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Experimental Investigation of Different Cooling Methods for Photovoltaic Module

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ABSTRACT

One of the most important difficulties in using photovoltaic systems is the low energy conversion efficiency of PV cells and, furthermore, this efficiency decreases further during the operational period by increasing the cells temperature above a certain limit.

To increase the efficiency of PV systems during operation period cooling systems are employed in the experimental work, three cooling systems: film water cooling, direct contact back water cooling and combining film - back cooling are presented and analyzed. The Infrared Camera used to obtain the module surface temperatures distribution.

Experimental measurements for the three cooling experiments indicate that the temperature of the cooling photovoltaic module is lower up to 16, 18, 25 ºc for film cooling module, back cooling module and combined film – back cooling module, respectively compared to non-cooling module. Reducing the module surface temperature causes an increase in module output power and module efficiency. The results show that the daily output power of the PV cooling module increased up to 22 %, 29.8% and 35% for film cooling, back cooling and combined film – back cooling module, respectively compared to non-cooling module.

Keywords – **photovoltaic, Cooling systems, film cooling, back cooling, combined cooling, Infrared Camera.**

1. INTRODUCTION

With the expected depletion of natural gas reserves within the next 50 years, Egypt is an investor's dream when it comes to sustainable energy resources. Egypt possesses an abundance of land, sunny weather and high wind speeds, making it a prime resource for three renewable energy sources: wind, solar and biomass.

Solar photovoltaic system which converts solar energy to electricity is a potential solution for the current energy needs, therefore Intensive efforts are being made to reduce The cost of photovoltaic cell production and improve efficiency and narrow the gap between photovoltaic and conventional power generation methods such as steam and gas turbine power generators. In order to decrease the cost of PV array production, improve the efficiency of the system and collecting more energy for unit surface area different efforts have been made.

The average ambient temperature in Egypt reaching up to 34 ºc in the summer the cell temperature could reach up to 80 ºc which decreases the output power 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 , E. Radziemska [1].

In order to overcome this problem, it is necessary to reduce the operating temperature of the module. Generally, some techniques, like air cooling and water cooling, are utilized to cool the PV module to maintain lower operating temperature.

One method for cooling photovoltaic module is to flow a film of water over the PV module to decrease its temperature. Water has the tendency to cool the cells temperature by absorbing the heat generated by the module during the day. S.Krauter [2] studied the effects of cooling photovoltaic array surface with film of water on the power generated by the array.

Abdolzadeh and Ameri [3] presented an experimental study to improve the operation of a photovoltaic water pumping system by spraying water over the front of the photovoltaic cells. K.MAJDI [4] presented an experimental study to improve the performance of

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photovoltaic panels through mitigation of surface temperature cooling and debris removal, using Fluke Ti25 infrared camera to obtain and analysis the surface temperature of cooling module and Conventional module.

Kordzadeh [5] studied the effects of nominal power array of 90 and 135 W on 16 m head of water pumping system on panel efficiency as well as the panel efficiency for 135W nominal power output on different heads of pumping system.

Another type of photovoltaic cooling is the passive cooling that refers to technologies or design features used to cool PV panels without power consumption, as the term "passive" implies that energy consuming mechanical components like pumps and fans are not used. Rahmat Subarkah et al. [6] presented a study for improved solar cells efficiency with forced cooling water that generated by the placing the water tank above the solar cell unit, so the water will flow due to gravity as the hot water replacement the cooler one.

The aim of the present experimental work is to study the effect of different cooling models on photovoltaic performance, through implementation of three PV cooling models which allows cooling of the module front surface, the module back surface and also combined cooling of both front and back surfaces.

2. EXPERIMENTAL SET-UP.

The experimental setup consists of 40 watt Mono crystalline solar module that used in the three cooling models. The output electric power generated from the module is fed to charger controller to Charger 24 -ampere hour solar battery. A general view of the complete experimental set-up is shown in Fig. 1.

2.1. Film cooling.

To produce a film of water over the photovoltaic panel, a perforated pipe with 1 cm internal diameter has been installed on the top end of the photovoltaic panel (see Fig. 2). A 1.5 lit/min of fresh water is pumped to the feeding pipe, leaves the holes and flows over the panel as a thin film. The water collected at the lower end of the module passes through a 180 litter water tank located under the panel and this cycle repeats itself.

Figure 1: General view of the experimental system used.

Figure 2: View of PV module with water film cooling system.

2.2. Back cooling.

22 Littre finned water duct with internal dimension (90 ×66 ×4 cm) was fabricated from galvanized sheet metal 2mm thickness and insulated by using 1 inch wool glass is attached underneath the PV module in order to make direct contact between the water and back surface of module as seen in Fig 3 and Fig 4 . Fins are fitted in the duct to increase the heat transfer rate from the PV panel to the moving fluid. DC water pump (see Table 1) which is

connected to the battery to pump the water from water tank into the water duct to cool the module. Then the over flow heating water back again to water tank and this cycle repeats itself.

Table1: Pump specification.

Description	Characteristic/Value
power	4.3 watt
Current & Voltage	0.36 ampere & 12 volt
flow rate max	1.5 L/min

2.3. Combined back & front cooling.

There is a combined case between the previous two cases in order to study the effects of back & front cooling together by using two DC water pumps. The first pump used to pump water through the perforated pipe installed on the top of the photovoltaic module to create a thin running film of water over the module front, the second pump used to recirculte the water through the finned duct attached underneath the PV module.

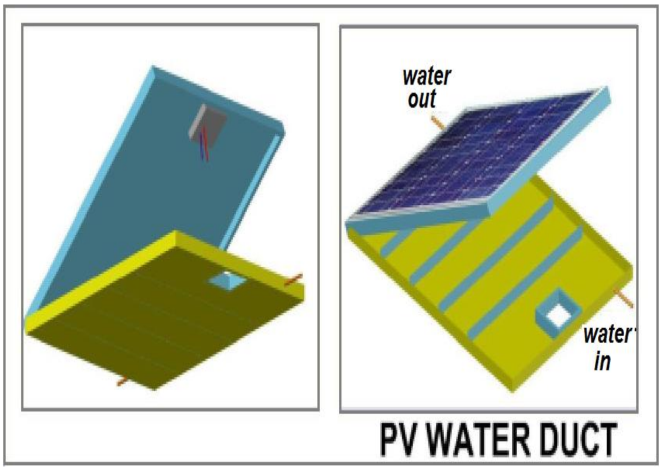

Figure 3: schematic drawing for water.

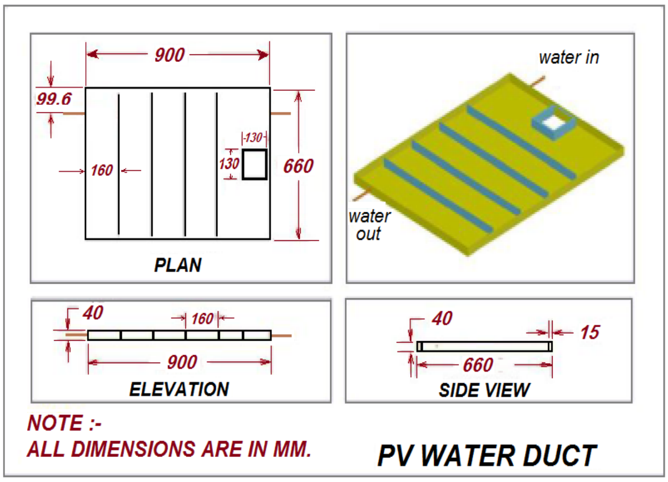

Figure 4: water duct assembly.

2.4. Experimental Procedure.

The experiments were conducted and the data was recorded every thirty minutes daily from 8 am to 5:00 pm during the period of 20 June to 20 July 2012 at the shoubra faculty of engineering, Cairo (latitude 30º 2´ N and longitudinal 31º 21´E), the photovoltaic module was titled facing south with an angle of inclination 15º.

TM-206 Solar power meter installed on the corner of the module normal to the module inclination was used to capture the daily global solar irradiation. The module maximum output power was determined from current and voltage measurement by using two multimeters with accuracy 1 miliamper and 1 milivolt that connected with variable resistance one of them in parallel to measure the output voltage and the other connected in series to measure the output current . The Temperature measurements were important in these experiments and therefore calibrated K-type thermocouples were installed on the back of the module.

The front surface temperature is 1.5 ºc above the temperature of the back surface. Therefore the temperature difference between the front and back surface is considered to be about 1.5 ºc, R.Hosseini [7]. Environmental meter is used to measure the weather parameter as the ambient air temperatures and relative humidity of air are measured in the shade, wind speed is measured at suitable distance above the module All the experimental test rig components that used have been calibrated.

3. Results and Discussions.

In this section the results of the three cooling experiments have been presented and analyzed for the three experiments nearest solar radiation test days(see Table 2) as shown in Fig. 5.

Test day	case
27th June 2012	Non cooling case in 1st experiment.
28th June 2012	Film cooling case in 1st experiment.
10th July 2012	Non cooling case in 2nd and 3rd experiment.
11th July 2012	Back cooling case in 2nd experiment.
15th July 2012	Combined cooling case in 3rd experiment.

Table 2: nearest conditions test days.

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The module surface temperature is reduced due to the three cooling systems compared to the non-cooling module with maximum temperatures difference of 16, 18 and 25 °c for film, back and combined cooling, respectively as shown in Fig 6.

The solar radiation that is falling on a solar cell is not fully converted into electrical energy. As the module plate absorbs the solar irradiance, the module surface temperature increase due to photon energy that absorbed by module surface.

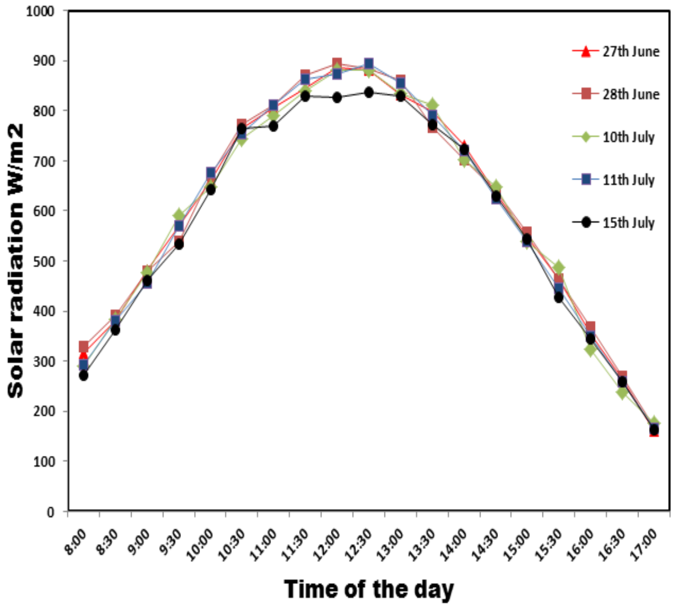

Figure. 5. Variation of irradiance during the test days.

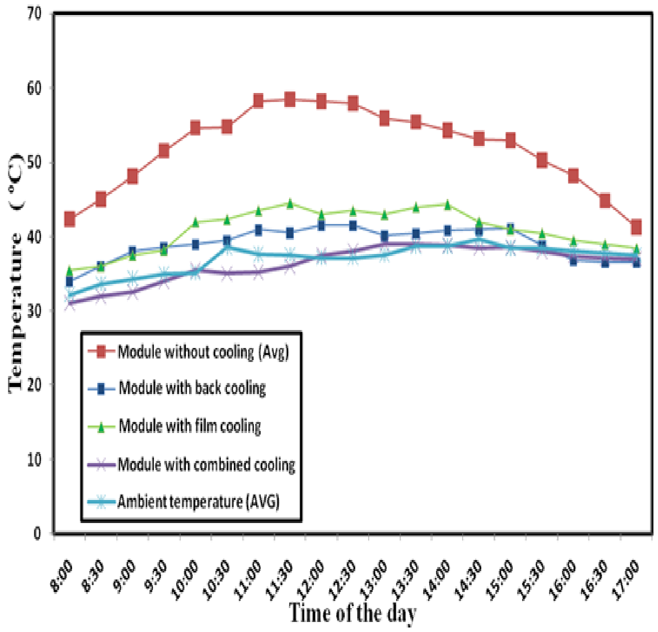

Figure. 6. Comparison of module surface temperature for the three cooling models vs. module without cooling.

The short circuit current is not strongly dependent on module surface temperature as shown in Fig 7. It is found that the increasing of module surface temperature, leads to slightly increase in the short circuit current. The current is decreased with cooling due to the decrease in module surface temperature by cooling in compared to non-cooling module. The second important parameter of solar cell is the open circuit voltage; it is found that the cooling system improved significantly the Voc of PV module as shown in Fig 7.

Another important parameter which is affected by the module surface temperature is the fill factor (FF). The fill factor is the ratio between the maximum output power to the multiplication of the short circuit current and the open circuit voltage.

$$FF = (P_m) / (V_{oc} \times I_{sc}) \qquad (1)$$

$$P_m = V_m \times I_m \qquad (2)$$

Figure 8 represents the effect of the module cooling on the fill factor. It can be note that, the fill factor is inversely proportional to the module surface temperature and it increases for the module with cooling rather than module without cooling.

The maximum power output of module is calculated by using the formula:

$$P_m = V_{oc} \times I_{sc} \times FF \qquad (3)$$

The improvement of PV parameter; open circuit voltage and fill factor is reflected into saving or increasing the power extracted from solar module.

Figure 9. Shows the I-V characteristic curve for the tested module at different temperature, the first curve is represents the module without cooling at surface temperature ts= 57 °c while the second curve is represented the module with film cooling at surface temperature ts = 41.5 °c. From the figure under consideration, the fill factor increased from 0.497 to 0.514 due to decrease the module surface temperature by cooling from 57 to 41.5°c, this leads to increase the maximum output power from 20.3 to 25.4 watt. The

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reduction in module surface temperature caused an increase in module output power as shown in Fig 10. The results show that the daily output power of the PV cooling module increased up to 22%, 29.8% and 35% for film, back and combined cooling module, respectively compared to non-cooling module.

There was a positive improvement in the performance of the three cooling system as shown in Fig .11. This proved that there was an improvement in efficiency with regards to the module with surface cooling for the three cooling systems as shown in Fig .12.

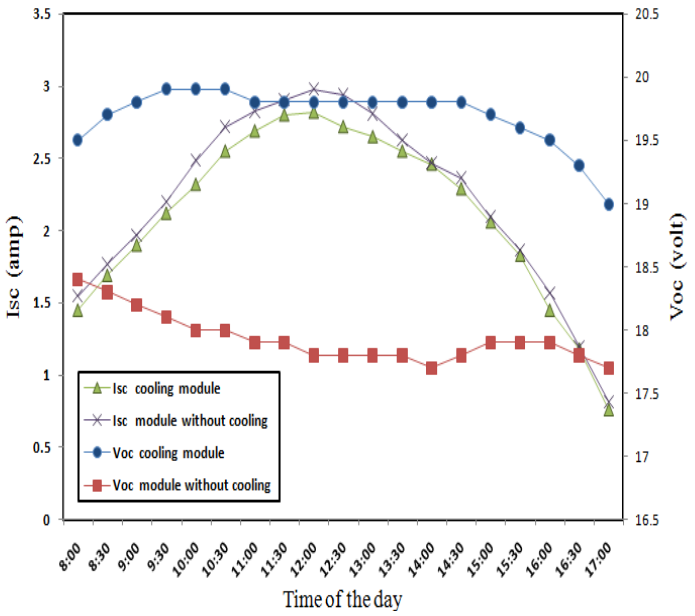

Figure. 7. Effects of cooling on the open circuit voltage and the short circuit current.

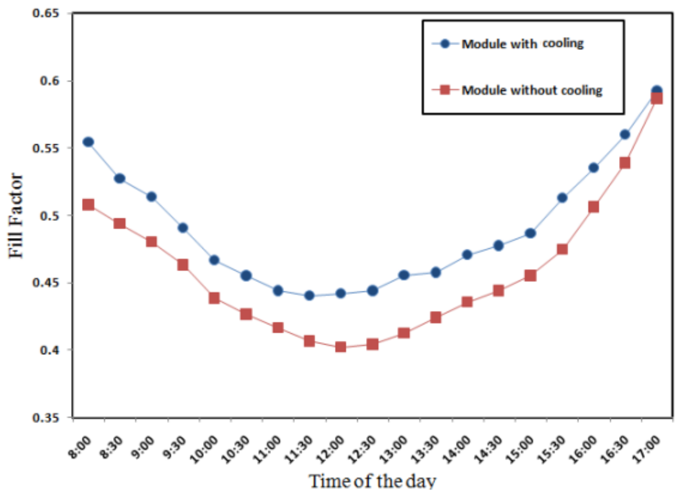

Figure.8. Comparison of fill factor of the PV-module with & without cooling.

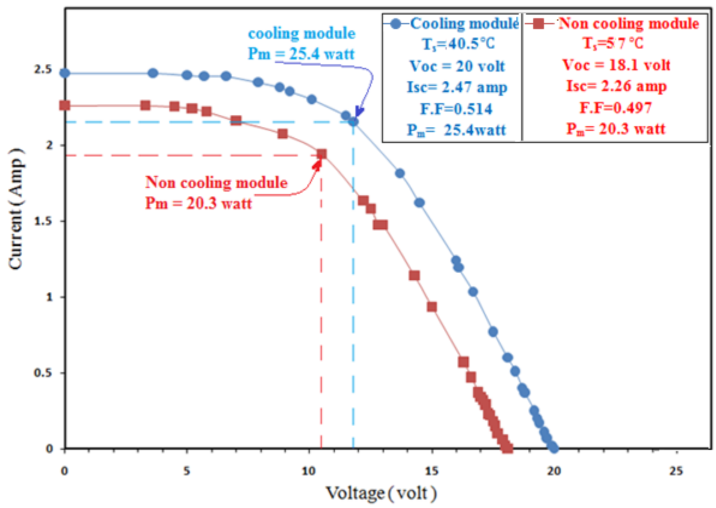

Figure.9. variation of I-V curves with the module surface temperature at 2 Pm with solar incident radiation 730 W.

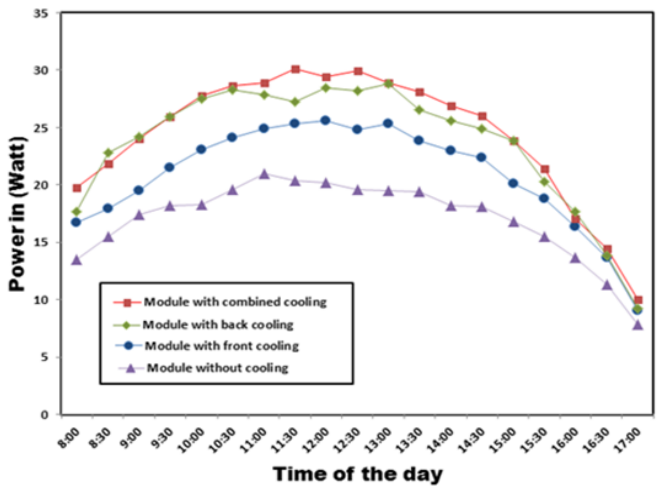

Figure. 10. Comparison of output power of the PV-module for three cooling models.

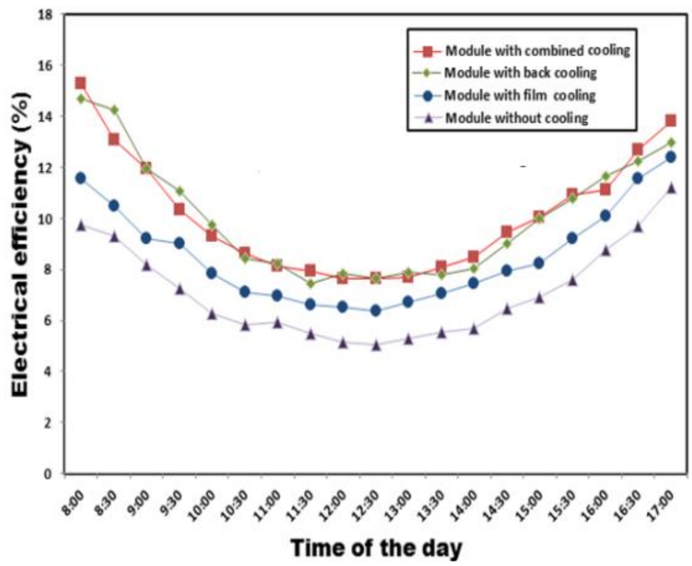

Figure. 11. Performance improvement for PV-module due to three cooling models.

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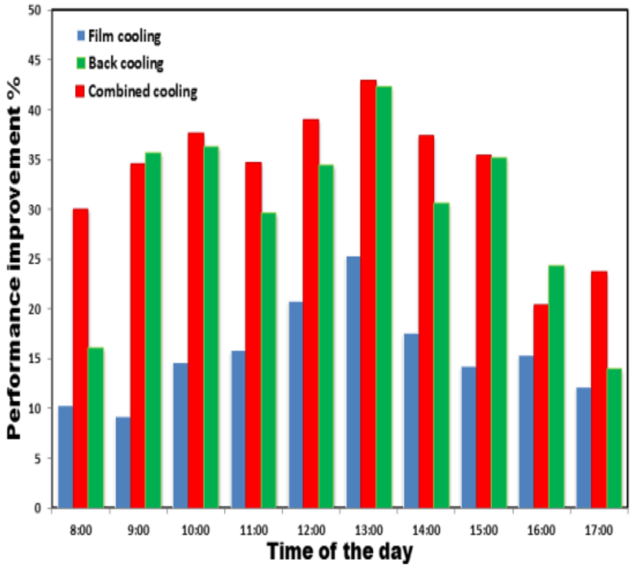

Figure. 12. Comparison of electrical efficiency of the PV-module for three cooling models

3.1. Thermal images for PV module

Figure 13: Infrared Camera Fluke Ti32.

Fluke Ti32 infrared camera is used to capture an infrared thermal image of the PV Panels during the day. The captured images act as additional supported information to the results obtained from the experiments conducted. To obtain a correct measurement of the images, the value of emissivity (e) is configured to 0.88 for mono-crystalline PV Panel (Barker and Norton, 2003) [8]. Figure 14 & 15 shows the thermal image of PV module with and without cooling respectively that taken on 15th July 2012 at 12 pm.

The cooling module image see that the temperature distribution on the PV panel’s surface is spread evenly, the image of non cooling module observed that the temperature of non-cooling module is higher than the temperature of cooling module, and the surface temperature is not evenly distributed along the module surface. This may be due to presences of dust accumulated on the PV panel surface.

From this figures, it is seen that with the temperature scale (28 – 65.9 ºC.) and the color palette (rainbow scale), it can be said that the measured temperature values of the PV module fluctuate within the region of (39 – 41.6 ºC.). Whereas the ambient temperature is measured to be 37 ºC. During the thermal image was captured. This small declination between the ambient temperature and the temperature of the module can be considered as normal, due to the heating of the surface of the panel due to the solar radiation.

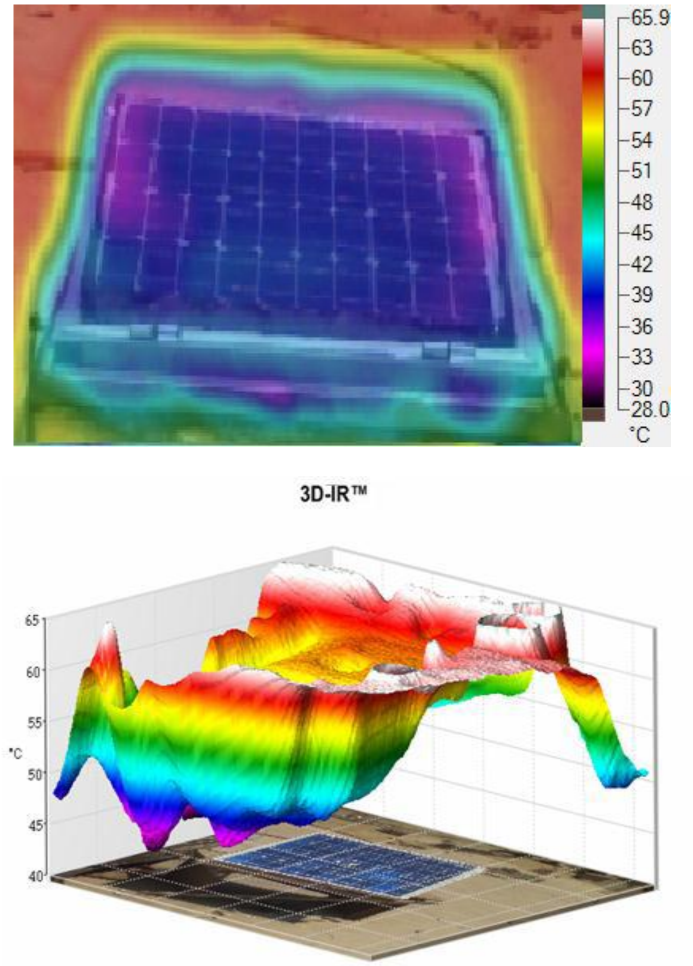

Figure14: Infrared image of Module with cooling 12 pm.

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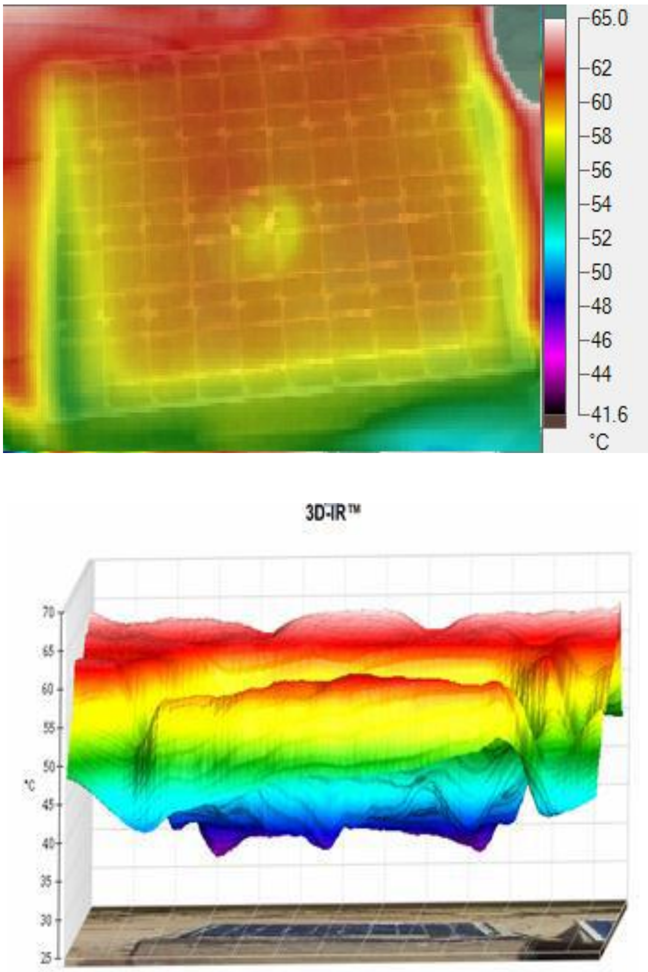

Figure 15: Infrared image of module without cooling12pm

4. Conclusion

Drop in photovoltaic efficiency due to increase in module surface temperature can be reduced by cooling of the photovoltaic module using different cooling techniques. The present study examines the performance of photovoltaic module during three cooling models; film cooling, back cooling and combined film back cooling model. Results of present work showed that by applying the cooling models the module surface temperature decreased causing an increase in output voltage and consequently the electrical efficiency and output power increased.

In the front cooling; the water refractive index is 1.3 which is intermediate between the glass (n_{glass}=1.5) and air (n_{air}=1.0) [2]. According to the reflection equation

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2 \qquad (4)$$

The water can be used as antireflection coating material that reduce the reflection by 2- 3.6 % in the visible region besides keeping the module surface clean. But the back cooling technique reduce the temperature more efficient than the front technique and therefore more power can be saved. So we try applying the two techniques together to benefit from the advantage of each one. Consequently the Combined back & front cooling system give the best results for increasing the output power from PV module.

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