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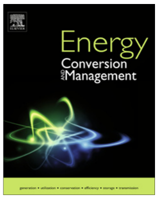

# Water spray cooling technique applied on a photovoltaic panel: The performance response

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## ABSTRACT

This paper presents an alternative cooling technique for photovoltaic (PV) panels that includes a water spray application over panel surfaces. An alternative cooling technique in the sense that both sides of the PV panel were cooled simultaneously, to investigate the total water spray cooling effect on the PV panel performance in circumstances of peak solar irradiation levels. A specific experimental setup was elaborated in detail and the developed cooling system for the PV panel was tested in a geographical location with a typical Mediterranean climate. The experimental result shows that it is possible to achieve a maximal total increase of 16.3% (effective 7.7%) in electric power output and a total increase of 14.1% (effective 5.9%) in PV panel electrical efficiency by using the proposed cooling technique in circumstances of peak solar irradiation. Furthermore, it was also possible to decrease panel temperature from an average 54 °C (non-cooled PV panel) to 24 °C in the case of simultaneous front and backside PV panel cooling. Economic feasibility was also determined for of the proposed water spray cooling technique, where the main advantage of the analyzed cooling technique is regarding the PV panel's surface and its self-cleaning effect, which additionally acts as a booster to the average delivered electricity.

## 1. Introduction

Photovoltaic (PV) technology [1] is widely used today in different applications [2–4] but due to relatively high initial investments and low overall efficiency, the number of installed capacities is lower than expected. The second major problem of the commercial PV technology is its cleaning issue, i.e. dust impact and other particles accumulated on the front PV panel surface that can significantly reduce the amount of delivered electricity (in some cases reduction can go up to 30%). The previously mentioned issues (facts) can be overbridged through the improvement of existing market available technologies or through development of novel PV technologies. One possible option is to provide an increase in panel electrical efficiency along with solving its cleaning issue and aiming to develop feasible cooling techniques for the PV panel.

Even though novel PV technologies are currently under research and more efficient PV technologies are bound to be discovered (it is just matter of time), their expected market price will probably be too high for current market capabilities, so a wider market implementation can be questionable long term. A second possible option, besides the development of novel PV technologies, is to modify and upgrade existing available PV technologies.

It is well known that electrical efficiency in PV systems can be improved if panel temperature is reduced. This problem has been thoroughly studied in past years through the development of different cooling techniques. For the current market available PV technologies, electrical efficiency degradation is due to the rise of panel temperature which ranges from 0.25%/ °C up to 0.5%/° (depending from the specific PV technology used), so possible electrical efficiency improvement can be obtained with a proper cooling technique and keeping in mind that each cooling technique should have proven feasibility.

The objective of this paper was to develop an experimental setup and to investigate a water spray cooling technique, implemented simultaneously on the front and back side of a PV panel as well as other different water spray cooling circumstances to ensure gained result comparison and to offer an optimal cooling solution (regime). The proposed water spray cooling technique can potentially increase PV panel performance due to an evaporation and self-cleaning effect, which is also a great benefit in terms of improved feasibility in the long run.

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**Nomenclature**

| | |
|---|---|
| $A_p$ | effective panel surface, m$^2$ |
| $a$ | absorptivity |
| $e$ | evaporation coefficient, kg m$^2$/s |
| $G_s$ | solar irradiation, W/m$^2$ |
| $h$ | convection heat transfer coefficient, W/m$^2$ K |
| $P_e$ | electric power output from the PV panel, W |
| $p$ | partial pressure, Pa |
| $r$ | latent heat of the water evaporation, J/kg |
| $U$ | internal energy of the PV panel, J |
| $\dot{V}_w$ | water spray flow, l/h |
| $t_{panel\_front}$ | front average panel temperature, °C |
| $t_{panel\_back}$ | backside panel temperature, °C |
| $\Delta T_p$ | temperature reduction of the PV panel, °C |
| $\dot{Q}_c$ | total convection heat loss from the PV panel, W |
| $\dot{Q}_r$ | total irradiation heat loss from the PV panel, W |
| $\dot{Q}_e$ | total evaporation heat loss from the PV panel, W |
| $\dot{Q}_{loss}$ | overall heat loss from the PV panel, W |

*Greek symbols*

| | |
|---|---|
| $\varepsilon$ | emissivity |
| $\eta_{el_{max}}$ | maximal electrical efficiency of the PV panel, % |
| $\tau$ | time period, s |
| $\sigma$ | Stefan–Boltzmann constant, W/m$^2$ K$^4$ |

## 2. Brief overview of the previous research findings regarding PV cooling techniques

The previous research work focused on different designs and experimental validation in cooling strategies for PV panels, to investigate their influence on overall efficiency and also to investigate specific energy losses in PV systems [5,6]. In the majority of the proposed cooling techniques, water was used as a coolant and cooling was implemented on the front or backside of the PV panel. For example, in [7] authors investigated the effect of evaporative cooling implemented on PV panels and the maximal detected total increase in power output was around 19%. Direct PV panel cooling with an established water flow over the front side of the panel was investigated in [8] and it was possible to increase power output by 9.5%. Furthermore, in [9] authors investigated a water spray cooling technique implemented just on the front side of the PV panel and significant improvement of electrical efficiency was established. A back surface water cooling method was investigated in [10] for hot climate conditions and it recorded an increase in electrical efficiency by around 9%. In addition, alternative cooling techniques that include water as a coolant were studied in [11–14], where the average achieved increase in power output ranged from 10% to 20%, depending from the specific implemented cooling technique.

However, there are a certain number of research studies [15–19] where air flow was used as a coolant instead of water or even their combination in some cases. In the previously mentioned studies where air was used as a coolant, the achieved PV panel power output was less in magnitude comparing to cases where water was used as a coolant. The water submerging method [20,21] turned out to be one of the most efficient cooling methods as heat rejection magnitude from the PV panel was the highest in comparison to other investigated cooling techniques. Conventional PV panel electrical efficiency can be increased by over 20% when implementing the water submerging method. It was also discovered that the submerged PV panel water increase depth has got a favorable influence on electrical efficiency and the optimal depth was found to be at around 6 cm (the pyranometer was flooded into the water during measurements). However, the key issue regarding the water submerging method is its final technical suitability (i.e. a potential problem for its wide commercial applicability) and there is also an ecological aspect that should be taken into account. A global photovoltaic energy output analysis enhanced by phase change material cooling (PCM) was obtained in [22] and it is found that PCM cooling is not a currently viable option for single-junction.

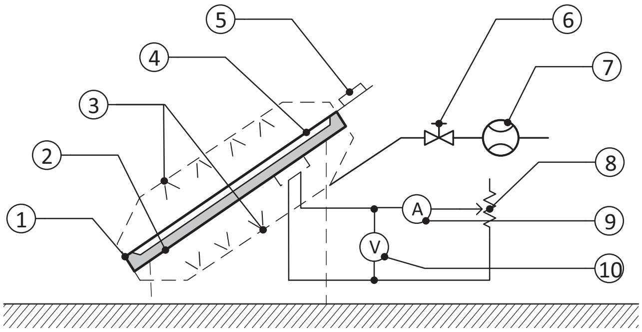
Besides different cooling techniques, there is also a possibility to improve overall system efficiency through the development of hybrid photovoltaic-thermal (PV/T) energy systems. A variety of research studies have been conducted to evaluate the performance of different proposed hybrid energy solutions [23–30], and in general, it can be concluded that developed hybrid energy systems are efficient ones and certainly encourage implementation of PV technology.

## 2. A specific experimental setup

### 2.1. The system configuration description

According to Fig. 1, an experimental configuration was assembled from a flat PV monocrystalline module of 50 W nominal maximal power with an effective surface of 0.31 m$^2$. The examined panel's general characteristic is specified in Table 1. The panel was equipped with a system of nozzles mounted on the PV panel front and rear sides to ensure proper water spray distribution on both sides of the PV panel.

The panel was fixed under a specific angle of 17° (to obtain the highest electricity output for the fixed slope and which is characteristic of the specific geographical location where the panel was tested), and mounted on a terrace of south orientation (the south orientated terrace of the Faculty building). The whole system was connected to an *I–V* (current–voltage) tracker with a rheostat so it was possible to determine specific PV panel power-voltage characteristics during the experimental measurements. Rheostat resistance was set to twelve different values ranging from 0 to



**Legend:**

1 – photovoltaic panel
2 – temperature sensor (back)
3 – nozzles
4 – temperature sensor (front)
5 – pyranometer
6 – water flow regulating valve
7 – water flow meter
8 – rheostat
9 – ammeter
10 – voltmeter

**Fig. 1.** Schematic layout of the specific experimental setup.