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Experimental Study of Temperature Influence on the Performance of PV/T Cell under Jordan Climate Conditions

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ABSTRACT

The electrical performance and the productivity of PV module depend on two main parameters, i.e. the radiation intensity and the cell operating temperature. The module electrical efficiency and productivity are significantly reduced as its temperature increases. Accordingly, cooling of PV modules is one of the most effective techniques to obtain higher efficiency and productivity as well as to reduce the degradation modes of PV modules due to high temperatures. This research work presents an experimental study carried out to investigate the effect of PV module cooling on the performance of PV module under Irbid city (Jordan) climate conditions. It was found that the electrical efficiency and the productivity of the PV modules were approximately enhanced by 14%. Therefore, water cooling of the PV modules is essential to enhance their performance.

Keywords: PV module, electrical conversion, electrical efficiency, water cooling, cooling, cell temperature.

INTRODUCTION

Solar energy is considered as the most promising form of renewable energies, therefore numerous researchers around the world work extensively to develop innovative technologies to improve the performance solar systems. These performance enhancements of solar systems open a new era for solar researcher. PV module cooling systems are designed to enhance electrical energy productivity and generate hot water or air at the same time. Zondag et al. (2002) presented a four numerical models to simulate the thermal and electrical performance of a combined PVT solar collector, they found that the prediction accuracy of all models against experiments results were about 5%. A PV module water cooling system using a submersible water pump, along with storage tank was proposed by Odeh and Behnia (2010). Hosseini and Khorasanizadeh (2011) carried out a comparative experimental investigation to study the performance of a PV solar module with and without water cooling. They proved that the performance of cooled solar panel is much better than the performance of un-cooled conventional module. Moharram et al. (2013) carried out an investigation to optimize water and electrical power requirements to cool PV modules particularly in hot and dry weather. The temperature coefficient of many types of commercially PV solar panels that were randomly selected from different manufactures was experimentally examined under New Delhi climate conditions (Dash and Gupta, 2015). Hussien et al. (2015) examined experimentally the influence of water cooling utilizing a heat exchanger on rear surface of PV module. It was shown that the cooling of the PV module tends to enhance the electrical energy productivity. Musthafa (2015) presented an experimental research work to demonstrate PV module cooling utilized to decrease the temperature of the solar PV module to improve its electrical efficiency. He found that the efficiency is inversely proportional to the cell temperature. Back and front double water-cooling of PV modules was developed and tested to improve the performance of PV modules under UAE climate conditions (Hachicha et al.

2015). Iqba et al. (2016) carried out an experimental investigation of water cooling influence on the efficiency of PV module. They found that PV module efficiency is inversely proportional to its operating temperature. The PV module efficiency increases from 7 to 12% for the PV module temperature drops by 4–5°C. A summary of various active and passive cooling methods to enhance the PV module efficiency and energy output productivity was reported in the literature (Indugowda and Ranjith, 2016). Colţ (2016) conducted a numerical and experimental investigation on the effects of cooling the PV module fitted with a water heat exchanger on the rear surface. An experimental study to examine the effect of PV module cooling on its performance was carried out (Prajapati et al. 2017). Peng et al. (2017) investigated experimentally the effects of solar PV surface temperature on electrical productivity and efficiency. They reported that the percentage increase in the efficiency of the cooled solar PV reaches 47%. Improving the efficiency and productivity of PV module via different cooling systems in order to keep its temperature within an optimum range was reported (Milind et al. 2017). Anbarasan et al. (2018) reported an experimental research in which they applied a copper coil heat exchanger fitted to the rear surface of the solar PV module. Reteri et al. (2018) examined experimentally the effect of PV module temperature on electrical performance. Dubey and Sahu (2018) experimentally studied the influence of the PV module cooling via an air cooled heat exchanger installed on the rear surface of the PV module on the performance of the PV module. Barbu et.al (2019) examined the feasibility of PVT solar collector for small domestic application under the effect of Bucharest, Romania, and Strasbourg, France climate conditions. A PV/T system is suggested for transitional applications in Strasbourg and Bucharest under variable climate conditions of these two cities. They show that the performance in Bucharest is higher the performance in Strasbourg by 10–12%.

Ahmed et al. (2019) reported an experimental investigation to assess the performance of a PV panel with and without water cooling under the effect of climate conditions of the city of Sohag in Egypt. Abdelgaied and Hamdy (2019) reported a study of the influence of different water cooling methods on the efficiency of PV modules under Egyptian climate condition. Luboń et al. (2020) reported an experimental study on the cooling methods utilized to reduce the operating and surface temperature of solar PV module. They measured the variations in output power and efficiency for two PV modules working with and without a cooling system. PV module temperature was considerably reduced with about 32% which in turns increase in the power productivity of the PV module by about 57%. Ale1 and. Rotipin (2019) conducted an experimental study to investigate the effects of cooling on solar PV module performance in a tropical region (Oyo State, Nigeria). Numerous researchers conducted a comprehensive review of the various methods and techniques used for the cooling of PV modules to enhance their productivity and efficiency (Verma et al. 2021, Shah et al. 2022 and Tiwari et al. 2022). Shalaby et al. (2022) reported an experimental study of the effect PV module rear surface cooling its electrical productivity and efficiency. They showed a significant enhancement of the PV module productivity and the electrical efficiency. Very recently Yildirim et al. (2022) reported a novel PV/T systems integrated with a thermal solar collector. The thermal performance of the PV module and the proposed cooling collector are integrated to obtain optimum thermal and electrical efficiencies of the PV/T system. Various mass flow rates and inlet temperatures were examined under normal operating cell temperature conditions (NOCT).

According to the literature review above the effect of operating temperature of the PV module on the electrical performance PV modules under Irbid city climate conditions has not been reported yet, which was the main motivation for this proposal. The main purpose of the present experimental investigation is to augment the electrical productivity and efficiency of PV module utilizing water cooled heat exchanger attached to the module back surface. Cooling of PV module is essential in PV applications mainly for two reasons: firstly to reduce the cell thermal deterioration and hence increase lifetime of the PV systems and secondly to improve power productivity of the module. The cooling heat exchanger in this experimental work was fitted to the rear surface of the PV module with different cooling water mass flow during selected sunny days in July 2022. Two identical PV modules with water cooling and the other without cooling were tested simultaneously; to exclusively identify the influence of cooling on the PV performance and productivity.

MATERIALS AND METHOD

Experimental test rig

In the presented experimental test rig a two identical commercially available PV module of polycrystalline type are used. Table 1 demonstrate s the specifications of the PV modules at hand. A brass heat exchanger was fitted to the back of one module while the other module not modified. The two PV modules were mounted at a fixed inclination angle of 28° and facing the south orientation to achieve the maximum electrical productivity. Figure 1 and 2 display an actual photo and the schematic diagram of the experimental test rig under consideration. The water cooling heat exchanger of the cooled module was fitted to the rear surface of the cooled PV module with a heat exchanger consists of circular brass pipe of 3/8 inch in diameter and length of 3 m.

A foam insulated feed water tank is utilized to keep the temperature of the supply cooling water approximately constant. The cooling water flows into the heat exchanger at the rear surface of the PV module inside a brass pipes attached to the cooled PV module and then it leaves the heat exchanger to the hot water system. A substantial amount of heat in the PV module is absorbed by the cooling water and the obtained hot water can be utilized for residential applications. The experimental tests were carried out at various flow rates of cooling water.

Table 1. Technical specifications of the PV modules under consideration

Item	Specifications
Model	SP160P6–36
Manufacturer	Sunpal Power China
Cell type	Polycrystalline
Cell number	36
Panel dimension (H/W/D)	1480×670×35 mm
Rated power	160 Wp
Voltage at maximum power V_{MPP}	18.32 V
Current at maximum power I_{MPP}	8.73 A
Open circuit voltage VOC	22.9 V
Short circuit current ISC	9.31 A
Power tolerance positive	+ 5%
Operating temperature range	-40~+85 °C
Temperature coefficient of P_{max}	-0.36 %/°C
Panel efficiency	16.14%
Weight	12 kg

EXPERIMENTAL MEASUREMENT AND DEVICES

Digital instruments were used to measure the relevant essential parameters required to study the performance and the productivity of both PV modules. The experiments under consideration were carried out on two identical modules (with and without water cooling) simultaneously daily from 8:00 to 18:00. The temperatures at various points on the experimental test rig were measured by the thermal gun (Infrared thermometer), including the front and rear sides of PV modules, cooling water inlet and outlet, and ambient air temperature. The temperature was measured at five points on the fronts and rear surfaces and the average front and rear surfaces temperatures were then calculated. Thermal gun presents fast and accurate temperature measurements and confirm to be an optimal devices for surface temperature on solar cells, modules and arrays, particularly in inaccessible areas. The current and voltage of each module are also measured using a digital multimeter. The solar radiation intensity (G) is measured throughout the day hours utilizing a PCE-SPM 1 is a photovoltaic (PV) light meter digital pyranometer. The readings were taken every hour's.

An electrical load requires in order measuring the actual output power output of a solar PV module. Conversely a simple multimeter can be utilized to measure the open current voltage (V_{OC}) and short circuit current (I_{SC}) in the case of the no load testing. Then the actual field of PV modules can be calculated. In this study multimeter with a current scale up to 10 A and 50 V was used.

Figure 2 displays the measuring devices used in the present investigation and Table 2 shows their technical specification.

Experimental procedure

The experimental setup was tested outdoor under the climatic conditions of Irbid-city, Jordan at latitude (32.551445. Two types of experiments were carried, with and without water cooling. In order to keep up steady-state conditions in each experiment, the subsequent procedures were taken into account:

1. Orientation and inclination angle of the PV module were fixed using a steel frame manually during the experimental trails to obtain steady incident radiation intensity on the PV module surface.

Fig. 1. The present experimental setup

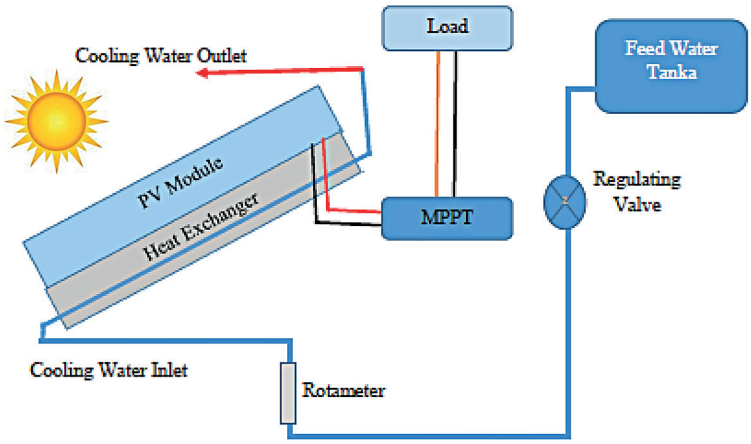

Fig. 2. Schematic of the cooled PV module under consideration

Fig. 3. Measuring devices used in the present experimental study

2. The operating temperature of the PV module, the solar radiation, the cooling water outlet and inlet temperature, the air ambient temperature and the output current and voltage were measured hourly at constant water flow rate.
3. Measurements were carried out at the same time on both modules.

Typical summer days were selected to carry out this experimental work in order to obtain maximum PV module operating temperature.

Table 2. Measuring devices technical specification

Instrument	Technical specification	
Digital multimeter	Range	0–600 V
	Accuracy	AC ±0.7%
		DC ±0.5%
Pyranometer	Range	0–2000 W/m²
	Accuracy	±10 W/m²
Thermal gun	Range	-40 to 800 °C
	Accuracy	±1.0 °C

GOVERNING EQUATIONS

Approximate estimation of the produced electrical power generated by the PV module can be obtained by multiplying V_{OC} and I_{SC}

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

For the PV module under consideration V_{oc} equals 22.9 V and I_{SC} current equals 9.31, thus the approximate estimation power is 213.2 W. Conversely, to calculate the maximum power (P_{MAX}, or MPP), fill factor (FF) should be taken into consideration. MPP power can be calculated as:

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

where: FF – fill factor.

The fill factor cannot be measured without a load but it is typically around 0.75. Therefore the MPP or P_{MAX} for the present PV module is equal to (213.3×0.75 = 159.7 W). An assessment of how close the real panel performance is to the optimum can be obtained by measuring the actual V_{OC}, I_{SC}, and estimated P_{MAX} of the PV module and comparing these values to the rating values.

Parameter FF is dentified as the fraction of the maximum output power to the product $I_{SC} \cdot V_{OC}$

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

The influence of temperature on the electrical performance of the PV module can be studied via measuring the effect of cooling on the short circuit current *Isc*, and the open circuit voltage *Voc*. The electrical efficiency value reported in modules data sheet is measured based on the Standard Test Conditions (STCs),which is defined as: cell temperature of 25°C, solar intensity of ardspach and air mass AM = 1.5. To compute the actual electrical efficiency of PV module, the output and also input power to the PV module should be computed as:\

$$P_{out} = V_{mp} \cdot I_{mp} \quad (4)$$

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

where: V_{mp} and I_{mp} – are measured voltage in (V) and current in (A), respectively;
G – is solar irradiation intensity (W/m^2);
A – is the PV module in (m^2).

Therefore, the electrical efficiency of PV module (η) can be computed as:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{MPP} \cdot I_{MPP}}{G \cdot A} \quad (6)$$

The slandered efficiency η_{stc} for the PV panel under consideration is equal to:

$$\eta_{stc} = \frac{160}{1000 \times 0.9916} = 16.14\%$$

which is identical to value reported in the data sheet.

RESULTS

In this work experiments were conducted to assess the electrical performance of the PV modules with and without water cooling. The present investigation was carried out under Irbid (Jordan) climate conditions. The weather data including ambient air temperature and solar radiation intensity were taken and recorded at each hour during the experiments. In addition to the operating parameters PV module current and voltage were recorded daily from 6.00 to 18.00 every day. The values of the relevant parameters such as power output and electrical efficiency of the two PV modules were computed. The examined parameters are during the examined month.

Weather meteorological data

The performance and the productivity of a PV module depend on many climatic parameters such as ambient air temperature and solar radiation intensity. The time variation of the solar radiation intensity (G) during the three testing days (25th June, 3rd July and 13th July) is illustrated in Figure 4. It can be seen that the solar intensity increases with time, until it reaches a maximum after that it decreases with time. The solar intensity reached maximum at 13:00 (solar noon) and it equals 946 W/m^2;conversely, its daily average was 630 W/m^2.

The time variations of the ambient air temperature (*Ta*) in Irbid City are plotted in Figure 5. It can be seen that that the ambient air temperature reaches it maximum at 14:00. The data obtained for the hottest day (25th July) were selected to obtain the results presented in the next section.

PV modules electrical efficiency and power productivity

The time variations of the front and rear side's surface temperatures of the cooled and un-cooled PV modules are depicted in Figure 6. It can be seen that the front surface average temperatures of both cooled and un-cooled modules were higher than the rear surface counterpart. Additionally, the surface temperatures on the front and backside of both PV modules were reduced via utilizing water cooling. Figure 7 shows the time variation of the electrical productivity (P_e) of both PV modules. It is obvious that the time variations of the electrical productivity of the cooled and un-cooled PV modules have a similar trend. The electrical power output productivity goes up from 6:00 to 13:00 and it achieves its maximum value at 13:00, then it reduces steadily.

This behavior occurs because the main factor that determines the electrical power productivity of the PV module is solar radiation intensity. Furthermore, the peak electrical power productivity of the cooled PV module equals 160 W, while the corresponding value of the un-cooled PV module equals 138.5 W. Therefore the maximum power productivity is enhanced significantly by about 14% due to water cooling of the PV module. This increase is attributed to the reduction in the temperatures of both front and rear surfaces of the cooled PV module which in turn reduces the electrons kinetic energy and consequently facilitates the steady motion of electrons resulting in increase the electrical power productivity of the PV module.

The electrical efficiency of the PV module depends mainly on the electrical power output and the input solar radiation energy. The electrical efficiency (η_e) of the PV module time variation of both cooled and un-cooled PV modules are demonstrated in Figure 8. It is clear that, in the period from 6:00 to 11:0 the electrical efficiency of the both modules increases significantly. The maximum electrical efficiency of both modules occurs at the period from 11:00 to 15:00, while the electrical efficiency of both PV modules decline during the period from 16:00 to 18:00. Moreover, the electrical conversion efficiency of the PV module was enhanced by about 14% due to the water cooling process.

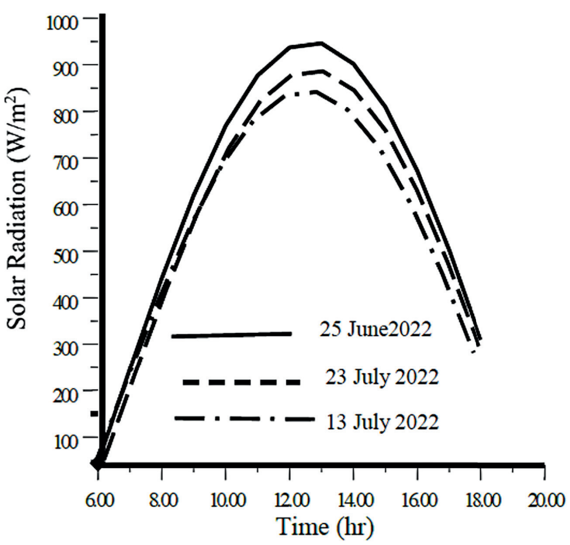

Fig. 4. Time variation of the solar radiation intensity in Irbid, Jordan

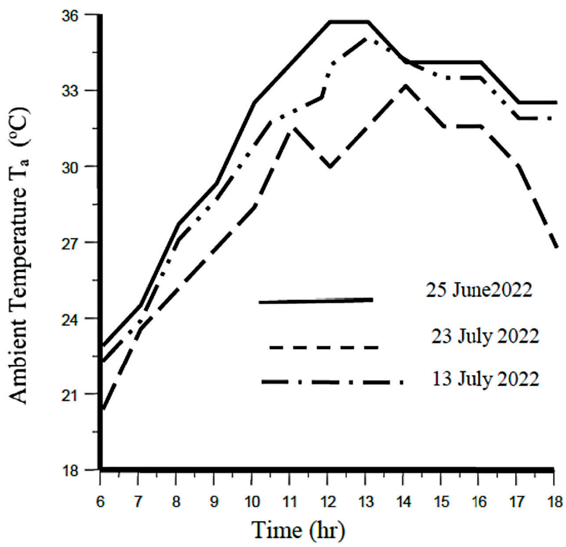

Fig. 5. Time variation of the ambient temperature in Irbid, Jordan

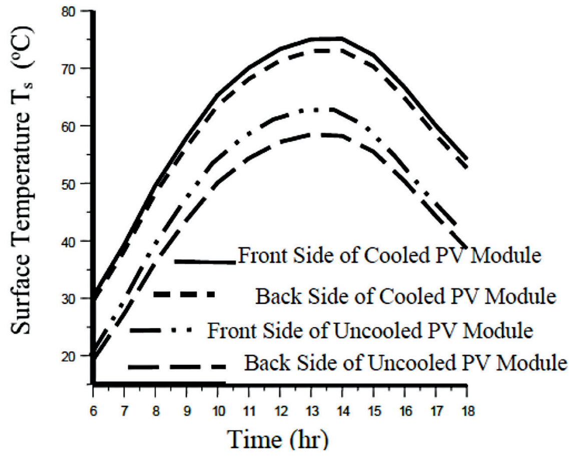

Fig. 6. Time variation the surface temperature on the front and rear surfaces of the cooled and uncooled PV modules

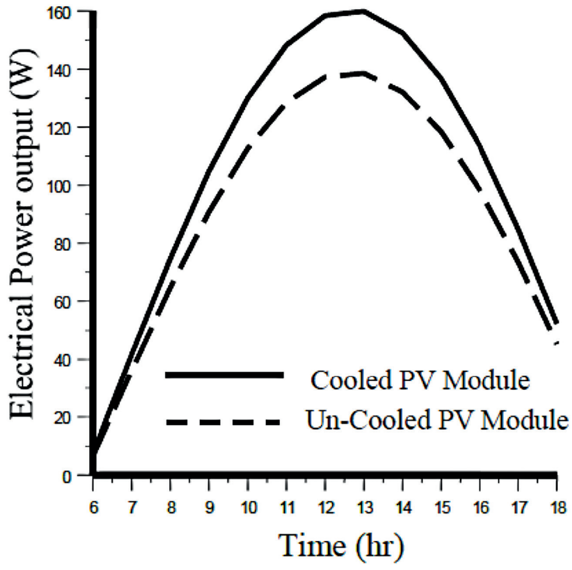

Fig. 7. Time variation of the produced electrical power t for cooled and uncooled PV modules

The influence of cooling water flow rate on the peak electrical efficiency of PV module is shown in Fiure 9. It obvious that, increasing the cooling water flow enhances the electrical efficiency until a flow rate of 2.5 L/hr. For flow rate above 2.5 L/hr an asymptotic behavior of the efficiency of the PV module was noted.

Figure 10 shows the effect of PV module average temperature on the conversion electrical efficiency. It is clear that the electrical efficiency decrease due the increase in the cell temperature. This behavior leads to significant drop in the output voltage accompanied with a slight increase in output current and hence reduction in the produced power. During the tested period, the increase of PV module temperature from 20 to 60°C resulted in efficiency decreasing of 10%.

CONCLUSIONS

A comparative experimental investigation was carried to study the influence of water cooling on the electrical efficiency and power productivity of PV module under Jordan climate conditions during selected days in July, 2022. Two identical PV modules one with water cooling and the other without were tested outdoor simultaneously. A brass heat exchanger was fitted to the

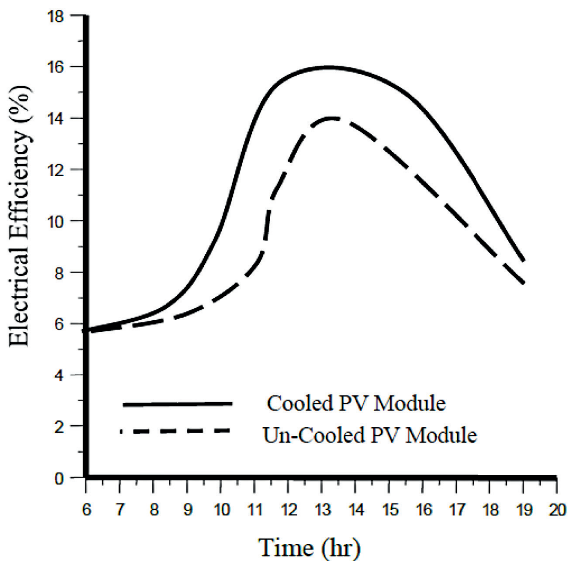

Fig. 8. Time variation of electrical efficiency of the cooled and uncooled PV modules

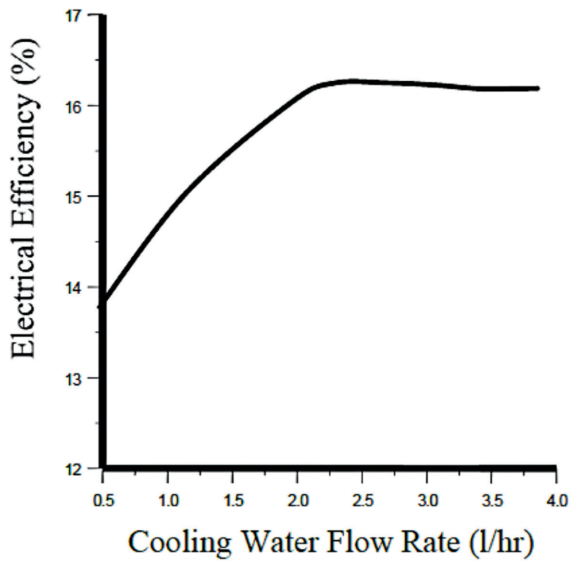

Fig. 9. Influence of cooling water flow rate on PV Module electrical efficiency

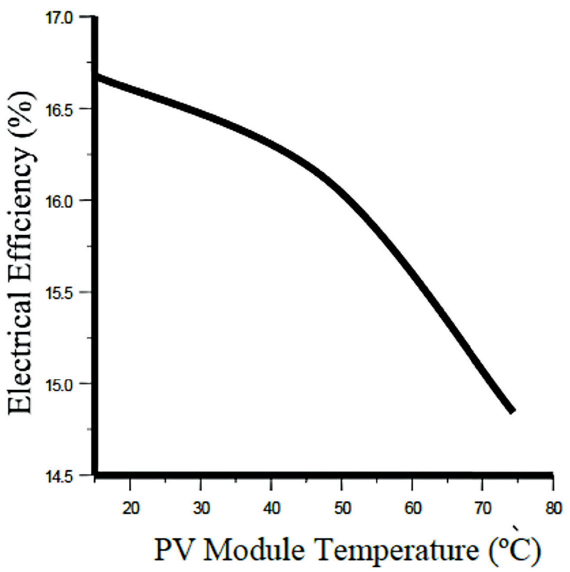

Fig. 10. Influence of PV Module temperature on its electrical efficiency

rear surface of cooled PV module. The results of this study show that the module temperature is the most important operating parameter that affecting the PV module electrical efficiency and power productivity. Water cooling can reduce the surface temperature on the front by about 20.0%. Moreover, the peak electrical power output of the PV increase by about 10%. Thus, utilizing water cooling method enhances the electrical conversion efficiency of the PV module by about 14%.

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