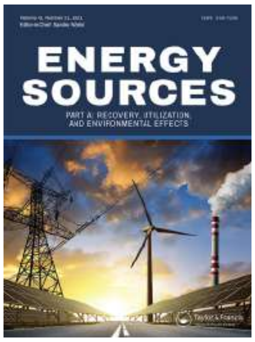

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Experimental performance evaluation of tracking photovoltaic system based on variable water flow rate with surface temperature

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ABSTRACT

A solar tracking system with an effective cooling technique is developed and implemented. Due to the solar radiation, high ambient temperature and dusty climate condition affected photovoltaic panel power production. A single east–west solar tracking system incorporating monocrystalline panel and a front surface spray water cooling system was conducted and compared to a fixed reference panel. The water flow rate is adjustable according to the set point temperature of the panel surface. The experiment was conducted during the summer season in north of Iraq (latitude 36.191° and longitude 44.009°). The study revealed that the implementation of the tracking system results in 4.19% increase in power production, while tracking with a cooling system has resulted in an improvement of up to 25.11% in Photovoltaic efficiency. The water consumption has been optimized, and the optimal cooling setting temperature was determined to be 40°C. Additionally, this model demonstrates that the performance of photovoltaic panel was decreased by only 0.2%–0.3%, when the surface temperature increased by 5°C within a range of 25–40°C.

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KEYWORDS
Photovoltaic panel; tracking system; flow rate; water cooling; electrical performance

Introduction

As the population and industrial activity increases, the demand of energy is growing, and it is also a significant agent of economic development in any country. Fossil fuels such as natural gas and oil are marked as the primary roots of energy. In 2035, in some developed countries, fossil fuels will be used to produce about 80% of energy (Fumo, Bortone, and Zambrano 2013). Producing energy in a conventional way will lead to gas emissions, atmospheric pollution, and global warming. Using renewable energy sources, such as solar energy, geothermal energy, and wind energy instead of the conventional way, is essential (Eicker et al. 2014). So, researchers and engineers are making a concerted effort to shift their focus to renewable energy. Solar energy has become an increasingly attractive, widely available, and clean alternative to conventional energy source, owing to the two ways of converting solar energy, thermal and electrical (Shahsavar et al. 2011). Solar energy is the energy that the sun gives off as radiation. The solar thermal system mainly counts upon the energy that heats the fluid by the radiation received, while photovoltaic systems convert the solar radiation into electricity. Typically, thermal and electrical energy is produced separately. Researchers and engineers are exploring the potential of hybrid solar panels as a new and more efficient means of simultaneously harvesting both thermal and electrical energy. Researchers and engineers are exploring the potential hybrid solar panels as a new and more efficient means of simultaneously harvesting both thermal and electrical energy. Hybrid solar panels have magnified the awareness of researchers and engineers in recent decades as they are more efficient compared with separate solar collectors.

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Along with the advantages of using PV panel system as an alternative resource for traditional electricity production, this technology has the challenge of dust and high ambient temperature of 46°C up to 50°C in our region. These parameters will increase the temperature of the PV panels. The high temperature will affect the efficiency of the system, while cooling the PV panel surface is considered a crucial factor for achieving high efficiency during the operation of the PV system. By selecting the proper cooling method, the electrical efficiency can be improved and the rate of cell degradation with time will reduce; meanwhile, the life cycle of photovoltaic modules will increase.

According to previous tracking system researches and studies, solar energy increased by 22% and 56% when compared to a fixed solar system (Tyagi et al. 2013). The control unit of most common tracking systems utilizes a photosensor instrument to receive a signal that follows the sun's radiation in order to operate on either a single-axis or dual-axis basis. Another way to enhance the output of the panel is to lower its operating temperature. The idea of using air to cool photovoltaics was initially investigated by the scientist (Florschuetz 1975) which cools down the panel temperature by utilizing ambient air. In 1979, another study was conducted to investigate the cooling effect of a water-based PV system connected with a flat plate solar collector (Florschuetz 1979). When compared to utilizing air as a coolant, they discovered that water significantly improved the performance of photovoltaics. In the same year, a study was conducted to further improve panel performance through the use of air and water (Hendrie 1979).

A researcher (Arefin 2019) studied numerically and experimentally the effect of cooling the panel surface by natural circulation of water, which was supplied for 2 min in each 15-min interval. The results concluded that the overall efficiency of the model is more remarkable than PV efficiency by five times, while the electrical efficiency was improved by 1.5% (Peng et. al. 2018). The team aimed to investigate practically the effect of minimizing the surface temperature of the solar panel on its performance. The study was conducted in a laboratory setting and employed spread ice to reduce the temperature and was used to see its effect on the performance and output power. The result indicated that an increase in radiation also increased the panel's temperature, resulting in a decrease in efficiency for generating electricity. The team aimed to investigate the effect of decreasing the surface temperature of the solar panel on its performance. The study was conducted in a laboratory setting and employed spread ice to reduce the temperature. Results indicated that an increase in radiation also increased the panel's temperature, resulting in a decrease in efficiency for generating electricity.

On the other hand, by using ice for cooling, the panel's efficiency was maximized by about 47%. Nateqi et al. investigated the effect of a water spray cooling system on PV performance; by testing the spray angle, they discovered that decreasing the spray angle to 15° increases efficiency, resulting in a decrease in panel temperature from 64°C to 24°C (Nateqi, Zargarabadi, and Rafee 2021). In research done in 2020 by Govardhanan et al., which compared panel front surface water cooling with non-cooling, it was shown that the cooled panel could generate 10 *watts* more than the non-cooled one and also had greater clarity since the dust was permanently removed (Govardhanan et al. 2020). Immersing the panel in water to cool, it has been found to improve efficiency, the most successful height being 0.5 *cm* (Safitra et al. 2018). The front cooling technique with a thin layer of water was tested; the result was an 8–9% enhancement in efficiency (Krauter 2004). In a different technique, Moharram et al. (2013) increase solar module efficiency by 12.5% by decreasing the panel temperature by 10°C, while Du, Hu, and Kolhe (2012) observed that by using concentrated solar cell, the electrical efficiency was increased 4.9 times more than the fixed one.

In addition to the above cooling techniques, several numerical and experimental studies for improving photovoltaic efficiency have been conducted (Hossain et al. 2020) that improved the efficiency of the PV panel by 13.8% by using spiral absorber at solar radiation 800 W/m^2 and flow rate 0.041 kg/s, on the other hand, Wu, Chen, and Xiao (2018) achieved maximum efficiency at flow rate 0.003 kg/s and the back surface cooling channel height of 5 mm. The electrical performance has been increased experimentally 3.67% by using water/MWCNT nanofluid for cooling the panel as compared to water only (Nasrin et al. 2018). Another experimental and numerical study by Hussien, Eltayesh, and El-Batsh (2023), which was made in Egypt to enhance the efficiency of the PV, used a small fan to cool down the backside of the module. The highest percentage increase in panel efficiency was 2.1, while the saved energy was increased by 7.9%.

Another study (Rosli et al. 2022) used ANSYS software to validate an experimental result of back cooling by using spiral absorber to determine the effect of water inlet temperature and solar radiation intensity on the temperature stability, they conclude that at flow rate 40 kg/h and solar irradiance range 800 to 1,000 W/m^2 is the most suitable operating condition to maintain temperature stability and high performance. A research conducted in Islamabad, Pakistan (Sattar et al. 2022) examined three different types of heat absorber layout at the backside of the panel. The result indicated that the highest power production was with multi-pass duct layout with 31 passes as it was 186.713 W and with water flow rate of 0.14 kg/s. While in United Kingdom, the scientist (Al-Amri et al. 2022) studied the effect of immersing the panel in different coolants. They conclude that the highest temperature drop was by immersing the heat pipe-based PV in the water, which was about 53%. Due to research conducted at Jourdan (Al-Odat 2022), it was found that cooling the front surface of the panel with water is essential to increase the panel performance by 14%.

Based on the literature review, the effect of simultaneous tracking and cooling of photovoltaic systems on water consumption based on panel operating temperature and panel efficiency has not been studied yet. Therefore, further research is needed to determine the impact of these variables on the PV panel.

The objective of this paper is to compare the performance of the two panels. The developed panel with the tracking system and spray water cooling system will be compared against the fixed panel as a benchmark. The methodology used in this work involves data collection from the two panels, where the water flow rate of the cooling system from the front surface is automatically adjusted by the panel surface temperature. On the other hand, this type of cooling will also lead to increasing performance due to self-cleaning, which has a significant influence, especially in countries with dusty weather. The key concepts for this work are briefly summarized in the following sections.

The system will begin to supply spray water when the panel surface temperature exceeds the set point temperature. A new methodology has been developed to increase panel efficiency in an economically feasible manner as the researches have not yet determined the PV performance when the water flow rate changes due to surface panel temperature.

The novelty of this study lies in the implementation of a single east west solar tracking system that is assisted by adjusted water flow rate, based on the set point temperature of the panel. In addition, the developed water spray was designed in a zigzag pattern.

Experimental setups

Experimental system

Experimental research has been conducted to assess the performance of a PV panel solar tracking system. The prototype was developed, fabricated, and installed at the Research Center/Erbil Polytechnic University. In obedience to Figure 1, a schematic diagram of two monocrystalline photovoltaic panels each of 210 watts with an active surface area of 0.8241 m^2.

Table 1 presents technical features of PV panel at nominal operating conditions 25°C temperature and solar irradiance of 1,000 W/m^2 and 1.5 m/s.

The experimental rig of the PV panels used during the test is presented in Figure 2. The present study determines the effect of PV tracking with water spray cooling systems on the front surface of the PV panel. The proposed solar tracking technique is controlled by two light intensity sensors that compare between the two-signal received to follow the sun's direction so that it keeps the optimum insulation during all the times of the day. The cooling system starts spraying water whenever the panel surface temperature exceeds the set design temperature. The cooling system starts with a water flow rate of 1.8 *l/min* and increases the flow rate every 2 *min*.

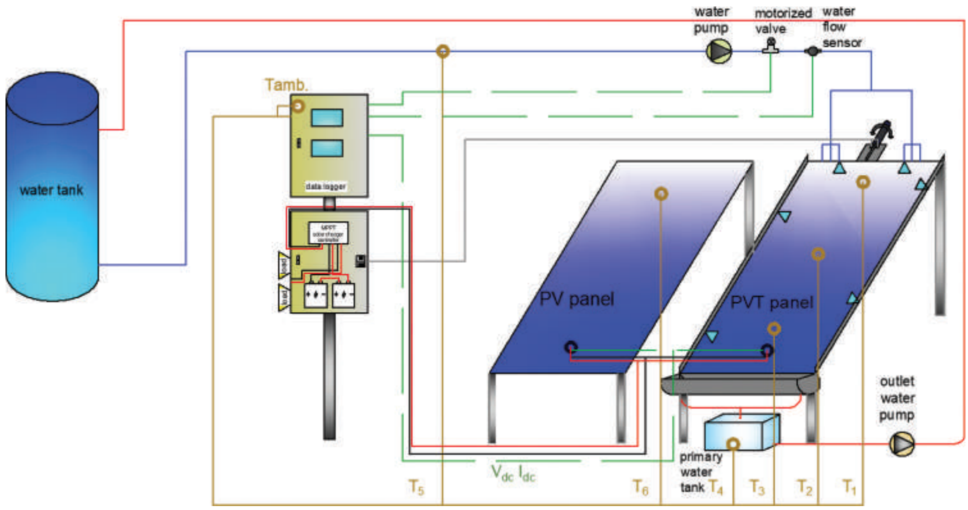

Figure 1. A schematic diagram of the experimental setup.

Table 1. Technical features of PV at nominal operating condition (25°C, 1,000 W/m^2, 1.5 m/s).

Parameters	PV
Module dimension	1,230 × 670 × 30mm
Module weight	9 kg
Nominal power	210 W
Cell efficiency	23%
Maximum power current (Impp)	7.68 A
Maximum power voltage (Vmpp)	27.31 V
Open circuit voltage (Voc)	31.41 V
Short circuit current (Isc)	8.2 A
Nominal operating cell temperature	25°C
Working temperature	−40°C to +80°C

Figure 2. PV with and without cooling module rig.

The water-cooling flow rate is regulated by a motorized valve and the surface PV panel temperature to ensure the optimal performance. The setting temperatures tested during this experiment were 35°C, 40°C, and 45°C. The experimental rig consists of a steel support structure: PV panels, water pumps, primary and secondary storage tanks of 250 l, a motorized valve, a water filter, a datalogger, batteries 25 V, 5A DC connected in series, an MPPT solar charger controller, and a DC load.

Measuring devices

The data logger was designed to record various data at each one-minute interval; it measured temperature, voltage, current, solar intensity, and water volume flow rate. The temperature sensors (k-type thermocouple) are connected to six analog channels measuring inlet and outlet water temperature from the PVT panel, three points on the PVT panel surface, and one sensor on the PV panel (without cooling), while the DHT11 temperature sensor measured the ambient temperature. Ambient light sensors are used to track solar radiation and a stepper motor to automatically move the system east west. The tracking system operating concept is based on comparing the light intensity between two TEMT6000X01 sensors installed normal to PV panel surface and separated by a plate as shown in Figure 3, thus based on the solar rays on both sensors, one of the sensors will be shaded while the other one lit up. The sensor that is illuminated will produce a stronger signal, while the other one will produce a weaker signal, so that the difference in output voltage will indicate the rotation direction of the panel. The signal will be transferred to the stepper motor, which results in movement of the panel to that direction. So that maximum incident radiation falling over the PV panel all the time will be maintained, as a result converting higher portion of radiation into electricity.

Figure 3

Two SEN32 REV1 volt sensors and two current sensors were utilized to measure the current and voltage of the panels. 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°, and the fixed panel faces the south direction. The daily test run from 8:00 to 15:00. Equation 1 was used to calculate the approximate estimation of the power generated (Al-Odat 2022):

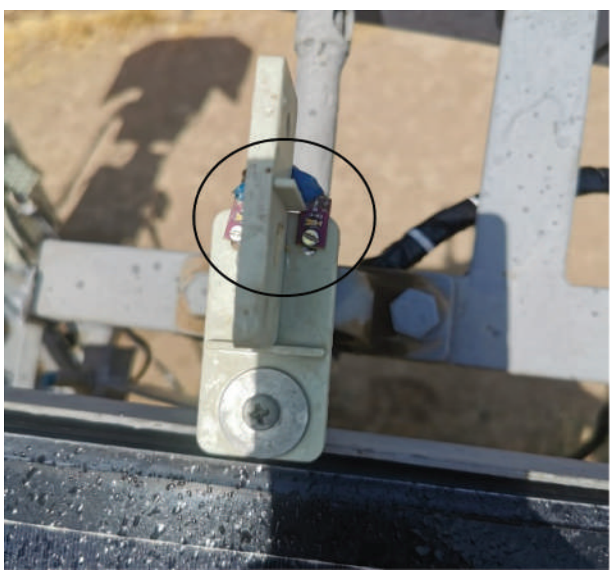

Figure 3. Tracking ambient light intensity sensors.

$$P_{es} = V_{OC} \times I_{SC} \quad (1)$$

While to calculate the maximum power (MPP), produced fill factor (FF) should be taken into the deliberation (MPP), which can be calculated as follows:

$$P_{MPP} = V_{OC} \times I_{SC} \times FF \quad (2)$$

Fill factor (FF) cannot be measured without a load. By measuring the actual values of (V_{oc}) and (I_{sc}), and MPP of the module, it is possible to assess the actual panel performance. The FF value is the proportion of MPP to the product of (V_{OC}) and (I_{SC}).

$$FF = \frac{V_{MPP} \times I_{MPP}}{V_{OC} \times I_{SC}} \quad (3)$$

The effect of temperature on module performance could be deliberated by marking the influence of cooling on (V_{OC}) and (I_{SC}); therefore, to determine the actual electrical performance of the PV, the input and output power should be calculated:

$$P_{out} = V_{MP}.I_{MP} \quad (4)$$

$$P_{in} = G.A \quad (5)$$

Where: $V_{MP} and I_{MP}$ are the voltage and current measured, while G and A are the solar irradiance and area of the panel, respectively. Therefore, the electrical efficiency $\eta_{electrical}$of PV panel can be calculated by the following equation:

$$\eta_{electrical} = \frac{P_{out}}{P_{IN}} = \frac{I_{MP}.V_{MP}\times}{G.A} \quad (6)$$

Result and discussion

As mentioned previously, the experiments were carried out between July and August from 8:00 to 15:00 in Erbil-Iraq. The performance of the photovoltaic system was evaluated using various set temperatures, with the valve opening being controlled by a temperature sensor placed on the back of the panel, and the pump set to start pumping water at 1.8 l/min. If the surface temperature is not within the set temperature after 2 min, the flow rate will be increased by approximately 1 l/min and so on until it reaches the maximum flow rate of 5.3 l/min. However, if the surface temperature is equal to the set temperature, then the pump will cease operation and the flow rate will register as zero, once the surface temperature rises above the set temperature then the pump will resume spraying water over the panel. Figure 4 illustrates the water pump's behavior when the set temperature is 45°C, 40°C, and 35°C, at 45°C set temperature the water is pumped over the panel until it reaches 4 or 3 l/min, and then it stops for a while before starting up again when the surface temperature exceeds the set temperature, while when the set temperature is 40°C at the morning, the pump cycles is turning on and off with a more frequently than when set to 45°C by 10:22, the pump has been running continuously as the surface temperature has not dropped below the setting temperature. On the other hand, at 35°C, the pump also runs continuously as the surface temperature remains above the set temperature.

Table 2 presents the solar radiation on the fixed and tracking solar panel. It is evident that there is a marked disparity in the solar radiation of fixed and tracking panels in the morning, which is 300 watt/ $m^{2,}$ this discrepancy lessens until 13:15, when the solar radiation of fixed and tracking panel is equal, as the panel orientation using tracking system is always perpendicular to the beam solar radiation, while the fixed panel only has the beam solar radiation perpendicular to its surface at noon.

Figure 5 presents the ambient temperature on August 2, 2022; the maximum ambient temperature for Erbil city in August is at 14:30, while the minimum was at 8:00 am.

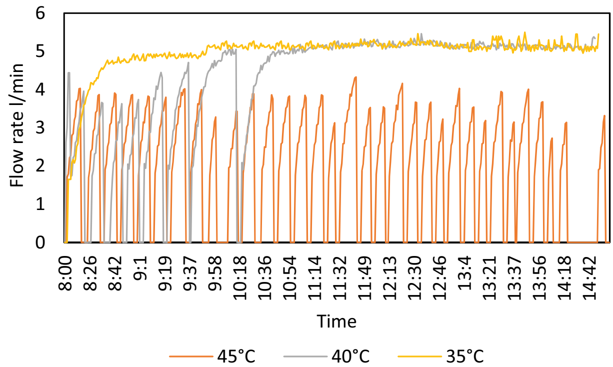

Figure 4. Variation of water flow rate supply at different panel surface temperature.

Table 2. Solar radiation difference between fixed and tracking PV.

Time	Fixed radiation W/m^2	Tracking radiation W/m^2
8:00	404	707
8:30	480	762
9:00	592	822
9:30	701	862
10:00	786	903
10:30	869	963
11:00	918	981
11:30	988	1,011
12:00	1,003	1,027
12:30	1,004	1,035
13:00	1,010	1,026
13:30	1,019	1,019
14:00	959	1,006
14:30	924	989
15:00	906	970

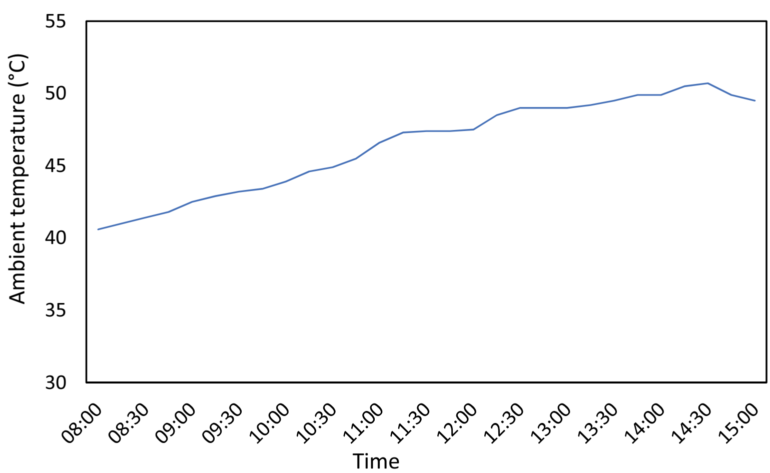

Figure 5. Ambient temperature on 2 August at Erbil city .

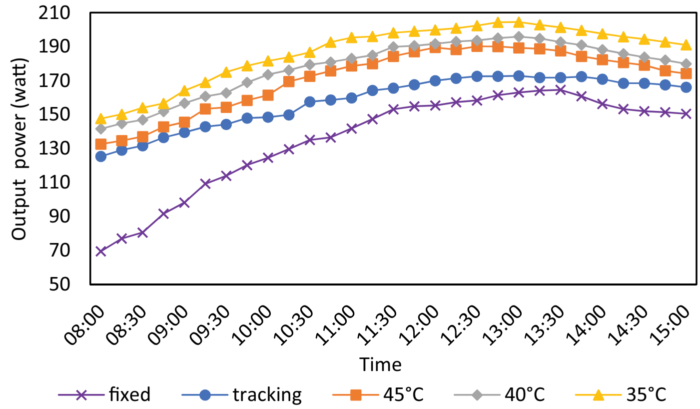

Figure 6. Variation of PV power production with time.

The power output of fixed reference PV, solar radiation tracking PV, and tracking PV with cooling at setting temperatures 45°C, 40°C, and 35°C are presented in Figure 6, the highest output power was observed for the tracking PV with cooling set at 35°C, while the lowest output power was for the fixed reference panel.

Figure 7 illustrates the change of the fill factor over time. The maximum fill factor is observed at noon, when the maximum power point voltage and current are highest, resulting in higher power production. The highest fill factor is observed at 35°C due to the fact that photovoltaic panels produce higher voltages at lower temperatures, thus leading to a higher fill factor that is directly proportional to it.

While the variations of electrical efficiencies for fixed reference PV, solar radiation tracking PV, and tracking PV with cooling at setting temperatures 45°C, 40°C, and 35°C are shown in Figure 8. The height electrical efficiency was observed in the PV panel with tracking and cooling at setting temperature of 35°C, while the lowest was found in the fixed panel without cooling.

The water consumption for cooling PV panel during an 8-h period (8:00 am to 3:00 pm) is illustrated in Figure 9, with surface temperature ranging from 35°C to 45°C. It can be seen that there is a substantial difference in water consumption between 40°C and 45°C, while the difference between 35°C and 40°C is slighter.

Figure 10 presents the output power and electrical efficiency of the PV panel at varying panel surface temperatures below 1,000 watt/m^2 solar radiation intensity. The power production sharply descended when the panel temperature exceeded 40°C. The data reveals a slight decrease in electrical

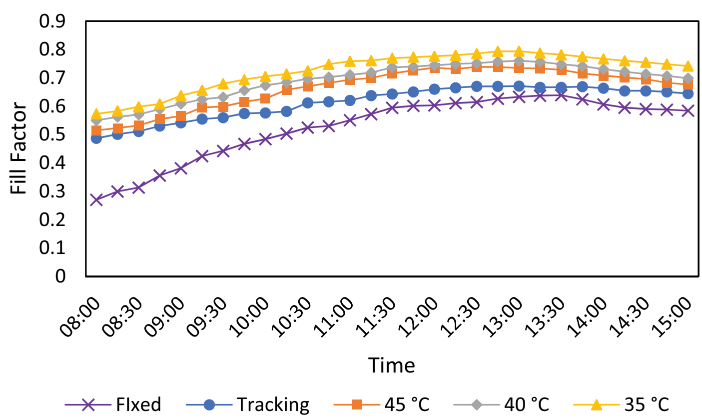

Figure 7. Variation of fill factor with time.

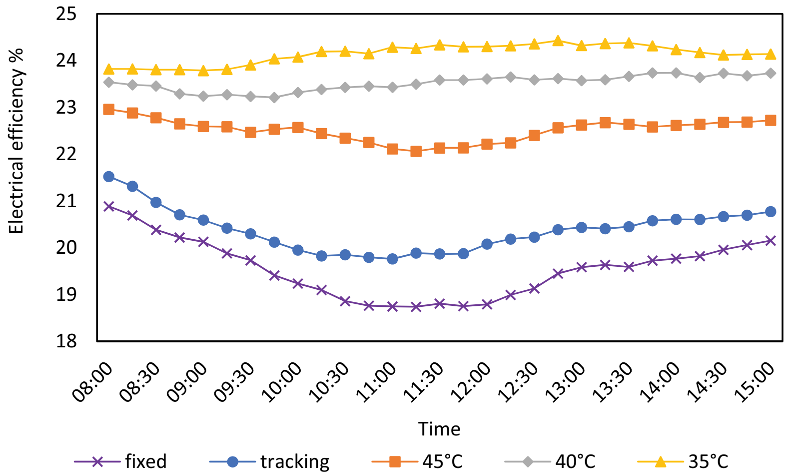

Figure 8. Variation of PV electrical efficiency with time.

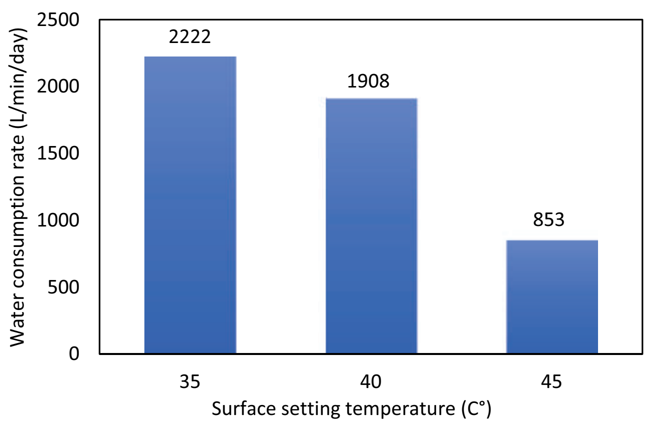

Figure 9. Water consumption rate at different panel setting temperature.

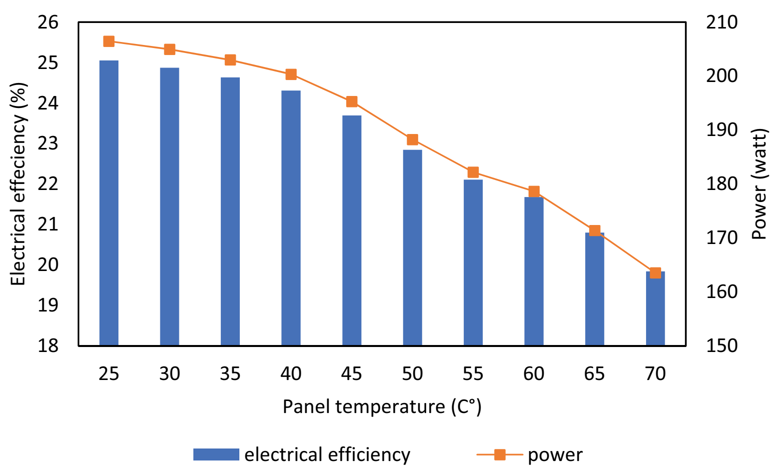

Figure 10. Variation of output power and electrical efficiency with panel temperature at 1,000 W/m^2 solar radiation.

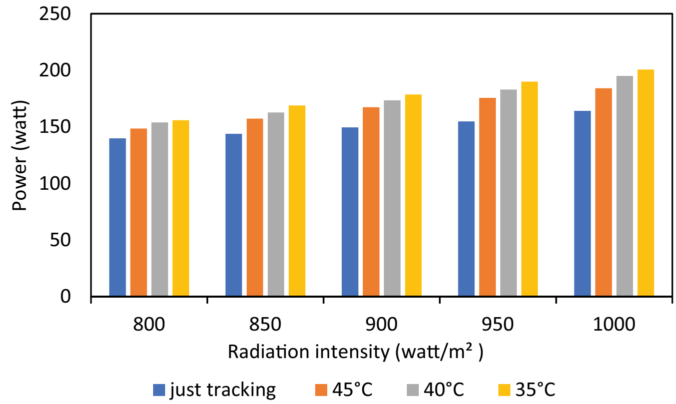

Figure 11. Variation of output power with solar radiation intensity.

efficiency when the panel temperatures range from 25°C to 40°C, by a 5°C increase in PV surface temperature, it was found to reduce electrical efficiency by 0.2%–0.3%; moreover, when the panel temperature exceeded 40°C, each 1°C increase in temperature was associated with 0.2% decrease in panel efficiency. This is due to the decrease in the voltage production of the panel, whereas the maximum operating temperature of the panel is 80°C. so that as the temperature of the panel approaches that range its ability to convert sun light to electricity decreases, as the temperature rises the electrons of the photovoltaic cell become more energetic and more likely to escape, this phenomina will reduce the efficiency of the panel. While Tan et al. (2017) observed that when the temperature on the panel exceeded 25°C, the efficiency decreases by 0.5% with each 1°C increasing of panel temperature.

The power production of the PV panel is heavily influenced by solar radiation. Figure 11 illustrates this, showing that when increasing the solar radiation from 800 to 1,000 watt/m^2, the power production increased by 24 watts when no cooling was utilized. Furthermore, when cooling was employed with varying setting temperatures, the power production increased further with the largest difference of 44 watt occurring at 35°C.

Figure 12 shows the maximum improvement in electrical efficiency production when the panel is modified with tracking; tracking and cooling at different setting temperatures of 45°C, 40°C, and 35°C compared to the reference panel. Cooling the panel at 45°C yielded a 7.5% improvement in efficiency compared to tracking alone, while the maximum enhancement was achieved at 35°C.

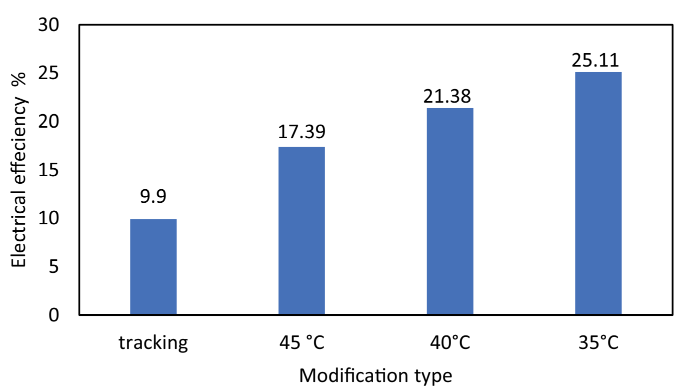

Figure 12. Maximum electrical efficiency improvement at different modifications.

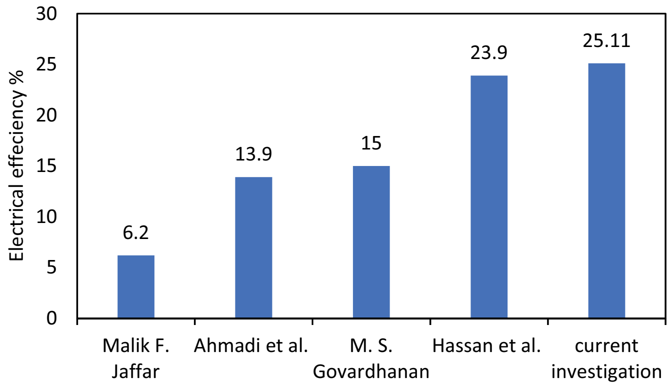

Figure 13. Comparison of panel electrical efficiency improvement.

The maximum electrical efficiency improvement of photovoltaic panel throughout this study was compared to previous literature, with results presented in Figure 13. Jaffar, Mohammad, and Ahmed (2022) used air cooling to enhance the performance of the panel, resulting in an improvement of 6.20%, Ahmadi, Monadinia, and Maleki (2021) applied PCM paraffin wax, yielding an enhancement rate of 13.9%, while Govardhanan et al. (2020) tested uniform water flow over PV panel resulting in a 15% improvement in electrical efficiency.

While (Hassan et al. 2020), utilized nano particles with PCM, the electrical efficiency enhanced by 23.90% at the end we could significantly recognize that a colossal enhancement is with the current experiment by using water spray technique at PV setting temperature 35°C and solar tracking system. Therefore, this study provides a clear contribution and novelty by offering a high percentage of electrical efficiency when compared to the other studies.

Conclusions

The objective of this study was to evaluate the efficacy of a one axis tracking system in conjunction with a spray water cooling system that was designed in a zigzag pattern to cover the surface of the PV panel. The flow rate of the water was controlled and adjusted based on the panel surface temperature, which was tested at three different temperatures 35, 40, 45°C, in Erbil, Iraq. The most prominent findings to emerge from this study are: as follows

- The water flow rate has been significantly reduced by regulating the water flow rate according to the panel surface temperature, this reduction will reduce the electric power required for pump operation. The lowest water consumption is achieved at 45°C, while the highest water consumption is observed at 35°C as the pump's maximum flow rate is maintained.
- The results have shown that single axis solar tracking system can significantly increase photovoltaic panel efficiency by 4.19%.
- The panel efficiency was enhanced by 17.39%, 21.38%, and 25.11% when the PV setting temperatures were 45°C, 40°C, and 35°C, respectively, compared to fixed panel without cooling.
- The output power and electrical efficiency of PV panel are optimal when operating at temperatures below 40°C.
- The most optimal temperature for cooling is 40°C, as the water consumption was less than the 35°C by 314 lit/min/day, with high electrical efficiency of 21.38%, which is only 0.3% lower than 35°C set point.
- Another contribution in this study confirmed that increasing the monocrystalline PV surface temperature by 5°C within a range of less than 40°C had a minimal effect on electrical efficiency, reducing it by only 0.2-0.3%, which is significantly lower than has previously been reported.

From the result, it was concluded that combined use of cooling and tracking system for PV panel yields superior result compared to using tracking alone or cooling without setting temperature due to the quantity of water used. It is suggested that the future studies consider incorporating a two-axis tracking system and a rear-cooling system with adjustment of flow rate in accordance with panel operating temperature, in addition to the existing front-cooling system, in order to enhance the system's performance.

Disclosure statement

The authors have declared that they do not have any financial or any other personal interest to disclose.

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Sally Afram Polus was born in Erbil Iraq in 1990. She holds Bachler degree in mechanical engineering (refrigeration and air conditioning from Erbil Technical Engineering College, Erbil, Iraq in 2012. She received a Master's degree in mechanical and energy engineering from the Mechanical and energy Engineering Department/ Erbil Polytechnic University, Erbil, Iraq in 2016. Currently, she is a lecturer and PhD student at Mechanical and Energy Engineering Techniques Department, Erbil Technical Engineering College, Erbil Polytechnic University, Erbil, Iraq.

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