

Experimental Investigation Of A Photovoltaic Panel Cooling System Using A Water Sprayer For Power Efficiency Enhancement

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Abstract:

An increase in photovoltaic (PV) panel temperature significantly reduces its electrical energy conversion efficiency. This study aims to analyze the effectiveness of a water sprayer-based cooling system in maintaining optimal panel surface temperature and improving power efficiency. The system was designed using an ESP32 microcontroller and an STC1000 sensor to monitor temperature, current, voltage, and water flow rate. The water pump is automatically activated when the panel surface temperature reaches 37°C and stops at 32°C. Tests were conducted on two 100 Wp monocrystalline photovoltaic panels, one equipped with the cooling system and the other without. The results show that the water sprayer system successfully reduced the average panel surface temperature from 51°C to 35°C and increased power efficiency from 16.84% to 18.44%, representing an improvement of 1.60%. In addition to maintaining efficiency, the cooling system potentially extends the panels lifespan with low operational costs. Therefore, the water sprayer cooling method is considered effective and suitable for application in tropical environments to support sustainable solar energy optimization.

Keyword: Photovoltaic Panel; Water Sprayer; Cooling System; Power Efficiency; ESP32.

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I. Introduction

Solar power systems are among the most promising renewable energy technologies that utilize photovoltaic panels to convert sunlight into electrical energy [1][2]. The performance of photovoltaic panels is significantly influenced by several factors, particularly ambient temperature and solar irradiance, which refers to the amount of solar energy received on a given surface over a specific time period [3][4].

PV panels typically achieve their optimal efficiency at around 25°C. However, in tropical climates such as Indonesia, where the average daily temperature ranges between 30°C and 35°C, the conversion efficiency tends to decrease [5]. An increase in the panel's surface temperature reduces the output voltage and power efficiency due to the higher internal resistance of the semiconductor material [6][7]. Therefore, an effective cooling system is required to stabilize the panel temperature and prevent overheating, which may accelerate degradation and reduce long-term performance [8].

Several cooling techniques have been developed, including the air cooling system, which uses fans or blowers but requires additional energy consumption [9]; the water cooling system, which uses water as the cooling medium but incurs higher implementation costs and corrosion risks [10]; the heat pipe system, which transfers heat using working fluid within pipes but requires higher investment [11]; and the water sprayer system, which sprays water directly onto the panel surface. The latter method is simple, cost-effective, and efficient since it not only reduces the temperature but also cleans dust and dirt from the panel surface [12].

This study aims to analyze the effectiveness of a *water sprayer*-based cooling system controlled automatically by an ESP32 microcontroller. The system is designed to activate the pump when the panel temperature exceeds 37°C and to stop operation when it decreases to 32°C. A comparative performance analysis was conducted between cooled and uncooled panels to evaluate power efficiency improvement. The results are expected to contribute to enhancing solar energy utilization and optimizing photovoltaic system performance under tropical conditions.

II. Material And Methods

System design

This study was designed to evaluate the effectiveness of a water sprayer-based cooling system for PV panels. Two monocrystalline PV panels, each rated at 100 Wp with dimensions of 100 × 67 cm, were used in

the experiment. One panel was equipped with the cooling system, while the other served as a reference operating under normal (non-cooled) conditions.

Both photovoltaic panels were connected to a DC power meter to monitor voltage and current outputs. The system was configured in parallel to record the independent performance of each panel. A Maximum Power Point Tracking (MPPT) solar charge controller (SCC) was employed to regulate the power flow from the panels to the DC load and storage battery. No inverter was included in the setup, as the system operated entirely with DC loads.

The cooling mechanism employed a 12 V DC diaphragm pump with a current of 2.2 A, flow rate of 3.1 L/min, and pressure of 80 PSI. Water was drawn from a 2.5 L storage tank and sprayed directly onto the panel surface through PU tubing to reduce temperature. A STC1000 temperature sensor monitored the panel surface temperature and transmitted data to the ESP32 microcontroller as the control unit. The pump was programmed to activate at 37°C and deactivate at 32°C. Data collected from the DC power meter and temperature sensors were analyzed to evaluate the cooling system's effectiveness in improving power efficiency.

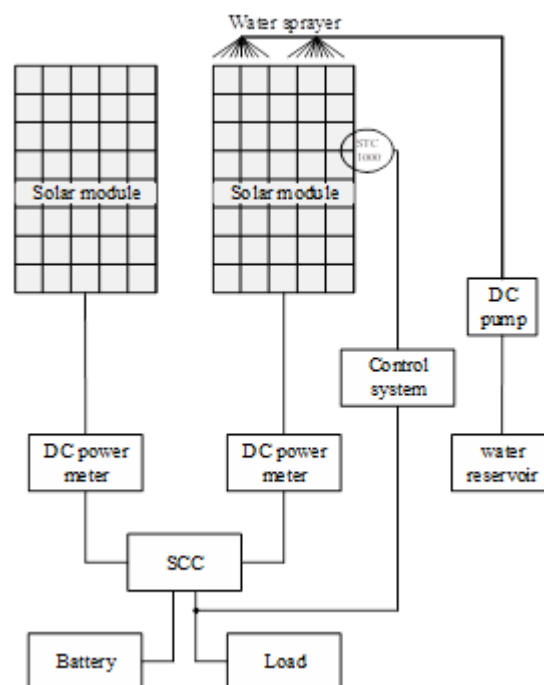


Fig.1 Block diagram of the PV panel cooling system using water sprayer

Research procedure

The research was carried out through several systematic stages to ensure accuracy and consistency of results. The first stage was a literature review, which involved examining previous studies related to photovoltaic panel cooling systems and their influence on energy conversion efficiency under high-temperature conditions. This step provided theoretical and empirical references for designing the system and defining the experimental framework.

The next stage was system planning, which included determining the type and capacity of the photovoltaic panels, selecting supporting components, defining the installation tilt angle between 10° and 20° to optimize sunlight absorption, and setting the operational temperature thresholds for the cooling system. Following the planning phase, a system assembly and installation process was performed by integrating the ESP32 microcontroller, sensors, pump, and electrical components according to the designed system layout.

Subsequently, the testing phase was conducted under two conditions: one photovoltaic panel equipped with the water sprayer cooling system and another without cooling as a control. The experiments were carried out under natural sunlight for seven hours (09:00-16:00 local time), with measurements taken every 30 minutes to monitor temperature, irradiance, current, and voltage. Finally, the data analysis stage involved processing and comparing the measurement results to evaluate the performance improvement achieved by applying the water sprayer system. The analysis focused on determining the extent to which the cooling mechanism enhanced power efficiency and maintained optimal operating conditions for the photovoltaic panels.

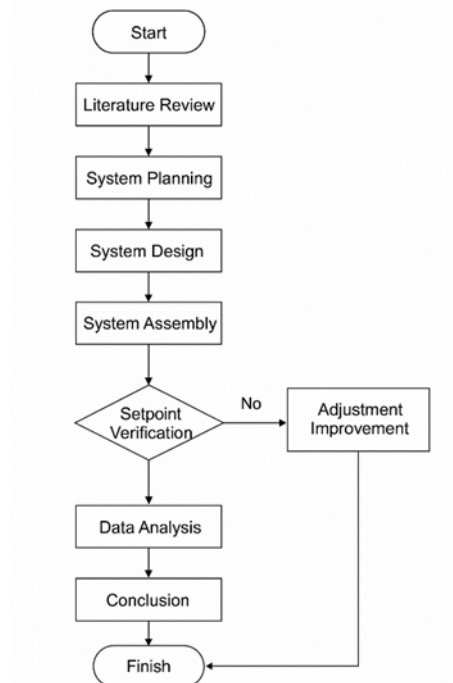


Fig.2 Flowchart of the research procedure

Observed Variables

The study focused on four main measurement parameters:

1. Solar Irradiance and panel surface temperature

Measured using an irradiance meter and an STC1000 temperature sensor. The irradiance data (W/m^2) represented the solar energy intensity, while panel surface temperature readings were validated using a *thermogun*.

2. PV panel output voltage and current

Monitored by a DC power meter to determine power output using $P = V \times I$. The average power value was used to calculate efficiency.

3. Water flow rate and volume

Measured using a *flowmeter* integrated with the ESP32 controller. The sensor detected water flow velocity and calculated total spray volume during operation.

4. Ambient temperature

Measured using both the STC1000 sensor and a *thermogun* to ensure consistent environmental conditions during testing.

Data analysis

The efficiency of the photovoltaic panel was calculated using the equation:

(1)

(2)

(3)

with G representing solar irradiance (W/m^2) and A representing the surface area of the PV panel (m^2).

A comparative analysis between the cooled and uncooled PV panels was conducted to determine the performance improvement resulting from the implementation of the *water sprayer* cooling system.

III. Result And Discussion

The experimental investigation was conducted to evaluate the performance of a photovoltaic panel equipped with a water sprayer-based cooling system compared to a similar panel without cooling. The measurements were performed under natural sunlight conditions for seven hours (09:00–16:00 local time) with data recorded every 30 minutes. The main observed parameters included solar irradiance, surface temperature, output power, and power conversion efficiency.



Fig.3 Layout design of the experimental setup

Solar irradiance measurement

Figure 4 illustrates the solar irradiance variation throughout the testing period. The irradiance increased gradually from 615.5 W/m² at 09:00 to its peak value of 1052.5 W/m² at 13:00, followed by a decline toward the afternoon. At 13:30, the irradiance dropped to 908.8 W/m² and reached its lowest point of 117.3 W/m² at 15:30 before slightly increasing to 280.7 W/m² at 16:00.

This pattern indicates the typical daily solar irradiance fluctuation under tropical weather conditions. The highest irradiance values between 11:00 and 13:00 represent the optimal period for maximum power generation of a photovoltaic panels.

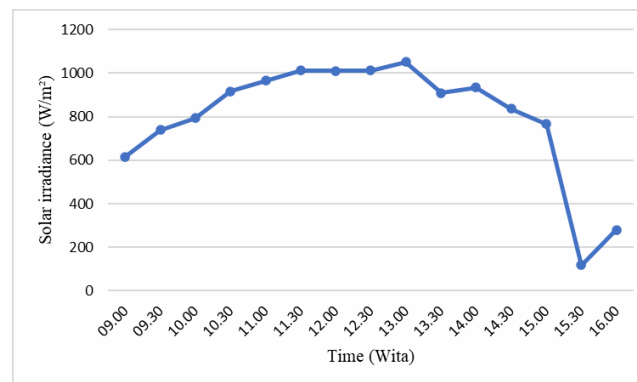


Fig.4 Solar irradiance variation during the test period

Surface temperature of photovoltaic panels

Figure 5 presents the comparison of panel surface temperatures between the cooled and uncooled systems. The panel without the cooling system recorded an average temperature of 51°C, whereas the cooled panel maintained an average temperature of 35°C, representing a reduction of approximately 16°C.

The temperature decrease was primarily due to the evaporative effect of the sprayed water, which accelerated heat dissipation from the panel surface. Maintaining a lower operating temperature reduces the internal resistance of the semiconductor materials, thereby improving current flow and overall electrical performance. This finding aligns with previous studies that confirmed the inverse relationship between PV temperature and electrical efficiency.

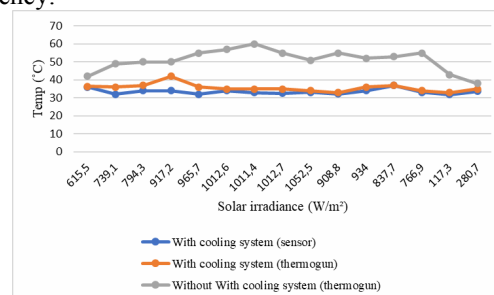


Fig.5 Surface temperature profile of the PV panels

Output power of PV panels

Figure 6 shows the relationship between solar irradiance and panel output power. At a solar irradiance of 934 W/m², the maximum power output of the cooled panel reached 105.7 W, while the uncooled panel produced 100 W. At the lowest irradiance of 117.3 W/m², the power outputs were 40.5 W (cooled) and 39.4 W (uncooled).

Over the full testing period, the total energy generated by the panel with the *water sprayer* cooling system was 572.5 Wh, compared to 519.2 Wh for the uncooled panel. The results clearly indicate that the cooling system enhanced the electrical power generation, particularly during high irradiance conditions when panel temperature tends to rise sharply.

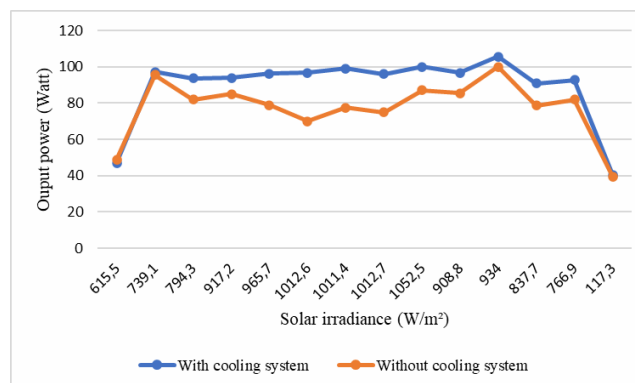


Fig.6 Output power of PV panels at different irradiance levels

Power conversion efficiency

Figure 7 compares the efficiency of both panels across various irradiance levels. In the range of 615.5–917.2 W/m², both panels exhibited similar efficiency values. However, at higher irradiance levels (965.7–1025.9 W/m²), the panel with the *water sprayer* system demonstrated more stable and higher efficiency compared to the uncooled panel.

During the afternoon period, when irradiance decreased to 908.8–280.7 W/m², the cooled panel consistently maintained better efficiency. This trend confirms that the *water sprayer* system successfully stabilized surface temperature and prevented thermal degradation, leading to higher and more consistent energy conversion rates.

The average comparison results are summarized in Table 1. Both panels received an average irradiance of 797.76 W/m² under identical conditions. The cooled panel maintained a surface temperature of 35.63°C, while the uncooled panel reached 51°C. The corresponding average power outputs were 85.88 W (cooled) and 75.45 W (uncooled), resulting in efficiencies of 18.44% and 16.84%, respectively. Hence, the implementation of the *water sprayer* cooling system improved the panel efficiency by 1.60%.

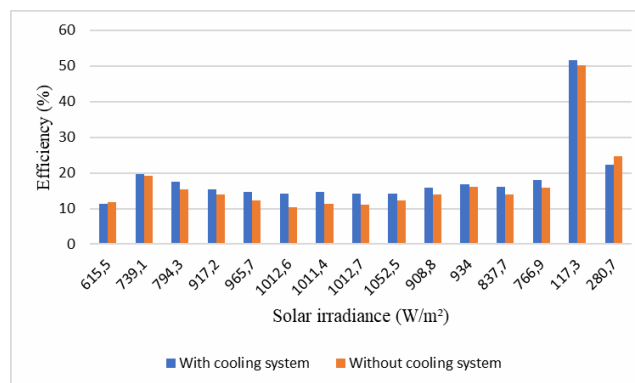


Fig.7 Comparison of power conversion efficiency

The results demonstrate that the *water sprayer*-based cooling system effectively enhances the performance of PV panels by reducing the thermal load on the PV panel surface. The temperature reduction of around 16°C significantly improved both the power output and the efficiency of the panels.

This finding is consistent with previous studies showing that excessive heat accumulation on PV panels decreases open-circuit voltage and short-circuit current due to increased semiconductor resistance. By

maintaining lower PV panel temperatures, the *water sprayer* system promotes optimal electron transport and reduces recombination losses, leading to higher energy conversion efficiency.

Additionally, the system's simplicity and automatic operation using an ESP32 microcontroller and STC1000 temperature sensor enable real-time temperature regulation with minimal power consumption. The water spray not only functions as a cooling medium but also helps remove dust and debris, ensuring better light absorption on the PV surface.

Overall, the proposed cooling system demonstrates high potential for application in tropical regions where ambient temperature significantly impacts PV panel performance. The experimental evidence confirms that active cooling using a *water sprayer* is an effective, low-cost, and practical solution for improving photovoltaic power generation efficiency.

Table 1 Average efficiency of PV panels

Average	Water Sprayer	Solar Irradiance (W/m ²)	Surface Temperature (°C)	Output Power (W)	Efficiency (%)	Difference
	With cooling	797,76	35	85,88	18,44	1,60
	Without cooling		51	75,45	16,84	

IV. Conclusion

This study concludes that the *water sprayer*-based cooling system effectively enhances the performance of PV panels under high-temperature conditions. The system reduced the PV panel surface temperature from 51°C to 35°C and increased the power conversion efficiency from 16.84% to 18.44%. The integration of the ESP32 microcontroller and STC1000 sensor enabled automatic temperature control and efficient operation with minimal energy consumption. The system's low cost, simplicity, and dual functionality as both a cooling and cleaning mechanism make it highly suitable for small-scale photovoltaic (PV) power applications. Future research should focus on optimizing spray patterns, minimizing water consumption, and scaling the system for larger PV installations. The combination of active *water sprayer* and passive cooling techniques is also recommended to achieve better overall system performance and sustainability.

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