Chapter 8
Water-Cooled Photovoltaic Panel Efficiency

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Abstract The purpose of this work is to improve the efficiency of a photovoltaic solar panel with water cooling system circulating along the back side of a PV panel. The numerical simulation was done on CFD code, the effect of water flow rate and the ambient air temperature on the conversion efficiency of the cooled PV panel were discussed. The results showed that at a flow rate of 100 g/s or more, the average temperature of the PV panel stabilizes, the distribution of the temperature field on the cooled solar panel with a water flow rate of 100 g/s is almost homogeneous over the entire solar panel, with the exception of the fixing zone of the electrical box which prevents the evacuation of the heat absorbed by the silicon, which raises the panel temperature locally. The results show that is enough to use 100 g/s of water flow rate to ensure a sufficient cooling. For air temperatures of 25, 35 and 45 °C, this cooling technique has improved the efficiency of the solar panel by 24.25, 28.92 and 33.92%. Concerning the junction box, which is often neglected, it has been shown that it affects the distribution of the temperature field of the PV panel and constitutes a localized area that can significantly alter the performance of the solar panel.

Keywords Junction box · Photovoltaic · Cooling

8.1 Introduction

In order to minimize the negative effect of the PV panel's temperature increase on its efficiency, we propose to cool it by water. Several cooling techniques were proposed, [1–3] have reviewed the different existing techniques. A distinction was made between active water cooling. [4] showed the influence of the heterogeneity of the temperature field distribution on a PV panel cooled by the circulation of

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water through pipes mounted on the back side of the PV panel. [5] proposed to cool a PV panel by water spray on its front side to reduce reflectivity and ensure the cleaning of the glass surface. This process improved the efficiency of the PV panel by 11.7% against 9% for the uncooled one. In the same way, [6] further improves this efficiency to 14% by simultaneously spraying water on both sides of a PV panel. [7] studied the effect of a water jet on a set of solar cells. They show that the PV panel cooled from 69.7 to 36.6 °C and 47.6 to 31.1 °C, which correspond to efficiency improvement of 17.9% and 15.5%, respectively, in June and December.

In this work we studied a PV panel (1580 × 808 × 45 mm) cooled by water which flows underside of the PV panel through a cavity of about 4 cm thickness. The influence of air temperature and water flow on the electrical efficiency of this PV panel is then studied.

8.2 Uncooled PV Panel

The temperature T_P of the uncooled PV panel is determined by solving the single equation of heat balance, expressed by:

$$\alpha R_G S - \Phi_c - \Phi_r = 0 \tag{8.1}$$

$\Phi_c = h\, S\, (T_P - T_{air})$ Convective heat flux.
$\Phi r = \sigma\, S\, (T_P^4 - T_V^4)$ Radiative flux exchanged between the panel and the sky.
$T_v = 0.0552\, Tair^{1.5}$ Temperature of the sky [8].
In situation of no wind, the convective exchange coefficient between the PV panel surface and the ambient air is evaluated by correlations [8]:

$$N_U = 0.54 \times (Ra)^{0.25} \text{ for } 10^4 < Ra < 10^6 \tag{8.2}$$

$$N_U = 0.15 \times (Ra)^{0.33} \text{ for } 10^6 < Ra < 10^{11} \tag{8.3}$$

8.3 Water-Cooled PV Panel

Temperature field of the glass and silicon media were determined by the thermal balance expressed by:

$$\Delta T + Q/\lambda = 0 \tag{8.4}$$

where the internal heat sources Q were deduced by the radiative heat balance between the PV panel and the sky, expressed by:

$$Q = \left(\varepsilon R_G S - \sigma \varepsilon \left(T_p^4 - T_v^4\right)\right)/e\left(W.m^{-3}\right) \tag{8.5}$$

Moreover, velocity and temperature field distribution of the water flowing underside the PV panel were determined by solving the coupled equations of continuity, momentum and energy. To do this, CFD-Fluent code was used.

8.4 PV Panel Efficiency

The electrical efficiency of the PV panel is calculated by the following relationship [9]:

$$\eta = \eta_{ref}\left[1 - \beta_{ref}\left(T_p - T_{ref}\right)\right] \tag{8.6}$$

β_{ref} = 0.37%/°C/Power temperature coefficient.
η_{ref} = 14.9% Electrical efficiency of the PV panel under reference conditions T_{PV} = 25 °C and R_G = 1000 W/m^2.
The comparison between the cooled PV panel and the uncooled one is given by the relative efficiency (Table 8.1):

$$\eta_r = 100 \times |\eta - \eta_0|/\eta_0 \tag{8.7}$$

where η_0 denotes the efficiency of the uncooled PV panel (Table 8.2).

Table 8.1 Properties of the PV panel [10]

Layers	e(mm)	λ (W/mK)	ρ (kg/m^2)	C_P(J/kg K)	ε
PV cell	0.3	148	2330	677	0.7
Glass	3.2	1.8	3000	500	

Table 8.2 Temperatures and efficiencies of the uncooled PV panel at R_G = 1000 W/m^2

T_{air} (°C)	45 °C	35 °C	25 °C
T_{pv} (°C)	101.84	93.76	85.65
η_0 (%)	10.66	11.1	11.55

8.5 Results and Discussion

Figure 8.1 shows the evolution of the average panel temperature for different air temperatures and water flow rates. It's shown that from a flow rate of 100 g/s the temperature of the PV panel is stabilized and reaches values of 34.80, 35.45 and 36.21 °C for air temperatures, respectively 25, 35 and 45 °C. Thus, the efficiencies of the PV panel increase (Fig. 8.2) from 11.6 to 14.35%, from 11.10 to 14.31% and from 10.70 to 14.27%, which corresponds, respectively, to the efficiency improvement of 24.25, 28.92 and 33.92% (Fig. 8.3).

Figure 8.4 illustrates the evolution of the average temperature of the cooled PV panel with 100 g/s of water flow rate under various radiations and air temperatures. We observe that the temperature of the PV panel increases with radiation. Indeed, at air temperature of 45 °C, the PV panel temperature reaches 31.80 and 36.21 °C, respectively, at radiations of 200 and 1000 W/m^2. However, the PV panel efficiency were not affected significantly. It vary from 14.52% to 14.27% Figs. 8.4 and 8.5.

Figures 8.6 and 8.7 show the distribution of the temperature field on the cooled PV panel with 100 g/s of water flow rate and air temperatures of 25, 35 and 45 °C. There is an almost homogeneous temperature distribution over the whole PV panel. Temperature field vary overall between 33 and 45 °C for T_{air} = 25 °C, T_{air} = 35 °C and T_{air} = 45 °C. However, it can be seen that the highest value of the temperature were observed at the region of the box electrical wires (Fig. 8.7).

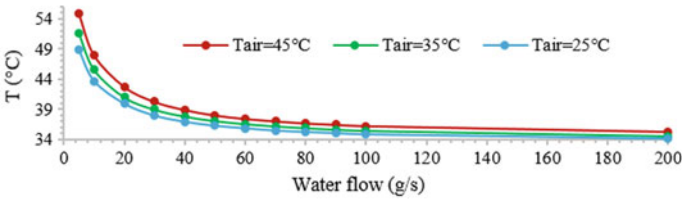

Fig. 8.1 Evolution of the average panel temperature for different air temperatures as a function of water flow

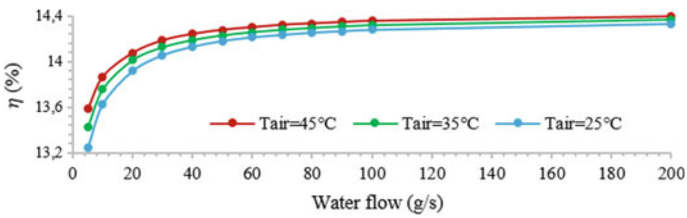

Fig. 8.2 Evolution of the efficiency of the solar panel with the water flow, for different air temperatures

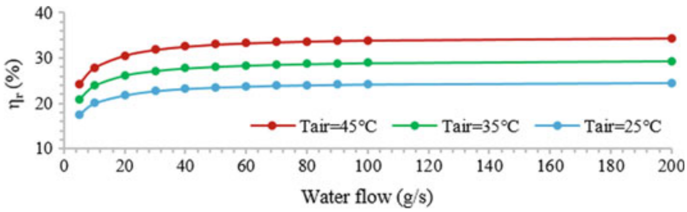

Fig. 8.3 Evolution of the relative difference between the yields of the cooled and uncooled solar panel with the water flow, for different air temperatures

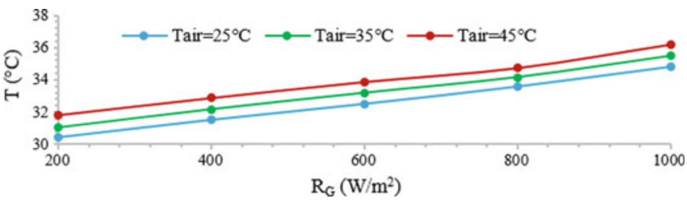

Fig. 8.4 Evolution of the average temperature of the cooled PV panel with a flow rate of 100 g/s for different air temperatures according to solar radiation

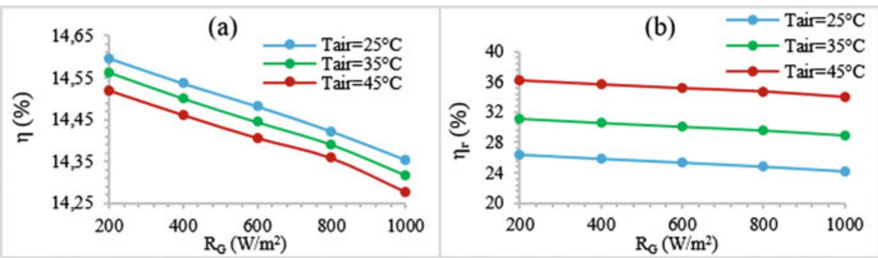

Fig. 8.5 Evolution of the efficiency (a) and relative deviation (b) of the cooled PV panel with a flow rate of 100 g/s for different air temperatures as a function of solar radiation

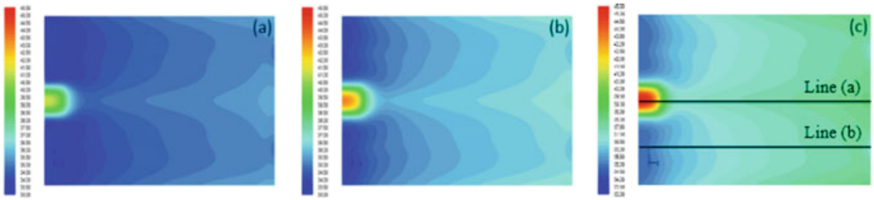

Fig. 8.6 Temperature field distribution on the cooled solar panel for a water flow rate of 100 g/s and an air temperature of 25 °C, 35 °C and 45 °C with RG = 1000 W/m^2

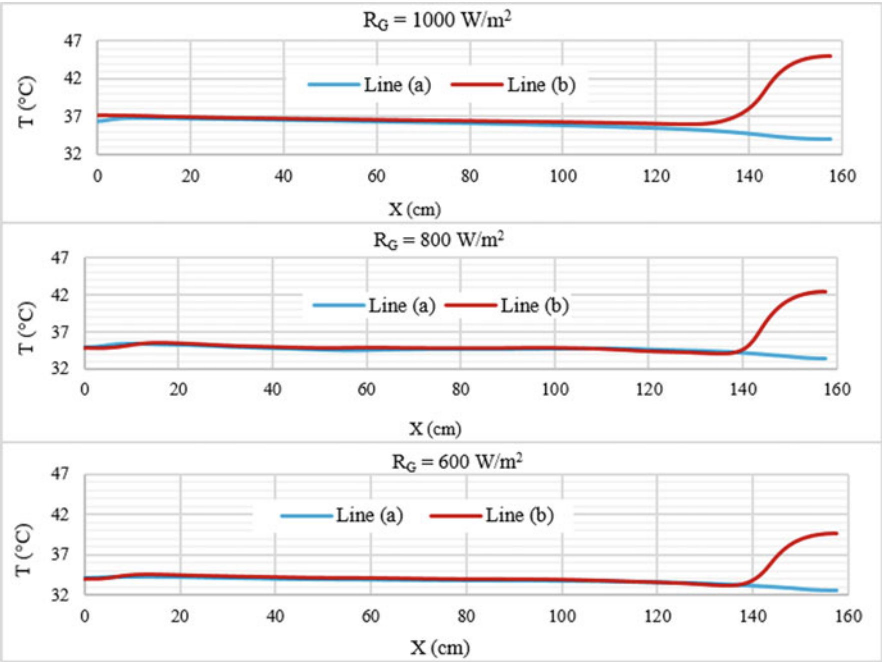

Fig. 8.7 Temperature of the cooled PV panel with a water flow rate of 100 g/s along lines (a) and (b) (Fig. 8.6c) under radiation of 1000, 800, 600 W/m^2 and an air temperature of 45 °C

8.6 Conclusion

The purpose of this work was to improve the electrical conversion performance of a PV panel cooled by water. Moreover, we highlight the influence of the box electrical wires on temperature homogenization.

The results show that is enough to use 100 g/s of water flow rate to ensure a sufficient cooling. For air temperatures of 25, 35 and 45 °C, this cooling technique has improved the efficiency of the solar panel by 24.25, 28.92 and 33.92%. Concerning the junction box, which is often neglected, it has been shown that it affects the distribution of the temperature field of the PV panel and constitutes a localized area that can significantly alter the performance of the solar panel.

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