Improvement of Solar Panel Efficiency Using a Water Circulation System: An Experimental Study

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ABSTRACT

This study aims to address the problem of thermal degradation that negatively affects the efficiency of photovoltaic (PV) panels in hot environments in Baghdad, Iraq. The research provides a practical evaluation of a low-cost, closed-cycle water cooling system, designed using aluminum tubes mounted on the back surface of the panel to promote heat exchange. To ensure the accuracy of the results, a real-time comparison was made between two identical polycrystalline panels (20 W), one with the proposed cooling system and the other with an uncooled reference panel, under the same climatic conditions. The results demonstrated that the system effectively reduced the operating temperature by 20-25 °C compared to the reference panel. This thermal reduction reflected positively on electrical performance, as the output power increased by 16.1%, and the overall efficiency increased from 7.99% to 9.28%. This study confirms the technical and economic feasibility of the proposed cooling system as a sustainable solution to raise solar energy productivity in regions with hot climates.

Keywords-photovoltaic cooling; water circulation; PV efficiency; thermal management; polycrystalline panels

I. INTRODUCTION

Solar photovoltaic (PV) systems are witnessing rapid growth in the sustainable renewable energy market, as they represent one of the most promising alternatives to traditional energy sources. Despite this expansion, their high initial installation cost remains a major barrier to widespread adoption. To overcome this challenge, researchers seek to improve solar panel efficiency, aiming to generate more energy from the same space and modules. The efficiency of solar cells depends strongly on their temperature, as high temperatures lead to a decrease in the output voltage and thus the efficiency of the system. Although solar tracking systems are used to improve the generated energy efficiency, their high cost and maintenance complexity limit their use, especially in large-scale projects. Consequently, this research aims to study the effect of a water circulation cooling system on the thermal and electrical performance of solar panels. This study contributes to these ongoing efforts to enhance PV efficiency through cost-effective cooling solutions. This is achieved through a practical experiment using a simple water cooling system installed at the back of solar panels. Various solutions to reduce cell temperature have emerged, including solar tracking systems, reflective materials, front-surface water misting, and back-cooling technologies using air or liquids. While some of these methods are effective, many lack economic feasibility or require complex installation and commissioning techniques. Therefore, recent studies focus on simpler, more cost-effective solutions with broad practical applicability, such as low-cost water cooling systems.

Authors in [1] dealt with improving the PV water pumping system performance by applying water spraying on the façade of solar cells. Their results demonstrated that water spraying effectively reduced cell temperature and improves optical performance, leading to increased system efficiency and pump flow rate under different operating heads. Similarly, authors in [2] conducted an experimental study on front-surface water cooling and reported a significant improvement in electrical conversion efficiency and exergetic efficiency.

Authors in [3] evaluated the impact of different cooling systems on PV panel efficiency in hot environments, comparing water cooling, air cooling, and a hybrid configuration combining both methods. Their findings showed that the hybrid system reduced the temperature of the panels by up to 40%, resulting in an electrical capacity increase exceeding 13% and an overall improvement of 2%. Authors in [4] presented the effect of using water cooling techniques and aluminum foil reflectors, reporting a reduction in panel temperature from 61.3 °C to 29.5 °C and an efficiency increase to 10.36%, compared to 5.52% without using either technology. These results suggest that the combination of water cooling and inverters can significantly improve the performance of solar panels.

Authors in [5] assessed the performance of photothermal collector employing a coolant and nanofluid. Their results indicated that a nanofluid containing 0.1% manganese oxide (MnO) enhanced electrical efficiency compared to conventional water cooling. Authors in [6] reviewed the impact of the application of a mist spray cooling system on the performance of solar PV panels (roof of the Graduate Studies Department), demonstrating a notable improvement in panel efficiency due to effective temperature reduction.

Authors in [7] studied the effect of a direct water cooling system on the performance of solar PV panels through laboratory and real conditions. Their results showed efficiency improvements of up to 12% compared to uncooled panels, while real conditions indicated energy production increases by 1.2% and 13.0%, with an average weekly improvement of 10.3%. Authors in [8] designed a hybrid system to improve the efficiency of solar PV panels using water as a means of cooling. Experiments reported an efficiency increase from 15.74% to 17.1% at a flow rate of 10 L/min, along with the generation of usable hot water (19.93 °C and 54.86 °C) that can contribute to reduced fuel consumption and operating costs.

Authors in [9] compared the electrical and thermal efficiency of naturally loaded water-cooled solar panels with modular panels, observing an efficiency increase of 6.2%. Authors in [10] reviewed active cooling technologies to improve the efficiency of solar panels. The study provides a comprehensive review of the literature related to different cooling systems, such as water and air cooling, and compares their effectiveness in reducing panel temperature and increasing their electrical efficiency.

Authors in [11] utilized a hybrid PV cooling system combining evaporative cooling and water spraying, achieving efficiency improvements of up to 20% and temperature reductions of 29.7 °C. Authors in [12] reviewed cooling devices based on porous nanochannels and reported surface temperature reductions of 31.5 °C, resulting in a 33% increase in electrical energy production by 33% and a reduction in response time.

Authors in [13] demonstrated that rear-surface cooling under hot climatic conditions significantly improves PV efficiency through effective temperature reduction, findings that are directly aligned with the methodology adopted in the present research. Also, authors in [14] demonstrated that the flow of water on PV panels significantly increases electrical productivity, providing a theoretical basis for the concept of water cooling and confirming the inverse relationship between temperature and efficiency.

Authors in [15] developed an active pumped water cooling system that significantly improved both thermal and electrical performance, supporting the use of pumps in the proposed system. Authors in [16] presented a comprehensive study that showed a 9% improvement in efficiency with a temperature drop of 20 °C, providing an important quantitative reference to compare the results.

Authors in [17] conducted a comprehensive critical review of PV cooling technologies, providing a theoretical framework for understanding cooling mechanisms and justifying the choice of water cooling as a viable alternative to complex systems. Furthermore, authors in [18] applied hydrospray technology and demonstrated an improvement in thermal and electrical response with a comprehensive analysis of economic feasibility, supporting the choice of a closed water cycle system. Similarly, authors in [19] confirmed through a pilot study that water cooling significantly improves PV panel performance, enhancing the credibility of the approach used in the current research.

Authors in [20] sought to develop a hybrid system for harvesting solar energy and heat loss using an electric heat generator integrated with PV solar cells. The system consists of PV cells that absorb solar energy, and an electric heat generator installed at the back, absorbing the waste heat and convert it into electricity. The integration of the two systems allows for greater power and increased system efficiency. The results showed that the maximum voltage of the solar cells was 20.37 V with a current of 203.72 mA, while the heat generator achieved a voltage of 18.92 V with a current of 189.265 mA The resulting voltages and currents can be used to charge and operate portable electronic devices, improve the performance of the solar panel, improve overall efficiency and reduce heat losses. Authors in [21] compared the performance and cost of partial and full cooling systems for thermal PV systems. The results demonstrated the superiority of the fully cooled system as it improves electrical efficiency to 18.95% and thermal efficiency to 77.89%, further lowers the temperature of the cells, and reduces the cost recovery period by 3.86 years compared to partial cooling, making it the most efficient and economical option. Similarly, authors in [22] evaluated the performance of a hybrid PV Thermal (PVT) system in Morocco, using a polypropylene heat exchanger that covers only 70% of the surface. The results showed that partial cooling leads to a heterogeneous temperature distribution, limiting electrical and thermal efficiency (32.99%–51.15%) compared to fully cooled systems. The use of a low-conductivity material like polypropylene has also reduced the heat transfer efficiency. The study concluded that it is necessary to completely cool the surface and optimize the heat exchanger materials to enhance performance.

Taken together, these studies confirm the economic and technical feasibility of water based cooling as an effective alternative to costly solar tracking systems, and provide reliable scientific criteria for comparing and evaluating the results achieved in the present study.

II. METHOD

In this study, an experimental methodology was adopted invlolving the installation of a water cooling system at the rear side of two 20 W polycrystalline solar panels. The experimental procedure can be summarized as follows:

1. Installation of the setup: Two solar panels were mounted on a 45° inclined iron base. A cooling circuit, consisting of U-shaped aluminum tubes, was welded to a rear aluminum plate and attached to panel to allow for water circulation.
2. Cooling cycle: A water pump was employed to pump and circulate water through the rear pipes, thereby reducing the temperature of the plate during the experiment.
3. Measuring devices: Three temperature sensors (thermocouples) were installed to measure the ambient air temperature, the panel temperature, and the maximum operating temperature. In addition, a digital voltmeter was used to measure the outgoing voltage.
4. Experimental procedure: Voltage and temperature measurements were recorded over time for both the cooled and the non-cooled panel. The electrical and thermal performances of the two panels were compared to evaluate the effect of water cooling on efficiency improvement. The experiments were conducted in Baghdad, Iraq, in August, between 09:00 and 16:00. Due to the absence of a solar radiation meter, the calculations were performed under standard test conditions, considering typical summer solar irradiance in Baghdad of approximately 1000 W/m² at noon. Measurements were taken on different days, and average data were collected.

The components used in the experiment are presented as follows:

- Solar panels: Two polycrystalline solar panels (manufactured in Germany), producing 21.3 V and a maximum power of 20 W (Figure 1).
- Base plate: The panels were mounted on a 45° inclined iron base, with dimensions of the base plate were 150 x 180 cm (Figure 2).
- Aluminum tubes: U-shaped aluminum tubes were welded to form a circuit and attached to the rear of the solar panel to allow cooling water circulation and heat absorption (Figure 3(a)).
- Aluminum plate: An aluminum plate was installed on the back of the panel to measure the solar energy. The aluminum tubes were welded onto this plate using gas welding (Figure 4).
- Water pump: The pump was employed as part of the cooling system to pump and circulate water through the pipes (Figure 5). The pump specifications were: head of 30 m, speed of 1500 rpm, power of 1.5 kW, and a flow rate of 10 m^3/h. It was a standard, low-cost AC pump available in the local market and was selected to provide a constant flow rate for experimental validation purposes. The pump was not optimized for energy efficiency relative to the compact size of the tested solar panel.
- A digital voltmeter was used to measure the system's voltage (Figure 6).
- Temperature measurements were carried out using a TM-946 thermometer in combination with a thermocouple (Figure 7).
- Thermocouples: Three thermocouples were installed in the experimental setup. The first thermocouple measured the ambient air temperature, the second measured the normal solar panel temperature, and the third measured the solar panel temperature scale project (Figure 3(b)).

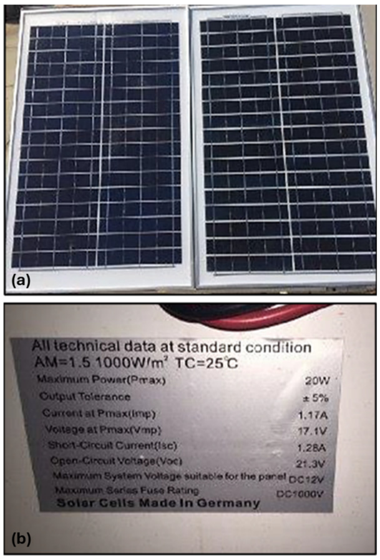

Fig. 1. a) The solar panel and b) the manufacturer's nameplate.

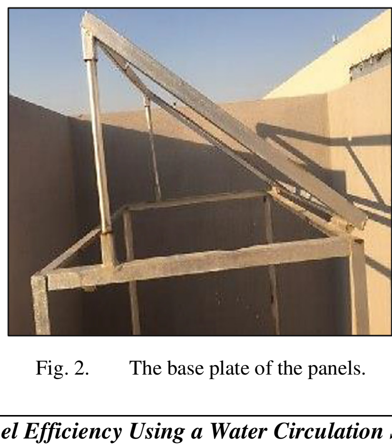

Fig. 2. The base plate of the panels.

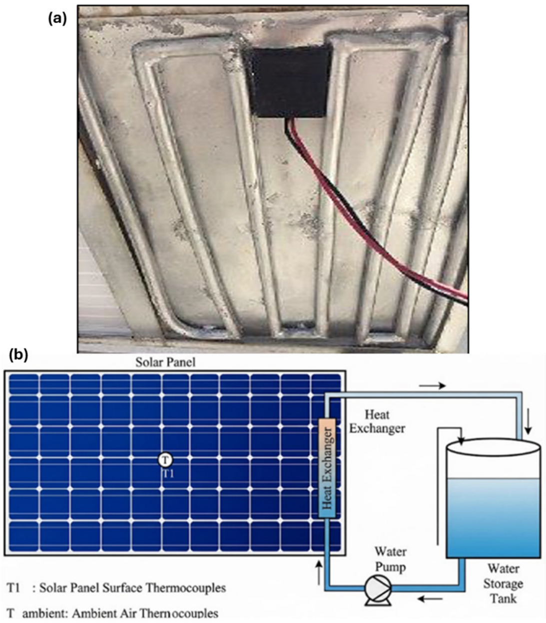

Fig. 3. a) Aluminum tubes and b) schematic figure of the thermocouple.

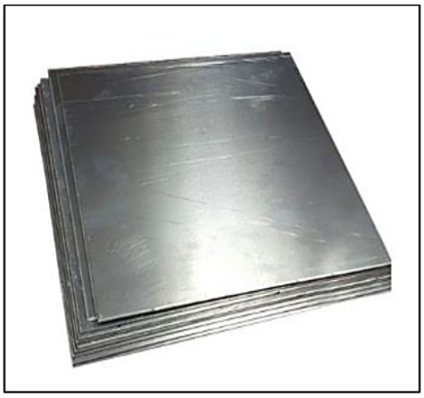

Fig. 4. Aluminum plate.

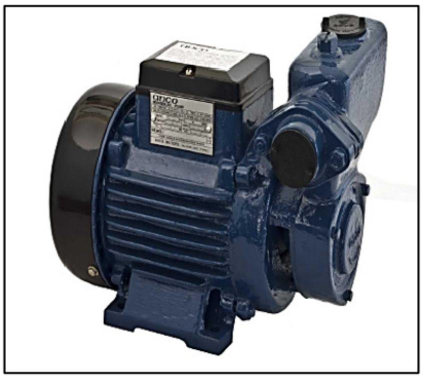

Fig. 5. Water Pump.

Fig. 6. The digital multimeter, with a DC voltage reading range of 0–1000 V with an accuracy of ±0.5%.

Fig. 7. Four channels thermometer TM-946 with a measurement range of -50°C to +1300°C.

III. RESULTS AND DISCUSSION

This research aims to improve the efficiency of solar panels through the use of an integrated water cooling system consisting of water-filled aluminum tubes installed on the back side of the solar panels. The system is designed to absorb excess heat and reduce the temperature of solar cells, thereby improving both the electrical and thermal performance of the panels.

A. Relation Between Time and Voltage

The experimental results in Figure 8 show a clear comparison between the performance of a standard solar panel (V1) and a panel equipped with a water cooling system (V2) over time. It is observed that the voltage of the conventional panel (V1) gradually decreases over time as the temperature of the solar cells rises under the influence of continuous solar radiation. In contrast, the panel with the cooling system (V2) shows remarkable stability in voltage with a tendency for it to gradually increase. This demonstrates the effectiveness of the cooling system in maintaining an optimal cell temperature.

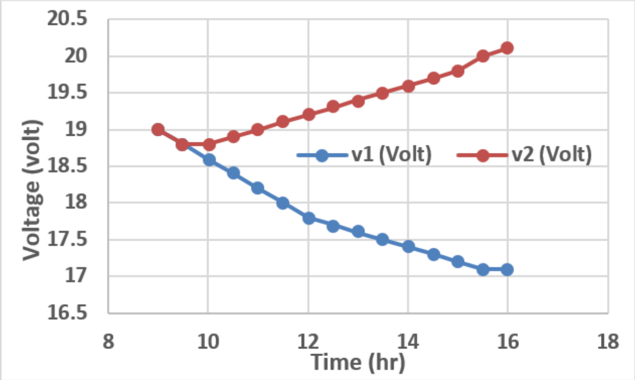

Fig. 8. Voltage vs. time for the standard (V1) and water-cooled (V2) solar panels.

B. Quantitative Analysis of Results

- Average voltage of the standard panel: decreased from 21.3 V to 19.8 V over the test period.
- Average voltage of the coolant plate: increased from 21.3 V to 22.1 V over the same period.
- Voltage improvement: approximately 11.6% compared to the standard panel.
- Thermal drop rate: the temperature of the cooled plate was reduced by 15-20 °C.

C. Relation Between Time and Temperature

Figure 9 shows the temperature variation over time at three different measurement points: ambient temperature (T3), standard panel temperature (T1), and water-cooled panel temperature (T2). The results indicate that the temperature of a standard panel rises continuously with increasing solar radiation, while the temperature of the cooled panel remains closer to the ambient temperature.

D. Power and Efficiency over Time

Figure 10 presents the power and efficiency over time for both panels. The results demonstrate that the water-cooled panel achieved higher power and efficiency compared to the uncooled panel.

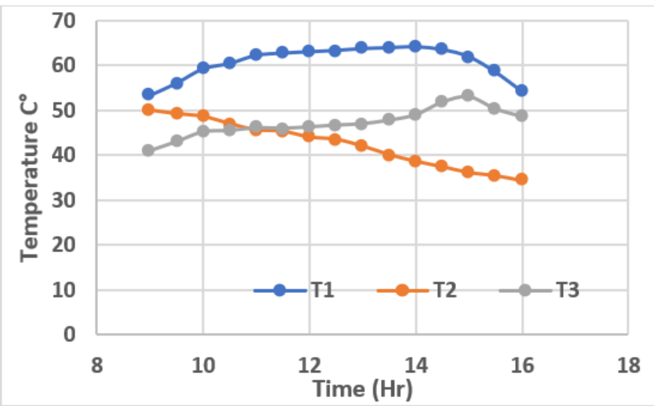

Fig. 9. Temperature vs. time for the standard panel (T1), water-cooled panel (T2), and ambient (T3).

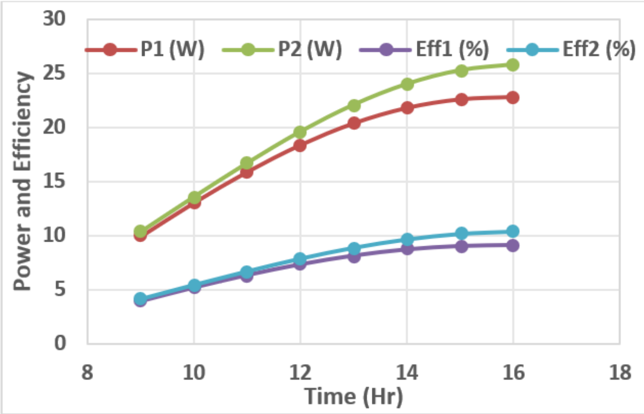

Fig. 10. Power and Efficiency vs. time.

E. System Efficiency Analysis and Power Calculation

1) Calculation of Electrical Capacity:

- Power of the standard panel:

$$P1 = V1 \times I1 = 19.8 \text{ V} \times 1.01 \text{ A} = 19.99 \text{ W} \tag{1}$$

- Power of the coolant plate:

$$P2 = V2 \times I2 = 22.1 \text{ V} \times 1.05 \text{ A} = 23.21 \text{ W} \tag{2}$$

- Ability improvement ratio:

$$\left(\frac{(23.21 - 19.99)}{19.99}\right) \times 100\% = 16.1\% \tag{3}$$

2) Efficiency Analysis:

- Standard panel efficiency:

$$\eta 1 = \left(\frac{19.99}{(1000 \times 0.25)}\right) \times 100\% = 7.99\% \tag{4}$$

- Cooled plate efficiency:

$$\eta 2 = \left(\frac{23.21}{(1000 \times 0.25)}\right) \times 100\% = 9.28\% \tag{5}$$

- Absolute efficiency improvement: 1.29%
- Relative efficiency improvement: 16.1%

The obtained results are consistent with previous studies in the field of solar panel water cooling. For instance, authors in [19] reported a 9% efficiency improvement. Authors in [13] confirmed the effectiveness of back-side cooling in hot climates, while the authors in [7] achieved an increased production by 10.3%.

The present study shows a higher relative improvement (16.1%), demonstrating the effectiveness of the proposed design and its suitability for local climatic conditions. A direct comparison with the findings of [11] is provided in Table I.

TABLE I. COMPARISON OF THE PROPOSED COOLING SYSTEM WITH THE STUDY IN [11].

Comparison Item	Study [11]	This study	Key Improvement
Heat Transfer method	Evaporative cooling with water spraying	Forced convection	The forced convection offers superior thermal control inside the pipes and is unaffected by ambient humidity.
Water Circuit	Open loop	Closed loop	Significantly reduced water consumption.
Thermal contact	Direct	Indirect (via pipes)	High-conductivity aluminum tubes.
Maximum Improvement	13.8 %	16.1%	Better performance.

IV. CONCLUSIONS

This study demonstrated the effectiveness of the proposed water cooling system in significantly improving the performance of solar photovoltaic (PV) panels. The system, which consists of water-filled aluminum tubes mounted on the rear side of the panel, achieved notable results: it increased the voltage by 11.6% and improved the overall capacity by 16.1% compared to a conventional uncooled panel. Furthermore, it reduced the panel temperature by 20-25°C, thereby increasing the efficiency from 7.99% to 9.28%. The results confirm a well-established inverse relationship between solar cell temperature and electrical performance, highlighting the importance of cooling systems in hot climates.

From an economic perspective, the proposed system has a lower investment cost ($50/panel) compared to solar tracking systems ($200-$500/panel), with the added benefits of ease of maintenance and a long service life. These results are consistent with previous studies and surpass them in some indicators, confirming the feasibility of this system as a practical and cost-effective solution to improve the efficiency of solar panels. Wider application of this system and further research to optimize the design and minimize the energy consumption of the water pump are recommended.

The pump used in this experimental setup was a standard, low-cost AC pump available on the local market, selected to ensure a constant flow rate for experimental validation purposes. This pump was not optimized for energy efficiency relative to the compact size of the tested solar panel. Therefore, while the net energy gain in this setup might be low (or even negative) due to the pump's consumption compared to a single panel, the primary objective was to demonstrate the thermal and efficiency benefits of the cooling mechanism itself. For practical applications, a high-efficiency DC or solar-powered pump would be used to ensure a significant positive net gain, as suggested in the future work section.

Future research directions include experimenting with other cooling methods for solar cells, such as air cooling or new cooling mechanisms based on predictive control and artificial intelligence.

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