

Experimental Study on a Photovoltaic Panel Using an Active Water Cooling Method

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DOI: <https://doi.org/10.47772/IJRISS.2025.91100619>

Received: 06 December 2025; Accepted: 13 December 2025; Published: 26 December 2025

ABSTRACT

Photovoltaic (PV) electric power generation is a promising technology for harvesting energy from the sun. However, it is difficult to obtain consistent and efficient energy from solar panels, which results in fluctuations in the battery's state of charge (SOC). This condition may cause overcharging or undercharging, both of which can reduce the battery's lifespan. Additionally, variations in solar irradiance, particularly changes in sunlight intensity, affect the efficiency of the solar panel and, consequently, the battery SOC. A major issue with solar panels arises when their temperature increases, as higher temperatures reduce their efficiency. This reduction in solar photovoltaic efficiency occurs under increasing and unstable environmental temperatures. To ensure the sustainability and improved performance of solar photovoltaic systems, this project proposes the development of an active water-cooling system using Arduino. This system is intended to help users enhance the efficiency of solar panels. This paper analyzes the effect of an active water-cooling system on the efficiency of a solar panel. The outcomes of this research align with SDG 7, SDG 9, SDG 12, and SDG 13 by enhancing photovoltaic efficiency through an active water-cooling method, thereby supporting clean energy, technological innovation, resource-efficient production, and climate action.

Keywords: Photovoltaic (PV) Efficiency; Active Water Cooling System; Solar Panel Temperature Control; Arduino Control; Renewable Energy Sustainability

INTRODUCTION

Solar energy is the fundamental energy source that sustains life on Earth for all plants, animals, and people. It provides a compelling solution for societies to meet their future needs for clean and abundant energy. The source of solar energy is the nuclear interactions occurring at the core of the Sun. Sunlight is readily available, secure from geopolitical tensions, and poses no threat to the environment or global climate systems through pollution emissions [1], [3].

Solar energy is currently widely utilized in residential areas and is increasingly adopted by various countries. The largest solar photovoltaic (PV) panel installations are located in China and India. Solar power generation is projected to supply around 16% and 10% of worldwide electricity consumption, respectively, making it one of

the largest contributors to global electricity production [2], [4].

This paper focuses on improving the efficiency of solar panels. An active cooling system was built to study the effects of temperature on the efficiency of photovoltaic (PV) panels. In addition, the system provides a constant voltage and current for charging a battery and supplying electricity to a load. PV panels often overheat due to excessive solar irradiance and high ambient temperatures. Solar cell performance decreases as temperature increases, resulting in a reduction in overall power output. This performance degradation is primarily caused by increased internal carrier recombination rates, which occur due to higher carrier concentrations [5].

Therefore, active cooling systems can be used to enhance the performance and efficiency of PV modules, thereby increasing their power output. By extracting heat from the PV module, it can operate at an optimal temperature. Consequently, both power output and efficiency can be improved. The cooling system designed in this project uses flowing water to reduce the temperature of the PV module. This project proposes the design of an active cooling system that uses an Arduino and a thermostat to automatically cool down the PV panel.

LITERATURE REVIEW

The performance of PV modules is generally specified under standard test conditions (STC). However, under real field conditions, module performance often differs from expectations based on STC results due to continuously changing environmental factors. Therefore, it is important to monitor PV module behaviour under actual operating conditions, particularly at temperatures higher than the STC reference temperature of 25 °C [5].

As PV module temperature increases, the band gap of the intrinsic semiconductor narrows, resulting in a decrease in open-circuit voltage (V_{oc}). At the same time, a smaller band gap allows more incident energy to be absorbed because a greater portion of the incoming light has sufficient energy to excite charge carriers from the valence band to the conduction band, increasing the photocurrent. However, higher temperatures also increase the internal resistance of the material and reduce electrical conductivity. Consequently, the increase in current with temperature is proportionally smaller than the decrease in voltage, leading to an overall reduction in cell efficiency [1], [2], [5].

To mitigate these temperature-induced losses, cooling systems are required to lower the operating temperature of PV modules and improve their efficiency. Based on a literature survey and previous studies, the following four cooling techniques were compared to identify the most effective method for solar PV systems [5], [6].

Passive Air-Cooling System

In a passive air-cooled system, heat sinks are installed on the rear side of the solar panel. These heat sinks help dissipate excess heat by transferring thermal energy from the high-temperature rear surface of the panel to the cooler surrounding air. For the heat sinks to function effectively, the temperature of the solar panel must be higher than the ambient air temperature. Heat is transferred through three mechanisms: conduction, convection, and radiation [6].



Fig. 1 PV panel with heat sinks on back side.



Fig. 2 Closed Loop Water Cooling System

Closed-Loop Water System

In this cooling approach, the PV module is integrated with a water-circulation pipe approximately 20 mm thick, attached to the rear side of the module. A storage tank supplies water to the cooling panel through an insulated pipe with an insulation thickness of 10 mm. A pump connected to the outlet of the tank circulates the water and regulates the flow through the cooling panel. As the coolant flows through the collector, it absorbs waste heat from the PV module, resulting in heated water being collected at the outlet [6].

Air-Cooled System

The effectiveness of air-cooled systems for solar panel cooling has been demonstrated in previous studies. In one investigation, halogen lamps were used as a light source to evaluate the performance of an air-cooling system under controlled indoor conditions. The impact of the system was observed under different levels of solar radiation and varying ambient temperatures. A brushless DC fan was used to reduce the temperature of the PV panel, and the power output was monitored as solar radiation increased.

This active cooling approach relies on forced convection generated by fans as the primary cooling mechanism. The DC fan installed at the rear side of the PV panel extracts heat from the module while simultaneously cooling it. The results indicate that an air-cooling system can effectively lower the PV module temperature and thereby improve its power output efficiency [7].



Fig. 3 Air Cooling System using DC Fan Motor.

Water Sprinkling System

The One of the most widely discussed cooling techniques involves cooling the solar panel by allowing water to flow over the irradiated surface of the PV module. The percentage reduction in panel temperature depends on the cooling rate of the PV material, which can be determined by obtaining accurate information about its thermal behaviour [8].

A popular method of active cooling is the hybrid Photovoltaic/Thermal (PV/T) system, which combines a photovoltaic module with a water-based cooling mechanism. In this system, water is circulated across the irradiated surface of the PV panel to cool the solar cells. The heated water leaving the panel is pumped back to a storage tank, where it mixes with cooler water before being recirculated through the system [8].

This hybrid cooling method helps mitigate the problem of PV panel overheating caused by uncontrolled solar radiation. It also maintains panel efficiency while using only a minimal amount of water [8].

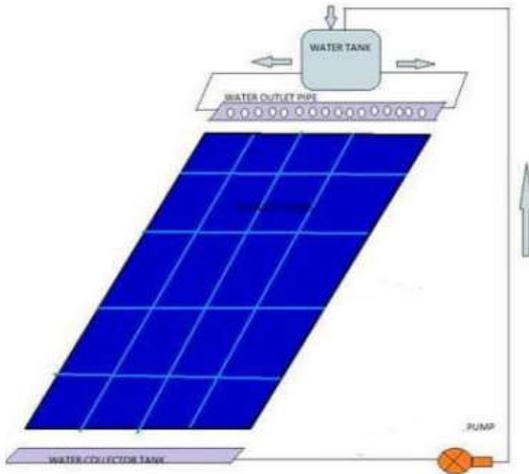


Fig. 4 Watering Cooling System.

METHODOLOGY

The hardware used in this project includes an Arduino Uno as the microcontroller, a 2-channel 5V/12V relay board with optocoupler isolation, a DS18B20 waterproof temperature sensor, a 12V DC mini brushless submersible water pump (240 L/H), an AC/DC 12V 2A power supply, and a PV panel. The software used in this project includes Fritzing and the Arduino Integrated Development Environment (IDE) for interfacing and programming.

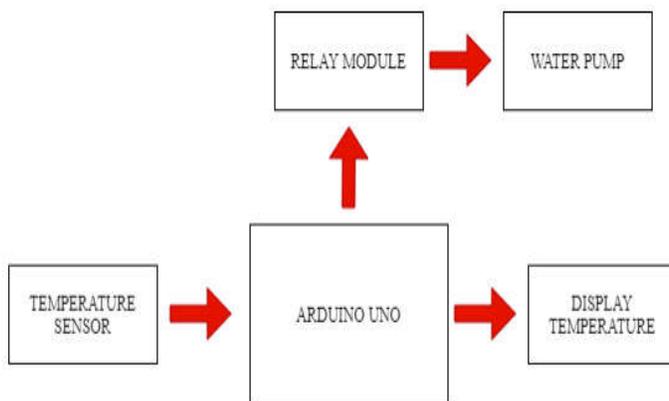


Fig. 5 Block Diagram of the Development Process.

Figure 5 illustrates the system architecture, in which a DS18B20 temperature sensor is mounted on the PV panel surface and interfaced with the Arduino Uno. The sensor continuously measures the panel temperature and transmits the data to the Arduino via a digital one-wire communication protocol. The Arduino processes the incoming temperature data based on the implemented control algorithm, and the measured values are monitored through the Arduino IDE serial interface. Similarly, the relay module is controlled by digital output signals from the Arduino. The microcontroller actuates the relay to drive the water pump according to predefined duty cycles,

enabling periodic activation and deactivation of the cooling system to maintain the PV panel within the desired operating temperature range.

Figure 6 presents the flowchart representing the operational sequence of the active cooling system. As the project utilizes a water-based active cooling approach, a DC water pump is incorporated to facilitate coolant circulation across the PV panel surface. The Arduino Uno serves as the central microcontroller responsible for executing the control algorithm and managing peripheral components.

Upon system startup, the Arduino Uno initializes its input/output configurations and begins running the programmed instructions uploaded via the Arduino IDE. The firmware includes routines for real-time temperature acquisition from the DS18B20 sensor and logic for actuating the relay module. For the cooling subsystem to function, the external power supply connected to the water pump must be switched on.

Following initialization, the relay module is triggered to transition from its Normally Open (NO) state to a closed state, thereby energizing the water pump for a predefined operational interval. Concurrently, the temperature sensor mounted on the PV panel continuously monitors the panel temperature and communicates the data to the microcontroller, where it is subsequently displayed through the Arduino IDE serial monitor. This control cycle is executed iteratively in a continuous loop, maintaining system operation until the primary power source is disconnected.

Figure 7 shows the hardware implementation of the active water-cooling system. The system uses an Arduino Uno powered via USB or battery (5V) to control a relay module that drives a 12V water pump. A DS18B20 temperature sensor monitors the PV panel temperature. The pump, mounted at the rear of the panel, circulates water over its surface to reduce temperature and improve efficiency.

This experiment was conducted at Kampung Pengkalan Minyak, Melaka. Data were collected every hour from 10:00 a.m. to 5:00 p.m. The temperature readings were recorded using the Serial Monitor on the Arduino Uno, while current and voltage were measured with a multimeter. The purpose of this experiment was to analyze the effect of PV panel temperature on its efficiency. The water pump was activated for one minute every hour.

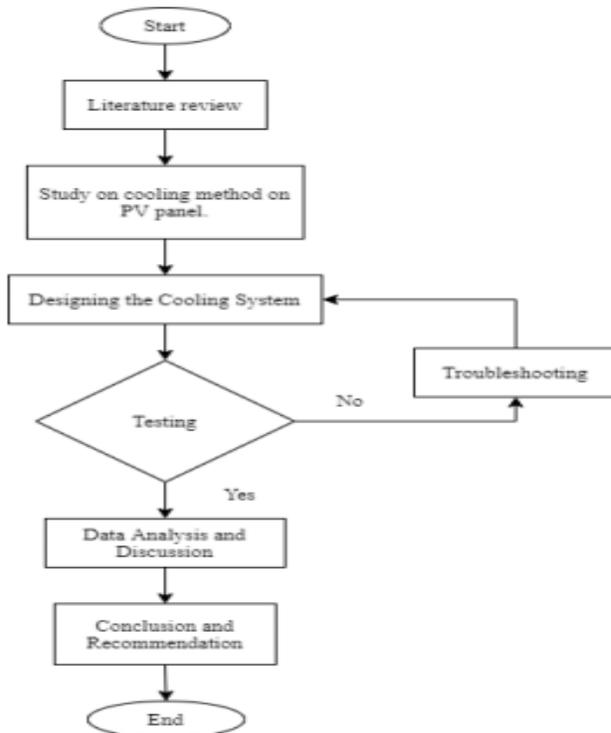


Fig. 6 Flowchart of the main process for the project.



Fig. 7 Diagram of the hardware setup.

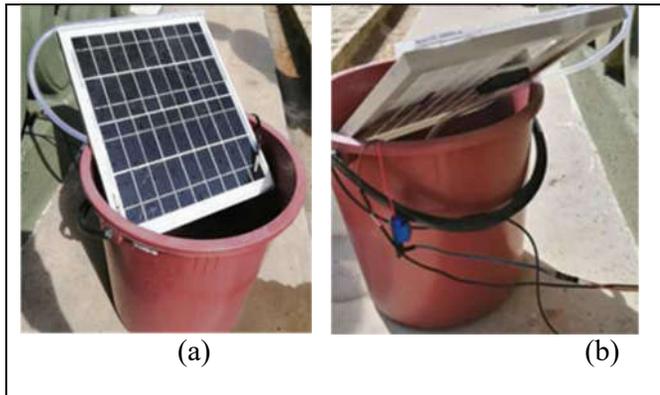


Fig. 8 (a) Front view of the PV panel. (b) Rear view of the PV panel.

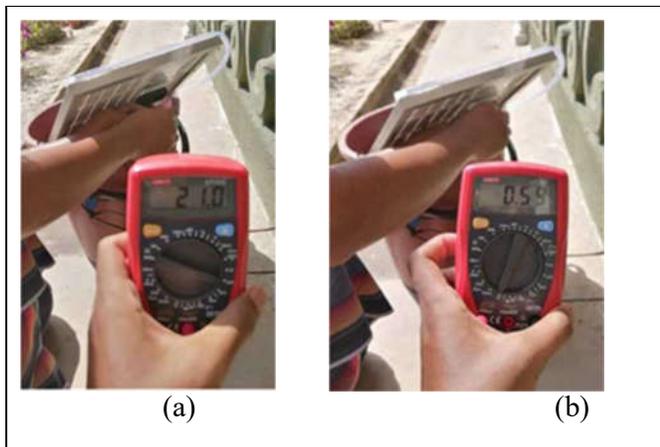


Fig. 9 (a) Measuring the voltage of the PV panel. (b) Measuring the current of the PV panel.

RESULT AND DISCUSSIONS

The result was taken in two condition, which is before the water pump activate and after the water pump activate. The observation has been during sunny day where the reading was taken every hour started from 10:00 am until 05:00 pm.

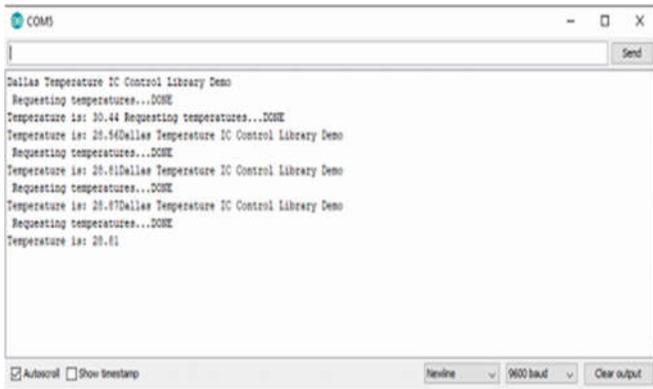


Fig. 10 Display of temperature measurements

Figure 10 shows the temperature displayed on the Serial Monitor in the Arduino IDE. The readings were transmitted by the DS18B20 temperature sensor through the Arduino board. All voltage, current, and front-surface temperature data were obtained using a multimeter and the Serial Monitor in the Arduino IDE. The experiment was conducted on a 10 W polycrystalline PV panel under ambient conditions. Data were collected between 10:00 a.m. and 5:00 p.m.

The water-cooling system increased the output current by up to 66.67%. The results show that the removal of heat through active cooling has a positive effect whenever water flows over the surface of the solar panel. This effect is most significant during peak sunlight hours, when both irradiance and panel temperature are at their highest. The installed water-cooling system effectively reduces the panel temperature, resulting in higher output voltage and current compared with the condition without cooling. Figures 11 and Figure 12 illustrate the differences in voltage and current, respectively, under conditions with and without the cooling system.

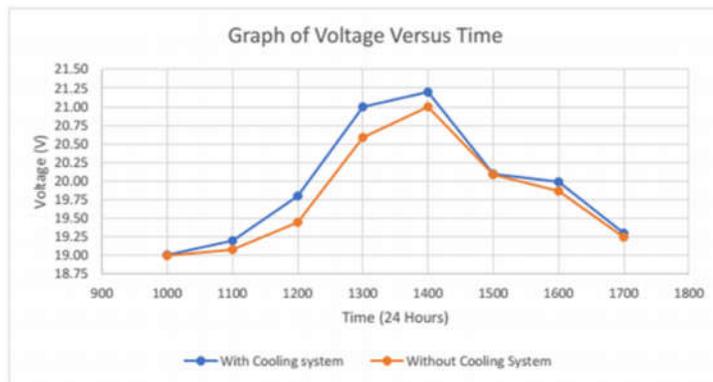


Fig.11 Voltage difference with and without the cooling system

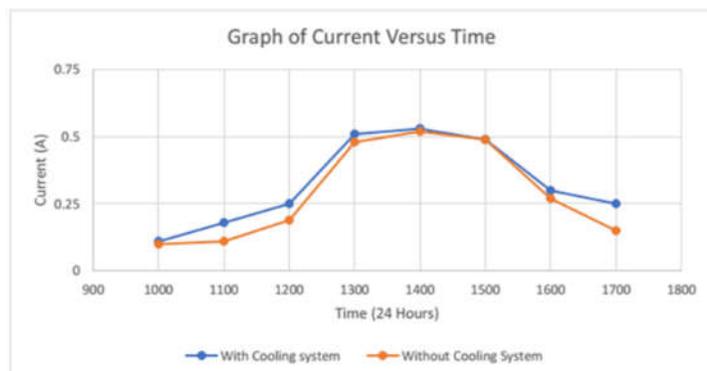


Fig.12 Current difference with and without the cooling system

This solar photovoltaic panel has dark-colored cells on its surface, which is a major factor contributing to high thermal absorption due to their material characteristics. Monitoring the temperature of the PV panel is important, as its efficiency is affected by temperature. Higher cell efficiency, combined with good irradiance, results in increased output voltage, current, and power. The aim of installing an active cooling system on the solar panel is to reduce the accumulated heat on its front surface.

Water has a high heat capacity, which minimizes temperature fluctuations. It is commonly used in nature for example, warm-blooded animals distribute heat through their bodies and in engineered systems, such as car cooling systems. In this study, water is used to transfer heat from warmer areas to cooler areas, effectively reducing the surface temperature of the solar panel. Figure 13 shows the temperature difference between a PV panel with an active cooling system and one without a cooling system.

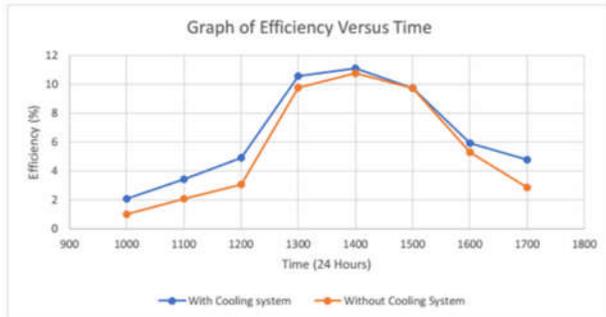


Fig. 13 Surface temperature of the PV panel versus time with and without an active cooling system

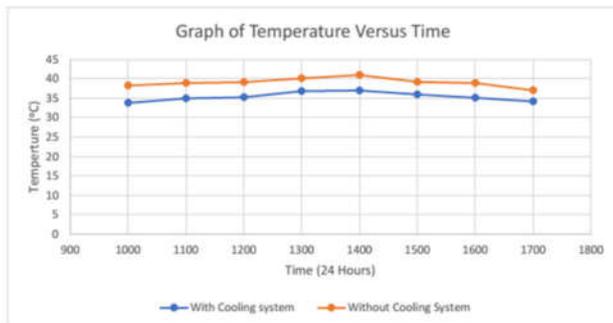


Fig. 14 Efficiency of the PV panel versus time with and without a cooling system

Figure 14 shows that the efficiency of the PV panel increases when using an active water-cooling system. The average efficiency of the PV panel with the cooling system is 6.58%, while without the cooling system it is 5.52%. This represents a difference of 1.06%, demonstrating that the use of an active cooling system can improve the panel’s efficiency.

CONCLUSION

In conclusion, the objectives of this project were successfully achieved. The purpose of this work was to reduce the surface temperature of the PV panel, and an active cooling method using water was designed to accomplish this goal. The results demonstrate that water-based cooling effectively lowers the temperature of the PV panel. Consequently, the efficiency of the cooled PV panel increases compared to a panel without a cooling system. By maintaining an optimum operating temperature, the PV panel is able to produce higher output power.

ACKNOWLEDGMENT

The authors would like to express their sincere appreciation to Universiti Teknikal Malaysia Melaka (UTeM), the Faculty of Electrical Technology and Engineering (FTKE), the Centre for Robotic and Industrial Automation (CERIA), the Centre for Smart System and Innovative Design (COSSID), and the Centre for Research and

Innovation Management (CRIM) for providing the support and funding that made this study possible.

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