An Autonomous Water Cooling System of PV

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Abstract: This study deals with the cooling of a photovoltaic solar panel (PV) by a water cooling system. We propose to use circulating water between an insulated tank and the back side of the PV panel, with a flow rate of 50 g/s over three periods of 24 hours. 3D numerical simulations are performed using a CFD code. The results show that the circulation of water in closed circuit, allows an effective and sustained cooling during the three periods. Moreover, uniform temperature distribution over the entire solar panel was observed. However, at the area of the box of electric wires the temperature rise locally.

1 INTRODUCTION

Energy consumption is steadily increasing worldwide. The use of fossil fuels led to a rapid increase in greenhouse gas emissions which contribute to global warming. Thus, renewable energies become an alternative, especially solar photovoltaic (PV). However, its exploitation remains dependent on climatic conditions that can significantly affect its energy conversion performance. Indeed, the increase in the temperature of the PV panel affects significantly its effectiveness. To overcome this, different cooling techniques were adopted (Sargunanathan, Elango, and TharvesMohideen, 2016) (Hassnuzaman et al, 2016).

(Browne et al, 2016) used the phase change materials to cool, the PV panel. Other studies focused on the air-cooling (Amelia et al., 2016; D. Nebbali, R. Nebbali and Ouibrahim., 2018). (Nizetic et al, 2016) proposed to cool the PV panel by spraying water simultaneously on both sides of the PV panel. This technique, in addition to being self-cleaning, provides an increase in electric power of 16.3%. (Elnozahy et al, 2015) provided cooling by flowing water on the glass of the PV panel. This reduces the reflectivity on the glass surface by 2-3.6% and ensures its cleaning. This technique provided 22°C PV panel cooling and 8-9% power improvement. Another study (krauter, 2004) using this same cooling technique but enhanced by a solenoid valve that controls the flow of water according to the temperature of the panel. This allows 40% reduction in panel temperature and improves its efficiency by 11.7%. (Muzaffar et al, 2015) use water flowing through the microchannels installed on the underside of the panel. The temperature of the PV panel drops by 15°C while its efficiency improves by 14%.

These techniques, although they are efficient, do not give any information on the origin of the water which ensures the cooling of the PV panel. To overcome this, (Jakhar et al, 2016) proposed to cool the solar panel with water from a water-ground heat exchanger. The results showed that with increasing length and diameter of the heat exchanger pipe, the temperature of the PV panel lowered from 79.31 to 47.13 ° C for a water flow of 18 g s^{-1}.

The objective of this work is to propose an autonomous cooling system using circulating water, in a closed circuit, between a storage tank and the PV panel. Numerical simulations are performed to determine the hourly evolution of the temperature of the panel and the water of the tank.

2 POSITION OF THE POBLEM

A water tank with a capacity of 50L is considered to provide a closed circuit cooling of a monocrystalline PV panel (Figure 1, Table 1). Water flows through the underside of the PV panelbefore being reintroduced back into the tank.The panel was cooled during three periods of 24 hours.

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Table 1: parameters of the solar panel.

Nominal power	200 W
Voltage Vmpp	36.5 V
Current Impp	5.48 A
Number of cells	72 Cells
Dimensions of cell	125×125 mm
Dimensions of the module	1580×808×45 mm

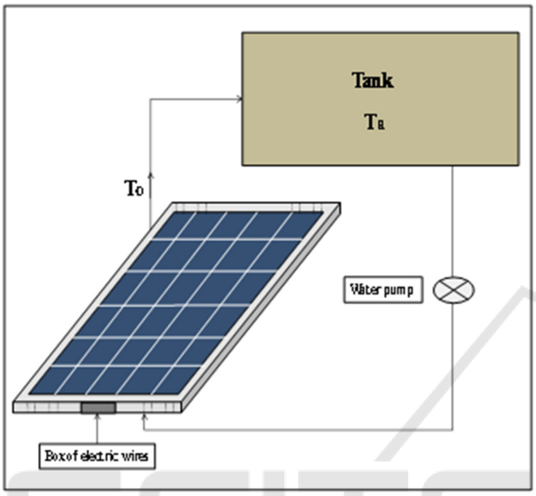

Figure 1: Sketch of water-cooling system of the PV.

3 METHOD

3.1 Associated Equations

The thermal balances performed on the PV panel are expressed for the solid media of glass and silicon (Table II), by:

3.1.1 Thermal Balance on the PV Panel

The thermal balances performed on the PV panel are expressed for the solid media of glass and silicon (Table II), by:

$$\Delta T + \frac{Q}{\lambda} = \frac{1}{a}\frac{dT}{dt} \tag{1}$$

With:

$$a = \frac{\lambda}{\rho C_P} \tag{2}$$

$$Q_g = \frac{\alpha_g R_G - \varepsilon\,\sigma(T_P{}^4 - T_V{}^4)}{e_g} \tag{3}$$

$$Q_{si} = \frac{\alpha_{si}\,\tau_g\,R_G}{e_{si}} \tag{4}$$

Where:

- a: is the thermal diffusivity (m2/s)
- Qg : internal heat source of glass (W/m^3)
- Qsi: internal heat source of silicon (W/m^3)
- α: absorption coefficient.
- ε: emissivity.
- σ: Stefan-Boltzmann constant.

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 a CFD-Fluent calculation code was used.

Furthermore, the upper face of the PV panel exchange by natural convection of heat with the ambient air. The convective exchange coefficient was evaluated by the following correlations (Holman, 1997)

$$N_u = 0.54 \times (R_a)^{0.25} \text{ for } 10^4 < Ra < 10^6 \tag{5}$$

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

3.1.2 Thermal Balance of the Tank

The thermal equilibrium of the water storage tank, assumed insulated, is expressed by:

$$\dot{m}C_P T_o = \dot{m}C_P T_R + MC_P\frac{dT_R}{dt} \tag{7}$$

Considering that:

$$\frac{dT_R}{dt} = \frac{T_R^{t+dt} - T_R^{t}}{dt} \tag{8}$$

It leads to:

$$T_R^{t+dt} = \frac{\dot{m}T_o + \frac{M}{dt}T_R^{t}}{\dot{m} + \frac{M}{dt}} \tag{9}$$

Where:

- T_o :the water output temperature from the PV panel.
- T_R :the water temperature of the tank.

TABLE. II. Properties of the solar photovoltaic panel(Armstrong and Hurley, 2010).

Layers	e (mm)	λ (W.m²k)	ρ (kg.m²)	C_P (Jkg°C)	ε
Glass	3.2	1.8	3000	500	0.7
PV cell	0.3	148	2330	677	

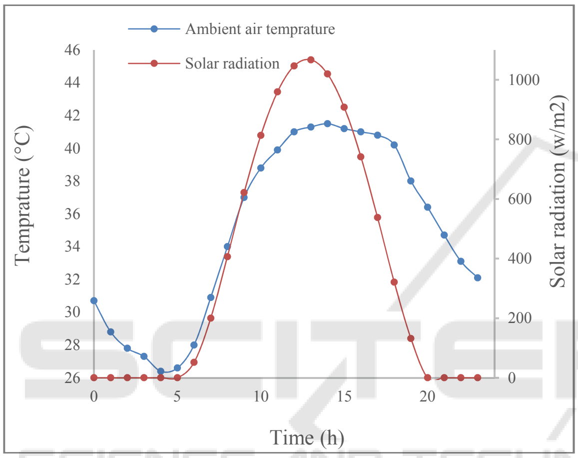

Figure 2: Hourly air temperature and solar radiation on 30rd June.

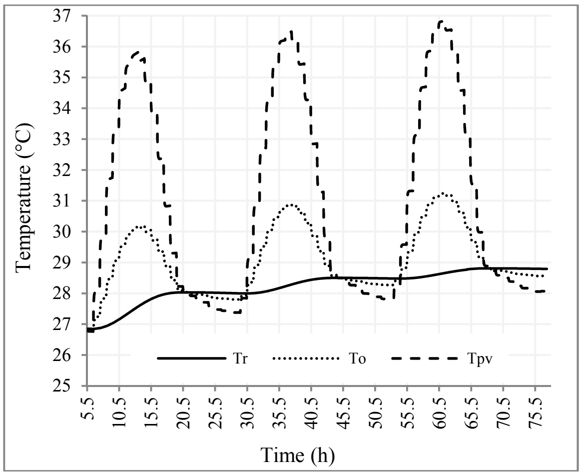

Figure 3: Hourly evolution of the water temperatures of the tank (T_r), the PV panel output (T_o) and the silicon layer (T_{pv}) during three periods of 24 hours.

3.2 Boundary and Initial Conditions

Initial condition corresponds to the time of sunrise (6.00 am), we consider that the reservoir water is 300K. The water circulates with a mass flow rate of 50g/s under a climate whose air temperature and solar radiation correspond to those prevailing in Ghardaïa (southern of Algeria) for the day of 30rdJune 30 (National Office of Meteorology of Algeria - ONM) (Figure 2).

4 RESULTS

4.1 Temperature of the PV Panel and the Tank Water

Figure 3, illustrates the evolution of the water temperatures of the tank, the output of the PV panel and the silicon layer during three periods of 24 hours. It should be noted that at midday, during the three periods, the mean temperature of the silicon layer reaches the maximum value of 35.82°C, 36.49°C and 36.83°C. In fact, the water of the tank, which feeds the PV panel, was initially at 26.85°C before reaching 28.03°C at the end of the first period, then 28.50°C at the second and 81°C at the third. In addition, the temperature of the water outlet is similar but lower than that of the silicon layer.

4.2 Temperature Field

Figure 4-6 shows the distribution of the temperature field on the cooled solar PV panel at midday of the three periods of 24 hours. An almost uniform temperature distribution is observed on the whole solar panel. Indeed, the temperature varies between 33 and 39.34°C for the first period, between 33.89 and 40.17°C for the second and between 34.27 and 40.54°C for the third one. However, at the area of the box of electric wires, PV reaches locally the temperatures of 44.73, 45.52 and 45.87°C. These localized areas can significantly alter the performances of the PV panel.

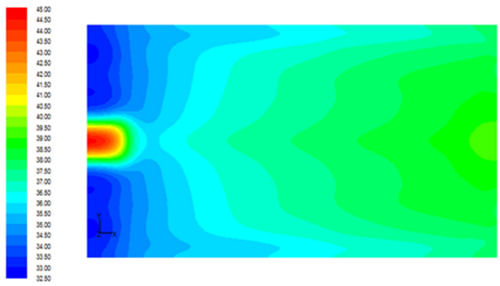

Figure 4:Temperature field on the PV panel at midday of the first period.

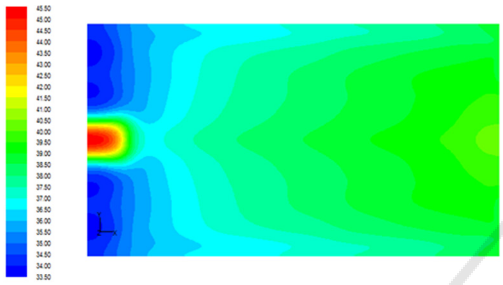

Figure 5:Temperature field on the PV panel at midday of the second period.

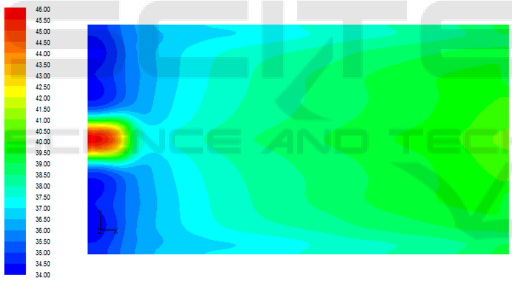

Figure 6:Temperature field on the PV panel at midday of the third period.

5 CONCLUSION

In this study it was proposed an autonomous cooling system using circulating water in a closed circuit, between a storage tank and a PV panel. The results showed that the PV panel temperature change throughout the day. In fact, during the cooling process of the PV panel, the water of the storage tank, which was initially at 26.85°C, warms up over the days to 28.03°C, then 28.50°C and 28.81°C, from the first to the third periods of 24 hours. Moreover, the temperature of the PV panel, during these three periods,increased from 35.82°C to 36.49°C and then to 36.83°C.In order to determine how much operating autonomy this cooling system could provide, we need more investigations over a longer period.

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