Enhancing Photovoltaic Efficiency Through Water Cooling System Design and Analysis

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Abstract

In this study a front surface spray water cooling system with a zigzag pattern was experimentally and theoretically designed and investigated. Since the effectiveness of any photovoltaic panels can be adversely affected by various weather-related conditions such as solar radiation intensity, ambient temperature and dust accumulation, and the temperature and rate of flow of water that is used for cooling. ANSYS Fluent was utilized to predict the effects of the proposed system on photovoltaic (PV) power production. The findings indicated that the proposed system, when operating at a rate of 5 L/min water, enhanced efficiency of PV by 20.25%, whilst providing a pristine and dust-free surface. The simulation results indicated that the solar radiation is mostly affecting parameter in increasing the power production with implementation of water-cooling system, upon an increase of 100 watt/m² in solar radiation, the PV power production augmented by 16.6%. Furthermore, decreasing the water inlet temperature by 5°C with a 5 L/min volume flow rate resulted in an increase in panel power production by 2.25%. Though, the ambient temperature has a slight influence on PV power production at all water volume flow rates.

1. Introduction

maximizing universal population and economy are leading to increase in Annual Primary Energy (PE) usage by 1.6% [1]. Authenticity increasing the indigence of energy is preferable to be offered by cheaper, reliable and no contamination sources. Now a day due to [1] 85% of energy that the universe consumes is from non-renewable energy roots, this rate should be decreased briskly by replacing it with renewable energy source due to its effect on global warming and environmental alter. Therefore, researchers focused on utilizing renewable energy instead of conventional once. Solar energy is the most widespread renewable energy nowadays. Typically, photovoltaic efficiency ranges 10–20% [2], due to the type of material used for manufacturing. [3] 80–90% photovoltaic panel low power production is related to converting solar radiation to heat energy. Converting solar energy into electrical and heat energy by using just one mechanism, will lead to a positive development for the future energy requirement named photovoltaic thermal collector. An essential point for photovoltaic to producing higher power is to have a low operation temperature. Cooling front surface of a photovoltaic panel will result in increasing the performance of the panel, therefore producing higher power. Lately researchers and scientist are working on developing different photovoltaic cooling design, some researchers were the first to start to cool the panel by utilizing air and water, [4] used a combined solar panel system with heating system, while [5]was the first scientist who implemented air to cooldown the panel, another study used water to cooldown PV panel in conjunction with flat plate solar collector[6], lately in same year [7] studied the effect of utilizing air and water to on improving panel efficiency.

1.1 Front surface cooling

Researcher [8] An examination was conducted to assess the influence of submerging the front face of the panel in water at varying levels and velocity of flow. The findings suggested that the lowest level of water
immersion generated the highest efficiency. The researchers outlined on optimization of panel cooling using spray water which was addressed as an effective method for the hot region, the result showed that the solar array efficiency was increased by 16.65%, also they conclude that this design need less space and also it is less expensive compared with other cooling system [9]. The PV performance was investigated [10] by examining the effect of water spray angle, as well as the distance between nozzles and PV, quantity of nozzles and oscillating water spray they conclude that the efficiency increase to 19.78% with decreasing spray angle to 15° which leads to decreasing in the panel’s from 64° C to 24° C. with decreasing the space between nozzles and PV panel to the smallest distance which was 10 cm the power output was increased to 25.86%. The authors progressed a cooling system which consist of three nozzles with 90° spraying angle, a water pressure 1.5 bar and an on/off controller was managed as 30 s on 180 s off was capable of maximizing the efficiency by 2.09°C and the panel temperature was minimized up to 24°C, so they got an effective cooling with minimum water consumption [11]. The research demonstrated that by applying forced water spraying over the surface of the panel, by using a water distribution hose, it was possible to reduce the temperature of the panel by up to 9.07°C over a period of 10 hours. This was accompanied by a 0.71% and 9.27% increase in efficiency and power generated by the system respectively. Thus, it was established that cooling the panel was effective in improving its efficiency and conserving water. In a separate study [13], the photovoltaic panel was cooled by having three distinct flows of uniform water go over the top surface of the panel, which was supplied from the tank which was mounted on the top of the panel. It was concluded that cooling the PV module reduced the panel temperature by 30%, resulting in increased power production from 19 watts to 23 watts. Additionally, it was concluded that the front surface water cooling system was advantageous for clearing the panel surface of dust, resulting in enhanced visual appearance. due to a study made in 2019 [14] using ANSYS CFX to determine the distribution of temperature of photovoltaic module by using front surface cooling at different water inlet temperature the findings showed that the panel mean temperature for not cooled one was about 50.68°C, while it was 45.34°C and 29.71°C for water inlet temperature 45°C and 20°C respectively. Another research by [15] utilized ANSYS Fluent to study the impact of five distinct water flow rates ranging from 0.01 to 0.05 kg/s on panel cooling and their effect on convection heat transfer rate. The results indicated that the convection heat transfer rate considerably will reduce by increasing the flow rate where it will be 235 watts at 0.05 kg/s. [16] studied the front surface cooling by applying six nozzles two from top, and two at each left and right side of the panel exactly facing each other, there outcome indicate that the maximum power output improvement rate using the proposed method was 15.5%.

1.2 Back surface cooling

Other researchers used PV back cooling to enhance the efficiency, [17] studied the panel performance by using four mirrors to concentrate the radiation on the panel and they used 8 rectangular aluminum tubes under the panel to cool down the panel they came out with that the output of bifacial concentrated panel with cooling is about three times the power produced by the normal panel. The researchers [18]used different ways to cool down the panels on the back surface by using water spraying and forced convection to overcome the high temperature. the results showed that the simple design was able to
maximize the efficiency by 1.6% and 8% maximization of daily average electrical efficiency. [19] they developed a novel type heat exchanger positioned at the back of the panel to cool down the cells by using air, the maximum improvement they came with in the voltage and output power were 1.3 volt and 7.4 watt respectively. Another study by [20] a cooling chamber attached with three different pane orientation with 60°, 30° and 0° angle to the back side of PV panel with two different flow directions up flow and down flow. The 0 module was uncooled and the modules 1, 2 and 3 where upward flow and 4, 5 down flows, where the panel was installed facing south with 33 ° tilt angle. The result showed that module 1 has maximum efficiency about 80% with flowrate 4 L/min and electrical efficiency 17% with 60° pane orientation. [21] used ANSYS software to validate an experimental result of back cooling by using spiral absorber to study the effect of water inlet temperature and solar radiation intensity over the temperature stability, they conclude that at flowrate 40 kg/h and solar irradiance range 800 to 1000 W/m² is the most suitable operating condition to maintain temperature stability and high performance.

In this study a new proposed pattern will be demonstrated, the zigzag spray pattern has not been studied yet based on the literature, and the impact of various parameters on the efficiency and power production of the photovoltaic panel to be determined.

This research aim is to study the photovoltaic performance with and without cooling experimentally and theoretically. And to analyze the factors that mostly influence the photovoltaic power production during summer season in north of Iraq., The theoretical model using ANSYS Fluent software is used for the proposed new pattern.

This research compares the observed and projected effects of applying a zigzag water spray pattern to a photovoltaic panel front surface to examine which factors will most affect its power production. The novelty of this study lies in the utilization of a specifically designed zigzag spray pattern with various water volume flow rate to improve the performance of the photovoltaic panel as well as identifying the factors that will most affect its power production. This study is expected to provide valuable insights for photovoltaic panel manufacturers and researchers to improve the efficiency and power production of their products.

This investigation examines the efficacy of a zigzag water spray pattern on a photovoltaic panel, and endeavors to identify which factors have the greatest influence on its power output. A unique feature of this study is the use of a bespoke zigzag spray pattern to enhance the performance of the photovoltaic panel, as well as to recognize the key factors influencing its power production. It is anticipated that the findings of this research will be beneficial to PV module manufacturers and researchers, allowing them to optimize the performance and output of their products.

2 Methodology

The monocrystalline photovoltaic panel was experimentally tested with and without surface cooling by spray water with a new design to maintain the thickness of water across the panel surface so that most
of the panel will have same temperature distribution, four different volume flow rate were examined 2, 3, 4 and 5 L/min and simulated by ANSYS Fluent with the same flow rates, also by using ANSYS Fluent it was tested which factor is mostly affecting the PV power production ambient temperature, solar radiation or water inlet temperature at all flow rates of water.

2.1 Experimental Investigation

An experimental system is formulated to enhance the performance of monocrystalline photovoltaic panel by front surface cooling by spray water at four different flow rates as compared to a reference one without cooling. The prototype is developed fabricated and installed at Erbil Polytechnical University-Research Center. Figure 1 presents schematic diagram of the two monocrystalline photovoltaic modules, which are facing south with an inclination angle of 36° corresponding to the latitude of Erbil.

Technical feature of PV panel at nominal operating conditions 25°C temperature and solar irradiance 1000 W/m² and 1.5 m/s are presented in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module dimension</td>
<td>1330<em>670</em>30mm</td>
</tr>
<tr>
<td>Module weight</td>
<td>9 kg</td>
</tr>
<tr>
<td>Nominal power</td>
<td>206 W</td>
</tr>
<tr>
<td>Cell efficiency</td>
<td>23%</td>
</tr>
<tr>
<td>Maximum power current (Impp)</td>
<td>7.68 A</td>
</tr>
<tr>
<td>Maximum power voltage (Vmpp)</td>
<td>27.31 V</td>
</tr>
<tr>
<td>Open circuit voltage (Voc)</td>
<td>31.41 V</td>
</tr>
<tr>
<td>Short circuit current (Isc)</td>
<td>8.2 A</td>
</tr>
<tr>
<td>Nominal operating cell temperature</td>
<td>25°C</td>
</tr>
<tr>
<td>Working temperature</td>
<td>-40°C - +80°C</td>
</tr>
</tbody>
</table>

The test apparatus employed in the experimental PV module is depicted in in Fig. 2. As it consists of steel support structure; PV panels, water pumps, primary and secondary storage tank of 250 liters, motorized valve, water filter, datalogger, batteries 25V, 5A DC connected in series, MPPT solar charger controller and DC load.
The cooling system consists of 6 nozzles placed over the panel in a zigzag pattern so that the thickness of water over the panel will be uniform and all the panel will be at the same temperature at all the time.

Figure 3 presented the schematic and experimental rig location of nozzles over the panel.

The data logger was designed to record data every one-minute interval system; it measured temperature, voltage, current, solar intensity and water volume flowrate. The Temperature sensors (k-type thermocouple) are connected to six analog channels measured inlet and outlet water temperature for the water-cooling panel with three points on the panel surface and one sensor on the reference panel (without cooling). While the DHT11 temperature sensor measured the ambient temperature. The two SEN32 REV1 volt sensors and two current sensors are utilized to gauge the panels' current and voltage. The water flow rate is measured by the YF-S401 sensor. Moreover, the solar irradiance was measured through Digital Solar Power Meter (DBTU1300). The experimental study was run during summer months. Longitude and latitude of Erbil city is 44.009 and 36.191, respectively. The tilt angle of both panels is 36°, facing the south direction. The daily test run from 8 am – 3 pm. Eq. 1 was employed to calculate the panel power while Eq. 2 was used to determine the electrical efficiency of the panels [22]

$$ P = I \times V $$

$$ \eta_{electrical} = \frac{I \times V}{I_s \times A_{panel}} $$

Where $P$ is the power output from the module and $\eta_{electrical}$ is the electrical efficiency, $I_s$ is the solar irradiation (Watt/m²), $A_{panel}$ is the panel area (m²), and $I$ and $V$ are the current (Amp) and voltage (Volt) of the panel, respectively.

### 2.2 Theoretical Investigation

The three-dimensional model geometry of the photovoltaic module with front surface water cooling was modeled using ANSYS R19.2 geometry tool which is presented in Fig. 4. The dimensions of PV panel were exactly same as the experimental study. A thin film of water is adhered to the topography of the PV panel, serving as a cooling system across the entirety of the module. A thin film of water is adhered to the front face of PV, serving as a cooling system across the entirety of the module.

This simulation was conducted using ANSYS Fluent, a computational fluid dynamics (CFD) software. An automatic mesh has been applied to the photovoltaic geometry, while for water layer inflation mesh was used to give precise temperature distribution as shown in Fig. 5. The generated mesh has zero skewness.

The grid independence test was also conducted to test the accuracy of the simulated result as shown in Fig. 6, were there was an average variation of (0.08%) from the achieved result.
Usually, the photovoltaic panel consist of five different solid layers: a glass covering on the outward-facing surface, Ethylene Vinyl Acetate (EVA1) serving as an encapsulation for the silicon, the silicon layer itself which converts radiation into electricity, EVA2, and tedlar on the rear surface. Each layer has its own specific thickness, heat capacity, density and thermal conductivity as it is presented in Table 2. The PV panel is topped by a layer of water that encompasses the entirety of the panel, with inlets located on the left, right, and upper sides, and an outlet on the lower side. Then solid and fluid domain in the current computational fluid analysis were connected in such a manner that the transfer thermal features at the interfaces will be on target.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Thickness (m)</th>
<th>Specific heat capacity (J/kg °C)</th>
<th>Density (kg/m$^3$)</th>
<th>Thermal conductivity (W/m °K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.0045</td>
<td>4180</td>
<td>997</td>
<td>0.59</td>
</tr>
<tr>
<td>Glass</td>
<td>0.003</td>
<td>500</td>
<td>3000</td>
<td>0.98</td>
</tr>
<tr>
<td>EVA 1</td>
<td>0.003</td>
<td>2090</td>
<td>960</td>
<td>0.23</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.004</td>
<td>712</td>
<td>2.329</td>
<td>148</td>
</tr>
<tr>
<td>EVA 2</td>
<td>0.003</td>
<td>2090</td>
<td>960</td>
<td>0.23</td>
</tr>
<tr>
<td>Tedlar</td>
<td>0.0001</td>
<td>1250</td>
<td>1200</td>
<td>0.36</td>
</tr>
</tbody>
</table>

CFD is a branch of fluid mechanics that is employed for the purpose of assessing the equations that govern the heat transfer in the photovoltaic (PV) water cooling system, which is comprised of both fluid and solid domains. The fluid domain is attributed to the water employed for cooling the PV, while the solid domain is attributed to the five distinct layers of the PV, equations (3) and (4) presents the heat transfer equation for solid and fluid domains respectively [23]:

\[
\rho_i C_{p,i} \frac{\partial T_i(x, y, z)}{\partial t} = \nabla \cdot (q_i) + Q_i, i = 1, 2, \ldots \ldots, n
\]

\[
\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T(x, y, z) = \nabla \cdot (q) + Q_{vh} \nabla \cdot u = 0
\]

While the equations of momentum and continuity equations are:
The radiation model used is discrete ordinary (DO) which was used to apply solar radiation to the domains. Equations (7) and (8) are (DO) radiative transfer equations:

$$\rho \frac{\delta u}{\delta t} + \rho (u \cdot \nabla) u = \nabla \left[ -pI + (\mu + \mu_T) \left( \nabla u + \nabla u^T \right) - \frac{2}{3} \rho kI \right]$$

$$\rho \nabla \cdot u = 0$$

A steady state condition was applied for the simulation. Different water inlet temperatures, different ambient temperature and different radiation intensity at different water flow rate were tested. To examine the effect of these factors on panel power production, in contrast to the reference PV. The water volume flow rate used in this simulation are 2, 3, 4 and 5 L/min, while inlet water temperature ranges from (25–40) °C, and the ambient temperature examined were (35, 40, 45 and 50) °C, and the solar intensity examined were (600,800 and 1000) Watt/m².

Different correlations were developed to calculate the power production for the simulation data of PV module, and in the present research the correlation used to calculate the power produced from the panel [24] is

$$P = G_t \tau_{pv} \eta_{T_{ref}} A \left[ 1 - 0.0045 \left( T_c - 25 \right) \right]$$

where $\tau_{pv}$ is the transmittance of the photovoltaic panel outer layers [25]

### 3 Result and Discussion

#### 3.1 Experimental Result
The experiments were conducted in Erbil, Iraq during August, from 8:00 AM to 3:00 PM. The purpose of the experiments was to analyze the efficacy of a photovoltaic system under varying water flow rates of (2, 3, 4 and 5) L/min in zigzag pattern, and compare it to a reference panel without cooling. Table 2 illustrates the ambient temperature (Tamb.) and solar irradiance (I) during test days at each 15 minutes interval from 8:00 AM to 3:00 PM.
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{\text{amb}}$ ($^\circ$C)</td>
<td>$I$ (watt/m$^2$)</td>
<td>$T_{\text{amb}}$ ($^\circ$C)</td>
<td>$I$ (watt/m$^2$)</td>
</tr>
<tr>
<td>8:00</td>
<td>39</td>
<td>435</td>
<td>36.9</td>
<td>410</td>
</tr>
<tr>
<td>8:15</td>
<td>39.7</td>
<td>465</td>
<td>37.1</td>
<td>463</td>
</tr>
<tr>
<td>8:30</td>
<td>40.2</td>
<td>530</td>
<td>37.2</td>
<td>531</td>
</tr>
<tr>
<td>8:45</td>
<td>41.9</td>
<td>605</td>
<td>37.8</td>
<td>620</td>
</tr>
<tr>
<td>9:00</td>
<td>43.3</td>
<td>660</td>
<td>40.7</td>
<td>655</td>
</tr>
<tr>
<td>9:15</td>
<td>43.6</td>
<td>730</td>
<td>41.5</td>
<td>739</td>
</tr>
<tr>
<td>9:30</td>
<td>44</td>
<td>770</td>
<td>40.7</td>
<td>786</td>
</tr>
<tr>
<td>9:45</td>
<td>43.7</td>
<td>820</td>
<td>40.9</td>
<td>823</td>
</tr>
<tr>
<td>10:00</td>
<td>43.6</td>
<td>865</td>
<td>42.7</td>
<td>879</td>
</tr>
<tr>
<td>10:15</td>
<td>43.7</td>
<td>895</td>
<td>43.4</td>
<td>898</td>
</tr>
<tr>
<td>10:30</td>
<td>44.6</td>
<td>914</td>
<td>42.4</td>
<td>912</td>
</tr>
<tr>
<td>10:45</td>
<td>43.9</td>
<td>950</td>
<td>45.3</td>
<td>940</td>
</tr>
<tr>
<td>11:00</td>
<td>44.6</td>
<td>976</td>
<td>43.4</td>
<td>973</td>
</tr>
<tr>
<td>11:15</td>
<td>43.6</td>
<td>983</td>
<td>43.8</td>
<td>998</td>
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<tr>
<td>11:30</td>
<td>45.3</td>
<td>995</td>
<td>44.4</td>
<td>1007</td>
</tr>
<tr>
<td>11:45</td>
<td>47.3</td>
<td>1012</td>
<td>44.7</td>
<td>1015</td>
</tr>
<tr>
<td>12:00</td>
<td>47.5</td>
<td>1036</td>
<td>43.4</td>
<td>1027</td>
</tr>
<tr>
<td>12:15</td>
<td>46.2</td>
<td>1030</td>
<td>46.7</td>
<td>1033</td>
</tr>
<tr>
<td>12:30</td>
<td>47.4</td>
<td>1039</td>
<td>45.5</td>
<td>1041</td>
</tr>
<tr>
<td>12:45</td>
<td>48.2</td>
<td>1037</td>
<td>46.2</td>
<td>1048</td>
</tr>
<tr>
<td>13:00</td>
<td>46</td>
<td>1022</td>
<td>46.8</td>
<td>1034</td>
</tr>
<tr>
<td>13:15</td>
<td>45.9</td>
<td>1010</td>
<td>46.3</td>
<td>1018</td>
</tr>
<tr>
<td>13:30</td>
<td>47</td>
<td>990</td>
<td>46.7</td>
<td>1009</td>
</tr>
<tr>
<td>13:45</td>
<td>46.3</td>
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<td>994</td>
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<tr>
<td>14:00</td>
<td>46.7</td>
<td>966</td>
<td>47.8</td>
<td>960</td>
</tr>
</tbody>
</table>
Figure 7 presents the temperature of the photovoltaic panel at various flow rates. The data demonstrate that as the flow rate increases from 0 to 5 L/min, the maximum temperature of the photovoltaic panel decreases from 71.5 to 39.25°C, it is evident that increasing the flow rate of the cooling system can significantly lower the temperature of the photovoltaic module. Therefore, increasing the rate of water utilized to cool down the PV is an effective measure for maintaining the optimal temperature of the photovoltaic panel.

Variation in power production during the daytime at different flow rates compared to the reference panel without cooling is illustrated in Fig. 8. It could be recognized that with increasing solar radiation the power output from PV is increased as well, the results indicate that cooling the panel with a flow rate of 5 L/min increases its power production more than all other flow rates at all solar radiation values. This increase is much more significant during high solar radiation time as the power production is increased up to 20.5%.

The results depicted in Fig. 9 demonstrate that there is a significant improvement in electrical efficiency when the panel is cooled. This suggests that cooling the panel can significantly enhance its capability of producing power at various flow rates, with higher efficiencies being attained at higher flow rates. Thus, it can be inferred that the panel is able to generate power efficiently at any given flow rate and can be adjusted to suit the desired power output.

The results of this experiment illustrate the importance of properly managing the cooling system for photovoltaic panels. As the rate of flow increases, the temperature of PV diminishes, making it more efficient and effective in its performance. Furthermore, the results suggest that proper flow rate of the cooling system is critical for optimal performance of the photovoltaic panel, whereas the average enhancement by cooling then panel with 5 L/min flow rate is 20.25%. While the 2 L/min volume flow rate enhances the PV performance by only 10.38%.

Figure 10 presents the comparison of spray water cooling technique applied on photovoltaic panels performed by different researchers. In 2020 [26] used 8 nozzles on the back and front surface of the panel and results in an improvement of 9.03%. While [27] they placed a header on the top of the panel to spray water over the panel and the maximum enhancement rate in power production was only 10%. However, in another study conducted in Egypt [16] studied the front surface cooling by applying six nozzles two from top, two at left and other two nozzles at the right side of the panel exactly facing the nozzles on the left.
side, and the maximum power output improvement rate was 15.5%. on the other hand a research where conducted in India [28] by using 20 nozzles, 10 on the front side fixed at angle 40° with panel surface and 10 on the backside fixed perpendicular to that surface of the panel but the improvement was just 16.3%.

The current study demonstrated that the use of spray water cooling from the front surface of a PV module at a volume flow rate of 5 l/min using 6 nozzles in a zigzag pattern resulted in an improvement of 19.04% in power production. This improvement was attributed to the full coverage of the panel with water, which led to a decrease in the temperature of all the cells within the module and thus increased its performance in converting solar energy into electrical power. This study offers a noteworthy contribution and novelty to the field by demonstrating a high level of power production improvement percentage when compared to previously conducted studies.

### 3.2 Validation Result

This suction provides the validation results of experimental and ANSYS Fluent simulation outcomes concerning the performance of PV panel. A comparison of the two revealed that the simulation outcomes were in close accordance with the experimental one. The simulation results were within 1.08% of the experimental results, indicating that the model was valid and reliable for forecasting the performance of solar cell.

The comparison between PV temperature and water outlet temperature at different volume flow rate using ANSYS and experimental result is illustrated in Fig. 11, the temperature of the PV surface obtained from ANSYS and measured data are highly concordant, with the greatest disparity amounting to 0.5°C and the least to 0.38°C.

The results demonstrate that ANSYS can accurately predict the PV temperature at various rates of water. Furthermore, the outcomes demonstrates that the cooling system can reduce the PV temperature, thus enhancing the dependability and steadiness of the photovoltaic system.

### 3.3 ANSYS Fluent Results

This suction presents the computational fluid dynamics (CFD) results of the influence of various parameters (ambient temperature, water inlet temperature and solar intensity) at various rates of water over the temperature and performance of panels. The investigation was conducted to evaluate the behavior of PV modules under diverse conditions.

Figure 12 illustrates the effect of ambient temperature over the panel power production and temperature at different water volume flow rate, while the water inlet temperature was fixed at 35°C and solar irradiance at 1000 watt/m². As the ambient temperature rises from 35°C to 50°C, the PV temperature, when cooled by a minimum flow rate of 2 L/min was increased by 3.7°C and the power production is decreased by 3.2 watt, while at maximum water-cooling flow rate 5 L/min the PV temperature was increased by 2.6°C and the power production decreased by 2.3 watt.
The impact of various irradiation intensity and water flow rate on PV temperature and power production are presented in Fig. 13, with constant water inlet temperature and ambient temperature (35°C and 40°C respectively). It can be observed from the figure by increasing irradiation intensity from 600 to 1000 watt/m² at 5 L/min water leads to a significant increase in the PV power production from 110.47 watt to 182.35 watt, while the PV surface temperature is increased by only 2°C. Conversely, a higher rate of water was seen to reduce the PV temperature substantially.

The influence of varying water inlet temperature on PV power production and surface temperature at 40°C ambient temperature and 1000 watt/m² solar irradiance is presented in Fig. 14, the findings of this study indicated that the temperature of inlet water is the most influential factor in PV module temperature, as the lower water inlet temperatures and higher flow rate result in lower PV surface temperatures, higher power output, and improved efficiency.

At water temperature 20°C the optimal water flow rate for cooling the panel for maximum power production was found to be 5 L/min. This resulted in a peak power output of 192.69 watt. However, at a rate of 2 L/min, generated power was 188.63 watt. Cooling the PV at 40°C water generated 175.58 watt and 178.54 watt respectively at 2 L/min and 5 L/min volume flow.

So, another contribution from this study is from the Ansys simulation as it suggested that the solar radiation intensity is the most influential factor in cooled PV module power production. Also increasing the water flow rate at a lower water inlet temperature can improve the performance of the PV panel by decreasing its surface temperature and increasing the power output. Furthermore, the optimal water flow rate for cooling the panel for maximum power production was found to be 5 L/min at water temperature 20°C. This can be used to improve the efficiency of PV systems in hot climates.

4. Conclusion

The study has shown that a combination of numerical simulations and experimental measurements can yield accurate and reliable results for determining the optimal spray water volume flow rate at zigzag pattern for cooling the panel. Also, the numerical simulation has been used to assess the impact of different parameters such as ambient temperature, water inlet temperature and solar radiation on the temperature and power production of a cooling panel. The ANSYS Fluent simulation provided a reliable estimation of the best water volume flow rate needed to achieve the desired panel temperature and power production. The most interesting out comes are:

- Analysis of results from the experiments conducted has demonstrated that application of a water volume flow rate of 5 L/min to cool photovoltaic (PV) panels can improve their performance by 20.25%. While the 2 L/min enhance the PV performance by only 10.38%.
- This study demonstrated the potential of zigzag pattern to increase the efficiency of PV panel production. The results of this study suggest that zigzag pattern can be a viable and cost-effective method for increasing the efficiency of PV panel production when compared to traditional spray
water cooling methods. Where the PV panel power production was enhanced by 19.04% using zigzag pattern at 5 l/min volume flow.

- ANSYS Fluent was used to accurately predict the performance of PV panels at various operating conditions, with error percentage of 1.08%.
- As the ambient temperature increased from 35°C to 50°C, cooling at a minimum flow rate of 2 L/min was able to limit the PV temperature increase of 3.7°C, resulting in a power production decrease of only 3.2 watt.
- Additionally, it was observed that an increase of 100 watt/m² in solar radiation at a volume flow rate of 5 L/min led to a significant increase in power production 16.6% with the PV surface temperature only increasing by 0.5°C.
- Furthermore, decreasing the water inlet temperature by 5°C at 5 L/min volume flow rate resulted in a 2.25% increase in power production.
- The contribution from ANSYS Fluent simulation was that the most influential parameter on power production from cooled PV is the solar intensity, so this study suggests to use PV panel at the region with high solar intensity and providing a cooling system with low water inlet temperature, no matter how hot is their climate.

The results of this study indicate that solar radiation intensity is the most influential factor in PV power production. Consequently, it is suggested to implement a solar tracking system with a cooling water flow rate of high volume and low temperature to optimize PV power production.

**Declarations**

The authors have declared that they don't have any financial or any other personal interest to disclose.

**References**


Figures
Figure 1

schematic diagram of experimental system
Figure 2

photovoltaic panels experimental rig
Figure 3

schematic diagram and experimental rig of nozzles location over the panel

Figure 4

1-Tedlar 2-EVA2  3-Silicon  4-EVA1  5-Glass  6-Water
geometry of the panel's layers with water cooling system

Figure 5

photovoltaic water-cooling diagram of mesh in ANSYS

![Figure 5](image)

Figure 6

grid independence test

![Figure 6](image)
Figure 7

PV surface temperature at different volume flow rate

Figure 8

variation of PV power production with time at different volume flow rates
Figure 9
variation of panel efficiency at different volume flow rate with time

Figure 10
comparision of panel power production improvement

Figure 11
comparision of numerical and experimental data at various volume flow rate

Figure 12
variation of PV temperature and power production with flow rate at various ambient temperature
Figure 13

variation of PV temperature and power production with water volume flow rate at different solar irradiance

Figure 14

variation of PV temperature and power production with different water volume flow rate at different water inlet