I A. Hasan
Electro mechanical Engineering Department, University of Technology
Baghdad., Iraq.
dr_ibtisam_ahmed@yahoo.com

S. R. Fafraj
Electro mechanical Engineering Department, University of Technology
Baghdad., Iraq.
dr.sahar_alsakini@yahoo.com

A.J. Kadem
Electromechanical Eng. Dept
University Of Technology
Baghdad., Iraq.
suramylovr@yahoo.com

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Enhancing Photoelectric Conversion Efficiency of Photovoltaic Panel Using Cooled Water by Evaporation

Abstract- *It has been found a linear progression between the panel temperature and its efficiency. A novel cellulose pad arrangement, which is saturated with water, at back surface of photovoltaic panel for cooling has achieved better results. The experimental results showed a reduction in maximum PV panel temperature at using the proposed water cooling system. The average temperature of the PV panel dropped 10.1°C and an increase in average solar panel efficiency about 20.8% during operating time. Then, a comparison between the PV panel results cooling by natural convection and using the proposed water cooling system will reveal the most efficient.*

Keywords- *cellulose pad, Photoelectric Conversion Efficiency, saturated.*

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1. Introduction

Renewable energy technologies presently supply more than 13.3% of the World's needs from primary energy, [1]. There are various forms of renewable energy but the incoming solar radiation is depended primarily, which totals annual energy about 23000 Teri Joules [2]. To use the resource of available solar energy effectively, the photovoltaic (PV) panel must be at a normal operating temperature, which is about 35ºC [3]. The high temperature for PV panel during operation causes a significant changing in the material properties of solar cells, which cause a decreasing in photoelectric conversion ability of PV panel, [14]. Numerous studies have been conducted to determine the most efficient method for decreasing operating photovoltaic cell or panel's temperature and enhancing module parameters, [13 and 5], submitted a comprehensive review for various methods, including passive and active, cooling processer for photovoltaic cells.

[5] pointed to a set of requirements concerning with cooling techniques in a review of the Photovoltaic cooling methodologies, which was used with concentrated illumination. The used cooling method needs to be ensuring that the PV cell's operating temperature does not override the limit at which irreversible deterioration happens in the cell. Moreover, the cooling method must provide; a uniform temperature across the cells, be effective and simple, and the needing for pumping power minimized. The authors noted that there is a deep desire for keeping the temperature low in order to boost electrical efficiency and having a high temperature to increase the benefit of the thermal energy. Forced convection using air or water as cooling fluids is required at high concentrations. The used cooling methods are too costly and the use of water as cooling fluid was more efficient, as reported.

[4] have proposed a new system for cooling PV panels, it has been called, the Ground-Coupled Central Panel Cooling System (GC-CPCS). Researchers have introduced the notion of central cooling for PV panels as well as used a buried heat exchanger in ground.

[3] developed a cooling system based on water spraying on PV panels. The spraying process was controlled in order to minimize the water and electrical energy requirements for cooling, in hot arid regions, due to its importance in this region. A mathematical model was used to determine starting cooling for panels. The maximum allowable panel temperature was determined by 45 C^{o}.

[6] used a water film cooling system. In this cooling method, a thinning film of water flowed on the front surface of the PV panels for lowering its temperature. The thin layer of water worked to

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

reduce the reflection and thereby increasing the conversion efficiency.

[7] presented an alternative cooling mechanism for photovoltaic panels. The mechanism has been worked by using a water spray on surfaces of panel, that mean both sides cooled simultaneously.

[8] examined a cooling system consisting from a water absorption sponge, which was fixed on the back surface of the photovoltaic panel and keep it moist by dropping water during operation time.

The intention of this work was to investigate the effects of cooling the PV panel using wet surface which is fixed on the back face of panel for improving photovoltaic cells performance by decreasing the module operating temperature. The present work scope is the design and installation for the proposed cooling system. The cooling system approach has been built using cellulose pad, it was saturated continuously by dropping water which was supplied through perforated pipe, from a tank. The basis of present cooling system depends on the heat dissipation due to water evaporation from saturated surface of the pad. The major purpose of the present work was to give an experimental approach to the proposed cooling technique through testing its influence on panel performance (module's temperature, output power and electrical efficiency), and to compare the results with a PV panel results without using any cooling technique. This technique is characterized by easily implementation, not noisy operation, needing a little pumping power, low cost for its structural and maintenance and its components are available in local market.

2. Experimental Setup

I. The description of system configuration

As shown in Fig. 1, an experimental setup was compiled from a solar panel type polycrystalline of nominal maximal power 10W and an effective surface area of (285×350 mm^2). The general characteristics of examined panel are specified in its name plate as: (22V) open circuit voltage, short circuit current (0.59A) and max system voltage (600V) at test condition 25^{o}C and 1000W/m^2. The panel was provided with a system of cooling mounted on the rear side of PV panel. And the structure of cooling system consists of a water absorber cellulose pad with a specific thickness, perforated pipe for dropping water on pad, water tank, hose , flow regulating valve, a draining water channel to collect the excess water, multi power supply(type 3005D)and control circuit. The PV panel was placed on 0.5 m high holder with 31.2° tilt angle and towards the south using a special mobile application, see figure (2).

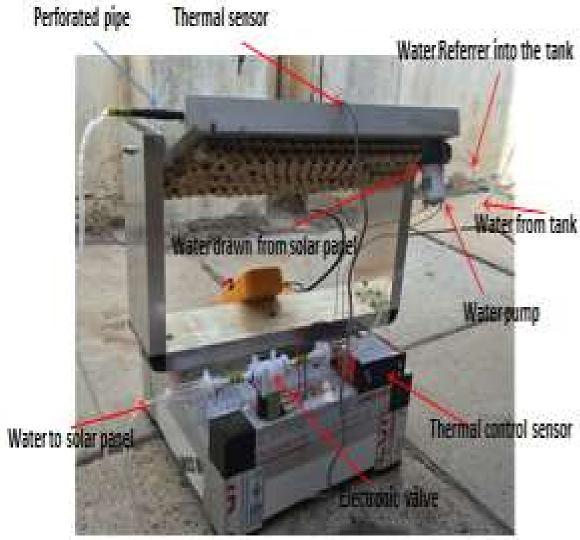


Figure (1) Experimental work Setup

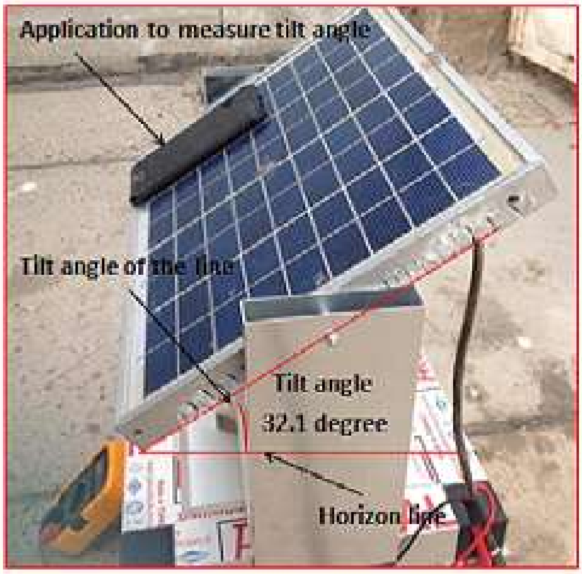


Figure (2) PV panel inclination

A control Circuit was designed to control the switch off/on of cooling system. It was adjusted to start the cooling system operation when the module temperature was 50°C. Figure (3) shows cooling system control circuit. A thermal sensor was installed on the top surface of PV panel. When the panel temperature reached a specific degree, an order was given to an electronic valve and motor to start the cooling process, as shown in figure (3). The selection for 50°C, as starting operation temperature, was depended on the climate condition in Baghdad, especially in the summer months, June and July and August, the period of present work measurements. At these months, solar panel temperature already increases more than 50°C. Therefore, the starting of cooling system operation at a temperature lower than 50 °C requires more consumption of energy.

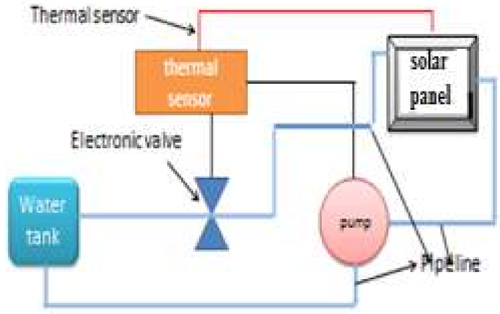


Figure (3) cooling system control circuit

The whole system was linked to a (10W) DC lamp through a current–voltage recorder so it can be determined the specific power-voltage characteristics of solar panel during the practical measurements. Voltage and current were recorded at each setting, as well as panel's temperature values.

In addition to the measurements of electrical parameters, the system was equipped with sensors to measure; solar irradiation using a pyranometer,(type SPM-1116SD) was installed on the solar panel, panel temperatures using multi channel recorder (type LUTRON BTM-4208SD), with digital thermometer which were installed on many location of the front panel surface with an accuracy of (±0.3 °C), the inlet and outlet cooling water temperature with the inlet and outlet mass flow rate and ambient air temperature, cooling water was distributed through 20 holes was perforated in a plastic pipe which was fixed on the upper side of the panel's rear surface, see Fig. 1. Water was ensured from a pipeline with flow rate 1.9 l /h by regulator valve. Local wind velocity at real time was measured at a holder rising (2 m) from the panel location.

II. Cooling technique and its theoretical approach

As it has been already confirmed on the present proposed approach, the evaporated water cooling technique was implemented on the back side of the panel, in order to achieve an increase in magnitude of a rejected heat to the surroundings and to gain a lower panel temperature, or to increase output electric power of panel. The general analyze of heat exchange circumstances, and in the case of proposed cooled PV panel method (cooling by evaporated water applied on rear side of the solar panel), was included the incoming solar radiance $\dot{Q}_s$ into surface panel Ap which it is converted to useful power just in a small fraction and the considerable part of solar irradiance loses on the increasing the internal energy of PV panel and on total heat losses ($\dot{Q}_{dis}$) to the around environment.

According to Fig. 5, total heat loss comprises the convection, (Q_{con}), radiation (Q_{rad}) and evaporation heat (Q_{evap}) losses.

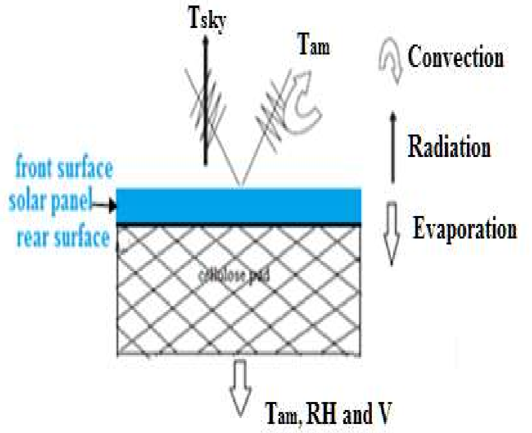


Figure (4) The Schematic of the solar panel with evaporated cooling system.

The available solar radiation which presents the input energy into the panel surface (Ap), expressed as:

$$\dot{Q}_s = \tau_g\, G_s\, Ap\, bc \qquad (1)$$

A_P is the cross section area of PV panel, (m^2), τ_g: glass cover's transmission coefficient, α_c: cell's absorption coefficient, G_s : solar radiation (W/m^2), bc: the backing factor, it can be defined as a fraction of absorber plate area which covered by solar cell area.

The electrical energy (E_{cell}) produced by the PV panel expressed as:

$$E_{cell} = \eta_p\, \tau_g\, Ap\, bc\, G_s \qquad (2)$$

η_p: cell or panel efficiency

Overall heat loss of solar panel, ($\dot{Q}_{dis}$)can be expressed as follows:

$$(\dot{Q}_{dis}) = (Q_{con}) + (Q_{rad}) + (Q_{evap}) \qquad (3)$$

Where,

$$\dot{Q}_{rad} = F_{(sky/G)-f}\, \varepsilon_g\, \sigma\, Ap\, (T_g^4 - T_{sky/am}^4) \qquad (4)$$

Where, T_g is the glass temperature (front surface of panel), K, $T_{sky/am}$ is the temperature of sky or ambient, ε_g; the emissivity of glass cover, $F_{(sky/am)-f}$: Front surface's shape factors with sky or ground.

and ,

$$Q_{con} = h\, Ap\, (T_g - T_{am}) \qquad (5)$$

T_{am}: the ambient temperature, K.

In the case of PV panel with water cooling system, convection and radiation losses are assumed to be happen only at front face, as shown in figure (4). While, at rear face of PV panel, heat dissipation is happened through a system of water cooling. This system uses the abilities of evaporative heat in decreasing the temperature of PV panel and ingredients of cooling system. The cellulose pad was wetted continuously and part of water is evaporated to the surrounding. The demand for determining needed amount of water evaporation in order to cool solar panels is very important issue, particularly at hot dry regions, as in Iraq.

The cooling system was adjusted to start water pumping, at 50° C panel temperature in order to minimize the amount of spending water.

The amount of evaporated water depends on ambient weather condition; wind velocities, the relative humidity and ambient temperature, which can be expressed as follows:

$$\dot{Q}_{eva}=h_e\dot{m}_{eva} \quad (6)$$

where, $\dot{Q}_{eva}$: the evaporation heat (kW), h_e : the latent heat of vaporization, the water latent heat of evaporation is 2257 kJ/kg, $\dot{m}_{eva}$: the mass rate of evaporated liquid (kg/s).

In the view of the importance of water and especially in dry remote areas, the consumption amount of water must be determined. To determine the amount of evaporated water, ASHRAE formula for free surface water is used because there is flow of water in a thin water film form over the saturated actual area of the pad, which will lead to free surface of water. The validation for using this formula is proved with intensive experimental work.

ASHRAE method is used to determine the amount of evaporation water (which represents the consumption amount of water during cooling processes) through the following formula given by Carrier, which was reported by [10]:

$$\dot{m}_{eva} = (0.089+0.0782V)(P_{ws}-P_r)\ A_{eva}\ /h_{fg}\,(3600) \quad (7)$$

Where, V: wind velocity above the wetted surface, (m/s), A_{eva} : The area of the wetted surface, m^2, P_{ws}: the partial saturation pressure of water vapor in moist air (Pa) and P_r: the actual partial pressure of water vapor in air (Pa).

The partial saturation pressure can be calculated by the following empirical correlation, [11]:

$$P_{ws} = e^{\frac{77.345+0.00577-\frac{7235}{T_{am}}}{T_{am}^{6.2}}} \quad (8)$$

Where, T_{am}: the ambient temperature, (K).

P_r can be calculated from the actual relative humidity, (H_{rel}). The relative humidity is defined as the ratio of water vapor presented in atmospheric air as:

$$H_{rel} = \frac{P_r}{P_{ws}}\,100\% \quad (9)$$

So the actual partial pressure can be calculated depending on real measurement value of relative humidity as:

$$P_r = H_{rel} * P_{ws}/100 \quad (10)$$

Evaporation of water from a wet surface (cellulose pad), the cooling system, (cellulose pad and remaining water) has been cooled and will be in thermal equilibrium the panel temperature will be decreasing due to contact between cooling system (cooled water and cooled cellulose pad) at the rear face of PV panel. The quantum of cooling energy will be equal to evaporation energy ($\dot{Q}_{eva}$), which will be supplied to PV panel and cooling system. In the present study, further analytical modeling of the proposed cooling method did not provide, because it is not the pivot of this paper.

In order to determine panel's electrical conversion efficiency, the output of PV voltage and current, the temperature of panel surface and solar radiation intensity (W/m^2) at real time, voltage and current have been measured. The efficiency of photoelectric conversion is calculated as [12]:

$$\eta = \frac{P}{A\,G_s} \quad (11)$$

Where η: the efficiency of photoelectric conversion (%), P (W): the generated power of PV panel which is estimated by the readings of voltmeter and ammeter.

3. Results and discussion

The thermal effect of cooling system in solar panel performance is shown in figure (5), by using different water flow rates, which was as follows (0.54, 0.702, 1.32, 1.902, 2.25, 2.4) l/h, conducted on 2&3/8/2016. As shown in this figure, the thermal effect for water flow rate has increased whenever its quantity increased. The experimental observations confirmed that the flow rate (1.902 L/h) has the best effect, although the larger quantities gave a slight enhancement in PV panel thermal performance from (1.902 l/h). But using a larger quantity for the flow rate is caused a loss in water by dropping it from the pad. Because the cellulose pad is in an excess saturation condition at using the larger quantity of flow rate . Figure (5) shows a comparison between daily temperature distribution for PV panel without cooling and another using the proposed cooling system with (1.902 l/h) water flow rate, which caused a (10.1°C) reduction in the temperature of PV panel. In the present cooling model are used a different thickness of cellulose pad which are (4, 5 and 6) cm. These thicknesses are tested with using (1.902 L/h) water flow rate. Figures (6), (7) and (8) are shown the solar panel performance that including the panel's temperatures, efficiencies and productive powers respectively, during operation time on (6/ 9 / 2016). The (4 cm) thickness pad gives low results with the using of the specified flow rate because it has small thickness which is caused in leaking out the water due to an excess saturation and these water leaks has reduced the cooling system effects. While the two others thicknesses (5and 6cm), have achieved a convergence results. The (5 cm) thickness pad is used in the present cooling system because it is available in local market while the other thickness (6cm) must be modified to be using.

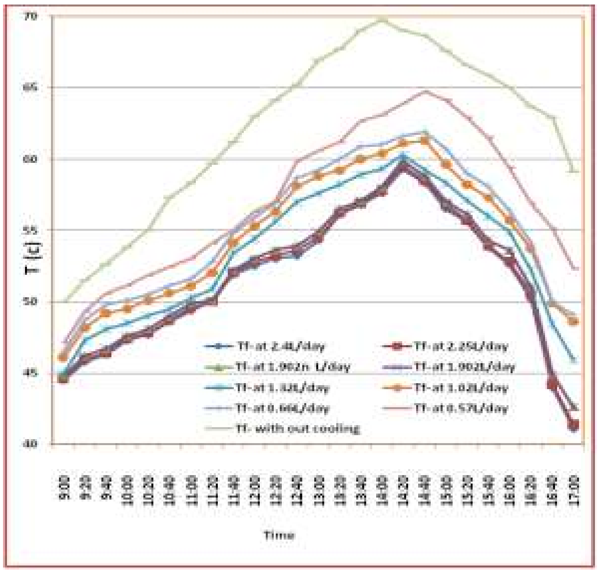
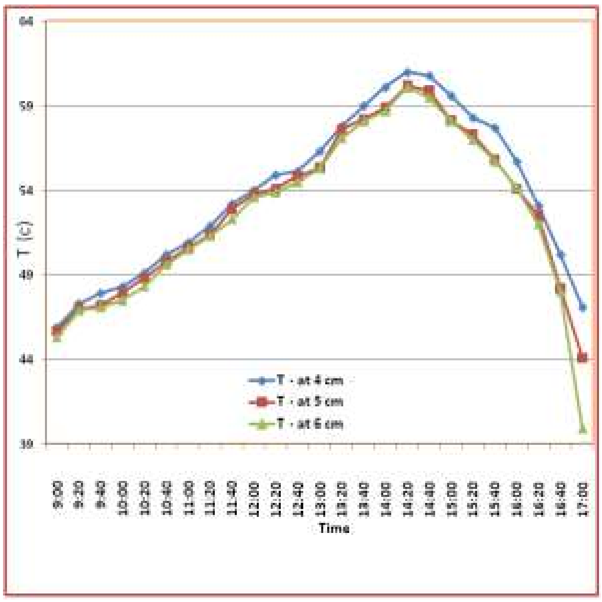


Figure (5) solar panel temperatures with various flow rates of water



Figure(6) PV panel temperatures with using different cellulose pad thickness

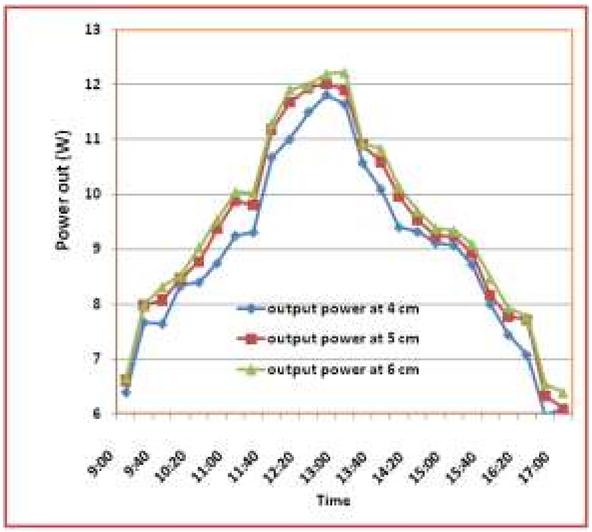


Figure (7) the power output of PV panel with using different thickness of cellulose pad

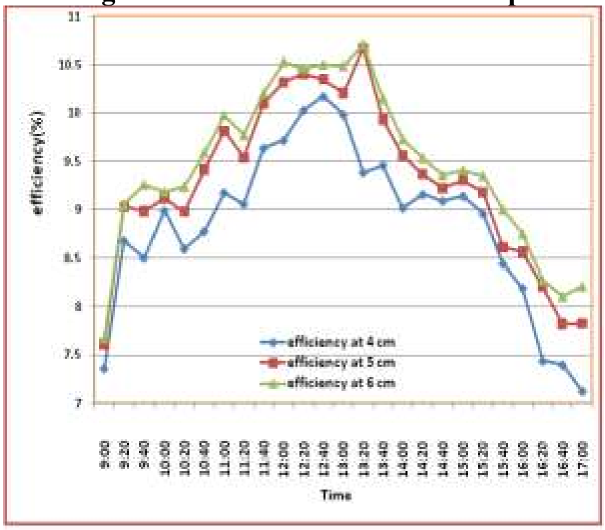


Figure (8) efficiency of PV panel with using different cellulose pad thickness

Figure (9) shows a comparison between the theoretical and experimental amount of water consumption due to evaporation during cooling process. The amount of water consumption depends on ambient temperature, relative humidity and wind velocity. The consumed water rate has varied during the time of operation and reached maximum rate of consumption at 2^{nd} PM to be (0.3261 L/h) theoretically and (0.31 L/h) experimentally, because ambient temperature at this time was close to peak. The total amounts of consumed water during operation period (from 9 AM to 17 PM) on 2-September-2016 are about (1.97 L and 1.91 L) for calculated and measured amounts, respectively**.** This convergence between the results gives reliability for the used formula.

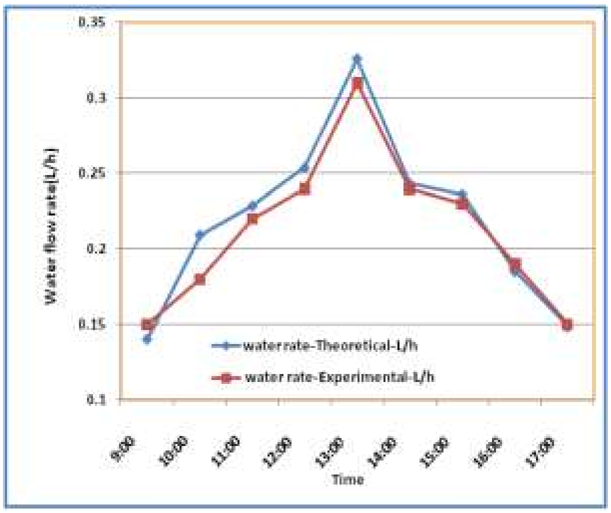


Figure (9) The Theoretical and experimental amounts of evaporated water during operation period.

Figures (10) display a comparison for the results of the solar panel performance without cooling and with cooling using (1.9 l/h) flow of cooling water and 5cm cellulose pad thickness. During operating time of testing on 7/9/2016 at Baghdad city, the maximal and average air temperature are 45.29°C, 42.9 °C, with the maximal and average wind speeds 8.1 m/s and 5.6 m/s, respectively. While the maximum and average solar radiation are (1052 and 873.8) W/m^2 .

Figure (10) shows a comparison for PV panel's temperatures between solar panel without and with cooling system. From the result, it has been observed that the temperatures of the solar panel with using water-cooling were significantly reduced. It caused a reduction in temperature of solar panel in range of (7 to 13 ° C) and as a daily average decreasing was (10.1° C).

Figure (11) shows that the comparison between output power of solar panel with cooling and without cooling increased and peak values of output power has represented from 11:00 to 13:00. The use of cooling system increased the daily average of power output about (20.7%). The maximum instantaneous output power achieved after 12:00 which is about 11W while the normal one was 9.3W.

Figure (12) shows a comparison for output efficiency of solar panel with and without cooling. The experimental results present that the solar panel efficiency with cooling increases as a daily average; it is 6.3% while the traditional one is 4.9%. The maximum efficiency in about 11.84% was achieved with water cooling system for the panel while the corresponding maximum efficiency of ordinary panel was in about 9.15%.

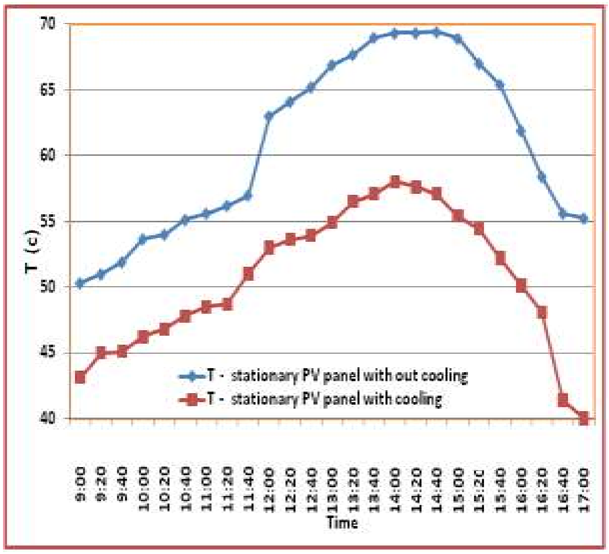


Figure (10) : A comparison between PV panel's temperature without and with cooling using (1.9 l/h) flow.

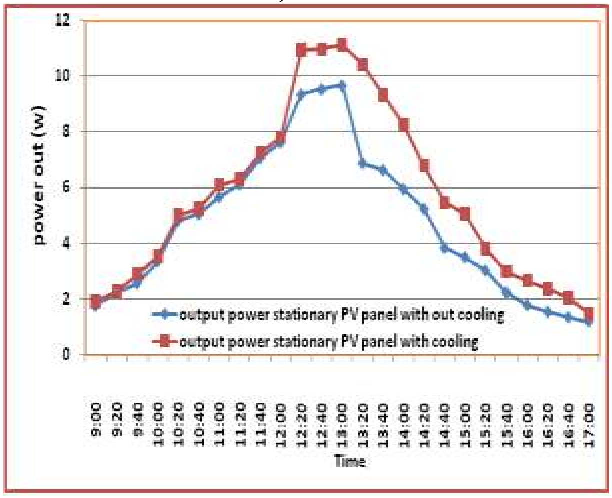


Figure (11) A comparison between PV panel's output power without and with cooling.

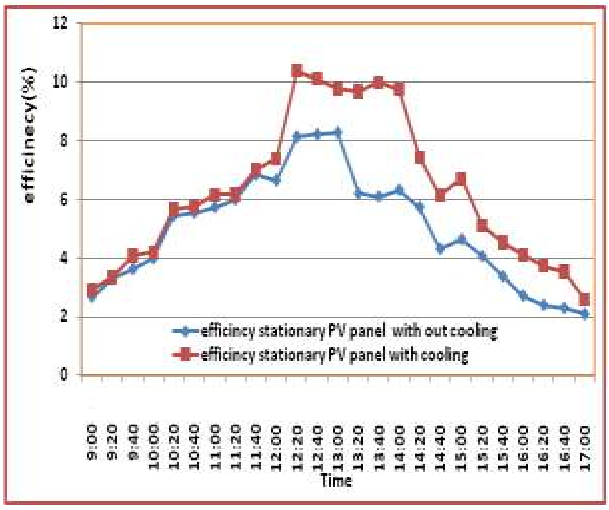


Figure (12) : Comparison between PV panel's efficiency without and with cooling.

4. Conclusions

A novel cellulose pad arrangement at back surface of photovoltaic panel for cooling has achieved better results. The experimental results indicated that with cooling condition, the panel's temperature can be decreased which effectively causes an increasing in the photoelectric conversion efficiency for PV panel in comparison with traditional one. The used arrangement of water cooling reduced the daily average cells temperature (10.1° C). The output power increases maximally about 20.7%, and increase in output efficiency is 20.8%. The low cost of water absorption cellulose pad may be utilized as a cooling attached component for PV panel in order to enhance photoelectric conversion efficiency. Cellulose pad is a simple attachment that can be easily and quickly replaced. In general, the use of a water saturated pad technique which was designed to extract sufficient heat from the rear surface of the PV panel, is more practical than other used cooling techniques. Because it was not expensive, easily equipped and not need to establish a specific heat exchanger as an integrated part from the PV panel.

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Author(s) biography

Asst.Prof. Ibtisam A. Hasan

, University of Technology – Baghdad – Iraq Electromechanical. Eng. Dept. Born in Iraq on 18th October 1958,Completed Bachelor of Engineering (Mechanical Engineering) in the year of 1981 and completed Master and Ph of Engineering (Thermal Engineering) in the year of 1986 and 1997. Her research area is heat transfer enhancement and renewable energy.

E-mail**: dr_ibtisam_ahmed@yahoo.com**

Lecturer. Dr.sahar R. Al Sakiny ,

University of Technology – Baghdad – Iraq, Electromechanical. Eng. Dept. Born in Iraq on 18h November 1965, Completed Bachelor of Engineering (electrical Engineering) in the year of 1987and completed Master and Ph of Engineering (engineering power system) in the year of 1999 and 2003. Her research area is power system and renewable energy

. E-mail: dr.sahar_alsakini@yahoo.com

Engineer. Abd Alhussien-Jawad Kadem,

The ministry of electricity. Born in Iraq Born in Iraq on 1975, Completed Bachelor of Engineering (electrical Engineering) in the year of 2004 and completed Master (energy and renewable energy Engineering) in the year of 2016. His research area is heat transfer enhancement and renewable energy.

E-mail**: suramylovr@yahoo.com**