Effect of Water Cooling and Dust Removal on Solar Photovoltaic Module Efficiency

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ABSTRACT

This paper is on the effect of water cooling and dust removal on solar photovoltaic module efficiency. Photovoltaic power generation suffers from low energy conversion efficiency, mainly caused by the photovoltaic module’s extraordinarily high operating surface temperatures and dust collection. This paper studies the effect of overheating and dust accumulation on the photovoltaic module performance. This paper presents a cooling and dust removal automatic system to increase performance. The objectives of this paper are, first, to develop a method for the cleaning and cooling of solar modules that are fully automated; second, to investigate the effect that the cooling system has on the surface of the solar modules; and lastly, to study the impact that dust and heated panel have on the performance of the solar system. The photovoltaic module was water-cooled using a prototype with a built-in motor and water pump that operated to cool and clean the photovoltaic module. Water-cooled modules are then compared to conventional modules (no modification). For the debris build-up investigation, the traditional module is covered with 20%, 30%, and 50% estimated dust coating on the module surface. The output power is compared to the module with a cleaning system (zero dust coverage). According to these findings, it takes the solar module only five weeks to lose 20% of its efficiency once it has been installed. The research found that the module had a low energy conversion efficiency when the surface temperature was relatively high. The increase in surface temperature can be attributed to the production of heat energy on the surface due to the module being exposed to intense sunlight.

Keywords:
Renewable energy; dust accumulation; photovoltaic cleaning; photovoltaic cooling; microcontroller

1. Introduction

Renewable energy is power from renewable resources such as sunlight, wind, rain, tides, and earth heat [1,2]. One popular method of renewable energy used in modern society is photovoltaics (PV) for electricity generation [3,4]. PV modules contain photovoltaic semiconductors. These modules convert solar irradiation into direct current energy to generate power. When a substance is illuminated by light, this phenomenon is known as the photovoltaic effect. Photovoltaic power
generation research reveals that nature, such as cloudiness and humidity, is the main factor affecting PV module efficiency [5]. The effectiveness and efficiency of PV power generation are negligible compared to a combination of factors, including ambient temperature and dust collection on PV modules. These factors impact PV power generation more. The solar industry has increasingly prioritized cooling and cleaning photovoltaic modules [6].

High-temperature sunlight hitting the PV module heats its exposed surface. Photovoltaic semiconductors usually keep a constant temperature; however, when the temperature increases, solar cell semiconductor efficiency decreases [7-15]. When the conducting material's temperature rises, its phonons get stimulated, which hinders electron movement. This impedance reduces solar module performance when it’s hot. Besides that, environmental dust develops a coating on modules placed in open places to get the most direct sunlight. Dust accumulates and prevents sunlight from reaching the solar module, making the photovoltaic modules convert energy poorly. The dust layer stores heat, keeping the modules warm. High temperatures reduce the module's energy conversion efficiency [16-20].

This paper aims to increase the PV module's performance by reducing the PV surface temperature and dust collection. The objectives of this paper are, first, to develop a method for the cleaning and cooling of solar modules that are fully automated; second, to investigate the effect that the cooling system has on the surface of the solar modules; and lastly, to study the impact that dust and heated panel have on the performance of the solar system. The modifications included in this project include the addition of water cooling and the elimination of debris build-up on the surface module. A comparison of the water-cooling module's and the standard module's power output is the primary focus of this project study. With an enhanced module, there is no dust accumulation in a water-cooled module because the constant flow of water eliminates the opportunity for dust to settle and collect.

2. Methodology

The paper aims to develop an automatic, remote, self-cleaning and cooling solar panel. Debris removal is essential in ensuring that the solar system operates efficiently. Removing dirt and debris from the surface of the solar panels increases their exposure to sunlight and maximizes energy production. The cooling system design ensures that the solar panels do not overheat, which can reduce their lifespan and efficiency. The diagram in Figure 1 shown the working process of a PV module. The method of developing the PV module system begins with developing the prototype of the system. This prototype serves as the project's foundation and helps identify the necessary components and requirements for the system. The prototype is tested at the School of Electrical Engineering, UiTM Shah Alam parking lot for one month from 23 October 2022 until 24 November 2022. Experiments to test for the effect of cooling and cleaning on the solar panel are done during that time.

This paper uses an 18W monocrystalline solar panel with a 30A solar controller and a 6000W power inverter. The solar controller is used as an interface, and the power inverter is used to change the power to be used by the home appliance. In this case, the power is used to operate the cleaning and cooling system. The cooling and cleaning system consists of a temperature sensor to measure the solar panel's surface temperature. This is to determine if the solar panel's temperature has reached a critical level. In this paper, the maximum temperature is set to 45°. If the temperature exceeds that, the cooling water pump will operate. A push button is installed to manually manage and reset the cooling and cleaning system for maintenance.
The maintenance ensures the panel's surface is cleaned and cooled, maximizing energy production. The system is also connected to an IoT part to enhance further the system, which can be controlled remotely using a smartphone[21, 22]. This paper uses the Blynk application with the ESP-32’s built-in Wi-Fi.

As shown in Figure 2, the Blynk application manually turns the cooling and cleaning system by turning ON or OFF the water pump and the motor. There is also a temperature reading of the PV solar module for monitoring purposes.
Figure 3 shows the block diagram of the solar module cooling and cleaning system. The system consists of a temperature sensor and a push button as input. The temperature sensor (DS18B20) measures the ambient temperature and sends the information to the microcontroller. The push button is used to initiate the manual operation of the system. The system's outputs are a window power lifter motor and a water pump. The window power lifter motor is used to clean the solar panel, and the water pump is used to cool the system.

![Block diagram of the control box of the solar module cooling and cleaning system](image1)

**Fig. 3.** Block diagram of the control box of the solar module cooling and cleaning system

Figure 4 shows the solar panel's whole cooling and cleaning system. The power obtained from the solar panel is stored in the rechargeable battery and used back to power the pump for the cooling system and move the wiper attached to the motor to clean the solar panel. The system design is self-sufficient and cost-effective as it reuses the generated power from the solar panel.

![Complete cooling and cleaning system for the solar panel](image2)

**Fig. 4.** The complete cooling and cleaning system for the solar panel

Figure 5 shows the simulation of dust coverage on the PV module. The dust coverage simulation by putting the dust manually on the solar panel with an estimation of coverage ranges from 20 % to 30 % to 50 %. This simulation is for the study of energy production before and after cleaning to determine the effectiveness of the cleaning system in improving PV solar panel performance.
3. Results

This project aimed to design and test a solar cooling and cleaning system that can improve the efficiency of photovoltaic panels. First, the solar panel efficiency over time is studied; next is the study of the effect of water cooling on the performance and lastly, the impact of debris removal on energy production. The results of these experiments provide valuable insights into the best practices for maintaining and improving the performance of solar panels.

3.1 Solar Panel Efficiency Over Time

For the initial study, the solar panel was exposed to direct sunlight for one month. The efficiency of the solar panel was measured using a digital multimeter and recorded at regular intervals. Figure 6 shows the power output produced by a single solar module. Solar irradiation in Malaysia from October to December is between 550 to 650 for solar irradiation. The graph in Figure 6 demonstrates that output power degraded over time. Based on this finding, the solar module loses around 20% of its efficiency without the cooling and cleaning system.

![Fig. 6. PV module power output within a month without the cooling and cleaning system](image-url)
Shown in Table 1 is the average reading at the beginning and end of the weeks during the observation period. G_measured represents the solar irradiation reading obtained from the solar irradiance meter, Temp_measured is the solar panel temperature reading using the temperature sensor, Isc_measured and Voc_measured is current, and voltage measured using the multimeter and Poc_measured is power calculated from the current and voltage reading of the solar panel. The same terms are used throughout this paper.

<table>
<thead>
<tr>
<th>Field Data</th>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
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<td>609</td>
<td>614</td>
<td>604</td>
<td>606</td>
<td>600</td>
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<tr>
<td>Temp_measured (°C)</td>
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<td>45.6</td>
<td>46.2</td>
<td>46.4</td>
<td>45.4</td>
<td>49.3</td>
</tr>
<tr>
<td>Isc_measured (A)</td>
<td>1.13</td>
<td>1.12</td>
<td>1.2</td>
<td>1.05</td>
<td>1.12</td>
<td>1.03</td>
</tr>
<tr>
<td>Voc_measured (V)</td>
<td>23.9</td>
<td>23.9</td>
<td>23.6</td>
<td>23.6</td>
<td>23.6</td>
<td>22.5</td>
</tr>
<tr>
<td>Poc_measured (W)</td>
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<td>28.32</td>
<td>24.78</td>
<td>26.43</td>
<td>24.31</td>
</tr>
</tbody>
</table>

3.2 Effect of Water Cooling

Solar panel overheating due to exposure to high temperatures can significantly decrease the output of solar panels, especially during peak hours when energy production is critical. The water cooling system in this paper reduces the effect of overheating and increases the solar panel's performance. Figure 7. shows that the power of the cooled solar panel is slightly higher and more stable than the uncooled solar panel, indicating the cooling system improved the solar panel's performance.

![PV Module with and without Cooling System](image)

Fig. 7. Comparison of conventional with cooled system solar panels

Table 2 shows the data of two PV modules, one with a cooling system and one without a cooling system. The observation duration is for five days. After the observation, data showed that, on
average, 20% more power is generated with a cooled PV solar module. With more power generated, the system is more efficient and cost-effective.

### Table 2
Comparison of conventional and cooling system solar panel

<table>
<thead>
<tr>
<th>Date of Experiment</th>
<th>Convention solar panel (PV1)</th>
<th>Cooling system solar panel (PV2)</th>
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<tr>
<td></td>
<td>Dec</td>
<td>Dec</td>
</tr>
<tr>
<td>Temperature(°C)</td>
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</tr>
<tr>
<td>Voc_measured (V)</td>
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<td>22.4</td>
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<tr>
<td>Isc_measured (A)</td>
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<td>1.02</td>
</tr>
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</table>

3.3 Effect of Dust Cleaning

The last part of this paper evaluates the impact of cleaning on the solar panel’s performance. For simulation, the solar panel was covered with dust with an estimation of 20%, 30% and 50% dust covering. As shown in Figure 8, the output power decreased significantly when the panel was covered by more dust. Without the cleaning system, with dust up to 50% covering the solar module, the power produced reduces drastically, reducing the solar panel performance.

![Fig. 8. Output power for different dust coverage](image)

Shown in Table 3 is the reading for 20%, 30% and 50% dust coverage on the solar panel. 20% coverage has the highest output power compared to the rest. The results of this experiment demonstrate that even a small amount of dust and debris can significantly reduce the performance of a solar module, which is an essential consideration for the design and placement of solar modules in real-world applications [20-22]. Cleaning the PV module increased the power generated compared to PV without the cleaning system. Furthermore, the cleaning system is powered back by the solar power collected by the panel, making it self-sufficient and cost-effective.
4. Conclusions

In conclusion, the experiments conducted in this study demonstrated that the performance of solar panels is directly proportional to their energy conversion efficiency. The research findings suggest that an increase in surface temperature can significantly reduce the energy conversion efficiency of solar panels. The heat energy produced on the surface of solar panels due to exposure to intense sunlight reduces the amount of light energy that can be converted into electrical energy, leading to energy waste. Therefore, to improve the efficiency of solar panels, it is essential to keep them cool and prevent them from overheating. Water cooling allows excess heat dissipation, preventing the panel's surface from overheating and reducing wasted energy. With reduced energy wasted, the system is proven to be cost-effective. Therefore, the design of solar cooling systems is a practical approach to improving the energy conversion efficiency of solar panels. This paper showed that regular cleaning significantly improves the efficiency of solar panels. The accumulation of dirt, dust, and debris on the surface of solar panels can reduce the amount of light energy that can be converted into electrical energy, leading to energy waste. Therefore, keeping solar panels clean and debris-free ensures maximum energy conversion efficiency. For the recommendation for future work, implementing IoT as a monitoring system to identify areas for improvement is the best way to optimize the system.

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