Monitoring and Controlling Solar Photovoltaic (PV) Performance with Active Cooling System using IoT

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Abstract Solar photovoltaic technologies are worldwide renewable energy sources. However, the elevated temperature in solar panels is one explanation for reducing the performance of solar systems. An active air cooling system can be mounted on the back of the solar panel to avoid this phenomenon. In order to ensure that the solar system runs smoothly, monitoring needs to be done at each place where this solar energy system is located. The Internet of Things (IoT) is a network of linked, internet-accessible physical objects. It is the technology of the next generation that will soon be extended to society. The IoT refers to the system or ecosystem in which devices are connected to the Internet in real-time. Based on IoT, a smartphone can track the temperature of the solar panel anytime and anywhere. To overcome this problem, a Blynk IoT system monitors solar power status and controls the cooling air system. NodeMCU was the main microcontroller used in IoT systems. The IoT framework can be implemented easily and efficiently using NodeMCU. The experimental results of this project will monitor the performance of the solar panel and monitor it.

1. Introduction

Solar energy has become the perfect alternative to reduce costs [1]. It is a renewable source notable for reliability, less operation, and fewer maintenance costs [2]. The PV system is an easy-to-access and familiar deployment technology. The source factor in its adoption to meet the world’s growing demand for electricity is solar energy abundance [3]. The sustainable power source is energy generated by traditional procedures that are continuously renewed. This includes geothermal warmth, water, daylight, wind, and various biomass types. This energy is constantly renewed and not exhausted. Renewable energy resources exist worldwide, limited or unlimited. The world now focuses on renewable energy because it realized that the benefits of using it, despite fossil fuels, are likely to run out over the years. The results suggest that global warming and greenhouse gas become liable for harm [4].

Encapsulation changes the heat flow to and from the PV module, which increases the operating temperature of the PV module. Such temperature variations directly affect the PV module by increasing the voltage and reducing the power output. While the temperature varies by season and location, the solar panel usually has the highest summer temperature. Many approaches were proposed to avoid the productivity decrease caused by such a rise in temperature. In this project, the fan cooling process has been chosen. There are several methods for addressing the issue of performance. The cooling fan is switched on automatically by the solar panel temperature. To implement such a system, and the Internet of Things (IoT) operating system is required. The IoT is an internet-linked physical objects network [5-7]. This is a technology of the next generation to be used in modern society shortly. The IoT refers to the network or environment where sensors are connected in real-time with the...
internet. Based on IoT, the temperature of the solar panel can be controlled anywhere through a smartphone. This main project is to manage and rack the solar panel output with an IoT system.

2. Methodology

Figure 1 shows the block diagram of the project. In the block diagram, there are parts of input devices. It contains temperature, voltage and current sensor. It also has a solar panel and a battery. In the middle of the block, it clearly shows the main part to process all the functions that use NodeMcu and the output devices in the right part of the block. There is a Wi-Fi module to go through mobile devices.

![Figure 1. Block diagram of the project.](image)

This project begins with the design of the prototype for the system cooling component using the software TinkerCAD. Each part of the system is TinkerCAD-designed. The figures below show TinkerCAD's cooling system part design. The front view is shown in Figure 2(a), the side view shown in Figure 2(b), the back view shown in Figure 2(c).

![Figure 2. (a) Front View of The Cooling Part. (b) Part Side View of The Cooling Part. (c) Back View of The Cooling Part.](image)

2.1. NodeMCU

NodeMCU is a Lua-based open-source firmware and development board that is primarily aimed at IoT-based applications. It includes firmware operating on the Espressive Systems on ESP8266 Wi-Fi SoC and hardware based on the ESP-12 module. The ESP-12E module with ESP8266 chip with Tensilica Xtensa 32-bit LX106 RISC microprocessor is included on the NodeMCU ESP8266 developer board. This microprocessor supports RTOS and runs at an adjustable frequency of 80MHz to 160MHz. NodeMCU has 128 KB of Flash Memory RAM and 4 MB for saving data and programmes. It is suitable for IoT projects because of the high computing capacity with combined Wi-Fi / Bluetooth and Deep Sleep Operating capabilities as shown in Figure 3.
2.2. Solar Panel and Solar Power Manager

Solar is the most efficient renewable energy in Malaysia. The solar panel is a device that used to convert sunlight into electrical energy. In this project, the 10W monocrystalline solar panel has been used since the monocrystalline solar panel will last longer. This solar panel open circuit voltage is 22.3V. Solar Power Manager 5V is a small power and high-efficiency solar power management module designed for 5V solar panels. It features as MPPT (Maximum Power Point Tracking) function, maximizing the efficiency of the solar panel. The module can provide up to 900mA charging current to 3.7V Li battery with a USB charger or solar panel. The ON/OFF controllable DC-DC converters with 5V 1A output satisfy the needs of various solar power projects and low-power applications. The module also employs various protection functions for battery, solar panel, and output, which greatly improves the stability and safety of solar projects. Figure 4 shows the solar power manager.

The circuit connection for the success of the project was one of the important parts and main parts of the project. The connection to the circuit should be ready to complete the programming part that the pin is used to know. Figure 3 shows the complete connection in the schematic of the right part of the block. There is a Wi-Fi module to go through mobile devices. Figure 5 below shown the circuit construction of the controlling and monitoring part of this project. DHT 11 was the temperature sensor that had been used in this project. The measured data parameters will be programmed and uploaded into NodeMCU. After that, it will send the data to the Blynk application and display the data on it.
Figure 5. Circuit Connection of The Project.

Figure 6(a) and (b) below shown the circuit construction of the controlling and monitoring part of this project. DHT 11 was the temperature sensor that had been used in this project. The measured data parameters will be programmed and uploaded into NodeMCU. After that, it will send the data to the Blynk application and display the data on it. The function of the controlling system was to detect the temperature of the solar PV panel to turn on/off the DC fan. The relays will control the on/off power of the DC fan. This Monitoring and Controlling Solar Photovoltaic Performance with Active Cooling System Using IoT is built using various types of materials. Figure 7 shows all the overall design of the project.

Figure 6.(a) Circuit Construction of Monitoring System.  
Figure 6.(b) Circuit Connection of Controlling System.
3. Result and Discussion

3.1 Blynk Displays Data
Blynk is an IoT tool that can display data via wireless communication. This application can do anything that relates to IoT development. This application has been built to make this data display visible anywhere. The data have been ultimately shown on the Blynk app in Figure 8 shown below. With this application, the user will be alerted to the solar panel’s current condition and take action about it. This Blynk application will display the value of panel temperature, ambient temperature, voltage, current, and power. It also has a switch button to control the on/off of the DC fan.

3.2 Performances of Without Cooling System and with Cooling System of PV
Figure 9 performances of PV panel temperature with and without a cooling system. The temperature with and without a cooling system remains the same at an initial value, but the temperature without the cooling system was raising slightly higher than with the cooling system. The PV panel with the cooling system had the highest temperature output of the PV panel at 39.6℃ while without the cooling system had the highest temperature output of the PV panel at 39.7℃.
It clearly shows that a few temperature differences along the panel surface were detected between the system with and without the cooling system. The result reported that measured temperature ranges distributed from 30°C to 39°C, respectively. The use of an aluminium heat sink enhances the heat exchanges between the PV panel and the heat sink and was cooled down by the DC fan. As a result, the cooling system's temperature could be lower down below 40°C while the temperature of the PV panel without the cooling system was rising and affected the PV panel's power output. High temperature distributed caused by existing difference temperature among surrounding and PV panel temperature. The temperature difference will lead to the heat generated and an increase in the PV panel's operating temperature. But by attaching a heat sink with two units of DC fan, the temperature could be maintained during the peak hour of the day.

3.3 Current Output against Time for Without Cooling System and With Cooling System of PV Panel.

Figure 10 shows the performances of PV panel current output with and without a cooling system. Based on this figure, it can be observed that the PV panel without the cooling system has a lower average output current compared to the PV panels with the cooling system. For the PV panel with the cooling system, the maximum current was 0.37 A, and the minimum current was 0.31 A. The PV panel's average current with the cooling system is 0.33 A. The current output of the initial time at 10:00 a.m. was at 0.31 A while the current output of the PV panel without a cooling system was 0.252 A. The current output for the cooling system at 14:00 was 0.37 while without the cooling system it is 0.321 A. It can be identified that the current has minor changes when the PV panel's temperature varies. When the temperature of the PV panel can be decreased, the output current will increase, thus improving the PV panel's output performance.
3.4 Power Output against Time for Without Cooling System and With Cooling System of PV Panel.

Figure 11 performances of PV panel power output with and without a cooling system. Based on this figure, it can be observed that the PV panel without the cooling system has a lower average power output compared to the PV panels with the cooling system. For the PV panel with the cooling system, the maximum power output was 7.15 W, and the minimum power was 5.43 W. The PV panel's average power output without a cooling system was 5.11 W. The power output of the PV panel with the cooling system at 10:00 a.m. was at 5.43 W while the power output of the PV panel without a cooling system was 3.264 W. The power output for the cooling system at 14:00 was 7.15 W while without the cooling system it is 6.2 W. It can be identified that power has minor changes when the PV panel temperature varies. When the temperature of the PV panel can be decreased, the output power will increase, thus improving the PV panel's output performance.

![Figure 11. Comparison Data of Power(W) with and without Cooling System.](image)

3.5 Power Output against Time for Without Cooling System and With Cooling System of PV Panel.

Below is shown the calculation of performance efficiency of a solar PV panel with and without a cooling system:

The maximum power output without a cooling system is 6.21 W. The incident radiation flux at standard test condition (STC) is assumed as 1000 W/m².

Area of collector solar panel = 0.445 m x 0.19 m

\[
\eta_{\text{max}} = \frac{P_{\text{max}} \text{(maximum power voltage)}}{\text{incident radiation flux}} \times 100\%
\]

\[
= \frac{6.21}{1000 \text{ W/m}^2 \times (0.445 \text{ m} \times 0.19 \text{ m})} \times 100\%
\]

\[
= 7.34\%
\]

The maximum power output with the cooling system is 7.15 W. The incident radiation flux at standard test condition (STC) is assumed as 1000 W/m².

Area of collector solar panel = 0.445 m x 0.19 m. By using equation (1),
\[ \eta_{\text{max}} = \frac{7.15}{1000 \text{ W}} \frac{\text{W}}{\text{m}^2} (0.445 \text{ m} \times 0.19 \text{ m}) \times 100\% \]

\[ = 8.46\% \]

4. Conclusion

The project is studying the effect of the cooling system affecting the performance of the PV panel. The cooling system has improved the power collected by the PV system and increases the PV panel's efficiency to get the maximum value of the power collected. Based on the result from equation 1, the efficiency PV with cooling system is better without cooling system of PV. The cooling system uses the dc fan, so it has a small amount of budget to produce a better cooling system of the panel. The PV panel uses the heat sink process to optimize the cooling process instead of using the dc fan only. The amount of dc fan being used in other cooling system configuration makes it easy to use the cooling system's best configuration.

5. References

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