The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 23, Pages 564-572

ICRETS 2023: International Conference on Research in Engineering, Technology and Science

Activation Condition of a Fan that Cools a PV Panel by Blowing Ambient Air on Its Rear Face

Djamila Zembri-Nebbali
Mouloud Mammeri University of Tizi-Ouzou

Idir Kecili
Mouloud Mammeri University of Tizi-Ouzou.

Sonia Ait-Saada
Mouloud Mammeri University of Tizi-Ouzou

Rezki Nebbali
Mouloud Mammeri University of Tizi-Ouzou

Abstract: Under particular climatic conditions, the equilibrium temperature of a PV panel can increase excessively.This can significantly affect its electrical efficiency.The use of a cooling system, minimizing the negative effect of this temperature increase, can improves the efficiency of the cooled PV panel. In this work, we are interested in the cooling by a fan which blows ambient air on the rear face of a PV panel. This fan was activated by the PV panel itself. Thus, for an efficient use of this cooling system, it was necessary to define the activation conditions of this fan. To do this, a thermal model was used to determine the equilibrium temperature of the uncooled PV panel. Then, numerical simulations were performed by CFD code to evaluate the new equilibrium temperature of the cooled PV panel. This allowed to determine, by a one-diode electrical model, the improvement of electrical efficiency. The fan will then be activated from 5% improvement. This difference is then associated to the minimum temperature difference between the uncooled PV panel and the ambient air. For different values of solar radiation and air temperature, a correlation was established with this minimum difference.

Keywords: Air cooling, Activation condition, CFD, Fan, Photovoltaic panel

Introduction

The efficiency of photovoltaic (PV) panel is strongly linked to climatic conditions (Cuce et Cuce, 2014; Skoplaki et Playvos, 2009). The combined effect of high intensities of solar radiation and ambient air temperature can contribute significantly to the temperature rise of the PV panel whose efficiency is then affected.

To overcome this negative effect, several technical cooling are used. We distinguish the hybrid systems PV/T (Amori et al., 2012 ; Sarhaddi et al., 2010 ; Tiwari & Sodha, 2006). Moreover, Armstrong and Hurley (2010) propose to produce electricity by the action of wind which first drives a turbine and then cools a PV panel. Thus, they improve the electricity production by 36%. Rahimi et al. (2014) optimized a water jet design on a PV panel under high solar concentrations. This design allowed to cool the PV panel with low water pump power consumption.

However, due to the difficulties of implementation, this method limits the practical implementation of this cooling system. Other complex systems include evaporative cooling (Royne & Dey, 2007) or water spray cooling (Bahaidarah, 2016). To overcome these implementation difficulties, the natural circulation of air through the PV panel is used. This process is easy to perform but offers a low cooling effect (Alami, 2014).

Nebbali et al. (2020) propose an autonomous air-cooling system, composed by a fan that blow the ambient air on the rear face of a PV panel. The fan was supplied by the PV panel itself. They showed that for the case of a small size PV panel, the optimum operating point of this cooling system corresponds to an air flow of 8 g/s. The objective of this work is precisely to determine the activation condition of the fan that cools this PV panel. Fan cooling must ensure an efficiency improvement of the cooled PV panel of at least 5%

Problem Position

It is proposed here to cool a PV panel using a fan which blows ambient air on its rear face with an air mass flow rate of 8g/s. The fan is activated by the PV panel itself. The fan is centered on a plywood mounted on the backside of the PV panel (Nebbali et al., 2020) (Figure 1).

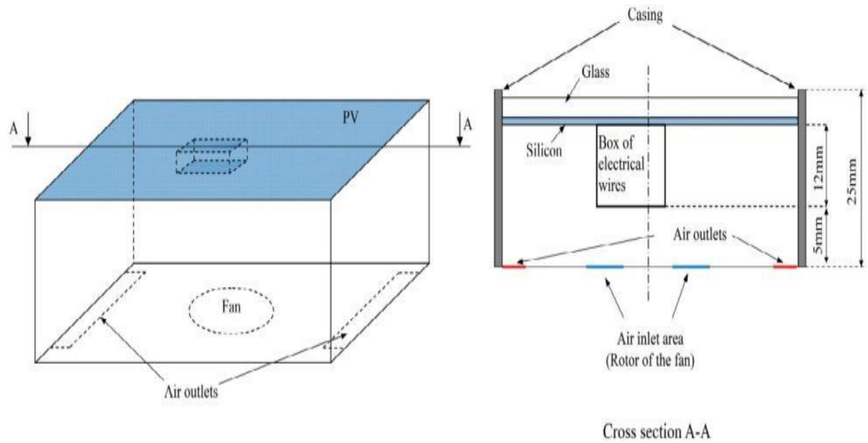

Figure 1. Sketch of the domain calculation (Nebbali et al., 2020).

This cooling system has already been modeled (Nebbali et al., 2020) and it has been established that the optimal operation is obtained for an airflow of 8g/s. With this air flow, we propose to determine from which temperature of the uncooled PV panel this fan must be activated to ensure a satisfactory efficiency improvement of the cooled PV panel. To do this, we need to detrmine the equilibrium temperature of the PV panel and the power it deliver at different climatic conditions.

The equilibrium temperature results from coupled equations of motion and energy. The complexity of these equations requires the use of the CFD tool for their resolutions. The electrical power delivered by the PV panel is then calculated using the one-diode electrical model. By taking into account the power consumed by the fan, we deduced the net power of the cooled PV panel. The efficiency improvement is then obtained by compared the efficiency of the cooled PV panel to that of the uncooled one.

Associated Equations

Fluid Media

The temperature distribution is determined by solving the equations of continuity, momentum, turbulent kinetic energy, dissipation rate and energy which are expressed by the following relationship, the variables of which are defined in the Table 1:

$$\frac{\partial}{\partial x_k}(\overline{u_k}.\varphi) = -\frac{\gamma}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i}\left(\Gamma.\frac{\partial \varphi}{\partial x_i}\right) + S_\varphi \quad (1)$$

Table 1.Governing equations in fluid medium (Nebbali et al., 2020)

Symboles	ϕ	γ	Γ	S_ϕ
Equation de Continuité	1	0	0	0
Momentum equation	u_i	1	0	$\nu \frac{\partial}{\partial x_j}\left(\frac{\partial \overline{u}_i}{\partial x_j}+\frac{\partial \overline{u}_j}{\partial x_i}\right)+\frac{\rho}{\rho_0} g_i - \frac{\partial}{\partial x_j}\left(\overline{u_i' u_j'}\right)$
Turbulente kinetic energy	k	0	$\nu+\frac{\nu_t}{\sigma_k}$	$\nu_t \boldsymbol{S}^2 - \varepsilon - 2\varepsilon M_t^2$
Dissipation rate	ε	0	$\nu+\frac{\nu_t}{\sigma_\varepsilon}$	$C_{1\varepsilon}\frac{\varepsilon}{k}\left(\nu_t \boldsymbol{S}^2\right) - C_{2\varepsilon}\frac{\varepsilon^2}{k}$
Energy equation	T	0	δ	0

Solid Media

The temperature fields in the glass and silicon layers were determined by carrying out steady-state heat balances, which led to the following expression

$$\Delta T + \Omega / \lambda = 0 \tag{2}$$

Where Δ is the Laplace operator, and Ω is a source term that correspond to the net radiative heat flux of the short and long wavelengths, expressed as follows:

$$\Omega = \frac{\alpha_g R_G - \varepsilon_g \sigma\left(T_g^4 - T_{Wall}^4\right)}{e_g}, \text{ for the glass layer.} \tag{3}$$

$$\Omega = \frac{\alpha_{PV} \tau_g R_g}{e_g}, \text{ for the silicon layer.} \tag{4}$$

A One-Diode Electrical Model

This model is expressed by the following equation (Nebbali et al, 2020) :

$$I = I_L - I_L\left[\exp\left(\frac{V + I.R_S}{a}\right) - 1\right] \tag{5}$$

Where :

I_L=0.311 A, I_s=3.662 10-6 A , *a*=1.681 and R_s=0.473 Ω are the constant of the one-diode model at reference conditions.

The electrical power delivred by the PV panel is the product of the voltage and the current it generates :

$$P = V.I \tag{6}$$

The optimal value I_{opt} is determined from the following relation:

$$\frac{dP}{dI}_{I=I_{opt}} = 0 \tag{7}$$

And then Vopt is obtained by the equation (5)

Moreover, the current-voltage characteristics of a PV panel highlight an operating point of maximum power which corresponds to :

$$P_m = V_{opt} I_{opt} \quad (8)$$

The efficiency of the uncooled PV panel is expressed by the ratio between the maximum power delivred by the PV panel and the intensity of the incident solar radiation.

$$\eta_{uncooled} = \frac{P_m}{R_G . S} \quad (9)$$

While the efficiency of the cooled PV panel , which considered the part of the energy consumed by the fan, is defined by this equation:

$$\eta_{cooled} = 100\left(P_m^{cooled} - P_{fan}\right)/(R_G S) \quad (10)$$

and:

$$P_{fan} = 1.88\ 10^{-4}\left(\frac{T_{air}}{T_{air}^0}\right)^2\left(\frac{q}{\rho_{air}^0}\right)^3 \quad (11)$$

and

$\rho_{air} = 1.185\ kg/m^3\ and\ q = 8\ gs^{-1}\ (Nebbali\ et\ al. 2020)$

In addition, in order to quantify the improvement in the efficiency of the performance of the PV panel, the efficiency improvement is evaluated by:

$$\eta_r = 100\ (\eta_{cooled} - \eta_{uncooled})/\eta_{uncooled} \quad (12)$$

Results and Discussion

Equilibrium Temperature

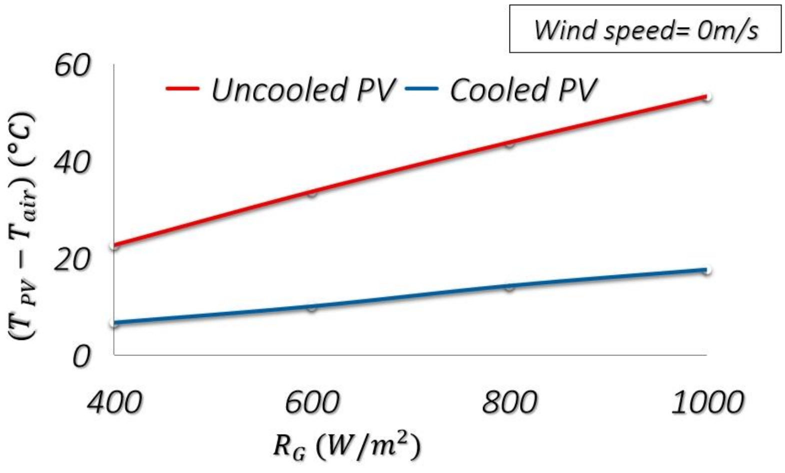

Figure 2. Temperature difference of the PV panel in absence of wind.

Figure (2) illustrates, in the absence of wind, the effect of the intensity of solar radiation on the temperature difference between the ambient air and the uncooled or cooled PV panel. We observe that in both uncooled and cooled PV panel situations, their equilibrium temperatures increases when the solar radiation increases. However, the temperature of the uncooled PV panel rises more than that of the cooled PV. Thus, the fan contributes to the cooling of the PV panel by about 30°C at RG=1000 W/m² and 15°C for RG= 400 W/m² (Table.2). Indeed, the ambient air blown by the fan improves the covective heat exchanges with the PV panel.

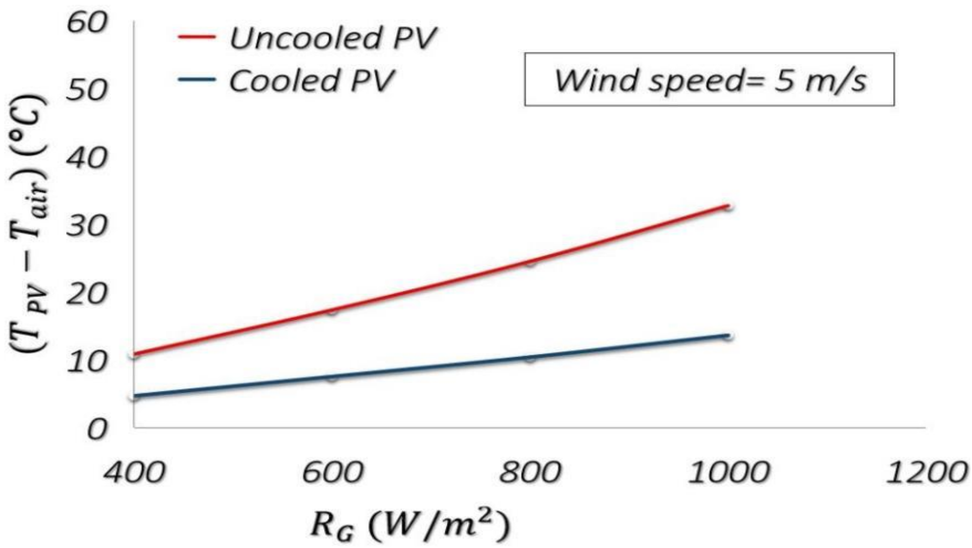

Figure 3. Temperature difference of the PV panel for a wind speed equal to 5m/s

In the presence of the wind speed of 5m/s (Figure 3, table.2), the temperature difference decreases to about 20°C at 1000W/m² and 5°C at 400 W/m². With 10 m/s of wind speed, the cooling occured by the fan is less important (Figure.4, table.2). The temperature difference between the uncooled and cooled PV panel reaches 10°C at 1000W/m² and only 2°C at 400 W/m². It appears that for appreciable wind speed, the cooling by the fan could be useless, consequently it is impotant to determine the activating conditions of this fan.

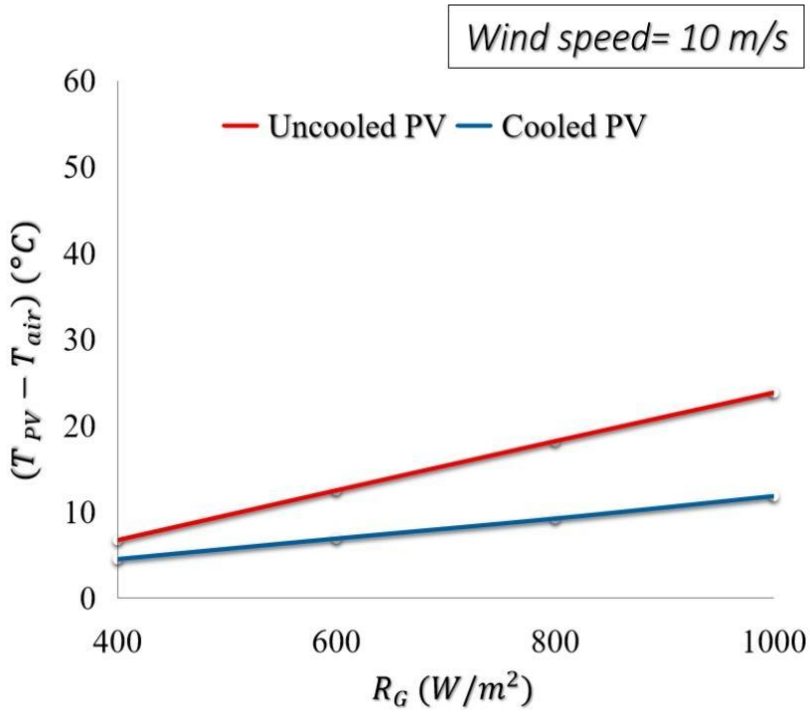

Figure 4. Temperature difference of the PV panel for a wind speed equal to 10 m/s

Table 2. Temperature difference between uncooled PV and cooled PV

Wind speed (m s^{-1})	R_G (W/m²)	Temperature difference (°C)
0	400	15
	1000	30
5	400	5
	1000	20
10	400	2
	1000	10

Efficiency of the PV Panel

Through the figure (5) which highlights the evolution of the efficiency of the uncooled PV panel with the solar radiation intensity at different wind speeds, it is observed that this efficiency decreases when the solar radiation increases. However, this efficiency improves significantly, with a wind speed of 5 m/s, compared to that obtained in the absence of wind. Whereas from 10m/s of wind speed, the effect of the wind becomes less important.

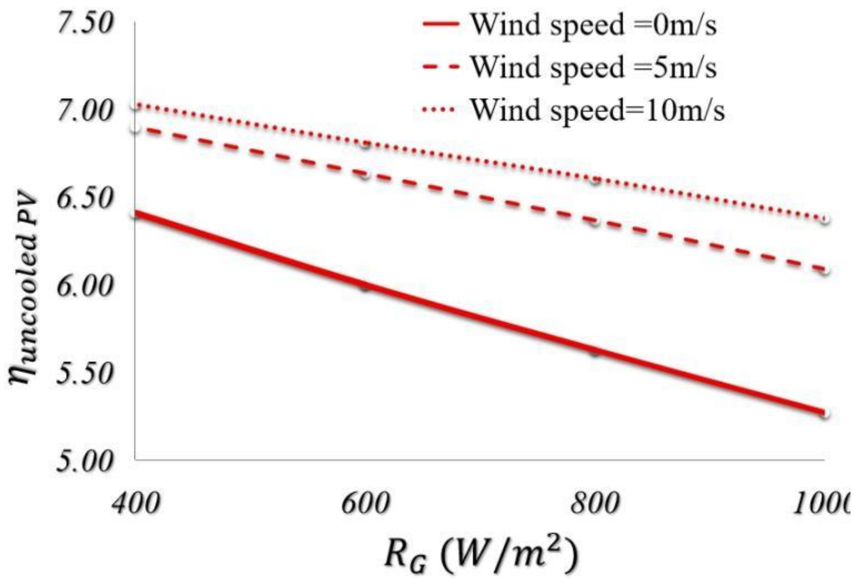

Figure 5. Efficiency evolution of the uncooled PV panel at different wind speed.

For the cooled PV panel (Figure.6), the same observation is made but with efficiencies more imprtant of those of the uncooled PV panel. However, The presence of wind with an intensity of 5 m/s compared to the situation of the absence of wind, improves the efficiency of the PV panel. Moreover, increasing the wind speed does not further improve the efficiency.

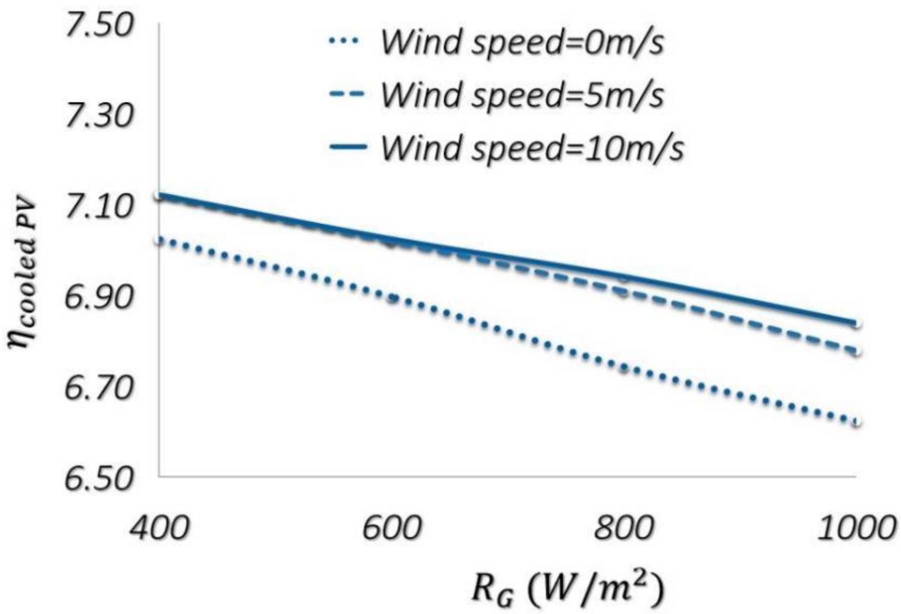

Figure 6. Efficiency evolution of the cooled PV panel at different wind speed.

As shown in figure (7), the efficiency improvement, in the absence of wind, is greater than that obtained in the presence of wind (Figure 7). We can observe the the presence of wind generates low or even negative efficiency improvements. Thus, the improvement provided by the PV panel is totaly consumed by the fan.

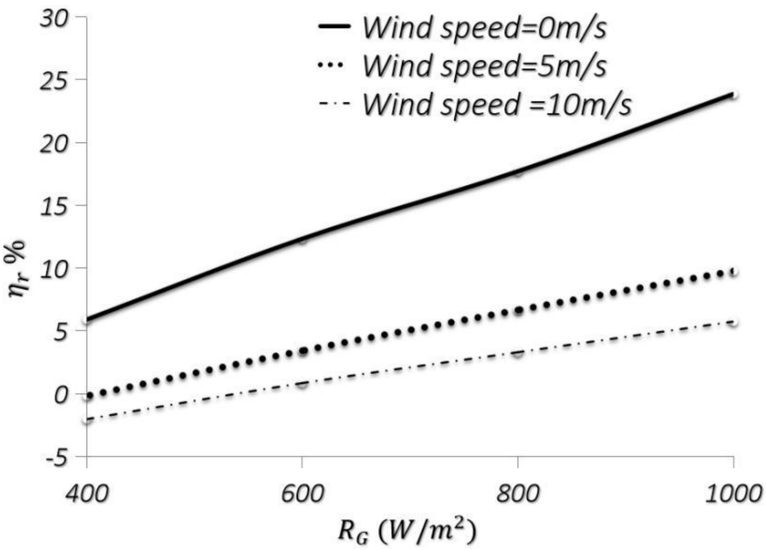

Figure 7. Efficiency improvement of the cooled PV for different wind speed.

Table 3. Efficiencies of the PV panel for various solar radiation intensities and wind speeds

Wind speed(m s^{-1})	RG (W/m²)	$\eta_{uncooled}$ (%)	η_{cooled} (%)	η_r (%)
0	400	6.50	7.00	5
	1000	5.25	6.70	22.5
5	400	6.95	7.10	5
	1000	6.75	6.88	8
10	400	7.25	7.10	-1
	1000	6.75	6.92	4

It can be seen from the table 3, that there are situations where the activation of the fan is not recommended. Indeed with a wind speed of 10m/s , the efficiency improvement of the cooled PV panel is negative. Thus, the excess electrical power delivered by the cooled PV panel may be totally consumed or insufficient to supply the fan. To overcome this, it is necessary to determine the activationconditions of the fan. To do this, we represent in Fig. 8 the evolution of the efficiency improvement of the cooled PV panel according to the temperature difference between the uncooled PV panel and the ambient air at different wind speeds. It appears that the efficiency improvement still greater than 5% from a temperature difference of 20°C. Therefore, the fan can be activated as soon as the temperature of the uncooled PV panel exceeds that of the ambient air by 20°C.

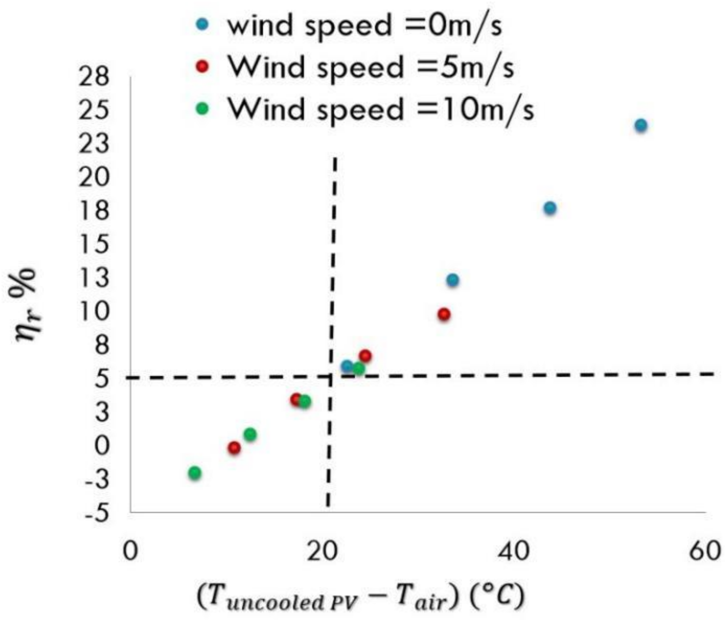

Figure 8. Efficiency improvement of PV panel as a function of temperature difference

Conclusion

Through this study we have shown that the use of a fan to cool a PV panel, allows significant efficiency improvement. It can be high in the absence of wind and low when the wind speed increases. Moreover, in the presence of wind, the efficiency improvement of the cooled PV panel can reach negative values. In order to overcome this negative effect, the fan must be activated as soon as the temperature difference between the uncooled PV panel and the ambient air exceeds 20°C. This ensures a minimum efficiency improvement of 5%.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Research in Engineering, Technology and Science (www.icrets.net) held in Budapest/Hungary on July 06-09, 2023.

References

Alami, A. H. (2014). Effects of evaporative cooling on efficiency of photovoltaic modules. *Energy Conversion and Management, 77,* 668–679.

Amori, K., & Al-Najjar E. H. M. T. (2012). Analysis of thermal and electrical performance of a hybrid 11 (PV/T) air based solar collector for Iraq. *Applied Energy, 98*(12), 384–395.

Armstrong, S., & Hurley, W.G. (2010). a thermal model for photovoltaic panels under varying 18 atmospheric conditions. *Applied Thermal Engineering*, *30*(19), 1488–1495.

Bahaidarah Haitham, M.S. (2016). Expermimental performance evaluation and modeling of jet impingement cooling for thermal management of photovoltaics. *Solar Energy,135*, 605–617.

Bandou F., Hadj Arab A., Belkaid M.S., Logerais P. O., Riou O., & Charki, A. (2015). Evaluation and performance of photovoltaic modules after a long time operation in Saharan environment. *9, Internatıonal Journal of Hydrogen Energy, 40,* 13839–13848.

Cuce, E., & Cuce, P. M. (2014). Improving thermodynamic performance parameters of silicon photovoltaic cells via air cooling. *International Journal of Ambient Energy,35*, 193–199.

Lu Z. H., & Yao, Q. (2007). Energy analysis of silicon solar cell modules based on an optical model for arbitrary layers. *Solar Energy*, *81*, 636–647.

Nebbali, D., Nebbali, R., & Ouibrahim, A. (2020). Improving photovoltaic panel performance via an autonomous air cooling system – experimental and numerical simulations. *International Journal of Ambient Energy 41,* 1387–1403.

Nebbali, D. (2019). *Caractérisation d'une cellule solaire et optimisation de sa capacité de conversion énergétique.* (Master thesis). Mouloud Mammeri University of Tizi-Ouzou, Algeria.

Odeh, S., & Behnia, M. (2009). Improving photovoltaic module efficiency using water cooling, *Heat Transfer Engineering*, *30*(6), 499-505.

Rahimi, M., Valeh-e-Sheyda, P., Parsamoghadam, M.A., Masahi, M.M., & Alsairafi, A.A. (2014). Design of a self-adjusted jet impingement system for cooling of photovoltaic cells. *Energy Conversion Management*, *83,* 48–57.

Royne, A., & Dey, C.J. (2007). Design of a jet impingement cooling device for densely packed PV 1 cells under high concentration. *Solar Energy, 81,* 1014–1024.

Sarhaddi, F., Farahat, S., Ajam, H., Behzadmehr, A., & Mahdavi Adeli, M. (2010). An improved thermal and electrical model for a solar photovoltaic thermal (PV/T) air collector. *Applied Energy,87,* 2328–2339.

Skoplaki, E., & Playvos J. A. (2009). On the temperature dependence of photovoltaic module 3 electrical performance. Review of efficiency/power correlations. *Solar Energy, 83,* 614–624.

Teo, H. G., Lee P. S., & Hawlader M. N. A. (2012). An active cooling system for photovoltaic Modules. *Applied Energy, 90*(1), 309–315.

Tiwari, A., & Sodha, M.S. (2006). Performance evaluation of solar PV/T system: A 16 experimental validation. *Solar Energy, 80,* 751–759.

Author Information

Djamila Zembri-Nebbali
Mouloud Mammeri Universiy of Tizi-Ouzou
Tizi-Ouzou. Algeria
Contact e-mail: *djamila.nebbali@ummto.dz*

Idir Kecili
Mouloud Mammeri Universiy of Tizi-Ouzou
Tizi-Ouzou. Algeria

Sonia Ait Saada
Mouloud Mammeri Universiy of Tizi-Ouzou.
Tizi-Ouzou. Algeria

Rezki Nebbali
Mouloud Mammeri Universiy of Tizi-Ouzou.
Tizi-Ouzou. Algeria

To cite this article:

Zembri-Nebbali, D., Kecili, I., Ait Saada, S., & Nebbali, R. (2023). Activation condition of a fan that cools a PV panel by blowing ambient air on its rear face. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 23*, 564-572.