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Analysis of the Effect of Tilt Position and Surface Temperature Levels of Solar Panels in Optimizing Solar Panel Performance

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ABSTRACT

The impact of increasing energy needs requires the search for alternative energy, one of which is the use of abundant solar energy. This solar energy is processed through solar panels to convert it into electrical energy. Solar panels can function optimally if they are exposed to maximum sunlight and are at the right working temperature. The challenge faced is, to get maximum sunlight, solar panels must be directed towards sunlight. However, continuous exposure to sunlight causes an increase in the surface temperature of the panel, which ultimately reduces the output power of the solar panel. Therefore, a special design is needed to overcome this problem. The solution implemented is a solar panel optimization system by adjusting the tilt of the panels and using a cooling system connected to the Internet of Things (IoT). The goal of this system is to maximize solar panel performance by maintaining maximum sunlight exposure and panel operating temperature within the appropriate range. The method used is to adjust the tilt of the panel so that it is always at the maximum angle of sunlight, and to use the Peltier effect on water as a surface cooling system for the solar panels. The parameters monitored in this research include voltage from the LDR light sensor, solar panel tilt angle, solar panel temperature, and cooling water temperature from the Peltier effect, as well as voltage, current, and power in comparison between standard solar panels (without a design system) and panels. solar using system design. Monitoring is carried out in real time using Internet of Things-based technology. The test results show that the system can function well as a solar panel optimization system integrated with the Internet of Things. A power increase of 36.91% was achieved by comparing the system without design with the design system (angle adjustment and cooling). In addition, the real-time remote monitoring concept has proven effective in observing the value of electrical energy produced by solar panels in an integrated Internet of Things application.

Keywords: solar panels, position, surface temperature, analysis.

INTRODUCTION

The use of alternative energy has become a global issue as a response to increasingly limited fossil energy sources. The use of renewable energy is attracting attention due to its abundant availability and positive impact on the environment. One form of alternative energy that comes from the sun is in the main spotlight because the need for electrical energy continues to increase every year, while fossil energy sources are decreasing or limited, which is a serious problem that must be addressed immediately. In this context, solar panels are one way to utilize solar energy sources and optimize their efficiency.

Solar panels operate with a photovoltaic effect, which converts sunlight energy into electrical energy. The efficiency of electrical energy produced by solar panels, in the form of voltage and electric current, is greatly influenced by two main factors, namely the level of sunlight intensity and the temperature of the solar panels. The lower the intensity of sunlight received by the solar panels, the lower the electrical energy produced. In addition, the high surface temperature of solar panels due to continuous exposure to sunlight causes a decrease in the electrical power produced. Every 1°C increase (starting from a temperature of 25°C) will reduce the solar panel output power by around 0.5%.

To overcome this problem, this research tries to implement a system that optimizes the work of solar panels by adjusting the degree of tilt and a cooling system integrated with the Internet of Things (IoT). The concept is to maximize the level of sunlight intensity that can be absorbed by the solar panels by adjusting the degree of tilt of the solar panels which has been integrated through a combination algorithm of light sensors to find the maximum sunlight point. In addition, this system includes cooling the surface temperature of the solar panels using the Peltier effect, which is a water cooling system directed at the surface of the solar panels. All of these systems are communicated via temperature sensors on solar panels and monitored in real time via Internet of Things-based technology.

The monitoring application will display the main parameters taken from this research, such as analog voltage data from the two LDR light sensors, tilt angle of solar panel movement, solar panel temperature, water temperature, output indicators such as east side pump work, west side pump, Peltier 1, and Peltier 2, as well as weather information and the direction of movement of the solar panels. The most important thing is the voltage, current and output power values of the solar panels compared between standard solar panels (without a design system) and solar panels that use a system design.

LITERATURE REVIEW

Energy has become a serious issue throughout almost the world, and is a crucial factor in a country's economic growth. Serious problems related to energy are increasing along with increasing energy needs. This causes energy reserves to decrease and even become scarce. Even though the need for energy continues to increase, human awareness of creating a clean and pollution-free environment is actually getting lower. Therefore, it is necessary to develop alternative energy sources as a solution to overcome the problem of energy scarcity.

2.1.Solar Panels

A solar panel is a component consisting of semiconductor material which functions as a converter of sunlight or solar energy into electrical energy through the working principle of photovoltaics. When sunlight shines on the surface of a solar cell, photons will convey their energy to the valence electrons in the semiconductor material, causing a spectral distribution of the light. When solar energy reaches a sufficient level, a potential difference will form which produces an electric current. The Fill Factor (FF) parameter is a term used to determine the efficiency level of solar panels. Calculation of the Fill Factor (FF) value can be done using the following equation:

$$FF = \frac{Imp\ .Vmp}{Isc\ .Voc}$$

Where:

FF =*Fill Factor*panel efficiency value
Imp =Maximum panel current
Vmp =Maximum panel voltage
Isc =Current in short circuit condition
Voc =Stress on conditions open_connect

To get the voltage (V) and current (I) values, the equation is used: V = IR, where V is voltage, I is current, and R is resistance. Likewise, to calculate the power value (P), the equation is used: P = V x I, with P being the electrical energy power.

The working principle of photovoltaics or what are usually called solar cells involves the connection of p-type and n-type semiconductor materials (pn-junction semiconductors), which causes a flow of electrons when exposed to sunlight, and this flow is known as electric current. Solar cells have three general characteristics, namely:

a) The power characteristic involves the product curve between current (I) and voltage (V), usually known as the VI characteristic curve, which shows the output power that can be produced by the solar cell at the maximum point referred to as MPP (Maximum Power Point), such as shown in figure 1.

b) Current (I) and voltage (V) characteristics based on irradiance, is a characteristic curve that shows the relationship between current (I) and voltage (V) at certain irradiance values, as seen in Figure 2.

c) Current (I) and voltage (V) characteristics based on temperature, is a characteristic curve that shows the relationship between current (I) and voltage (V) at a certain temperature value, as seen in Figure 3.

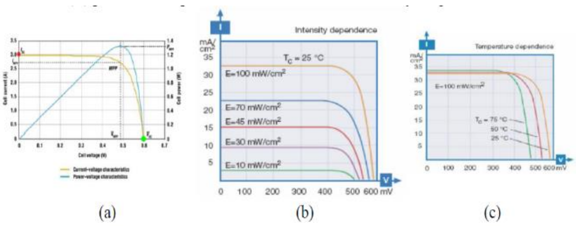


Figure 1. (a) IV curve against irradiance, (b) IV curve against temperature

2.2.Internet of Things

Internet of Things (IoT) uses computing technology connected via an internet network, allowing devices to identify each other, thus enabling long-distance communication without using cables. One common application using Internet of Things technology is a monitoring system, where the device you want to monitor can be easily accessed via smartphone or laptop without having to be physically at the location you want to monitor. With the adoption of the Internet of Things, the process of transferring information or data can be done quickly.

2.3.Heatsinks and the Peltier Effect

A cooling system is a device designed to maintain the temperature of an object at ideal conditions by transferring heat from the object to the air. The heat transfer process occurs when there is a temperature difference between two parts of the object. Heatsinks are a type of cooling system made of aluminum or copper plates, equipped with cooling fins to increase the contact area with air or other cooling fluids. Heatsinks function as passive thermal controllers that absorb heat emitted or generated by electronic components, and then transfer it to the surrounding liquid medium, which can be air or liquid.

The Peltier effect is a phenomenon that causes heat on one side and cold on the other when a direct current passes through strands of two different types of materials. The materials involved in the Peltier effect are semiconductor materials and thermoelectric element materials. Some semiconductor materials that can be used as thermoelectric elements include lead telluride (Bi2Te3), lead telluride (PbTe), silicon germanium (SiGe), and bismuth antimony (BiSb). Bismuth telluride has recently been widely used due to its excellent properties. Two types of semiconductors, "N" (negative) and "P" (positive), are made from this semiconductor material.

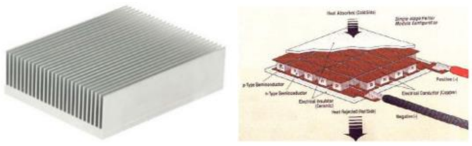


Figure 2. One type of heatsink and Peltier Element

METHOD

In analyzing the influence of tilt position and surface temperature level of solar panels in optimizing solar panel performance, a combined approach between hardware and software was used as a research method. Hardware development consists of two core elements, namely mechanical system design and electronic system design. Mechanical design focuses on the physical aspects of the system, while electronic design includes various electronic components such as controllers, sensors, and motors. The mechanical design of the system can be seen in Figure 3, while Figure 4 shows the block diagram for the overall hardware design.

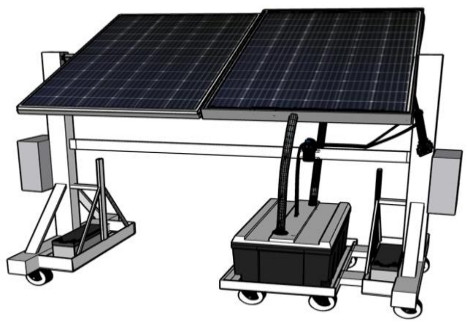


Figure 3. System mechanical design

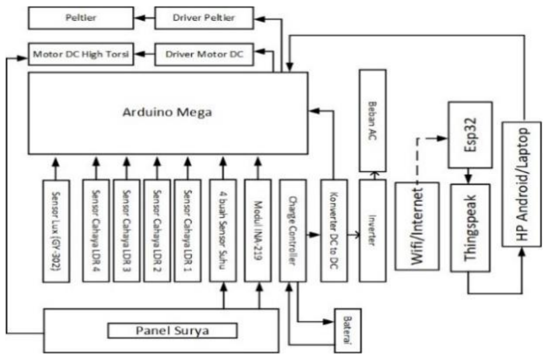


Figure 4. Block diagram of the entire system

In mechanical design, various main materials such as hollow iron, iron plate, aluminum plate, and hydraulic DC motor are used to ensure strength and ease of forming according to system requirements. From the design drawing, it can be explained that this system involves several core components. These components include Arduino Mega as the input/output processing center and communication with the ESP32 WiFi module. The 100 WP Solar Panel is tasked with producing electricity from sunlight, while the High Torque DC motor functions to move the solar panel based on instructions from the LDR light sensor. Peltier is used as a water cooling system that operates according to instructions from the temperature sensor. The DC Motor Driver controls the movement of the DC motor, setting the direction and speed of rotation. Apart from that, there are 4 LDR light sensors which function as solar light focus detectors, converting changes in light resistance into signals.

The DS18B20 temperature sensor is used to measure solar panel temperatures in the range -55oC to 125oC. Meanwhile the GY-302 Lux sensor acts as a light intensity meter in Lux units with a resolution range from 0 to 65535 lux. The INA219 module plays a role in measuring current and voltage on solar panels with a monitoring voltage range of 0 to 26 V and an operating voltage of 3 to 5 V. The ESP32 functions as a WiFi module in IoT designs. The 20x4 LCD Display is used as a display to visualize monitoring results with 20 columns and 4 rows. A 12 Volt 20 Amp power supply is used as a voltage source for system needs. Deep Cycle batteries are used to store power from solar panels. The Charge Controller functions to control the voltage and current flowing to the battery. Apart from that, there is a DC to DC converter which plays a role in changing the DC input voltage level into a different DC output voltage level according to needs. Finally, the inverter is used to convert DC voltage to AC voltage in order to activate the AC load used in the system.

Software creation is carried out by programming using C language via Arduino IDE software, which functions as the main application for managing the system controller, including control and monitoring processes. Apart from that, the Blynk application is also used as an Internet of Things interface design.

The following is a flow diagram that describes the stages of research implementation:

Figure 5. Flow diagram of research stages

Based on the flow diagram above, the research implementation stage begins with conducting a literature study to collect research supporting references and identify the components needed to implement the system. After obtaining references, the next step is to determine and design the mechanical aspects and circuit modules required by the system. This includes mechanical design, circuit module requirements such as controllers, sensors, circuit modules, types of DC motors and drivers, indicator displays, as well as WiFi modules used for Internet of Things-based system integration. After the mechanical design and circuit modules are complete, testing is carried out to ensure that all the designs function properly. The next step is to connect the entire circuit according to system requirements and design the software by creating a program algorithm. After you have finished designing the program algorithm, the next step is to upload it to the controller as the center for controlling input and output. The next stage is to carry out tool testing to ensure that the designed system runs as expected. If problems are found, repairs will be carried out according to the problems that occur. Once the system is in accordance with the research, the work or system design stage is considered complete. Next, data collection, report preparation and publication of research results are carried out.

The planned research design includes the use of an Arduino Mega as a data processing center, which will receive input from various sensors such as the LDR light sensor, temperature sensor, GY-302 lux sensor, and INA-219 module. Apart from that, there is DC motor control via a DC motor driver to regulate the movement of the solar panels and adjust the tilt so that they follow the direction of the sun. For the water-cooling system, Peltier control will be carried out through a Peltier driver, which will flow water evenly over the surface of the solar panels as needed, using the Pulse Width Modulation concept. This system design is also equipped with an LCD display and has a monitoring function via an integrated Internet of Things application. This monitoring application is tasked with displaying important parameters in the system, so that the system can function well and be monitored efficiently. In full, the overall system design diagram can be seen in the following image:

Data collection techniques involve measuring values from various sensors. The value read from the LDR light sensor will be converted into a maximum light detection value, which reflects the point at which the light value reaches the maximum by setting the analog value from the LDR sensor. The GY-302 lux sensor will produce light intensity values, the DS18B20 temperature sensor will provide solar panel temperature values, and the INA-219 module will provide voltage, current and power values for the solar panels. Next, the movement of the DC motor involving the encoder feature will produce a tilt degree value. All these parameters will be recorded or databased so that the data can be processed and analyzed. Furthermore, the parameter data will be displayed in the monitoring application, which allows real-time monitoring. The data parameters that will be collected and analyzed include temperature, degree of tilt, voltage, current and power when comparing standard solar panels (without a system design) with solar panels that use a system design.

RESULTS AND DISCUSSION

4.1. Research Analysis.

The results and discussion of the research Analysis of The Effect of Tilt Position And Surface Temperature Levels of Solar Panels In Optimizing Solar Panel Performance consists of five tests, namely testing to adjust the tilt angle of solar panels, testing the cooling system for solar panels, testing panel output power solar panels with and without a Tilt Position control system, and Testing the output power of solar panels with and without a Surface Temperature Level setting system and Testing the output power of solar panels with and without a Tilt Position setting system + Surface Temperature Level setting. The following are the results of the overall system design.

Figure 6. View of the overall results of the system design

4.2.Testing to adjust the tilt angle of the solar panel

The test design for adjusting the tilt angle of the solar panels is intended to show how the motor moves to adjust the tilt angle with a single axis concept, where the servo motor uses hydraulic mechanics that function well, in accordance with a predetermined direction to achieve maximum movement of sunlight. The results of this test are shown in Table 1.

Table 1. Tests to adjust the tilt angle of solar panels

Test Time (WIB)	LDR sensor analog voltage value (volts)		Tilt Angle (o)	Solar Panel Direction
	LDR1	LDR2		
08.00	0.22	0.15	51	East
10.00	0.29	0.21	68	East
12.00	0.34	0.33	87	Perpendicular
14.00	0.29	0.31	103	West
16.00	0.26	0.27	112	West

From the test results listed in Table 1, it can be seen that the motor functions well in determining the position of the solar panel with single_axis movement. The combination of the two LDR light sensors is used to determine the tilt angle and direction of the solar panel. The working process is as follows: The LDR1 sensor is in the upper position and the LDR2 sensor is in the lower position. If the analog voltage value of the LDR1 sensor is higher than the analog voltage value of the LDR2 sensor, the hydraulic motor will continue to move the solar panel to the east. Conversely, if the analog voltage value of the LDR1 sensor is lower than the analog voltage value of the LDR2 sensor, the hydraulic motor will continue to move the solar panel westward. However, if the analog voltage values of the LDR1 and LDR2 sensors are almost the same (within 3 degrees), the hydraulic motor will stop. To determine the degree of tilt position of the solar panel, the information will be read by the Accelerometer & Gyroscope sensor.

4.3.Testing of cooling systems for solar panels

Testing of the solar panel cooling system illustrates how the process of cooling the surface of the solar panel works with the aim of improving panel performance and obtaining increased output power. The results of this test are recorded in Table 2.

Table 2. Testing of cooling systems for solar panels

No.	Condition East Pump	Condition West Pump	Cooling Water (oC)	Time	Solar Panel Direction
1	Life	Dead	21	09.57	East
2	Life	Dead	23	11.35	East
3	Dead	Life	23	12.11	Perpendicular
4	Dead	Life	24	13.58	West
5	Dead	Life	25	15.03	West

The results from Table 1 show the function of the cooling system on solar panels, where the cooling process will be activated when the solar panel temperature reaches a value of ≥ 35oC, and the system will stop when the panel temperature is in the range of 25oC to 30oC. This cooling system operates by flowing cold water to the surface of the solar panels through two pumps located on the east and west sides. The east side pump functions when the solar panels face west, while the west side pump operates when the solar panels face east. The cooling water temperature will be maintained between 15oC to 25oC using the Peltier effect to cool the water.

4.4.Testing the output power of solar panels with and without the Tilt Position adjustment system

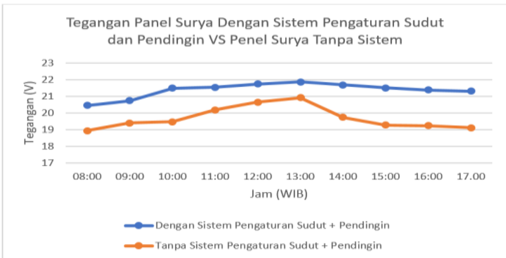
Testing the output power of solar panels with and without a tilt position adjustment system shows how the process of optimizing the performance of solar panels can be improved by adjusting the tilt position compared to static solar panels. This test can be seen in Table.3.

Table 3. Testing voltage and current of solar panels with and without the Tilt Position + cooling control system

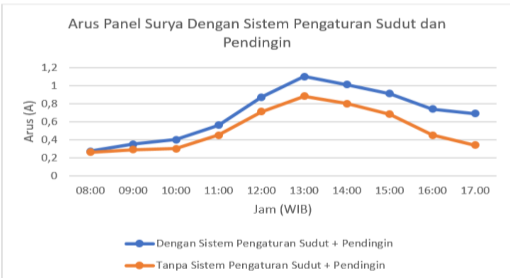
Time Test	Condition Weather	No System Design		With System Design	
		Voltage (V)	Current (A)	Voltage (V)	Current (A)
08.00	Bright	19.02	0.35	20.54	0.36
10.00	Bright	19.55	0.39	21.57	0.49
12.00	Bright	20.73	0.80	21.82	0.96
14.00	Bright	19.81	0.89	21.77	1.10
16.00	Cloudy	19.31	0.54	21.46	0.83

Table 4. Testing the output power of solar panels with and without the Tilt Position + cooling control system

Time Test	Condition Weather	No System Design Power (W)	With System Design Power (W)
08.00	Bright	6.66	7.39
10.00	Bright	7.62	10.57
12.00	Bright	16.58	20.95
14.00	Bright	17.63	23.95
16.00	Cloudy	10.43	17.81



(a)



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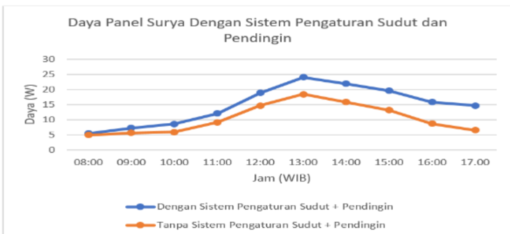

(c)

Figure 7. Result Of Solat Cell

From the results of testing the output power of solar panels with and without the Tilt Position control system, where without the system design the total power is 58.92 W, while the solar panels with the system design are 80.67 W. Therefore, the difference in power can be calculated as follows:
Difference Ptotal =Ptotal with system design - Ptotal without system design
= 80.67 Watts – 58.92 Watts
= 21.75 Watts
% Increase in P = (Difference of Ptotal system / Ptotal without system) x 100
= (21.75 / 58.92) x 100
= 36.91 %
The percentage increase in panel output power is 36.91%.
From the tests carried out, all monitoring data includes second analog voltage data, solar panel movement tilt angle, solar panel temperature, water temperature, output indicators such as the work of the east side pump, west side pump, peltier 1 and peltier 2, display of weather and direction information. The movement of the solar panels and most importantly the voltage, current and output power values of the solar panels can be monitored properly in analyzing the influence of the tilt position and surface temperature level of the solar panels in optimizing the performance of the solar panels.

CONCLUSION

The conclusion of this research is that the entire regulatory system is carried out automatically in one system which is equipped with real-time monitoring application features that are integrated with the Internet of Things. This monitoring application provides second analog voltage data, tilt angle of solar panel movement, solar panel temperature, water temperature, and output indicators such as the operation of the east side pump, west side pump, peltier 1, and peltier 2. Apart from that, there is also a weather information display. and the direction of movement of the solar panels, as well as the most important information, namely the voltage, current and output power values of the solar panels. With this system, errors in position movements or inappropriate variable values can be immediately resolved.
The test results show that the system works well as a solar panel optimization system that has been integrated with the Internet of Things. Setting the tilt angle of the solar panels functions well through input from a combination of light sensors, so that the solar panels can follow the movement of the tilt angle and direction of the sun over time. In testing the output power of solar panels, there was an increase in power of 36.91% compared to solar panels without a system design. The cooling system also operates well by activating the solar panel surface watering pump based on the surface temperature of the solar panel, water temperature and information on the direction of the solar panel. In addition, testing of the Internet of Things integrated system shows that the remote monitoring concept is effective in monitoring all system parameters through one Blynk application that is integrated with the Internet of Things.

Declaration by Authors

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