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A review of photovoltaic cells cooling techniques

Swar A. Zubeer[1,*], *H.A.* Mohammed[1], and *Mustafa* Ilkan[2]

[1] Department of Energy Engineering, Technical College of Engineering, Duhok Polytechnic University (DPU), 61 Zakho Road, 1006 Mazi Qr, Duhok-Kurdistan Region, Iraq
[2] School of Computing and Technology, Eastern Mediterranean University, Famagusta North Cyprus

Abstract. This paper highlights different cooling techniques to reduce the operating temperature of the PV cells. This review paper focuses on the improvement of the performance of the small domestic use PV systems by keeping the temperature of the cells as low as possible and uniform. Different cooling techniques have been investigated experimentally and numerically the impact of the operating temperature of the cells on the electrical and thermal performance of the PV systems. The advantages and disadvantages of ribbed wall heat sink cooling, array air duct cooling installed beneath the PV panel, water spray cooling technique and back surface water cooling are examined in this paper to identify their effective impact on the PV panel performance. It was identified that the water spray cooling system has a proper impact on the PV panel performance. So the water cooling is one way to enhance the electrical efficiency of the PV panel.

1 Introduction

The renewable energy use becomes more popular during the increase of human population and the environmental issues. The solar energy is one of the important type of the renewable energy sources that has attracted many researchers around the world to work on. There are two types of energy that can be produced from the solar energy: electrical energy and thermal energy. The electrical energy can be produced by using photovoltaic (PV) cells. The PV cell directly converts the incident solar irradiance to electricity. The most efficient, sustainable, and eco-friendly systems are the PV modules which convert small part of the solar irradiance to electricity. The remaining part of the solar irradiation then converts into heat, which increases the temperature of the cells and reduces the performance of the PV module [1]. The maximum expected PV cells temperature with solar irradiance of 1000 W/m^2, 70% of absorption rate and no-winds is 60°C while for the winds speed of higher than 4 m/s the PV cells temperature is lower than 40°C [2]. The maximum output power, open circuit voltage, and short circuit current are the main parameters which are influenced by the temperature variation of the cells temperature. Thus, the open circuit voltage and the maximum output power reduce with the temperature increase whereas the short circuit current rises [3]. Chander et al. [4] investigated experimentally the impact of the temperature of the cell on the performance of mono-crystalline silicon photovoltaic. A remarkable effect on the performance of the photovoltaic was presented by the cell

* Corresponding author: szubeer@yahoo.com

temperature. They noticed that the temperature coefficient was negative for the fill factor, open circuit voltage and maximum output power whilst was positive for the short circuit current. Ike [5] reported that the output power of the photovoltaic and the ambient temperature of the site are indirectly proportional. Therefore, the output power produced by the photovoltaic is higher for the low ambient temperature interval than the high ambient temperature interval. Ahmad et al. [6] studied experimentally the impact of the temperature on a poly-crystalline solar panel at hot climate of Malaysia. It was noticed that the temperature increase led to decrease the efficiency and the maximum power. Zaoui et al. [7] investigated experimentally and numerically the impact of the cell temperature on the performance of the photovoltaic panel with constant irradiance value. Results indicated that the efficiency and output power were reduced with the raised temperature of the cell. The decrease in efficiency is caused by the temperature difference and therefore the location of the PV panel is an important factor to be considered. It is shown from the above literature review that the cell temperature has a significant impact on the performance of the small domestic use photovoltaic cells. Therefore, the present study focuses on reviewing the two types of cooling techniques (passive cooling and active cooling) to remove the heat transfer and enhance the performance of the PV cells.

2 Air cooling

2.1 Heat sink

Heat sink is one of the cooling ways which uses a high thermal conductivity metal to remove the heat from the photovoltaic cell. Popovici et al. [8] investigated numerically the temperature reduction of the PV panels during a clear day of summer by using different arrangements of ribbed wall heat sink of air and passive cooling. It was found that the maximum temperature of the panel for the angle 45° was less than that for the angle 135°. The study found that the maximum power produced by PV panel in case of using heat sink was increased by 6.97% and 7.55% compared to the reference case, for angles of the ribs from 90° and 45°, respectively. Farhana et al. [9] studied experimentally the operating temperature variation for the PV module with and without active cooling system to realize the electrical performance of the PV module.

Fig. 1. Back side of PV module.

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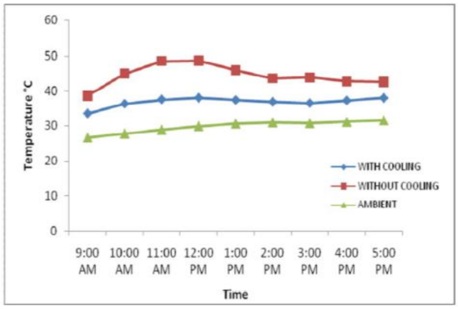

Fig. 2. Comparison between ambient temperature and average module temperature under cooling and without cooling condition.

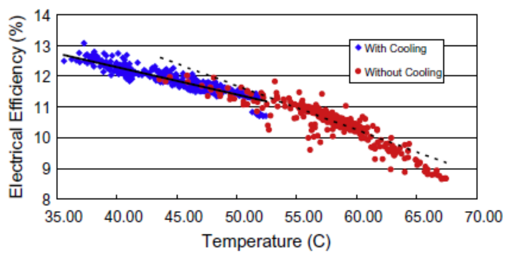

Fig. 3. Electrical efficiency as a function of PV temperature.

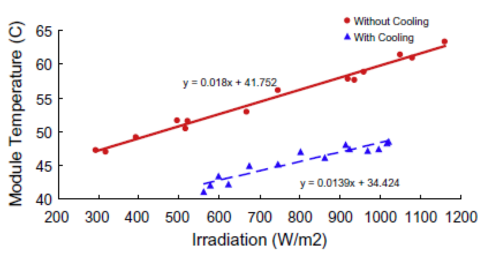

Fig. 4. Module temperature as a function of solar irradiation.

Two multi-crystal silicon solar modules with 13% of peak efficiency at standard condition (25°C, 1000 W/m^2) were used in the test. One of the modules was used as a reference and the other an aluminium was installed at the bottom of the PV panel as a heat sink and a DC brushless fan was installed on the heat sink as shown in Fig. 1. The temperature for the PV module with and without cooling system was higher than ambient temperature by 30% and 70%, respectively as shown in Fig. 2. Hence, the open circuit voltage (V_{oc}) of the PV module with cooling system was little higher than PV module without cooling system.

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2.2 Air channels

Several studies investigated the performance of the PV cells with active cooling by using air channels connected to the back of the PV panel. Teo et al. [10] concentrated on the comparison of the PV module electrical efficiency with and without active cooling. The study investigated experimentally and numerically the influence of the operating temperature on the efficiency of the hybrid photovoltaic/thermal solar system. It was noticed that the electrical efficiency was decreased when the cells operating temperature increased for both cooling and non-cooling cases, but for the cooling case the electrical efficiency was higher as shown in Fig. 3. In addition, the experiments found that there was a linear proportional relation between the PV panel temperature and the irradiation as displaced in Fig. 4. Tonui et al. [11] investigated experimentally the performance of PV/T solar collector using forced or natural air circulation to extract heat. The air channel was modified by two different ways to boost the heat transfer from the channel walls to airflow. The first one was inserting a thin flat metallic sheet at the middle of the channel (TMS system), and the second one was joining rectangular fins at the back of the channel (FIN system) as shown in Fig. 5. The study achieved that the modified PVT/Air systems would participate considerably in enhancing the performance of larger applications of PV systems. Ameri et al. [12] investigated experimentally the performance of photovoltaic/thermal air collector. The panels were installed on the channel of air and on the top of a thin metal (aluminium) sheet (TMS) as shown in Fig. 6. The study indicated that the electrical efficiency of the system had a direct relationship with the solar radiation intensity, PV cells temperature, and the power rate consumed by fans. Therefore, the electrical efficiency in case of forced convection was not always increased with number of fans, but there were an optimum number of fans for high electrical efficiency as presented in Fig. 7.

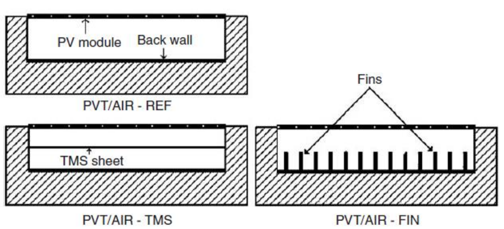

Fig. 5. Cross-sectional view of PVT/AIR collector models. Flow direction is perpendicular to the page.

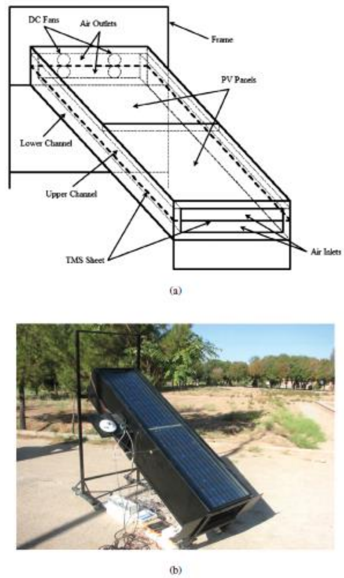

Fig. 6. (a) Schematic diagram of studied PV/T air system. (b) Photograph of experimental setup of the studied PV/T air system.

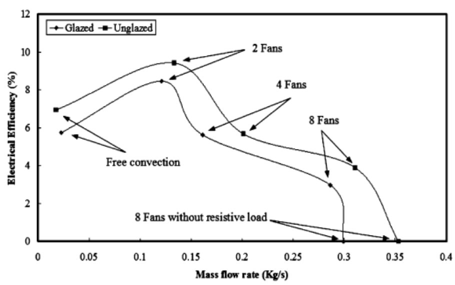

Fig. 7. Effect of air mass flow rate on electrical efficiency of the studied system in similar environmental conditions.

3 Water cooling

3.1 Water spray

Several studies have investigated experimentally the performance of the PV cells with active cooling water. Nizetic et al. [13] investigated experimentally the impact of water spray cooling on the performance of the PV panel in highest solar irradiation level environment. Both sides of the PV panel were cooled at the same time by utilizing twenty nozzles, ten on each side as shown in Fig. 8. The results were measured for three different cases of cooling: front side cooling, rear side cooling and both sides together and compared with non-cooling case. The research indicated that the water spray cooling has achieved a suitable effect on the PV panel performance and the best case was the simultaneous front and back sides cooling PV panel. Lastly, depending on the experimental results, as presented in Table 1, the water spray cooling system had a proper impact on the PV panel performance. Abdolzadeh et al. [14] studied experimentally the impact of the water spray

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cooling on the performance of photovoltaic water pumping. The configuration with two modules and 25 lit/h/module water spray was called case 'A' and the configuration with three modules and 5 lit/h/module and 25 lit/h/module water spray were called case 'B_1' and case 'B_2', respectively were used in the test. In case A and B_1 the module temperature was decreased, and the reduction in case A was higher than case B_1 as shown in Fig. 9. The experimental results indicated that the system performance was significantly improved by spraying water on the PV module. Irwan et al. [15] studied experimentally the performance of the PV panel by using water cooling method. Indoor test was carried out by a solar simulator consisted of twenty 500 W halogen lamps. Two units of 50W Monocrystalline PV panel were used in the test. A DC water pump was used to spray water was connected to the front surface of one of the panel and the other panel was used as a base panel. It was observed from the experimental results that the operating temperature of the PV panel with water cooling system was reduced by 5–23°C and the power output was increased by 9–22%. So the water cooling is one way to enhance the electrical efficiency of the PV panel as shown in Figs. 10–11.

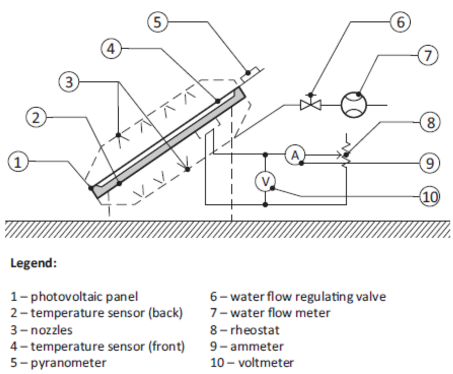

Fig. 8. Schematic layout of the specific experimental setup.

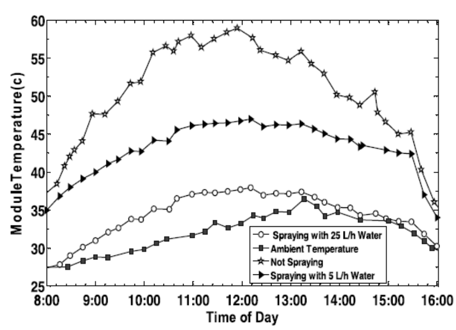

Fig. 9. Effect of water spray on the module temperature.

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Table 1. PV panel mean performance parameters for different examined cooling circumstances.

Applied cooling options	Maximal power output (W)	Relative increase in power output (%)	Effective increase in power output (%)	Average panel temperature (°C)	Electrical efficiency (%)	Effective increase in el. efficiency (%)
Without cooling	35	–	–	56	13.92	–
Back surface cooling	39.9	14.0	5.4↑	33.7	15.59	3.6↑
Front surface cooling	40.1	14.6	6.0↑	29.6	15.42	2.5↑
Simultaneous cooling	40.7	16.3	7.7↑	24.1	15.92	5.9↑

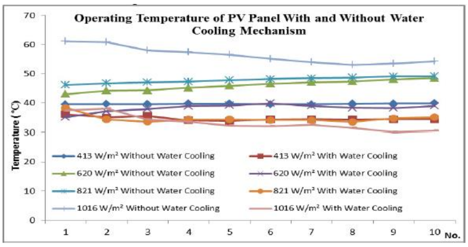

Fig. 10. Operating temperature of PV panel with and without water cooling mechanism.

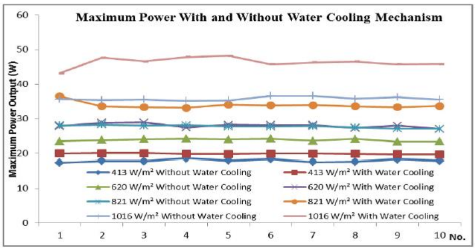

Fig. 11. Maximum power output of PV panel with and without water cooling mechanism.

3.2 Heat exchanger

Several studies have investigated numerically and experimentally the performance of the PV cells using active cooling water with the aid of heat exchanger. Hussien et al. [16] implemented an experimental investigation of improving the electrical efficiency of photovoltaic /thermal system by using water cooling technique. The cooling mechanism was contained of heat exchanger and seven pipes of water attached to the back of the PV panel. The electrical efficiency of the PV panel was improved more in the case of 0.3 L/s water flow rate compared to the other cases of water flow rate as shown in Fig. 12. Bahaidarah. [17] compared the performance of the PV panel with rectangular heat exchanger cooling (RHX) attached to the back with the PV panel without cooling. The maximum cell efficiency for the rectangular heat exchanger cooling was 13.07%, while for uncooled PV cells was 7.82% as shown in Fig. 13. Bahaidarah et al. [18] studied experimentally and numerically the performance of a hybrid PV water cooled system. A heat exchanger was connected to the back of the PV cells to enhance the performance of the PV panel for the climate of Dhahran, Saudi Arabia. The hybrid PV-water cooled system was consisted of a 230 W mono-crystalline type, cooling panel (heat exchanger) was connected to the back side of the PV module, and insulated tank to store the cooling water. It was found that the operating temperature of the water cooled PV panel was reduced remarkably to about 20% as shown in Fig. 14 and the electrical efficiency increase was 9%. In addition, the energy collection of the water cooled PV system was almost 4 times more than the PV only system.

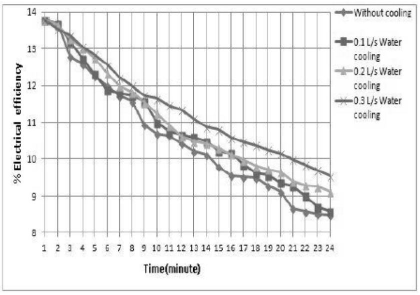

Fig. 12. Effects of water mass flow rate on electrical efficiency of the PV panel.

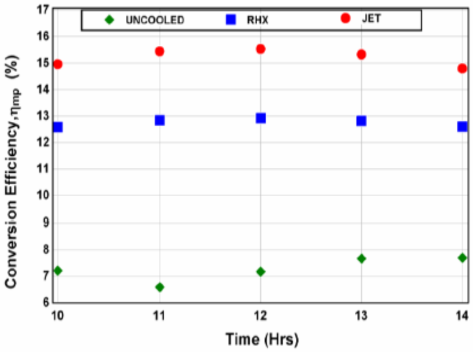

Fig. 13. Conversion Efficiency variation for PV with jet cooling, RHX cooling and an uncooled panel.

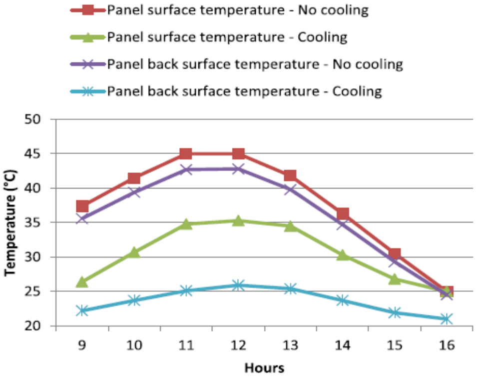

Fig. 14. Conversion Efficiency variation for PV with jet cooling, RHX cooling and an uncooled panel.

4 Fins cooling

Several studies have investigated numerically and experimentally the performance of the PV cells using different types and shapes of fins. Chandrasekar et al. [19] used aluminium fins combined with cotton wick as a passive cooling system to maintain the temperature of the PV panel. The cooling system was consisted of three aluminium fins (630 × 100 × 60 mm) with cotton wick attached to the back side of the crystalline silicon PV cells as shown in Fig. 15.

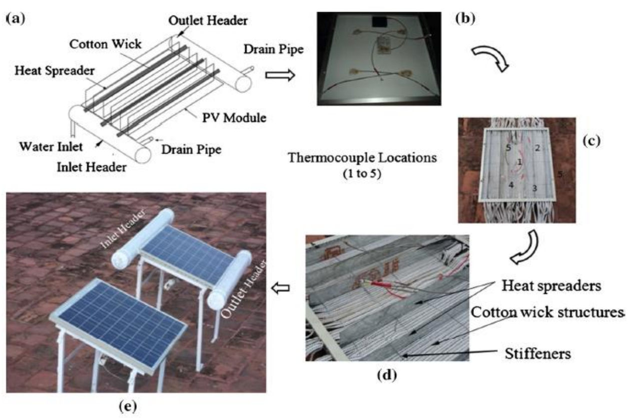

Fig. 15. Photographic view of the experimental PV module with stages of fabrication. (a) Desired rear side of PV module (b) location of thermocouples (c) fins in conjunction with wick structures (d) details of the stiffeners and (e) final fabricated experimental setup with headers.

It was observed from the experimental results that the maximum temperature of the PV panel was decreased 12% by using the cooling system and the output power was increased by 14%. Nehari et al. [20] numerically investigated the proper length of the fins to identify the enhancement of the PV panel power during the passive cooling by phase change material (PCM). It was noted that the fins was remarkably decreased the temperature of the PV cells compared to the case without fins. In addition, the fins length of 25, 30, and 35 mm provide a preferable PV cell cooling. Gotmare et al [21] studied experimentally the performance enhancement of PV cell by using fins cooling under natural convection. Two 37 W PV panel were used in the test and 9 fins of aluminium were attached to the back of the one panel. The experimental results indicated that the cell temperature for the PV panel with fins cooling was decreased by 4.2% compared with the panel without fins and the average output power was enhanced by 5.5% in case of PV panel with fins as shown in Figs. 16–17.

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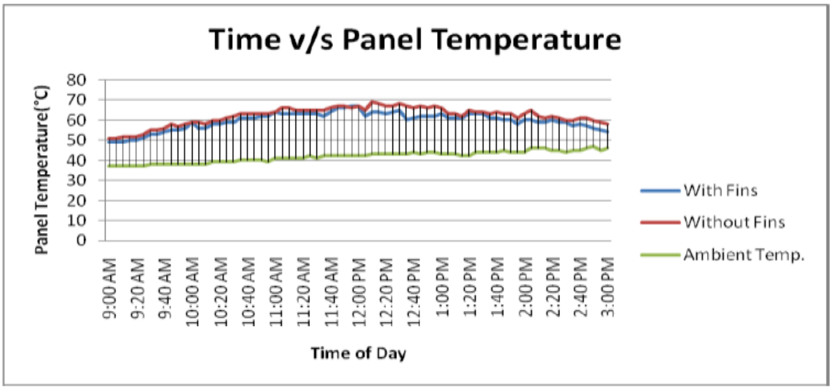

Fig. 16. Comparison of PV panel temperatures with & without fin cooling.

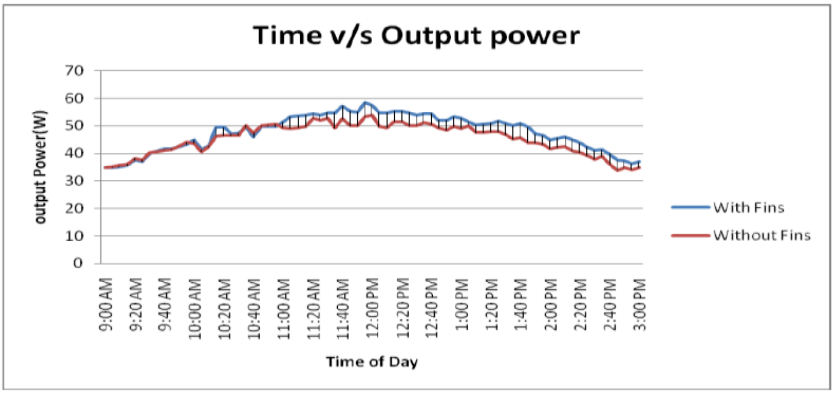

Fig. 17. Comparison of output power with & without fin cooling.

5 Conclusions

The present article has highlighted different techniques of cooling for small domestic use photovoltaic panel. It is concluded that:

- The temperature of the PV cell decreases about 12° C by using heat sink with air cooling.
- In case of air cooling the electrical efficiency of the system does not always increase with increasing the mass flow rate of the air but there is an optimum value of mass flow rate.
- Water spray cooling has a considerable effect on the performance of the PV cell, even for the low flow rate of the water spray the performance of the system enhances remarkably.

- Water cooling has the most impact on the reduction of the operating temperature of the PV cell and improve the electrical performance of the PV panel.
- Cooling system with fins is efficient to reduce the temperature of the PV panel and enhance the electrical efficiency of the PV panel.

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