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Enhancing The Performance of Photovoltaic Panels Through Active Cooling

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ABSTRACT

Photovoltaic (PV) panels are widely used for renewable energy generation, but their efficiency decreases due to high operating temperatures and dust accumulation on the surface. This work presents a simple and effective system to address both issues through active cooling and cleaning. A temperature sensor continuously monitors the panel condition, and an Arduino-based controller activates a water-spraying mechanism when the temperature exceeds a set limit. The sprayed water not only cools the panel through convection and evaporation but also removes dust and dirt, improving light absorption. The system operates automatically, ensuring efficient use of water and energy. By maintaining a lower temperature and cleaner surface, the proposed method enhances the efficiency, power output, and lifespan of PV panels, especially in hot and dusty environments.

Introduction:

The increasing demand for electrical energy, along with the rapid depletion of fossil fuel resources, has created a strong need for sustainable and renewable energy sources. Among the available options, solar energy has emerged as one of the most widely used sources due to its abundance, cleanliness, and environmental friendliness. Photovoltaic (PV) panels are commonly employed to convert solar energy directly into electrical energy and are widely used in residential, commercial, and industrial applications.

However, the performance of PV panels is significantly influenced by environmental factors such as solar irradiance, dust accumulation, and operating temperature. Among these, temperature plays a critical role in determining panel efficiency. Continuous exposure to solar radiation increases the panel temperature, which leads to a reduction in electrical efficiency and power output. In addition, dust and dirt deposited on the panel surface further reduce light absorption, thereby affecting overall performance. These issues become more pronounced in regions with high solar radiation and elevated ambient temperatures.

To address these challenges, it is essential to maintain the PV panel within an optimal temperature range while also ensuring a clean surface for effective energy conversion. Various cooling techniques have been developed, broadly classified into passive and active methods. Passive cooling relies on natural processes, whereas active cooling employs external mechanisms to achieve more effective temperature control.

In this work, an active cooling and cleaning system is proposed to enhance the performance of photovoltaic panels. The system reduces panel temperature while simultaneously removing dust from the surface, thereby improving efficiency and power output. The proposed approach is simple, cost-effective, and suitable for real-time applications, particularly in high-temperature and dusty environments.

Related Work:

Shaaban et al. [1] conducted a comprehensive review on enhancing PV panel performance through various cooling strategies. Their study examined water-based, air-based, and phase-change cooling methods, concluding that active water cooling consistently delivers the highest efficiency improvement across diverse climatic conditions. The review established the foundational benchmarks referenced in the present work.

Moharram et al. [2] experimentally investigated water cooling of PV panels under outdoor conditions and reported a notable reduction in operating temperature and a corresponding increase in electrical output. Their work validated the direct correlation between surface temperature reduction and power gain, supporting the approach adopted in this study.

Sinaga et al. [3] proposed an integrated system combining a dual-axis solar tracker with active cooling to maximize energy capture. Their results demonstrated that combining mechanical sun-tracking with active thermal management yields significantly higher performance gains compared to either method alone, highlighting the potential for future enhancements to the proposed system.

Habiballahi et al. [4] explored water flow beneath PV cells as a passive-active hybrid cooling method for water pumping systems. Their findings showed that subsurface water circulation effectively dissipates heat from the rear of the panel, providing a useful comparative reference for evaluating the front-surface spraying approach employed in the present work.

Firoozzadeh et al. [5] studied fin-based passive cooling as an economic alternative to active systems. While fins reduced temperatures moderately, the study confirmed that active methods such as water spraying remain more effective in high-temperature, dust-prone environments, directly motivating the design choices made in this work.

System Architecture

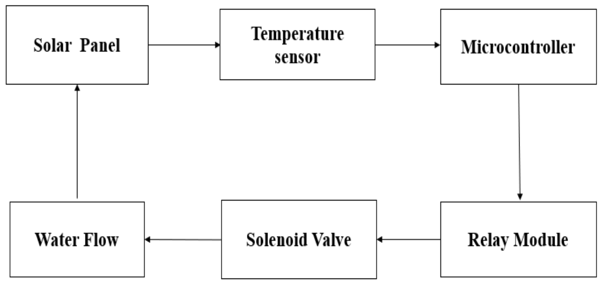
A. Materials

The experimental setup consists of a polycrystalline photovoltaic (PV) panel integrated with an active cooling and cleaning system. The specifications of the PV panel used in this study are as follows:

- Type: Polycrystalline PV panel
- Maximum Power (Pmax): 10 W
- Open Circuit Voltage (Voc): 22.0 V
- Short Circuit Current (Isc): 0.60 A
- Maximum Power Voltage (Vmp): 18.0 V
- Maximum Power Current (Imp): 0.56 A

The system is implemented using an Arduino microcontroller, DHT11 temperature sensor, relay module, solenoid valve, LCD display, breadboard, and connecting wires. The Arduino serves as the main control unit, while the relay module is used to control the operation of the solenoid valve.

B. Block diagram



C. Experimental Setup

The complete hardware setup of the proposed system is shown in **Fig. 1.1** The PV panel is placed under direct sunlight to evaluate its performance under real environmental conditions. A DHT11 temperature sensor is positioned near the panel surface to continuously monitor the temperature.

The Arduino microcontroller is interfaced with the temperature sensor, relay module, and LCD display. The LCD provides real-time information such as temperature readings and system status (valve ON/OFF). The relay module acts as an interface between the Arduino and the solenoid valve, enabling safe switching of the water flow system.

A water spraying arrangement is connected to the solenoid valve and positioned above the PV panel to ensure uniform distribution of water over the panel surface. The entire circuit is assembled using a breadboard and powered through an external supply, as illustrated in Fig. 1.1

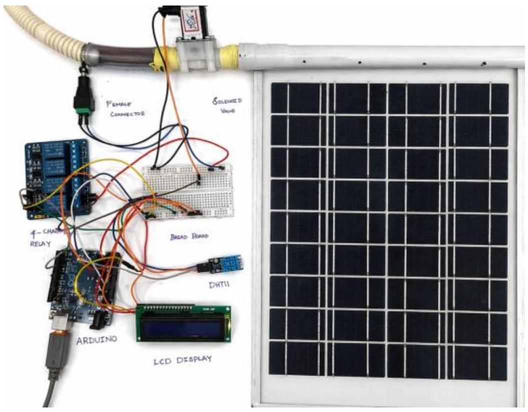


Fig.1.1: Hardware Prototype

D. Methodology

The system operates based on real-time temperature monitoring. When the panel temperature exceeds a predefined threshold value, the Arduino microcontroller activates the relay module, which in turn opens the solenoid valve. Water is then sprayed over the panel surface.

This process performs two main functions: it reduces the panel temperature through convection and evaporation, and it removes dust and dirt accumulated on the surface, thereby improving solar radiation absorption. Once the temperature falls below the threshold value or after a specified duration, the Arduino deactivates the relay, stopping the water flow.

E. System Operation and Observation

The system operation is evaluated based on real-time temperature monitoring. The DHT11 sensor continuously measures the PV panel temperature and displays it on the LCD. When the temperature exceeds the set threshold of **35°C**, the Arduino activates the relay, turning ON the solenoid valve to spray water for 10 seconds. After this, the valve is turned OFF and the system waits for 5 seconds before rechecking the temperature.

If the temperature is below the threshold, the valve remains OFF. The system operates automatically and the LCD displays both temperature and valve status, confirming proper functioning of the control mechanism.

Hardware Components

S.No	Component	Model / Rating	Purpose
1	PV Panel	Polycrystalline, 10 W	Solar energy conversion
2	Arduino Uno	ATmega328P, 5 V	Central control unit
3	DHT11 Sensor	3.3–5 V, ±2°C accuracy	Temperature monitoring
4	Relay Module	5 V, 10 A/250 VAC	Solenoid valve switching
5	Solenoid Valve	12 V DC, N/C type	Water flow control
6	LCD Display	16×2, I2C, 5 V	Real-time status display
7	Water Pump	12 V DC mini pump	Water pressurization
8	Nozzle Array	Mist spray type	Uniform water distribution
9	Breadboard	830 tie-point	Circuit prototyping
10	Power Supply	12 V / 5 V DC adapter	System power source

Results and Discussion

The proposed photovoltaic (PV) cooling and cleaning system was tested under real-time conditions to evaluate its operation. The panel temperature was continuously monitored using a DHT11 sensor, and the readings were displayed on an LCD.

When the temperature exceeded the set threshold of 35°C, the Arduino activated the relay, which opened the solenoid valve and allowed water to flow over the panel surface.

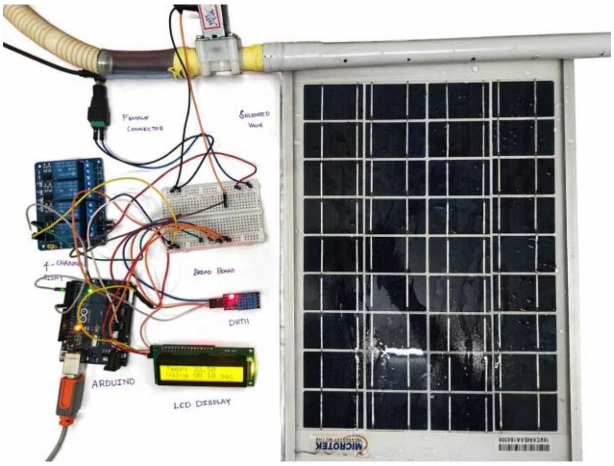


Fig:1.2:Valve On

Fig:1.2 This condition confirms that the system responds effectively to high temperature by initiating the cooling process. The LCD display shows both the temperature and valve status, providing clear real-time feedback.

As the cooling process continued, the panel temperature reduced. Once it dropped below the threshold value, the Arduino deactivated the relay, turning OFF the solenoid valve and stopping the water flow.

Conclusion

This work presents a simple and effective photovoltaic (PV) panel cooling and cleaning system based on temperature control. The system automatically monitors the panel temperature and activates water spraying when the temperature exceeds a predefined threshold. This ensures that the panel operates within a suitable temperature range without manual intervention.

The cooling process helps in reducing the panel temperature, which in turn supports improved electrical performance by minimizing temperature-related losses. In addition, the water spray performs a cleaning function by removing dust and dirt accumulated on the panel surface. This enhances solar radiation absorption and ensures better utilization of available sunlight.

The combined effect of cooling and cleaning leads to improved overall performance and efficiency of the PV panel. The system is simple, cost-effective, and suitable for practical implementation, particularly in high-temperature and dusty environments. Future work can focus on incorporating performance measurements and optimizing water usage for enhanced system efficiency.

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