Enhancing the Performance of a Photovoltaic Module Using Different Cooling Methods

Ahmed Amine Hachicha, Chaouki Ghenai, Abdul Kadir Hamid

***Abstract*—**Temperature effect on the performance of a photovoltaic module is one of the main concerns that face this renewable energy, especially in hot arid region, e.g. United Arab Emirates. Overheating of the PV modules reduces the open circuit voltage and the efficiency of the modules dramatically. In this work, water-cooling is developed to enhance the performance of PV modules. Different scenarios are tested under UAE weather conditions: front, back and double cooling. A spraying system is used for the front cooling whether a direct contact water system is used for the back cooling.

The experimental results are compared to non-cooling module and the performance of the PV module is determined for different situations. The experimental results show that the front cooling is more effective than the back cooling and may decrease the temperature of the PV module significantly.

***Keywords*—**PV cooling, solar energy, cooling methods, electrical efficiency, temperature effect.

I. Introduction

PHOTOVOLTAIC cell is one of the most popular renewable energy devices to directly convert the solar radiation into electricity. However, during operation conditions its performance can be affected by various factors and may significantly decrease its electrical performance. Temperature is one of the major factors to affect the electrical output especially in hot weather such as in the UAE when cell temperature can reach up to 70 °C. Under these conditions, the output power may decrease by up to 0.65%/K, fill factor to 0.2%/K and conversion efficiency to 0.08%/K of the PV module above the operating temperature [1]. In fact, more than 80% of the solar radiation falling on photovoltaic (PV) cells is not converted to electricity, but either reflected or converted to thermal energy [2]. In order to overcome this problem, a cooling system is essential at high solar irradiation and hot conditions. Generally, some techniques like air-cooling and water-cooling are used to cool the PV module to increase its efficiency. Water-cooling is one of the most important methods for cooling photovoltaic modules, as it is more coolant that is efficient. In this paper, back front and combined cooling are investigated and compared to enhance the performance of a photovoltaic module.

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II. Literature Review

Many researches and studies have been carried out on increasing the PV efficiency by different cooling techniques. Krauter [3] suggested a method of reducing reflection to cool the PV by replacing the front glass layer with a thin layer of 1 mm running directly over the PV face. As a result, the PV temperature reduced to 22 °C and the electrical performance increased to 10.3 % over the day. One of the drawbacks of this design is the non-homogenous thickness of the water film which is necessary to determine the optimum water film in order to improve the optical performance.

Hosseini et al. [4] studied the effectiveness of spraying water over the PV instead of making it running continuously over the surface. Without taking into account the pump power they were able to achieve an increase in the electrical system performance by 17% from 8 am to 5 pm in summer. And by readjusting the system water pump to produce a continuous flow of water over the PV surface they obtained 26% improvement in the instantaneous peak output of the panel.

Dorobantu and Popescu [5] achieved an electrical yield of about 9.5% by cooling the PV front surface using a thin film of water. The advantage of this cooling system is decreasing the temperature of the panel in addition to obtaining better electrical efficiency due to decreasing the reflection losses. Moharram et al. [6] were able to calculate the maximum allowable temperature of PV panel (45°C) at which cooling by spraying should start to improve the overall power output. They observed that the cooling system needs to operate for 5 min to decrease the module temperature by 10°C.

Abdulgafar et al. [7] studied the efficiency of a solar panel by submerged it in distillated water at different depths. Their experiments showed that efficiency increase with water depth. An 11% increase of panel efficiency was found at depth of 6 cm after which the efficiency started to decrease due to electrolytic reaction at the electrodes or connections of the PV panel.

Balamuralikrishnan et al. [8] tested the improvement of efficiency of PV module by applying many techniques. They designed a system consisting of cooling unit and sun tracking unit. The cooling unit is an electronic controller circuit that excites DC pump-to-pump water and form water film on the PV surface, by a signal from a temperature sensor that sends the signal once temperature of PV exceeds 35^0C. It saves energy as well as water. Their system reduced the temperature by 8^0C and increases efficiency by 3%.

III. System Design

In the present work, a 20 W poly-crystalline panel is investigated using different water cooling techniques in contact with the surface of the panel. The cooling system consists of a direct contact system in the back side of the panel and a spraying system in the front side (Fig. 1).

Fig. 1 PV panel and cooling system used during experiment

Besides the cooling of the PV module, the cooling system has the advantage of reducing losses due to radiation reflectivity as well as the possibility of cleaning the dust and dry leaves on the front surface of the panel.

The poly-crystalline silicon panel has the following nominal parameters (Table I).

In the present experiment, a simple manual pumping system has been used to circulate the water in the spraying system and the back cooling box. Different characteristics of PV panel, solar irradiation, PV temperature are measured using PROFITEST PV ANALYZER.

TABLE I
PARAMETERS OF THE PV MODULE

Parameter	Value
Open circuit voltage Voc	22 V
Short-circuit current Isc	1.36 A
Maximum V_{MPP}	17.56 V
Maximum I_{MPP}	1.15 A
Maximum Power P_{MPP}	20 W
Dimension	495*350*25 mm

The effect of temperature on the electrical performance of the PV panel is investigated by measuring the influence of cooling techniques upon the short circuit current I_{sc}, and the open circuit voltage V_{oc} as well as the maximum power point P_{MPP}, which is given by:

$$P_{MPP} = I_{MPP} V_{MPP} = (FF) V_{oc} I_{sc} \quad (1)$$

This expression defines a quality parameter of the PV panel which is the fill factor FF. In practice, both the open circuit voltage and the fill factor decrease with temperature while the short circuit current increase slightly.

The electrical efficiency can be calculated as the following formula for different incident solar irradiation.

$$\eta_{elec} = \frac{I_{MPP} V_{MPP}}{GA} \quad (2)$$

where A is the aperture area (m^2) of the PV panel, G s the incoming solar radiation (W/ m^2).

The effect of temperature on the electrical performance of the photovoltaic system is given by the temperature coefficient β_{ref} at a reference temperature T_{ref} proposed by the manufacturer. Thus, the effective electrical efficiency is presented by the linear relation in the form:

$$\eta_{elec} = \eta_{ref} \left[1 - \beta_{ref} (T - T_{ref}) \right] \quad (3)$$

The temperature coefficient is mainly a material property which is about 0.004 $K^{-1}$for crystalline silicon modules. Normally, the values of T_{ref} and β_{ref} are given by the PV manufacturer [9].

The rate of thermal energy extracted by the cooling water is given by:

$$\dot{Q} = \dot{m}_{water} C_p (T_{outlet} - T_{inlet}) \quad (4)$$

where $\dot{m}_{water}$ and C_p are the mass flow rate and specific heat of the water, respectively.

The thermal efficiency of the system is calculated as

$$\eta_{th} = \frac{\dot{Q}}{GA} \quad (5)$$

The net efficiency of the PV module includes both electrical and thermal energy converted from the solar energy.

$$\eta_o = \eta_{th} + \eta_{elec} \quad (6)$$

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In this section results of measurements on the 15th of June 2015 have been presented and analyzed. Experiments were conducted using three cooling methods: back cooling, front cooling and double cooling (combining both methods). Temperature and electrical performance were tested during one hour at solar noon when the radiation and ambient temperature are higher. Fig. 2 shows the evolution of temperature of the panel and the maximum power point using different cooling methods. It can be seen from Fig. 2 that the performance of the PV panel is enhanced using different cooling methods by reducing the cell temperature and increasing the maximum power point.

Front and double cooling are more efficient than back cooling. This can be explained by the fact that the cell temperature is more sensitive to the front surface and the thermal diffusivity of the glass.

I-V and power curves for different scenarios obtained from PROFITEST PV power measurement are shown in Figs. 3 and 4 respectively.

Experimental data are compared for different scenarios in Table II. It is clear from this table that water cooling decreases the temperature of the PV cell for all scenarios. The effect of cooling the PV panel causes an increase in the open circuit voltage and slight decrease in the short circuit current.

TABLE II
TEST RESULTS

	Tcell (°C)	G (W/m²)	Voc (V)	Isc (A)	P_{MPP} (W)
No cooling	42.1	849	20.38	1.11	15.5
Back cooling	41.37	850	20.69	1.11	15.9
Front cooling	37.32	863	20.72	1.11	16.1
Double cooling	34.36	862	21.09	1.10	16.4

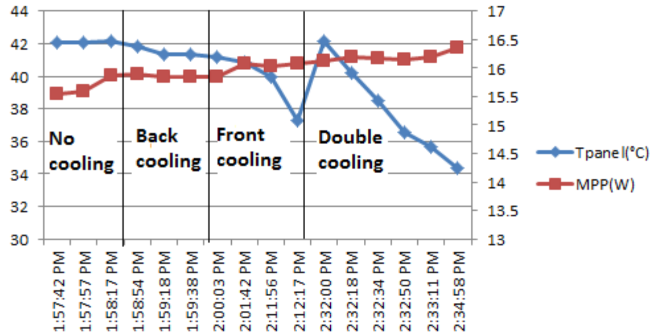

Fig. 2 Evolution of the module temperature and maximum power point during experimental test

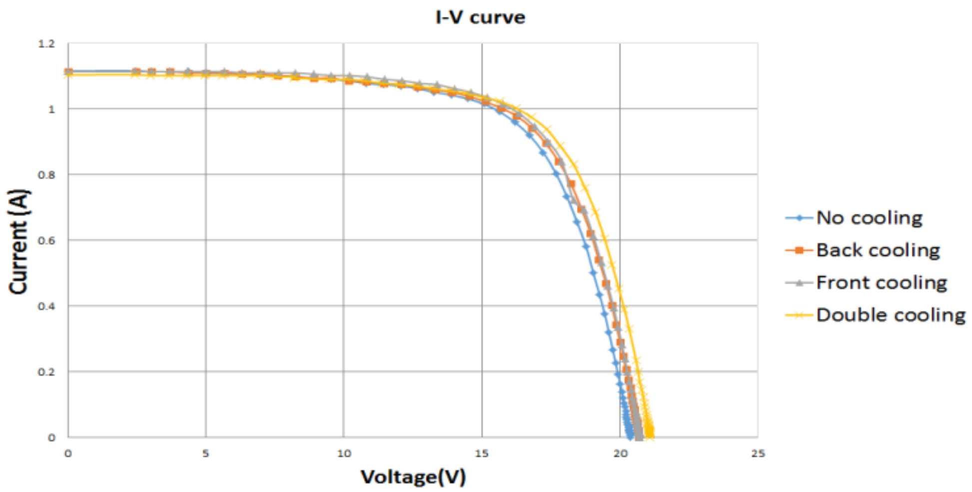

Fig. 3 Experimental results of I-V for different scenarios

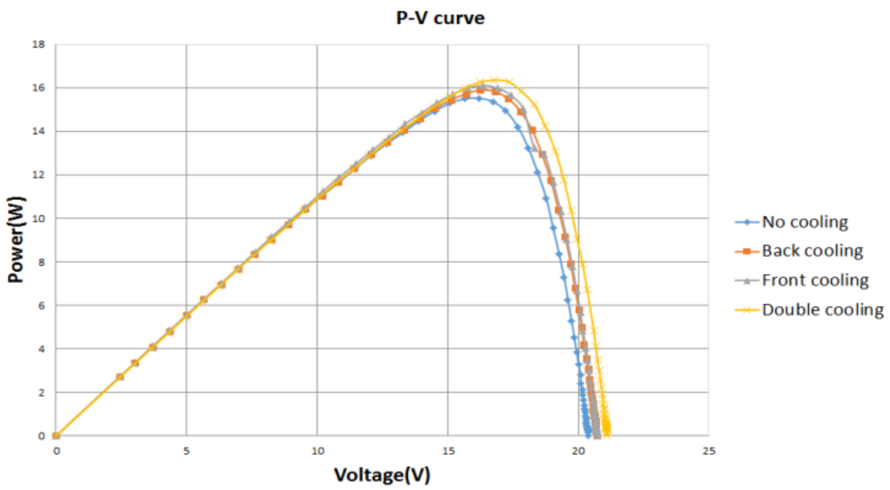

Fig. 4 Experimental results of power curve for different scenarios

For almost the same irradiance back cooling is able to decrease the temperature of the PV cell by 1.7% compared to the uncooled case, while the power is increased by 2.3%.

For front cooling, an increase of 3.6% in output power has been observed and the open circuit voltage increases from 20.38 V to 20.72 V. A significant decrease of 11.3% of the cell temperature is observed with front cooling leading to an increase of electrical efficiency by 3.6% respect to the uncooled case.

The cell temperature is decreased by 7.7°C using the double cooling corresponding to a drop of 18.3 % compared to the uncooled case. As a consequence, the maximum power point is increased by 5.5% which is consistent with the temperature coefficient for silicon solar cell (0.065%/K).

The short circuit current is almost constant for different scenario and only a slight decrease is observed when double cooling were implemented.

The electrical efficiency and the fill factor of the PV panel has been calculated for different cooling techniques and compared to the uncooled case (Table III).

The double cooling shows an increase of 4% in electrical efficiency of the PV panel which means a relative increase of 0.5%/K. However, the fill factor is increased by only 2.9% which corresponds to a relative increase of 3.5%/K.

TABLE III
ELECTRICAL PERFORMANCE OF THE PV PANEL

	η (%)	FF
No cooling	10.58	0.686
Back cooling	10.81	0.692
Front cooling	10.78	0.700
Double cooling	10.99	0.706

V. CONCLUSION

The electrical performance of a PV panel is sensitive to its operating temperature and can significantly affected when cell temperature start to rise. In order to overcome this problem, a cooling system is required to decrease the temperature and enhance the electrical performance. Different cooling methods are presented and analyzed to improve the operation of the photovoltaic system.

Cooling the PV panel is more effective from the front side than the back side and may also increase the optical efficiency by removing the dust and impurities from the PV surface. Module temperature is decreased by 11% using front cooling while it is decreased by less than 2% with back cooling.

In this study, the temperature of the PV cell is reduced by up to 18% when water is circulated in the front and back side of the PV module. As a consequence the electrical efficiency is increased by 4%. Such solution can be combined with a solar thermal system to produce hot water while cooling the PV panel and achieving higher energy conversion of the absorbed solar radiation.

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