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Monitoring System for Solar Panel Characteristics Using the *Internet of Things* (IoT)

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ABSTRACT

Continuous monitoring of solar panel performance is essential to ensure effective and efficient generation of electrical energy. Developing a monitoring system such as an I-V characteristic curve tracker enables real-time monitoring and identification of potential problems or efficiency improvements. The system utilizes a circuit switching system for accurate and continuous measurement, providing insight into how the solar panel responds to changing environmental and load conditions. The data recorded by temperature, light intensity, current, and voltage sensors on the solar panel provides valuable information about its condition and the environmental factors affecting it. Utilizing IoT technology allows real-time monitoring of the data, accessible via a web page and presented graphically. The data is also stored in Excel format for further analysis, so users can access and monitor continuously as long as they are connected to the internet. From the experimental results, the Voc of the solar panel ranged from 18.7 V to 20.42 V, and Isc between 0.0727 A to 0.2145 A, which were tested under solar irradiation ranging from 100 to 500 W/m². This research demonstrates the importance of continuous monitoring and the effectiveness of the developed monitoring system in providing real-time data for analysis and optimization of solar panel performance. The system has been tested to meet the IEC No. 13B-23 standard for accuracy classes 0.2 and 0.5. A comparison between manual testing and sensor testing shows that despite the difference in accuracy levels, the sensor measurements have a relatively low average error (1.04% for voltage and 0.64% for current) compared to manual measurements, indicating that the sensor is reliable in providing accurate data. This demonstrates the reliability and effectiveness of using the sensor in the solar panel characteristics monitoring system.

Keywords: Solar panel performance, I-V characteristic curve tracker, IoT technology, Accuracy, Sensor reliability

1. Introduction

The Internet of Things (IoT) has changed the way renewable energy is understood and optimized, especially in the context of solar energy. The development of solar panels as alternative energy is becoming a major focus, with the testing of solar panel characteristics being an important concern. Various test methods, such as I-V, EL, thermal, and endurance, are used to ensure the performance and reliability of solar panels under various environmental conditions[1][2][3][4][5][6].

However, existing monitoring systems still have limitations in providing accurate and real-time information on solar panel performance. Therefore, this research designs a monitoring tool equipped with an automatic load variation system and supporting sensors. This aims to provide more accurate information about the performance of solar panels in various conditions, as well as detect problems early for faster and more efficient corrective action [7][8].

Some previous research has been done, but there are still limitations where previous research used microcontrollers and supporting sensors to measure the characteristics of solar panels, comparing polycrystalline and monocrystalline. This method is less accurate because testing is done in the field, causing limitations in measuring response and reliability to load changes [9] [10]. Another study examined the surface temperature characteristics of solar panels using the True Experimental Research method, but also experienced limitations in measuring the response to load changes because the tests were conducted outdoors[10].

From several studies that have been conducted, to maximize the use of panels, it is necessary to conduct research that aims to design a monitoring tool that can track the I-V curve and environmental parameters of solar panels in real time using the IoT Platform. By using a circuit switching system, this tool monitors the performance of solar panels at various load conditions and stores the data in Excel format. Users can access the data in real time through the website to analyze the performance of solar panels and their positional efficiency. This research is expected to maximize the use of solar panels, make it easier for users to manage the system, and identify and optimize the system.

2. Research method

The energy produced by PV is affected by changes in solar radiation and temperature. The higher the solar irradiation, the greater the current produced, and the effect of increasing temperature on PV will reduce the value of voltage and power produced [11]. Monitoring is the process of regularly collecting and analyzing data to evaluate the success of an activity or program. It enables the identification of problems and opportunities for improvement by providing information on status and trends over time. To improve performance and efficiency in the use of technology, a monitoring system is needed that can monitor important parameters of solar panels in real-time. In this tool design, a system is created to monitor the characteristics of solar panels more effectively, allowing integration with Excel spreadsheets [3]. Solar panels receive different variations in light intensity at all times, which is reflected in the I-V graph that describes the relationship between current and voltage on a solar cell. The characteristics of solar panel modules can be described through parameters such as open circuit voltage (Voc), short circuit current (Isc), fill factor (FF), maximum power (Pmax), maximum current (Im), maximum voltage (Vm), and efficiency (η). Understanding these parameters is important to optimize the performance and applications of solar panel modules [12].

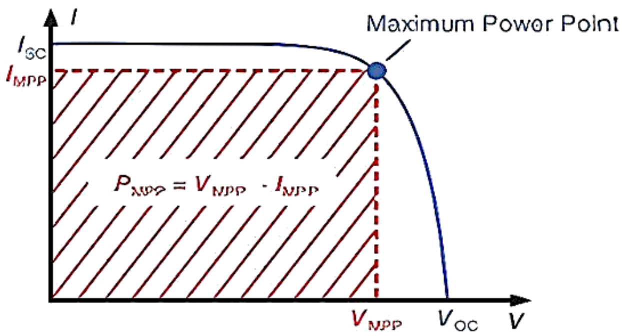

Figure 1. Current and Voltage Characteristics

The I-V characteristics of solar modules show that at the point of open circuit voltage (Voc) the current is zero, while at the point of short circuit current (Isc) the voltage is zero. Normal operation of the solar module achieves maximum power when the I-V characteristics are at the point of maximum power (Imp, Vmp). In the graph, the curve shows the relationship between current and voltage when the solar module is operating, and the peak is the point where the electrical power generated by the module is maximum.

2.1 Resistive load method for testing solar panel characteristics (I-V Curve Tracer)

The process of simplifying the I-V curve of a PV cell is done using a tool called an I-V characteristic curve tracer. Designing an I-V curve tracer requires careful planning to understand the overall output parameters of the solar cell. In designing the tool, research was conducted by applying the resistive load method, where the PV cell or PV module is directly connected to a variable resistor or resistive load bank. By changing the resistor value from minimum to maximum, the I-V trace from short circuit to open circuit can be moved, and the characteristic graph of the solar cell can be measured and simplified[13] [14] [8].

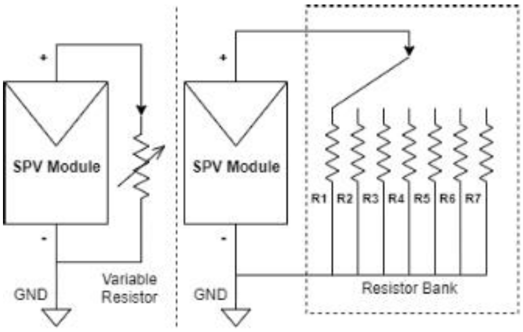

Figure 2. Resistive Load Method

2.2 Internet of Things (IoT)

Internet of Things (IoT) is a concept where physical objects are connected and communicate through the internet without human intervention. With the development of Internet infrastructure, almost all physical objects can be connected to the internet, allowing them to have an identity and communicate through the Internet network. in this research, an IoT platform will be used, namely thinger IO where Thinger.io provides various features for visualizing data collected from IoT devices. We can display data in the form of graphs, tables, or other widgets for easy understanding and analysis. Graphs can display data trends from sensors such as temperature, humidity, or light intensity. Tables can be used to display detailed data, such as sensor values at a specific time. [1][15][16][17][18].

2.3 Measurement Error Analysis

Precise and accurate measurements are important in many fields. The qualification standards for measuring instruments are described in IEC No. 13B-23, providing guidelines on the characteristics that measuring instruments must possess to ensure measurement accuracy. These standards cover accuracy, resolution, measurement range, stability, and other characteristics.

The standard specifies eight accuracy classes for measuring instruments, from class 0.05 to 5.0, which indicate the level of precision in measurement. The use of the appropriate accuracy class depends on the application and the level of precision required, with relative error calculations and statistical analysis of a series of measurements to assess the reliability of the measuring instrument.

3. Results and discussion

3.1 Blog diagram of working system

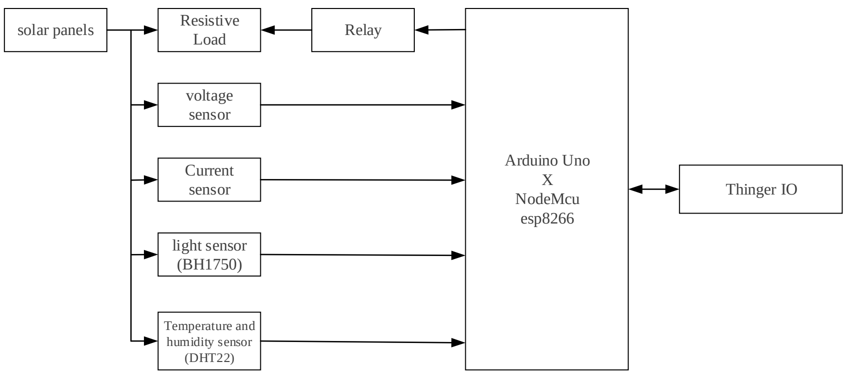

Figure 3. Diagram of Working system

Arduino UNO acts as the center of data processing from current, voltage, light, and temperature sensors on solar panels. The current and voltage sensors measure the current and voltage values produced by the solar panel, the BH1750 sensor measures the light intensity [19] [5], and the DHT11 sensor detects the temperature and humidity [20] [21][22] [23]. The data is processed by Arduino UNO and displayed in real-time on the ThingerIO platform, including a graph of the waves received from the sensors. This research tests the parameters of current, voltage, power, light intensity, temperature, and humidity to analyze the performance of solar panels.

3.2 Working principle of the system

It uses Arduino Uno as the main controller, with five relays (R1-R5) to adjust the load value and characteristics of the solar panel. INA219 current and voltage sensors, BH1750 light sensor, and DHT22 temperature and humidity sensor are connected to the Arduino Uno to read environmental data. The data from these sensors is collected in an array along with the relay configuration number, voltage (V), current (I), power (D), light level (LUX), humidity (H), and temperature (T). This data array is sent to the nodemcu via a serial connection, then to the cloud system to be processed by web services and sent to the application. The data obtained can be accessed in real time through the control station and the ThingerIO application on a smartphone or PC/computer.

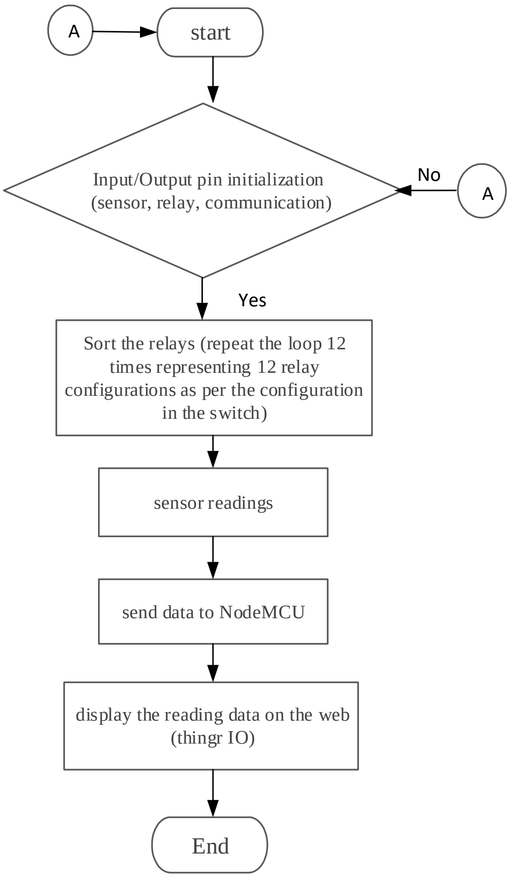

Figure 4. Flowchart program

3.3 Device testing process

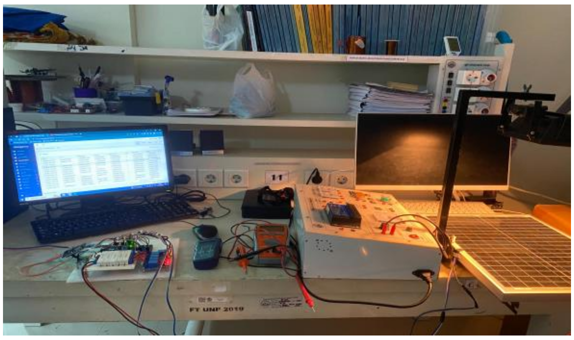

Figure 5. Hardware design results which are used for final testing of the system built.

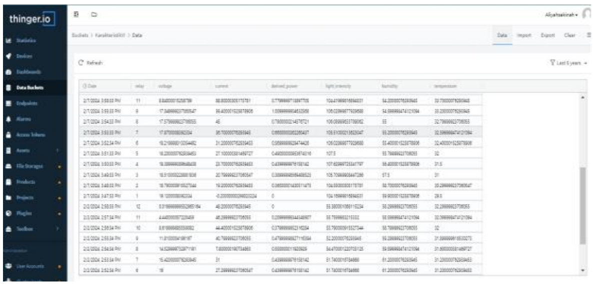

Figure 6. Data display on thinger IO that can be exported into excel form

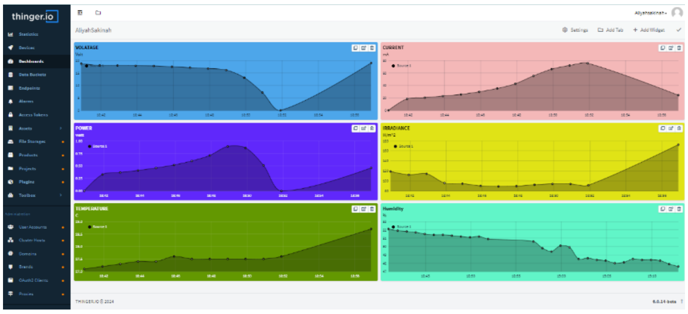

Figure 7. Display data in graph form on thinger IO platform

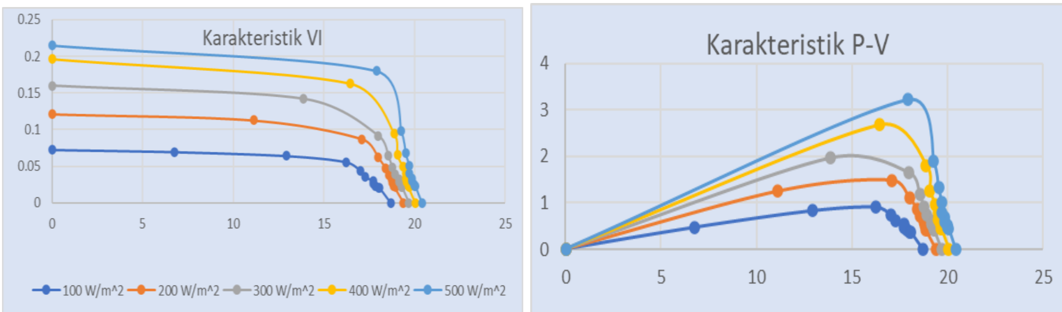

Figure 8. Characteristic Graph V-I, P-V of system test results

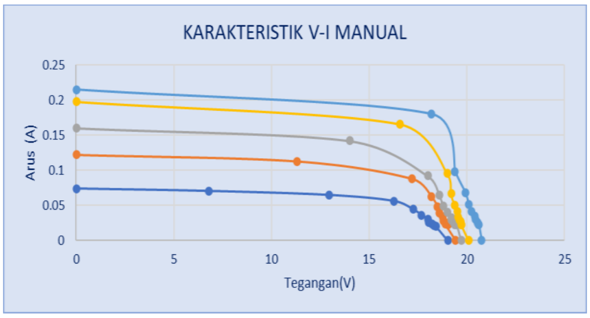

Figure 9. Characteristic Graph VI of manual test results with fluke 112 multimeter measuring instrument

3.4 Sensor reading accuracy analysis

Manual measurements were used as the reference standard as they are considered to have the highest level of accuracy, with an average error of 0%. The test results show a good level of accuracy for the sensor in measuring voltage and current, with an average error of 1.04% and 0.64% respectively. The sensor errors tend to vary between 0.00% to 2.44% for voltage and 0.00% to 1.94% for current, with a tendency for the errors to be smaller at higher loads for voltage and at lower loads for current. This variation may be due to the more stable and easily measurable measurement characteristics at certain load conditions.

3.5 System performance reliability analysis

from the results of the tests carried out the system has met the international standard IEC No. 13B-23 for accuracy classes 0.2 and 0.5. The accuracy class of 0.2 indicates that this tool has a high level of accuracy, suitable for use in general measurements in industry and research, as well as measurements in the field that require medium precision according to the type of this tool which is a test tool with class 0.2. This shows that this tool has been tested and proven capable of providing accurate and reliable measurement results.

4. Conclusions

The solar panel characteristics monitoring tool designed using Arduino Uno has successfully controlled the load circuit with relays and made measurements of current, voltage, power, temperature, humidity, and light intensity using INA219, DHT22, and BH150 sensors. Although there is a difference between the accuracy of manual measurements and using sensors, the difference is not significant. Manual measurements are considered to be the standard with the highest level of accuracy (0% error), while measurements using sensors have a relatively low average error (1.04% for voltage and 0.64% for current), indicating that sensors are reliable in providing accurate data. The tool has met the international test standard IEC No. 13B-23 for accuracy classes of 0.2 and 0.5, with the accuracy class of 0.2 indicating a high level of accuracy suitable for use in general measurements in industry, research, and in the field that require medium precision. Overall, current measurements are more consistent compared to voltage measurements.

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