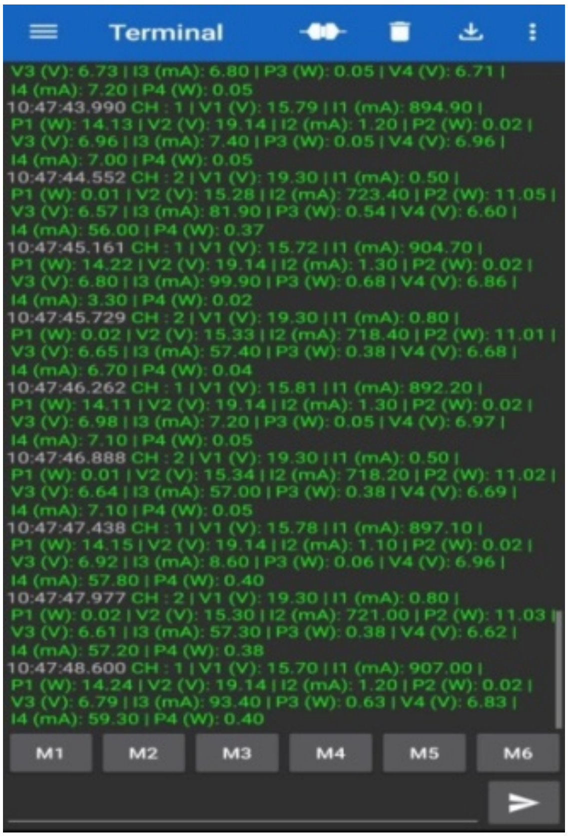
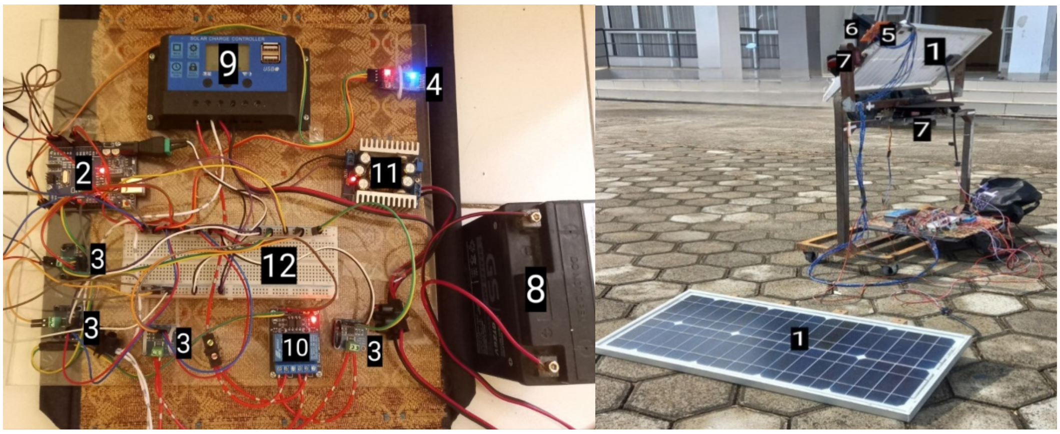


Figure 5. Data display on a smartphone

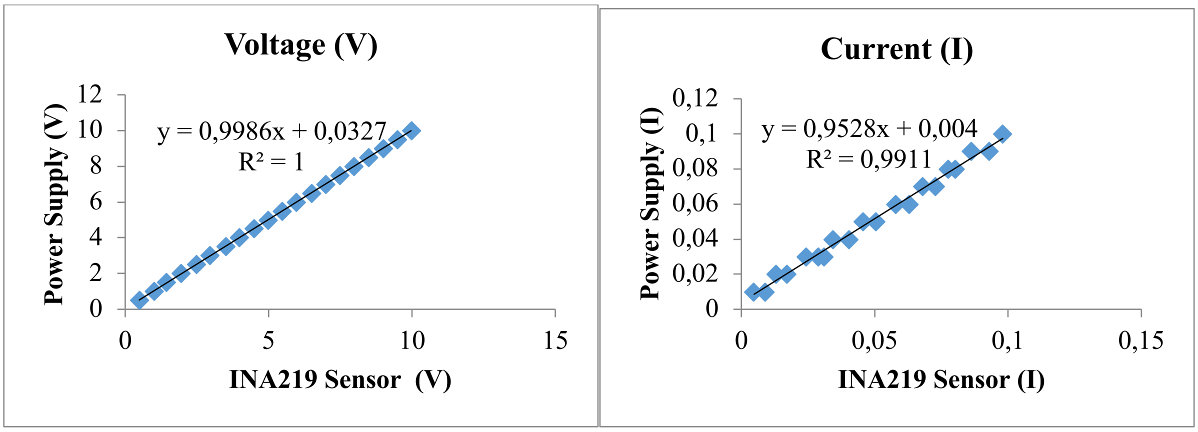
Another advantage is the device's ability to automatically save data in.txt format on a smartphone device, allowing users to monitor and record real-time data more easily and efficiently. In the installation of this effectiveness measurement system, different supports are used depending on the type of solar panel system used. The static solar panel system uses wood to form a fixed angle of 15° to the north, and the dual-axis solar tracker system uses iron that has been designed to move in the direction of the sun's movement. The results of the electronic circuit arrangement design and solar panel system installation design can be seen in Figure 6. The description of the numbers in the figure can be seen in Table 1.



(a) (b)

Figure 6. (a) Electronics circuitry design results and (b) Solar panel system installation design

The results of the design specifications are related to sensor characterization, namely the characterization of the INA219 sensor. The INA219 sensor has been tested for characterization, which involves evaluating the linearity of the sensor against a standard measuring instrument that has the ability to measure the same parameters, namely a multimeter. The results of this linearity test show very satisfactory results in terms of measurements on voltage and current parameters. R-Square values that reach 1 and 0.99 in the voltage and current parameters confirm that the INA219 sensor has a very high level of linearity in measuring voltage and current. This result is in accordance with the existing theory that the R-Square value describes the extent to which the line equation fits the data variation, and the value scale ranges from 0 to 1. When the R-Square value is close to 1, it indicates that the line equation used fits the data variation very well. In other words, the closer to 1 the R-Square value is, the better the line equation describes the variation in the data [24]. The graph of the INA219 sensor linearity test can be seen in Figure 7.



(a) (b)

Figure 7. (a) INA219 sensor voltage linearity test chart and (b) INA219 sensor currnet linearity test chart

The second design specification focuses on the accuracy of the INA219 sensor used for power measurement. In terms of voltage measurement accuracy, test results indicate an average percentage accuracy of 97.78%, with a corresponding error rate of approximately 2.22%. This suggests that the INA219 sensor reliably captures voltage levels with a high degree of precision. Detailed data for voltage parameters can be found in Table 2.

Table 2. Solar Panel System Accuracy (Voltage)

Multimeter (V)	INA219 Sensor (V)	Error (%)	Accuracy (%)
0.54	0.55	1.48	98.52
1.02	1.04	1.96	98.04
1.41	1.44	1.91	98.09
1.92	1.96	2.30	97.70
2.34	2.40	2.48	97.52
2.84	2.91	2.43	97.57
3.27	3.35	2.45	97.55
3.76	3.85	2.48	97.52
4.25	4.35	2.35	97.65
4.67	4.78	2.36	97.64
Average		2.22	97.78

Similarly, regarding current measurement accuracy, the INA219 sensor demonstrates an average percentage accuracy of 96.21%, with an average error rate of only about 3.79%. This indicates robust performance in accurately measuring current flow within the system. Further details on current parameters can be referenced in Table 3. These findings underscore the reliability and effectiveness of the INA219 sensor in accurately monitoring both voltage and current, crucial aspects for ensuring the precise measurement of power in the system. The low error rates observed validate its suitability for applications requiring accurate power measurement, thereby contributing to the overall fidelity and performance of the designed system.

Table 3. Solar Panel System Accuracy (Current)

Multimeter (mA)	INA219 Sensor (mA)	Error (%)	Accuracy (%)
5.45	5.7	4.59	95.41
10.25	10.6	3.41	96.59
14.25	14.8	3.86	96.14
19.32	20	3.52	96.48
23.63	24.5	3.68	96.32
28.68	29.8	3.91	96.09
33.07	34.3	3.72	96.28
37.98	39.3	3.48	96.52
42.9	44.7	4.20	95.80
47.4	49.1	3.59	96.41
Average		3.79	96.21

The third design specification involves evaluating the precision of the INA219 sensor through repeated measurements of voltage and current values over 10 repetitions. In assessing the precision of voltage measurements, an average precision of 100% was observed. This indicates that the variations in measured voltage values across multiple trials were minimal, suggesting high consistency and accuracy in the sensor's voltage readings. These results are detailed in Table 4, which documents the systematic data analysis for voltage parameters.

Table 4. Solar Panel System Precision (Voltage)

Measurement	V (V)	Average	Δx	Error (%)
1	5.03	5.03	0	100
2	5.03	5.03	0	100
3	5.03	5.03	0	100
4	5.03	5.03	0	100
5	5.03	5.03	0	100
6	5.03	5.03	0	100
7	5.03	5.03	0	100
8	5.03	5.03	0	100
9	5.03	5.03	0	100
10	5.03	5.03	0	100
Average				100

Conversely, the precision of current measurements averaged around 91%, as revealed in Table 5. Although slightly lower than the precision for voltage, a 91% average still signifies strong consistency and reliability in current measurements. This outcome underscores the effectiveness of the solar panel evaluation tool in accurately capturing and analyzing current data

Overall, the findings suggest that the INA219 sensor, utilized for both voltage and current measurements, performs admirably well in terms of precision. The high percentage values affirm the tool's capability to provide dependable and reproducible measurements, essential for assessing the efficiency and performance of solar panels with certainty.

Table 5. Solar Panel System Precision (Current)

Measurement	I (mA)	Average	Δx	Error (%)
1	24.2	24.1	0.1	90
2	24.1	24.1	0.0	100
3	24	24.1	0.1	90
4	23.9	24.1	0.2	80
5	24.3	24.1	0.2	80
6	24.1	24.1	0.0	100
7	24.1	24.1	0.0	100
8	24.3	24.1	0.2	80
9	24.1	24.1	0.0	100
10	24.2	24.1	0.1	90
Average				91

Referring to the existing theory, the higher the accuracy value achieved, the superior the performance of the tool. Also, the higher the precision value, the more accurate the measurement. This confirms that the INA219 sensor has an exceptional level of accuracy and precision, making it very suitable for detecting voltage and current. In other words, the higher the accuracy and precision, the better the INA219 sensor is at measuring voltage and current precisely [24].

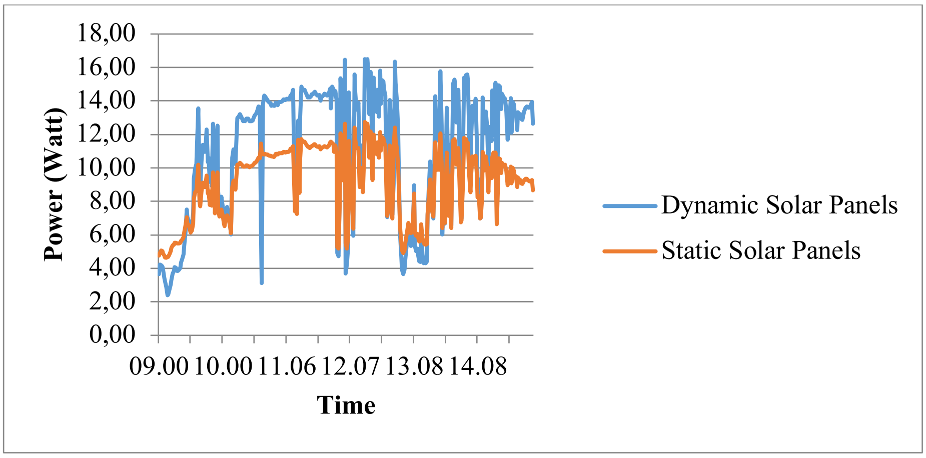


Figure 8. Solar panel power comparison chart

In this study, the performance of two types of solar panel systems was measured, namely static solar panel systems and dual-axis solar tracker systems. The measurement results show that the static solar panel system produces a total power of 3229.81 watts, with the maximum power occurring at 12:21 p.m., reaching 12.75 watts, while the minimum power is recorded at 09:07 a.m., with only 4.63 watts. On the other hand, the dual-axis solar tracker system produces a total power of 3865.92 Watts, with the peak power reaching 16.50 Watts at 12.21 WIB and the minimum power of 2.40 Watts at 09.08 WIB. A comparison graph of solar panel power can be seen in Figure 8.

Based on the comparative analysis of the total power generated by solar panels, it can be seen that the dual-axis solar tracker system produces more power than the static system. This shows that the dual-axis solar tracker system is more efficient in generating power compared to the static system, with a percentage increase in power of 19.7%.

These results were obtained in accordance with the reference journal, where it was found that solar panels with solar trackers absorb sunlight more effectively and efficiently than solar panels without solar trackers (static). The reason is because solar panels that use solar trackers are arranged to always be perpendicular to the direction of sunlight. This allows the solar panel to absorb more energy as it is always facing directly into the sun. Static solar panels, on the other hand, only stay in one particular position and cannot follow the movement of the sun, so they can only take advantage of the maximum intensity of sunlight when they are in that position [16]. The Earth's orbit has an elliptical shape, with one of its focal points being the sun. Since the sun moves in the sky and forms a constantly changing angle, a static position of the solar panel will not produce optimal electrical energy. To maximize energy collection, sunlight must always fall perpendicularly on the surface of the solar cell. Therefore, the solar cell system must be equipped with a controller that can adjust the orientation of the solar panel to always face the sun. In this way, energy collection from the sun can be optimized as the position of the sun changes while the Earth moves in its orbit [25].

4. Conclusion

This system uses INA219 sensors that function to measure two different physical parameters in order to measure the effectiveness of solar panels, namely voltage and current. The results of the performance specifications on the serial Bluetooth terminal display show that the process starts by downloading the serial Bluetooth terminal software, then connecting it to the Bluetooth module that has been installed on the Arduino Uno board. The results of the measurements and data displayed on the smartphone reflect what was previously only visible through the serial monitor in the Arduino IDE. The static solar panel system uses wood to form a fixed angle of 15° to the north, and the dual-axis solar tracker system uses iron that has been designed to move in the direction of the sun's movement. The test results show that the INA219 sensor has a linearity level of 1 for voltage and 0.99 for current. The INA219 sensor accuracy value is 97.78% for voltage and 96.21% for current. The precision value of the INA219 sensor is 100% for voltage and 91% for current. The power generated by the static solar panel system is 3229.81 watts, and the power generated by the dual-axis solar tracker system is 3865.92 watts, with a percentage increase in power of 19.7%. It can be concluded that the dual-axis solar tracker system is more efficient in generating power compared to static systems.

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