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Study the Performance of Cooled Photovoltaic Thermal Solar Panel Using New Cooling Technology

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Abstract— In this work, experimental and numerical analyses have been executed to investigate the effect of using cooling techniques on the performance of the photovoltaic thermal solar panel (PV/T). It is well known that a decrease in the panel temperature will lead to an increase in the electrical efficiency. The photovoltaic/thermal (PV/T) collector is a combination of PV cells and a solar thermal collector in one unit, which can together generate electrical and thermal energy. In the theoretical study, the electrical characteristics of PV were analyzed by using (MATLAB PROGRAM). The panels were oriented south and tilted at 45°. All tests are carried out in Baghdad city at (May, June and July) in 2018; under clear sky conditions. The experimental study includes four cases (modules). Module I contains open cell aluminum metal located in water passages box of a 9-liter capacity in the back of PV panel. Module II contains only water pass. Module III comprises copper slices that are located in the water box. The first three cases are compared with the conventional PV panel under the same conditions. compares between the PV with open cell aluminum metal and the other PV with copper slices. The results manifested that the cooling of PV panel in the module III is better than the others, but economically, the use of module I is the best, therefor it is found a more acceptable technique for hot climate conditions

Keywords— Cooling photovoltaic panel, Open-cell aluminum metal

1. Introduction

Currently, most of the world's energy (80%) is produced from fossil fuels. Massive exploitation is leading to the exhaustion of these resources and imposes a real threat to the environment, apparent mainly through global warming and acidification of the water cycle. The spreading of fossil fuels around the world is equally uneven. More than half of the known oil reserves are present in Middle East. Renewable energy is one of the most promising alternatives to the above problems. PV panels in particular can deliver a good source of producing clean electricity. The PV panel effect was first discovered by the physicist Edmund Becquerel in 1839. Despite that, this technology is considered to be a very recent one. The first cell which could be considered as PV was constructed in 1941 with an efficiency of 1%. The present photovoltaic technology has been well developed since 1941. PV panels are used as the primary electricity source in space missions and satellites. The hybrid PV panel is one relative new type of PV panels. This kind of panel converts the sun's radiation to electricity while providing heat to the system for other purposes [6]. The active cooling system for PV module was Studied**.** The electrical efficiency of PV panel cells is adversely affected by the significant increase of cell operating temperature during the absorption of solar radiation. The hybrid photovoltaic/thermal (PV/T) solar system was designed, invented and experimentally investigated. A parallel array of ducts with inlet and outlet manifold designed for uniform airflow distribution was attached to the back of the PV panel, to actively cool the photovoltaic cells. Experiments were performed with and without active cooling. It was found a linear tendency between the efficiency and the temperature. Without active cooling, the temperature of module was high, and the solar cells can only achieve an efficiency of 8–9%.

However, when the module was worked under active cooling condition, the temperature decreased significantly leading to an increase in the efficiency of photovoltaic cells between 12% and 14% [9]. Un-glazed flat-plate photovoltaic thermal system established with a 240 W poly-crystalline silicon PV/T collector, 120 L storage tank, pump controller and water pump was studied. The photovoltaic thermal collector was made with copper tube and copper sheet with supersonic welding and adhesive on photovoltaic panel backside. The results indicated that the system thermal efficiency can reach 35.33%, and the PV conversion efficiency can reach 12.77% during the the testing period. The water tank temperature can be raised from 26.2 ºC to 40.02 ºC [4]. The cooling strategy of photovoltaic panel in Romani was Studied. They experimentally investigated a photovoltaic module cooled by a continuously thin film of free flow water running on the front of the panel. The benefit of this cooling system, in addition to decreasing the temperature of the panels, is in obtaining better electrical efficiency due to the decreasing of the reflection loss (refractive index of water is 1.3, which is intermediate between glass with 1.5 and air with 1.0). To produce film flow water over the photovoltaic panel, a plastic pipe of 1.5 mm diameter with 25 holes was installed on the top end of the photovoltaic panel. The water at 24ºC added to the feeding tube leaves the holes and flows over the photovoltaic panel as a thin film. The flow rate is two liters per minute. A Fluke thermo-vision camera was used to measure the temperature of the front and back surfaces of the photovoltaic. The temperature on the back of photovoltaic panel reduced from 48ºC to 35.5ºC. The temperature difference between back and front side of the photovoltaic remained the same, about 7 to 8ºC. It is interesting to note that before the water cooling on the photovoltaic panel surface, there was a small temperature differnce of about 2.5ºC because of a dust deposition, which was removed later by the water flow. Due to the front water cooling, the electrical income returned a surplus of about 8.4%, which cover the power needed to pump the water from the bottom of the photovoltaic to its top end [12]. The reduction of the amount of water and electrical energy needed for cooling of the solar panel in hot dry regions, was experimentally investigated. The desert areas in Egypt by using spraying cooling system. Water is sprayed using water nozzles, which are installed at the upper side of the modules. A cooling model was developed to determine how long it takes to cool down the PV panels to its normal operating temperature 35ºC. The result showed that the photovoltaic panels yield the highest output energy if the cooling of the panels starts when the temperature of the photovoltaic panels reaches a maximum allowable temperature of 45ºC. The maximum allowable temperature is a compromise temperature between the output energy from the photovoltaic panels and the energy needed for cooling [17]. An effective way for improving the efficiency and decreasing the rate of thermal degradation of a photovoltaic module to reduce the operating temperature of photovoltaic module was experimentally studied**.** This can be accomplished by cooling the photovoltaic module during the operation. A simple passive cooling system with cotton wick structures was developed for stand-alone flat photovoltaic modules. The cotton wick having a diameter of 7 mm was fixed to the back side of the photovoltaic module in a circular ring fashion with their free ends immersed in the fluid kept in the reservoir. Three different fluids were used and considered for the cooling system. The nanofluids were formulated with 0.1% volume concentration. The experimental results were also compared with the thermal and electrical performance of flat PV module without cooling system. A maximum module efficiency of 10.4% is obtained with the use of wick structures in combination with water, while the efficiency is 9% without cooling arrangement**.** The module efficiency is about 9.7% and 9.5% when cooling is provided with wick structures in combination with Al_2O_3/water and CuO/water nanofluid, respectively [15]. An experiment by using a mono-crystalline photovoltaic panel, which was cooled by a continuous film of water that shed on the working surface of the PV panel, was presented by Loredana and Octavian (2013) [13]. The advantages of this system, in addition to the cooling of photovoltaic panel, are the loss reduction caused by the radiation reflectivity (refractive index of water is 1.3, which is an intermediate value between 1.5 for glass and 1.0 for air) and the ability to clean the deposits, such as dust or dry left on the surface of the photovoltaic panels. Also, the advantage of this cooling system, in addition to decreasing the temperature of the photovoltaic panels, leads to gain better electrical efficiency due to reducing the reflection loss. Due to the front water cooling of the photovoltaic panel, the electrical efficiency was increased by 9.5%. Solar energy presents the prime source of energy for life on earth, and for humans' progress, in particular. It is not only that the sunlight conversion into electricity or heat that is essential for various applications, but also a reliable storage of the sunlight converted energy that is highly useful, since many applications require storing the harvested solar energy to meet a certain consumption pattern [7]. A method of decreasing the reflection of photovoltaic panels by a flow of water over the front surface of PV was experimentally Investigated. In addition to help keeping the surface clean, the water decreased the reflection by (2–3.6) %, the reduction of cell temperatures was up to 22ºC and the electrical production can return a surplus of 10.3%; a net advantage can be achieved which is equal to (8–9%) even when accounting for power required to run the pump. About two liters of water/min were pumped from a large tank placed under the PV panel module into a small tank above this module [11]. Cooling of the PV panel by an alternative cooling technique for photovoltaic panel was Achieved.The PV panel module was connected to the upper portion of the aluminum alloy thermal absorber [5]. Evaporative cooling was experimentally investigated when a small portion of a fluid changes phase and withdraws its latent heat of vaporization (per unit mass) away from the target environment. The results verified the technical feasibility of the proposed approach by exhibiting a maximum rise of (19.4%) and (19.1%) to the output voltage and output power, respectively. The combination of clay is very active, cheap, silent and environmentally frierndly [1]. An alternative cooling technique for PV panels that contains a water spray application over panel surfaces was Studied. The experimental result revealed that it was possible to reach a maximal total increase of 16.3% in electric power output, 7.7 % effective, and a total increase of 14.1 % in photovoltaic panel electrical efficiency, 5.9 % effective, by using the suggested cooling technique in the conditions of the highest solar irradiation. Also, it was possible to reduce the average temperature of the photovoltaic panel from 54ºC (non-cooled PV panel) to 24ºC in the case of simultaneous front and backside photovoltaic panel cooling [18].

2. Experimental Setup

The experimental setup with the measuring devices, viewed photographically in **Fig. (1)**, was fabricated in this work. The test system consists of several parts: photovoltaic module, aluminum metal, water passages box and water tank.

The experimental study includes the following four (modules):

- Module I: Comparison between cooling PV by using open cell aluminum metal in water box and conventional panel at flow rates (5,8,10 and 15) lph.
- Module II: Comparison between cooling PV by (direct contact back water cooling film) and conventional panel at flow rate (10) lph.
- Module III: Comparison between cooling PV by using copper slices in water passages box and conventional panel at flow rate (10) lph.
- Comparison between module I and module III at flow rate (10) lph.

Two photovoltaic panels with and without aluminum metal were used in the experimental work. The specifications of the used polycrystalline solar module (FRS-50W) are given in **table (1)**.

Table1: Electrical characteristics data of the used solar module. At STC (1000 W/m^2, cell temperature 25 ºC).

Model	(FRS-50W)
Peak power(Pmax)	50 W
Voltage At Maximum Power (Vmp)	18V
Current At Maximum Power (Imp)	2.8 A
Open Circuit Voltage(Voc)	22 V
Short Circuit Current (Isc)	3.17 A
Total Number Of Cells	36 (4×9)
Module dimension	(640×540×25)mm

Figure 1: Experimental setup system with the measuring devices.

2.1 *Open-cell Aluminum Metal*

A new technique was employed by using porous material (open cell aluminum metal with 80% porosity) for heat transfer enhancement in heat exchangers. It is a potential material for lightweight structures, energy absorption, and thermal management applications because it has a high surface area to volume ratio and mix fluid flow. All back surface of the photovoltaic panel has been covered by aluminum metal to increase the contact surface area, as shown in **Fig. 2**.

Figure 2: Aluminum metal

2.2 *Water Passages Box*

It is a box of dimensions (640 mm * 540 mm) and configuration with thickness (25 mm) containing five passages. The water enters these passages from the bottom and flows through the water box pathways and exits from the top, as shown in **Fig. 3**.

Figure 3: Water passages box

3. Mathematical Analysis of Photovoltaic Module

This section describes and discusses the electrical model. There exist several mathematical models in the literature to describe photovoltaic cells, from simple to more complex models ranging that account for different reverse saturation currents. The two-diode equations with the saturation currents and with the diode factors describe diffusion and recombination characteristics of the charge carriers in the material itself and in the space-charge zone. The model presented the current-voltage characteristic of photovoltaic converters and its dependence on solar radiation and cell temperature based on the information available from the manufacturer. The model presents the current-voltage characteristic of photovoltaic converters and its dependence on solar radiation and cell temperature.

The diode factors, the two-diode equations with the saturation currents describe diffusion and recombination characteristics of the charge carriers in the material itself and in the space-charge zone. To simplify parameter adjustment, the two-diode model can be reduced to a one-diode model in which, according to the Shockley theory, recombination in the space-charge zone is neglected, so the second diode term is omitted [3,8]. Figure.4 is an equivalent circuit that can be used for a different cell, a module containing of several cells, or an array involving of several modules [10].

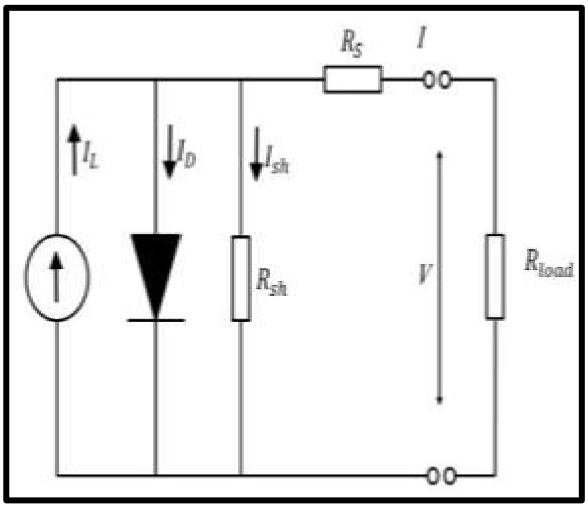


Figure 4: Equivalent electrical-circuit for a photovoltaic module [10].

The current–voltage (I–V) characteristic of a photovoltaic module can be described with a single diode as:

$$I = I_L - I_o\left[exp\left(\frac{V+IR_S}{a}\right) - 1\right] - \frac{V+IR_S}{R_{sh}} \quad (1)$$

Where, a is a parameter depending on the cell temperature and is calculated as:

$$a \equiv \frac{nKT_cN_s}{q} \quad (2)$$

Factor n equals to 1 for an ideal diode and typically between 1 and 2 for real diodes.

Boltzmann's constant K equals (1.381×10^{-23} J/K),

The cell temperature Tc , and N_s is the number of cells in series. q is the electronic charge [1.602×10^{-19} coulomb $(1\,C = 1\,A\,s)$] [10].

From a, one can calculate a_{ref} by:

$$a = a_{ref}\frac{T_c}{T_{c.ref}} \Rightarrow a_{ref} = \frac{a \times T_{c.ref}}{T_c} \quad (3)$$

But, when a_{ref} is computed in the equation below, the result is more close to the practical results [2]:

$$a_{ref} = \frac{\mu_{V,oc}T_{c,ref} - V_{oc,ref} + E_qN_s}{\frac{T_{c,ref}\mu_{I,ref}}{I_{L,ref}} - 3} \quad (4)$$

Where, Eq is the band gap energy of silicon (eV). This circuit needs four parameters be known: the diode reverse saturation current I_o, the light current I_L, the series resistance R_s and a. The shunt resistance R_{sh} is infinite, and neglecting it in the third term of equation in (1) yields:

$$I = I_L - I_o\left[exp\left(\frac{V+IR_s}{a}\right) - 1\right] \quad (5)$$

All four parameters are functions of the absorbed solar radiation and cell temperature.

At short circuit current, $I = I_{sc}.V = 0$, and Eq. (5) will be:

$$\boldsymbol{I_{sc} = I_L - I_o\left[exp\left(\frac{I_{sc}R_s}{a}\right) - 1\right]} \quad (6)$$

At the open circuit voltage, $I = 0\ and\ V = V_{oc}$, and Eq. (5) will be:

$$0 = I_L - I_o\left[ex\left(\frac{V_{oc}}{a}\right) - 1\right] \quad (7)$$

$$(8) V_{oc} = a\ln\left(\frac{I_L}{I_o} + 1\right)$$

At the maximum power point: $I = I_{mp.ref}\ and\ V = V_{mp.ref}$. Eq. (5) will be:

$$I_{mp.ref} = I_{L.ref} - I_{o.ref}\left[exp\left(\frac{V_{mp.ref} + I_{mp.ref}R_{s.ref}}{a_{ref}}\right) - 1\right] \quad (9)$$

The general *I-V* equation at the maximum power point must also be satisfied:

$$(10) I_{mp} = I_L - I_o\left[exp\left(\frac{V_{mp} + I_{mp}R_s}{a}\right) - 1\right]$$

Eteiba et al. (2013) [14] simplified the equations and obtained the following relations:

$$(11) V_{mp} \approx 0.8\,V_{oc}\ and\quad I_{mp} \approx 0.8\,I_{sh}$$

The above equations were tested, and the result was corrected to be more accurate when the constant is 0.88 for the current equation.

R_s is assumed to be independent of both temperature and solar radiation so that:

$R_s = R_{s,ref}$

$R_{s,ref}$ is calculated as:

$$(12) R_{s,ref} = \frac{a_{ref}\ln\left(1 - \frac{I_{mP,ref}}{I_{L,ref}}\right) - V_{mp,ref} - V_{OC,ref}}{I_{mP,ref}}$$

$T_{c,ref} = 298\ (K)$

The light current I_L for any operating conditions is related to the light current at reference conditions by [13]:

$$I_L = \frac{G}{G_{ref}}\left[I_{L,ref} + \mu_{I,ref}\left(T_c - T_{c,ref}\right)\right] \quad (13)$$

Messenger and Ventre (2004) [16] presented an equation from diode theory for the diode reverse saturation current, I_o. The ratio of their equation at the new operating temperature to that at the reference temperature yields:

$$I_o = I_{o,ref}\left(\frac{T_c}{T_{c,ref}}\right)^3 exp\left[\left(\frac{E_q q}{ka}\right)\left(1 - \frac{T_{c.ref}}{T_c}\right)\right] \quad (14)$$

$Eq\ is$ the band gap energy of silicon (E_q=1.14 (eV) = 1.82×10^{-19} J) for poly-crystalline silicon.

$$I_{o,ref} = \frac{I_{L.ref}}{\exp\left(\frac{V_{oc,ref}}{a_{ref}}\right) - 1} \quad (15)$$

The electrical efficiency of the module at max-power point can be calculated by [19]:

$$\eta = \frac{P_{mp}}{GA} \times 100 = \frac{I_{mp}V_{mp}}{GA} \times 100 \quad (16)$$

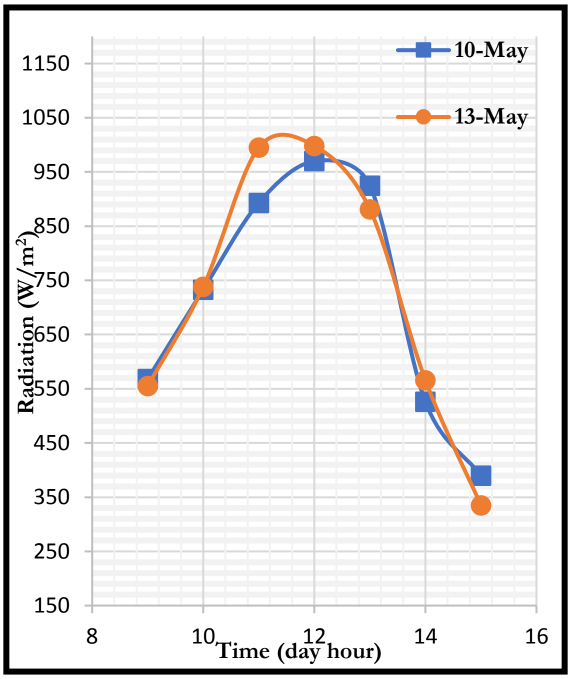
A is the PV area (m^2)

4. Result and Discussion:

In this section, the experimental results of (PV/T) were taken from the readings of the instruments used in the experiment. Many outdoor tests were carried out to modify and enhance the thermal performance of photovoltaic panel, under Iraq-Baghdad climate conditions.

4.1 *Solar Intensity (Radiation)*

Figure (5) shows the variation of solar radiation with time in all testes performed in this study. The results revealed that the solar radiation increased gradually to reach the highest value at (11:00, 12:00 and 13:00) and then decreased



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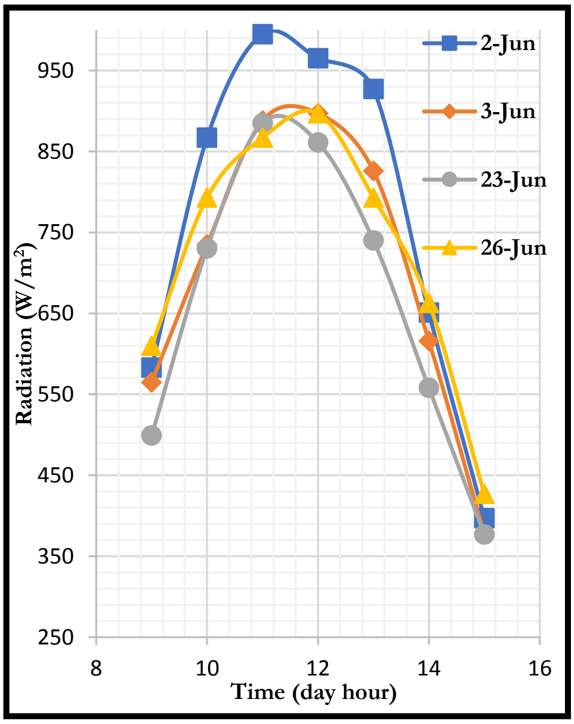

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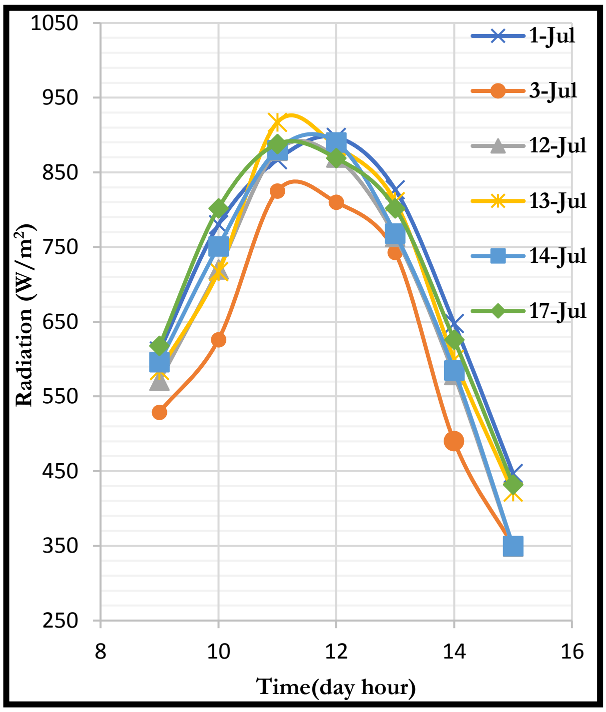


(c)

Figure 5: Variation solar radiation (W/m^2) with time;(a) May, (b) Jun and (c) July

4.2 *Average Temperature*

The photovoltaic panel is influenced by several factors that effects on the efficiency. These factors are solar radiation, angle of inclination in addition to the temperature of ambient. In this study, the angle of inclination is fixed at 45° to the south. Therefore, the main influencing factors are the solar radiation and the ambient temperature, in general, the results exibited that the average temperature of the photovoltaic in the conventional panel is higher than that for the other modules. This is due to the effect of cooling techniques that leads to decrease the average temperature with respect to the conventional one, as shown in Fig. 6.

On 10/5, the average temperature of module I at 11:00, 12:00 is 13:00 is (42.5, 38.39, 38.18)ºC respectively, while for the conventional panel, it is (54.3, 50.12, 52.29)ºC. The decrease in average temperatures are (21.73, 23.4, 26.9) %, respectively with flow rate 5 l/h, where the ambient temperatures are (37.45 , 37.2, 38.26)ºC.

On 13/5, when increasing the flow rate to 8 L/h, the percentage decrease of average temperatures as compared with the conventional one is (26.8, 32.4, 34.9) %, where the ambient temperatures are (38.07, 39.69, 38.5)ºC.

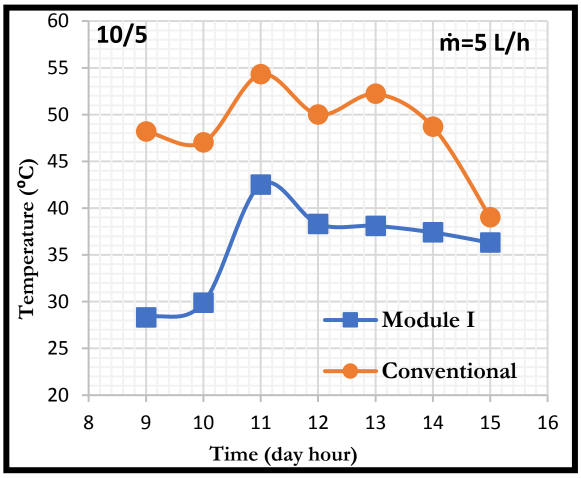
The first test for module II was done on 12/7 with flow rate ṁ=10 L/h. The average temperatures at 11:00, 12:00 and 13:00 are (48.62, 51.675, 45.63)°C, respectively for module II and for the conventional panel, they are (63.13, 65.68, 59.1)°C with the ambient temperatures (47.5, 48.32, 48.03)°C. This indicates that the module II operates good at hot weather and its average temperatures are less than those for the conventional panel in the rate of (22.9, 21.3, 22.7) % for module II, respectively.

On 13/7, the test was carried out on module I with the same mass flow rate, the decrease in average temperatures is in the rate of (37.2,33.2,33.5) % for module I with the ambient temperatures (48.45,48.05,49.96)˚C, respectively. Therefore, the module I is more effective than module II at the same mass flow rate.

On 14/7, the test was done for module III at 10 L/h, the decrease in average temperatures are in the rate of (45.6,33.8,37.3) % for module III with the ambient temperatures (47.4,46.23,49.06)°C, repectively. Therefore, module III is more influential than module I and module II at the same flow rate.

On 17/7, a comparison was made between cooling by copper slices and cooling by aluminum metal with the same mass flow rate 10 L/h. The results evinced that the average temperature when cooling by copper slices decreased in the rate of (7.6, 11.2, 8.2) % as compared with aluminum metal. This indicates that the cooling by copper fins is better than aluminum metal, but economically, the use of aluminum metal in cooling the photovoltaic is better than copper slices at the same flow rate and water condition.

Figure (6) (c) demonstrates the comparison the average temperature between all modules presented in this study. The results showed that the average temperature in module III is less than the other cases at the same mass flow rate.



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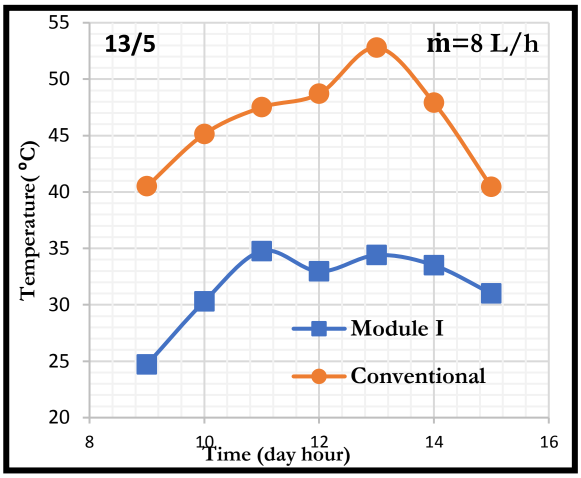

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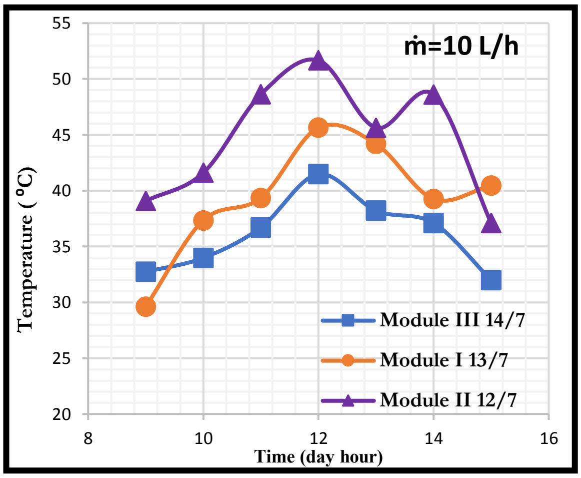


(c)

Figure 6: Variation of the average temperature with time ;(a) ṁ= 5L/h, (b) ṁ= 8L/h and (c) ṁ=10L/h

4.3 *Characteristics of PV Panel*

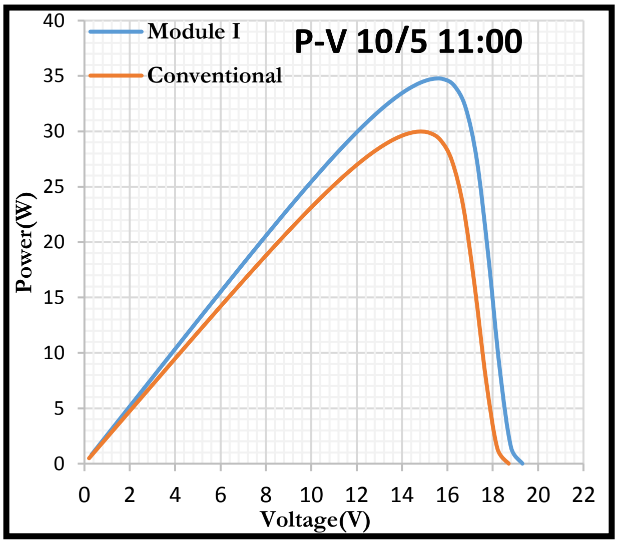
This section elucidates the effect of decreasing the cell temperature on the photovoltaic characteristics (current, voltage, power and electrical efficiency).

The highest solar radiation intensity was recorded at the hours 11:00, 12:00 and 13:00, and due to the large number of experimental readings, the readings of these times at (11:00, 12:00 and 13:00) will be only focused on.

On 10/5 in Fig. 8, at 11:00, the open voltage is 19.308 V, short current is 2.583 Ampere, max power is 34.56 Watt, max voltage is 18.18 Volt, max current is 1.9 Ampere and the efficiency is 9.57 % for themodule I. While for the conventional panel, the open voltage is 18.703 Volt, short current is 2.37Ampere, max power is 31.23 Watt, max voltage is 17.34 Volt, max current is 1.801 Ampere and the efficiency is 8.65 %, with average temperature is

42.51ºC for module I and 54.38ºC for conventional panel. This means that the overall characteristics are changed to the best with the photovoltaic temperature decrease. Also, on 13/5 at 13:00, the open voltage, max power and efficiency increased with the panel temperature decrease in the rate of (4,7.7,7.78) %, respectively with average temperature is 34.4 ºC for module I and 52.87 ºC for conventional panel, this means that the overall characteristics are changed to the best with thr photovoltaic temperature decrease. On 12/7, 13/7 and 14/7, the experimental tests were conducted for module II, module I and module III, the results were taken at 12:00, and the open voltage, max power and efficiency increased with the panel temperature decrease in the rate of (3.1,5.6,7.9) %, (4.4,8.4,8.8) % and (4.4,8.4,8.9) %, respectively. The average temperature is 51.67ºC for module II and 65.68ºC for the conventional panel, the average temperature is 43.7ºC for module I and 65.48ºC for the conventional panel and the average temperature is 41.48ºC for module III and 62.7ºC for the conventional panel. This indicates that at the constant flow rate, the characteristics of photovoltaic panel of model III are more effective than model I and module II, and module I is more effective than module II at the hot weather condition, as shown in Fig. 7.

On 17/7, the experimental tests were done for module IV, a comparison was made between aluminum and copper in the same external conditions of the temperature and intensity of radiation. The open voltage, max power and efficiency increased with the panel temperature decrease in the rate of (5.3,5.9,5.9) %, respectively for module IV copper. The result indicated that the cell cooling by copper is better than the cooling by aluminum. This result confirms that the module III is better than the module I. The average temperature is 52.8ºC for module copper and 61.6ºC for module aluminum, as depicted in figure 7.



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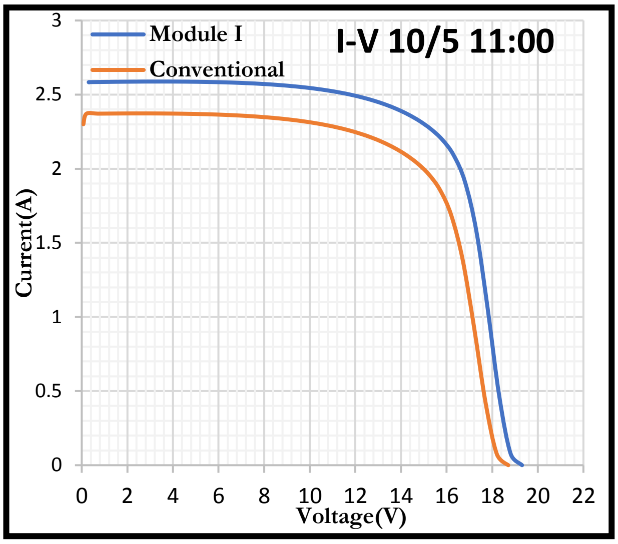

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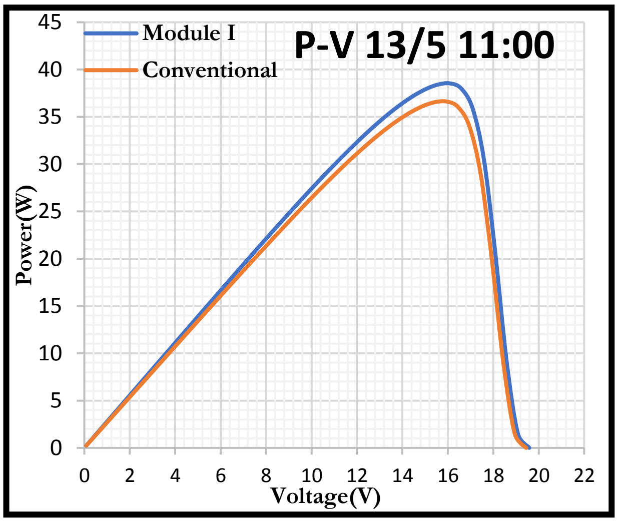

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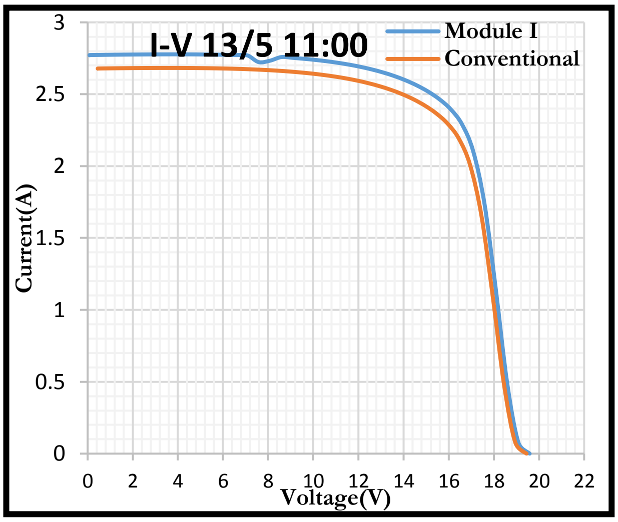

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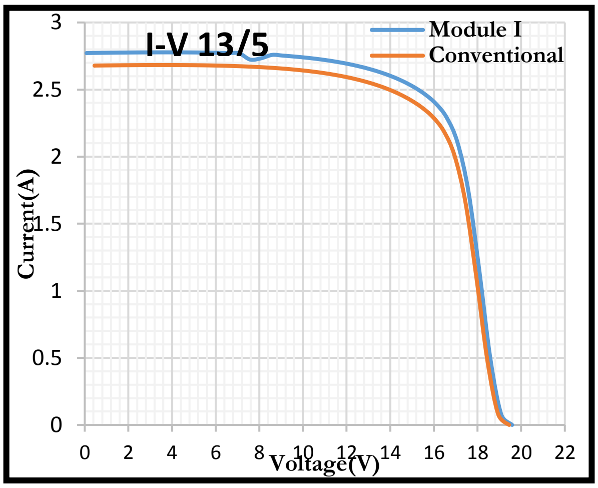

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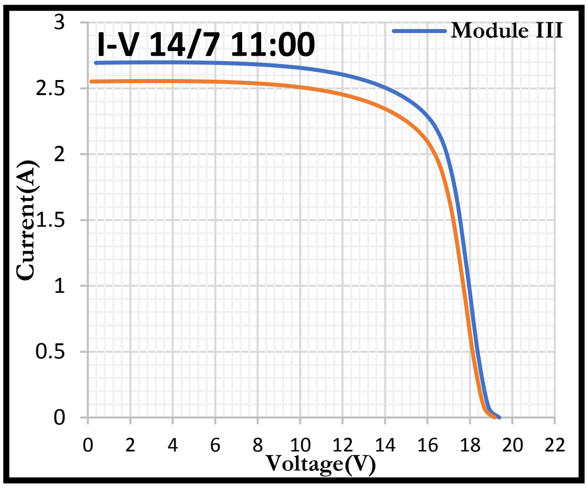

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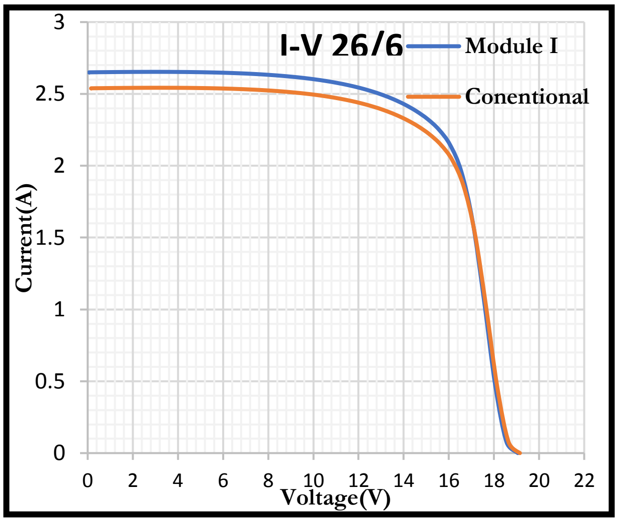
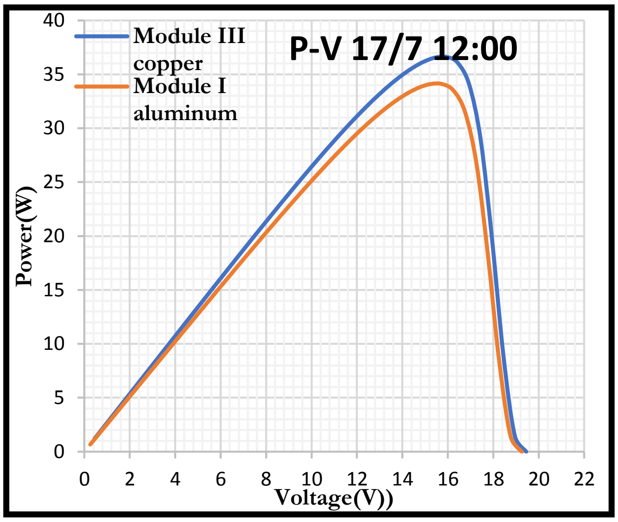
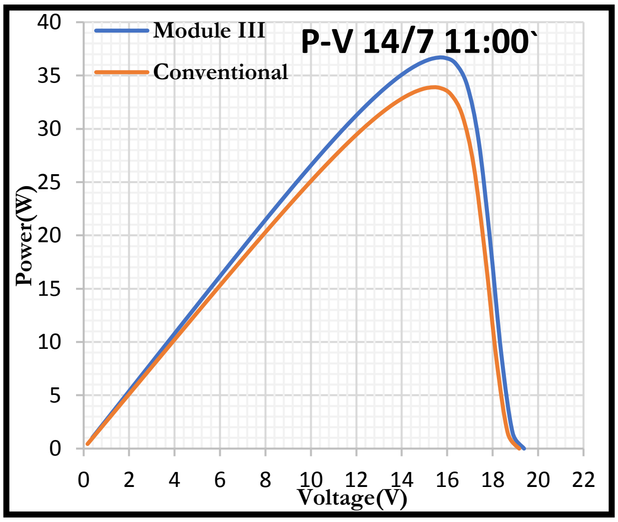


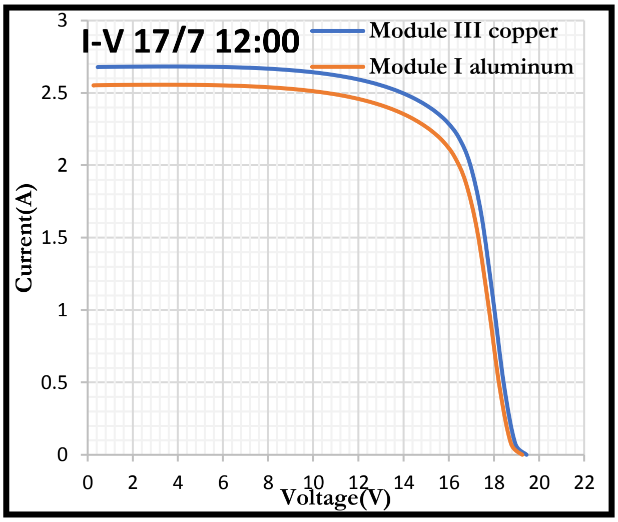
(f)



(i)



(g)



(j)

Figure 7: (a-j) Characteristics of PV panel (I-V) and (P-V) curves

5. Electrical Numerical Results

MATLAB computer program was used to solve the four-parameter model to evaluate the characteristics of photovoltaic panel. The photovoltaic cell temperature and intensity of solar radiation were adopted from the experimental data. Due to the large number of readings, few days were chosen to compare and study the difference between the theoretical and practical results, these results are sufficient to show the differences between them. The theoretical results were taken to module I only. Figure (9), for a sample of the theoretical characteristic of panels, displays the compassion between experimental and theoretical work according to the following equation:

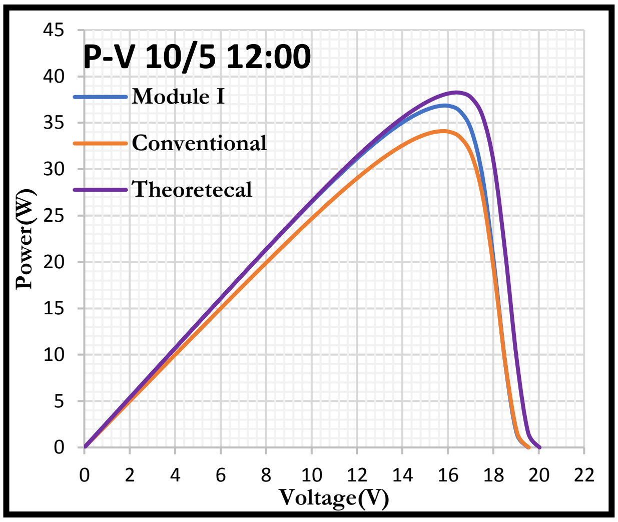
$$Percentage\ deviation = \frac{Theoretical\ results - Experimental\ results}{Theoretical\ results}$$

The theoretical characteristic is better than the experimental one in all testes.

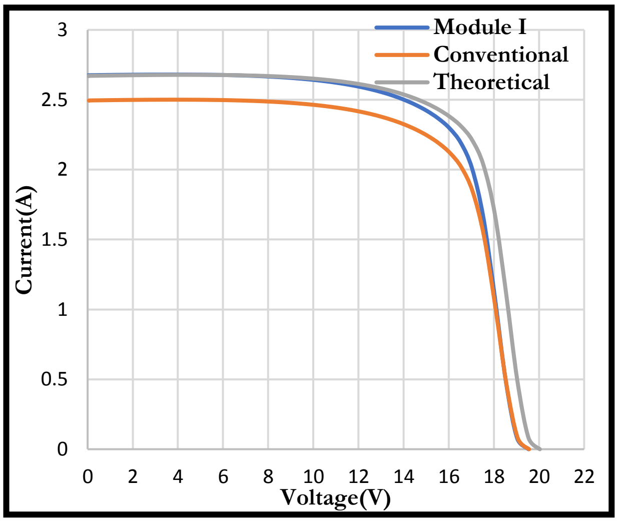
On10/5 at 12:00, it was observed that the theoretical characteristics are slightly higher than those for module I and the conventional panels with radiation (850 W/m^2) and temperature (38.39^{o}C). While, the increase in the open voltage, short circuit current and max power is (1.8,1.4,3.3) %, respectively for module I and (2.5,3.8,8.3) %, respectively for conventional panel on 13/5 at 11:00, with radiation and temperature (847 W/m^2), (34.76 ^{o}C), respectively.

On 12/7 at 13:00, it was observed that the theoretical characteristics are higher than those for the conventional panel and nearer to the module II by (1.43, 2.5,2.9) % for the open voltage, short circuit current and max power, respectively with radiation and temperature (655 W/m^2), (45.63^{o}C), respectively. As well as, on 13/7, the rate of max power and efficiency are (4.65, 5.68) and (12.7, 13.6) %, respectively.

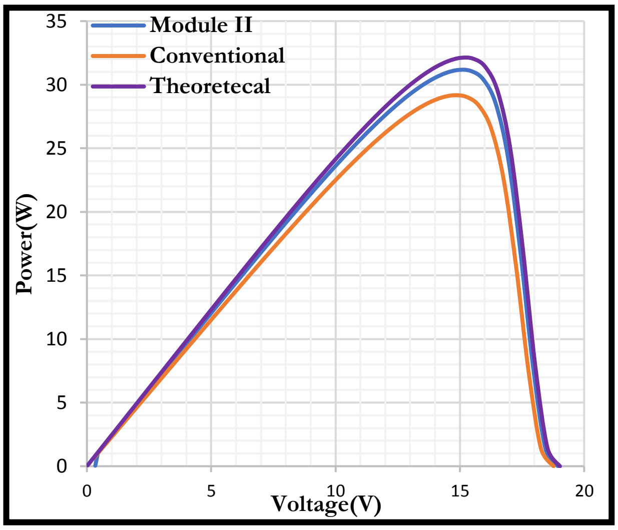
On 14/7 and 17/7 at 12:00, also the theoretical characteristic is higher than and module III module IV, respectively. Figure (8) refers to that the module I, module II, module III and module IV characteristics in all testes are better with the cooling cases than the conventional panel. This variance between theoretical work and experimental work is because of the climate that effects on the PV panel and the accuracy of measuring devices.



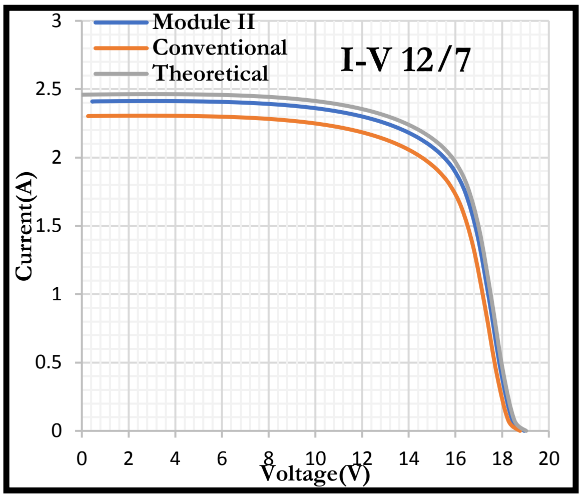
(a)



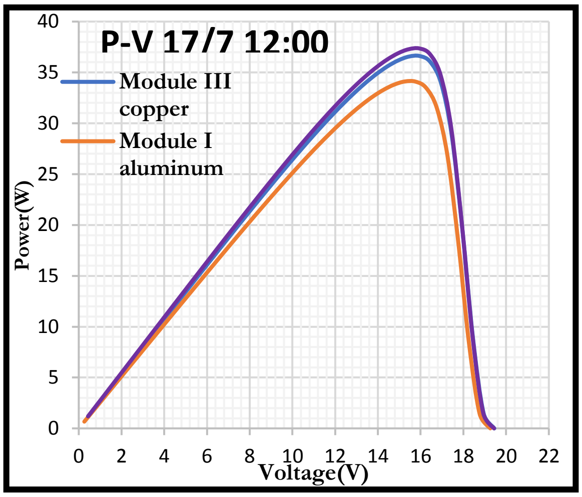
(b)



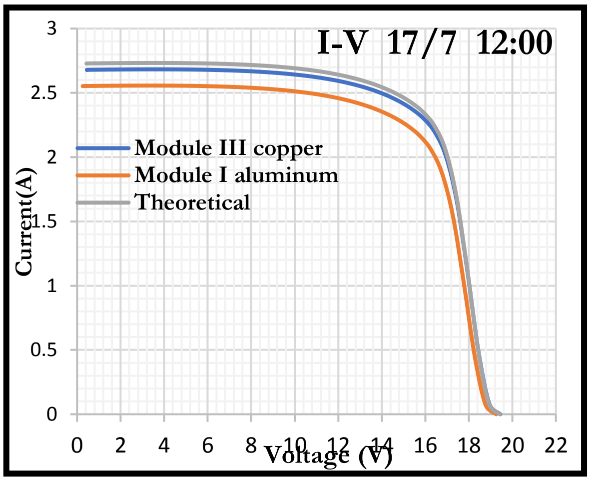
(c)



(d)



(e)



(f)

Figure 8: (a-f): I-V and P-V experimental and theoretical curves for photovoltaic with efficiency, for different days.

6. Conclusions

Numerical and experimental analysis of a PV-water cooled hybrid system is studied regarding its electrical and thermal performance. The system is tested under the climatic conditions of Baghdad, Iraq. Based on the results obtained, the following conclusions are drawn:

- The results manifested that the percentage of reduction in the average temperatures increased from (21.73, 23.4, 26.9) % to (26.8, 32.4, 34.9) % when the flow rate (m°) was increased from (5 L/h) to (8 L/h) for module I. And, the average temperatures of the three modules are less than ththoseat for the conventional panel and depend on the ambient temperature.
- The rate of the average temperature in case of cooling the photovoltaic panel by copper slices is less than that for aluminum filter, water passes and conventional one by about (11.4%,25%,57%) respectively.
- The efficiency of module III was improved by (8.92) %, module I by (8.42) % and module II by (4.45) % compared with the conventional one in July (12/7, 13/7 and 14/7 at 12:00). In module IV, the copper slices improved the efficiency by (5.9) % as compared with the aluminum filter at the same weather conditions.
- Economically, using aluminum filter is better than copper slices at the same conditions.
- A good agreement was found between the experiential and numerical results.

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Nomenclature

a	Curve-fitting limitation for the four-parameter model
a_{ref}	Curve-fitting limitation for the four-parameter model at reference condition
A	Module area (m^2)
E_q	Energy-band gap (J)
I	Current of the module (A)
I_L	Light-generated current (A)
$I_{L,ref}$	Light-generated current at reference condition (A)
I_{mp}	Current at maximum-power point (A)
$I_{mp,ref}$	Current at maximum-power point at reference condition (A)
I_o	Diode opposite saturation-current (A)
$I_{o,ref}$	Diode opposite saturation-current at reference condition(A)
I_{sc}	Short-circuit current (A)
$I_{sc,ref}$	Short-circuit current at reference condition (A)
K	Boltzmann's constant (J/K)
n_I	Diode ideality factor (---)
N_S	Number of cells in series in one (--) module
P	Power of the module (W)
P_{max}	Power at maximum-power point (W)
$P_{mp,ref}$	Power at maximum-power point at reference condition (W)
q	Electron charge (1.60218×10-19) (Coulomb)

R_S	Series resistance (Ω)
$R_{s,ref}$	Series resistance at reference condition (Ω)
Rsh	Shunt resistance (Ω)
R_{sho}	Reciprocal of slope at short-circuit point (Ω)
R_{so}	Reciprocal of slope at open-circuit point (Ω)
V	Voltage of the module (V)
V_{mp}	Voltage at maximum-power point
$V_{mp.,ref}$	Voltage at maximum-power point at reference condition (V)
V_{OC}	Open-circuit voltage (V)
Voc,ref	Open-circuit voltage at reference condition (V)

دراسة أداء ألالواح الكهروضوئية الحرارية الشمسية المبردة باستخدام تكنولوجيا تبريد جديدة

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استلم في: نشر في: 30 حزيران 2020

الخلاصة:- في هذا العمل الدراسة النظرية والعملية انجزت حيث تبين أن انخفاض درجة حرارة اللوح سيؤدي إلى زيادة في الكفاءة الكهربائية ، لذلك في السنوات الأخيرة تم اقتراح واختبار تقنيات تبريد مختلفة تجريبياً. تنخفض الفعالية مع ارتفاع درجة الحرارة. جهاز تجميع الطاقة الكهروضوئية / الحرارية هو تكامل للخلايا الكهروضوئية ومجمع حراري شمسي في وحدة واحدة ، والتي يمكنها في الوقت نفسه توليد الطاقة الكهربائية والحرارية. في الدراسة النظرية تم حساب الخصائص الكهربائية الكهروضوئية باستخدام برنامج الماتلاب . وتشمل الدراسة التجريبية أربع حالات (وحدات). في الوحدة الأولى ، أضع معدن الألمنيوم المفتوح في صندوق الماء (مبادل حراري) بسعة 9 لتر في الجزء الخلفي من اللوحة الكهروضوئية. وفي الوحدة الثانية تحتوي فقط ممرات على تمرير المياه فقط. الوحدة الثالثة تحتوي على زعانف نحاس وضعت في صندوق الماء. وتمت مقارنة الحالات الثلاث الأولى مع لوحة الكهروضوئية التقليدية في نفس الظروف. وفي الوحدة الرابعة تمت المقارنة بين خلية كهروضوئية مع معدن الألومنيوم وخلية كهروضوئية مع زعانف النحاس في نفس الظروف . أظهرت النتائج أن تبريد اللوحة الكهروضوئية في الوحدة الثالثة أفضل من غيرها ، ولكن من الناحية الاقتصادية استخدام الوحدة الاولى لوحة التبريد افضل في ظروف الطقس الحار.

كلمات المفتاحية: "لوحة ضوئية مبردة ، معدن الألومنيوم مفتوح الخلية"