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Experimental and numerical investigation of a backside convective cooling mechanism on photovoltaic panels

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ABSTRACT

In this paper, two generic photovoltaic (PV) panels (poly-Si and mono-Si) were experimentally tested in typical Mediterranean climatic conditions. The focus of the applied experimental approach was to examine the effect of backside convective thermal profile and its impact on temperature distribution, i.e. on panel electrical efficiency. Therefore, a series of measurements was made in 2015, from April to July, as well as CFD modeling in order to obtain a detailed analysis of the possible working regimes. According to the obtained experimental and CFD results, the present design of typical PV panels have an unfavorable impact on PV panel electrical efficiency. Namely, typical contemporary panel designs lead to two typical backside convective air temperature profiles which have a direct impact on the effectiveness of natural cooling. As shown in the obtained measurements, the specific convective profiles at the backside of PV panels have a significant influence on the degradation rate of panel electrical efficiency in the estimated amount of 2.5% up to 4.5%. The results of the research discussed in this paper signal the need to provide a possible redesign of the backside surface in conventional PV panels, in order to increase their average efficiency (more efficient backside thermal dissipation).

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1. Introduction

Sufficient production of electricity from photovoltaic systems strongly depends on the average achieved electrical efficiency of photovoltaic panels (PV), i.e. PV systems, apart from the specific climate circumstances given in which a PV system operates. The most widely used contemporary photovoltaic technologies are siliceous based ones, mono-or polycrystalline, [1,2]. Despite the significant progress that has been made since the early 1990s, raising electrical efficiency in PV systems and reducing their production cost are still major research goals, both in basic and applied ones, especially when considering the relatively high overall investment in PV systems [3].

One possible way of achieving increase in PV efficiency is by applying a financially feasible cooling technique that can lead to the decrease of panel temperature and therefore increase its electrical efficiency. There are several research studies related to the investigation of different cooling techniques and their effect on panel performance, [4–10]. As these studies showed, there is a potential of increasing PV efficiency in that manner, but the achieved increase is generally modest which questions the feasibility of certain cooling techniques. In most of these studies, emphasis was placed on technical issues and the economic aspects were linked to them. A comparison of different cooling techniques for PV panels in relation to the obtained relative increase in specific panel power output can be found in Ref. [5].

The development of efficient hybrid PVT systems is also important in order to enable a more efficient utilization of existing PV technologies and also to penetrate into the market more deeply. The main advantage of PVT systems is the possibility of simultaneous heat and electricity production, whereby the total achieved efficiency of the considered PVT systems can be relatively high. In the specific topic of PVT systems, research efforts are considerable and different PVT concepts have been investigated in recent years, [11–16].

Another option that can lead to the increase of overall electricity

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production in PV systems is to provide maximization of power output through a suitable MPP tracking strategy [17–22], which needs to be economically viable. Technically speaking, this does not lead to an increase in panel electrical efficiency as such; the efficiency increase is due to prolonged time exposure at more effective solar radiation angles. Moreover, MPP tracking technologies have significantly improved, and their costs have decreased drastically in the 2010s and have become a very attractive investment option.

Novel photovoltaic technologies that are more efficient than currently available ones are still under research. The main problem generally lies in their economic aspect. It is therefore clear that emphasis needs to be placed on novel, more efficient photovoltaic technologies that are cost-effective. However, the improvement of existing PV technologies should not be neglected, as it would be much easier to push modified and improved PV systems to the market than a new technology that may lead to reservations on behalf of investors.

The main objective of this paper is to examine the effect of the convective thermal profile that occurs on the backside of photovoltaic panels and of its overall impact on panel backside temperature distribution, i.e. on electrical efficiency. Besides an experimental approach, CFD modeling was also used and the results obtained were compared to the experimental readings, a task accompanied by a sensitivity analysis in relation to the PV panel temperature distribution. The main research outcome of the herein presented study can lead to the consideration of PV panel backside surface redesign in order to achieve an increase in panel electrical efficiency.

2. Theoretical background basis

Photovoltaic cells gain energy directly from solar irradiance where just one part of incident irradiation is converted into useful electrical energy by means of the photoelectric effect. The rest of the incident solar energy is mostly accumulated on the PV panel by absorption as heat gain; a smaller portion is reradiated to the surroundings. Since the ambient is almost always at a lower temperature than the PV cell, heat tends to dissipate into the surroundings. The intensity of heat dissipation varies due to many parameters such as air flow (direction and magnitude), average air temperature and surrounding relative humidity, bracket shape, reflectivity of surrounding surfaces, etc., i.e. it is certainly a complex issue. For the purpose of this analysis, a simplified theoretical overview is provided, which briefly explains energy fluxes through the PV cell and is useful to understand the root of possible impacts on panel performance. Basic heat fluxes are presented in Fig. 1 for the case of typical PV panels.

In steady-state conditions, the incoming energy is equal to the energy dissipation from the considered system presented in Fig. 1, $\dot{E}_{in} = \dot{E}_{out}$. Since all energy flows originate from incoming solar irradiance, direct insolation is significantly greater than diffuse radiation at peak heat gains. The heat income can be defined as follows:

$$\dot{Q}_{in} = \dot{E}_{in} = a \cdot G_s \cdot A_p, \tag{1}$$

where a presents the overall solar absorption coefficient for the whole PV cell.

A standard PV panel usually consists of glass, silica, ethylene vinyl acetate (EVA) and polyvinyl fluoride (PVF) layers (Tedlar layer in Fig. 1). As every material has a different absorptivity coefficient, it is difficult to accurately predict the amount of absorbed heat. Moreover, it is also a complex issue to measure the spectrum of irradiance, in order to show which wavelengths are emitted from the sun, and what fraction of each wavelength is transmitted (absorbed) into different layers of the PV panel. Although the previously mentioned information can be computed, it strongly depends on atmospheric conditions such as humidity, overcast and the amount of dust in the air. Time of day is also in direct correlation with the shape of irradiance spectrum.

Overall PV cell heat output cannot be strictly defined, as it depends on cell efficiency as well as on surrounding circumstances in which the PV system operates and finally from the cell material. Further, overall PV panel energy output can be written as follows,

$$\dot{E}_{out} = \dot{Q}_{heat} + \dot{E}_{current} \tag{2}$$

where $\dot{Q}_{heat}$ is heat rejected from the PV panel in steady-state conditions to the surroundings and $\dot{E}_{current}$ is the produced electrical output. Overall PV panel rejected heat is due to convection and thermal radiation, respectively,

$$\dot{Q}_{heat} = \dot{Q}_{convection} + \dot{Q}_{radiation}. \tag{3}$$

Heat dissipation to the surroundings as a result of convection depends in general on a series of factors such as tilt angle, material type, surrounding air speed and temperature, average panel surface temperatures, time of day, etc. Besides temperature, thermal radiation depends upon the emissivity and reflectivity of the material. Furthermore, emissivity defines how much of the heat will be dissipated to the surroundings, while reflection defines how much of the surrounding heat will transfer to the PV cell from the back side and lateral frame of the PV panel. As PV panel temperature is almost always higher than the temperature of surrounding air, it can be concluded that dissipation will always be greater, in comparison with diffuse insolation absorption, mainly the reflected insolation from surrounding surfaces back to the PV panel. Nevertheless, radiation intensity is strongly correlated to the ambient temperature and reflectivity of surrounding surfaces.

Therefore, a basic heat equation (energy balance equation) can be written for the considered PV panel in steady state conditions,

$$\dot{Q}_{heat} = \dot{E}_{current} + \dot{Q}_{convection\_frontside} + \dot{Q}_{convection\_backside} + \dot{Q}_{radiation\_frontside} + \dot{Q}_{radiation\_backside} \tag{4}$$

$$a \cdot G_s \cdot A_p = G_s \cdot A_p \cdot \eta_{cell} + \left(A_p \cdot \overline{\alpha}_{front} \cdot \Delta T_{eq.}\right)_{front} + \left(A_p \cdot \overline{\alpha}_{back} \cdot \Delta T_{eq.}\right)_{back} + \left[\varepsilon \cdot \sigma \cdot A_p \cdot \left(T^4_{panel} - T^4_{amb.}\right)\right]_{front} + \left[\varepsilon \cdot \sigma \cdot A_p \cdot \left(T^4_{panel} - T^4_{amb}\right)\right]_{back} \tag{5}$$

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