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THERMAL REGULATION OF A PHOTOVOLTAIC PANEL BY PIN FINS: A NUMERICAL AND EXPERIMENTAL ANALYSIS

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Abstract. Due to the growing interest in solar radiation to generate electricity, the use of photovoltaic panels (PV) has been increasingly explored in recent years. Most photovoltaic modules have low efficiency in converting solar energy to electricity, even under ideal operating conditions. Due to this low efficiency, the remaining energy is converted into heat, increasing panel temperature and decreasing efficiency. In addition, the effect of operating at high temperatures reduces the module's lifespan. Therefore, it is crucial to apply a cooling system to regulate its temperature; this system can be passive or active, which the latter is often unsuitable due to the power required to operate the compressor or pump used in the cooling process. Thus, in the current work, an experimental and numerical investigation is performed considering a passive cooling system consisting of 4 segmented L-shaped aluminum fins arranged in the central region on the rear surface of a PV panel. A serial experiment was conducted on different days with clear sky conditions for December 2021. The fins decrease the panel temperature (up to 4.7 °C) and the efficiency and the output power increase by 2.4% and 2.1%, respectively, compared to the reference panel. Moreover, the ANSYS program was used to predict the PV surface temperature; the numerical results were validated with the experimental results for a conventional PV panel without a cooling system. By the numerical analysis considering the fins on the rear surface of the PV panel, satisfactory results were obtained compared to the experimental values, with an average deviation of about 2.7%. The proposed cooling method improved the convective heat exchange and cooled the PV system for all days considered in the current analysis; reducing the PV surface temperature can avoid electrical conversion efficiency losses and increase the PV system lifespan.

Keywords: Photovoltaic Energy, Cooling System, Efficiency, Numerical Analysis.

1 Introduction

The latest technological advances are significantly increasing the use of electric energy, produced mainly from non-renewable sources, which is worrying since the resources that generate this energy will be increasingly scarce and expensive. Because of this scenario, photovoltaic energy has been widely studied as a solution to cover future energy demand. In Brazil, it becomes even more promising since the country has sunlight during most of the year, in addition to the positive cost-benefit in the long term.

However, according to the 2022 Brazilian Energy Balance (BEB) [1], carried out by the Energy Research Company, a company linked to the Ministry of Mines and Energy, solar energy contributed only 0.32% of the domestic electricity supply in 2020; despite this, its generation grew by 61.2% compared to the previous year.

The BEB [1] presents data regarding the participation of micro-generators (those that generate up to 75 kW from alternative sources such as photovoltaic, wind, or biomass with their consumer units on rooftops, in vacant lots, condominiums, or farms) and mini-generators (those that produce 75 kW to 5,000 kW), where the participation of solar energy is 88,3% due to the use of small-scale PV panels, especially in residential buildings.

The main barrier to increasing solar energy in the energy matrix is the low energy conversion; PV conversion of solar radiation into electrical energy can be performed with maximum efficiency in the order of 20% [2], and the rest is changed to the heat, which increases the unit temperature. According to [3], for each °C of increase in the PV operating temperature, its efficiency is reduced by 0.4-0.5%. In addition to lower efficiency, high temperatures decrease the panel's lifespan, making its cost-effectiveness less attractive.

Managing the PV thermal parameters is essential for sustaining performance and maximizing the productive life of solar PV panels. Therefore, it is important to use cooling techniques to maintain the PV temperature as close to the optimum temperature as possible. Among the techniques, we have the so-called active techniques, which depend on an external power source being deducted from the power produced from the PV cells, reducing the net output power produced from the PV cells, and passive techniques, which do not consume electrical energy.

Previous studies, such as [4], used an aluminum finned plate (60 cm long, 28 cm in width, and 4 cm thick) on the back side of the photovoltaic panel, obtaining an average reduction of 6 °C in temperature and a gain of 1.7% in output power; whereas [5] analyzed two specific rib configurations (parallel positioned aluminum fins and randomly positioned perforated L profiles). The authors observed an average increase in efficiency of about 2% during peak power for the latter configuration. In addition, [6] tested ten aluminum fins with 4 cm width and thermal conductivity of 204 W/m.K behind a PV panel and observed a temperature reduction of 6 °C and a gain of 2.4%.

In the current work, we use rectangular fins applied to the rear surface of a PV panel, aiming to extend the heat transfer area. Among the advantages are its low cost, easy application, and use in micro and mini-generators in order to optimize the PV panel operation and temperature reduction.

2 Methodology

2.1 Experimental apparatus

The experimental setup consists of two identical polycrystalline silicon modules (model CS3U-350P) with 144 polycrystalline high-efficiency cells distributed over an area of 2000 x 992 mm, Figure 1. According to the manufacturer, the PV module has a nominal output power of 350 W and an energy conversion efficiency of 17.64% in STC. More information about the experimental apparatus can be found in [2].

Figure 1. Experimental apparatus without the presence of the cooling system.

The passive cooling system consists of four aluminum L-shaped fins (150 mm in length, 2 mm in thickness, and 100 mm in height), which are coupled using a double-sided thermal tape (TR Series, model 5320F) to the central region of the rear surface of one of the PV panels (PV2); the other one (PV1) is mounted without the cooling system for comparison.

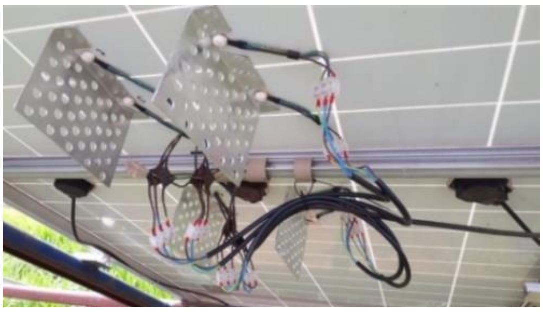

Figure 2. Passive cooling system coupled to the rear surface of PV panel (PV2).

The experimental apparatus includes 18 digital temperature sensors, DS18B20 from *Dallas Semiconductor Corp*; 6 halogen lamps of 50 W and 12 V for energy dissipation; an anemometer; a global irradiance sensor, model MES-200 from *Instrutherm*; two voltage sensors; two current sensors. The sensors collected information about the ambient temperature, ground temperature, relative humidity, wind velocity, global irradiance, and temperature in 8 places on the PV panel's rear surface between sunrise and sunset every 30 seconds.

2.2 Numerical analysis

The PV panel was modeled using a two-way coupled system in ANSYS, Mechanical and Fluent software, aiming to predict the average temperature of the photovoltaic panel by providing the input data of solar irradiation, instantaneous produced power, ambient temperature, and wind velocity. The geometry was created in the Space Claim software, assuming that the panel consists only of a photovoltaic cell layer, so the panel had the following dimensions 2000 x 992 x 0,225 mm. For the panel with the presence of the passive cooling system, fins were drawn as in the experimental apparatus since they influence fluid flow. The fluid enclosure was determined following the Abu-Zidan [7] optimized domain. Figure 3 shows the numerical domain.

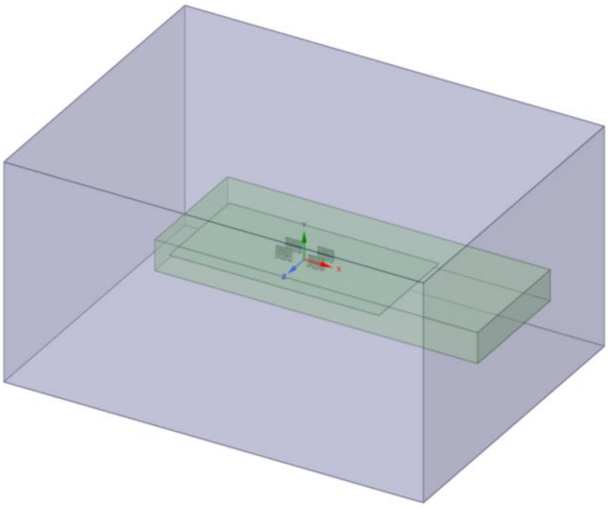

Figure 3. Numerical domain for the PV panel with the passive cooling system.

As done by Abu-Zidan [7], a test was performed to verify if the enclosure's sizing influenced the results. For such analysis, the optimized domain was used, shown in Figure 3, and the domain recommended by Franke et al. [8]. Table 1 shows the temperature results.

Table 1. Numerical domain size independence.

Time	T_{panel} [°C] (Abu-Zidan's domain)	T_{panel} [°C] (Franke's domain)	Deviation
10:00	38.86	38.81	0.,12%
11:00	43.81	43.76	0.12%
12:30	49.24	49.18	0.12%
13:00	47.81	47.76	0.11%
14:00	45.44	45.40	0.11%
15:00	38.86	38.81	0.12%

As shown in Table 1, the deviation between the average PV temperature values was minimal, not justifying the high computational cost associated with the domain size based on [8]; therefore, the analysis was performed based on the optimized domain [7].

Moreover, a mesh independence test was carried out to obtain results not influenced by the mesh density. We intended to verify if the flow result was independent of the mesh; thus, fluid velocity was used as the parameter for this analysis at a specific point between the fins and near the outlet domain region. Figure 4 shows the results; the highlighted (red) was chosen for the current work. It is worth mentioning that the mesh selection considered the obtained velocity value, the mesh quality parameters (such as skewness, aspect ratio, etc.), and a careful visual inspection.

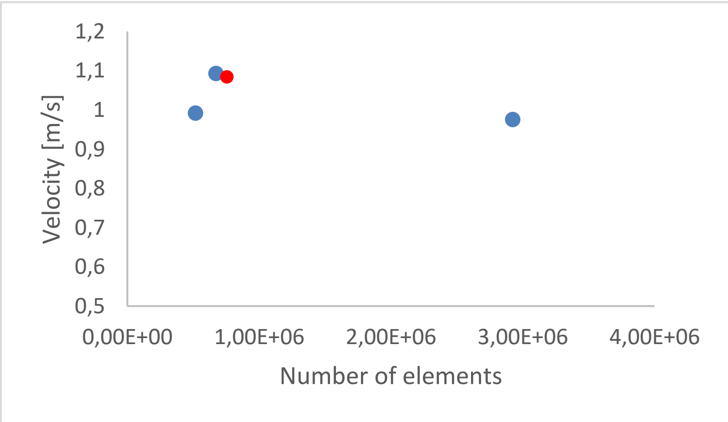

Figure 4. Mesh independence analysis.

The grid-independence analysis was performed for the PV panel with the presence of the passive cooling system since it requires more complex analysis.

Equations of continuity, momentum, and energy were solved using the finite volume method with the second order upwind using the FLUENT computational tool (Figure 5). The computational domain was discretized using a second-order upwind method with the SIMPLE scheme for pressure–velocity coupling. The numerical simulation was realized using the k-Omega SST model of turbulence. The air velocity and ambient temperature were set according to conditions on the analyzed day; a heat flux boundary condition is imposed on the front surface of the PV module, corresponding to the solar irradiation minus the power produced by the panel, and the generated heat is lost through convection and radiation to the ambient. The solution was converged when the absolute residuals for the continuity and velocity components were less than 10^{-4} and the energy equation less than 10^{-3}.

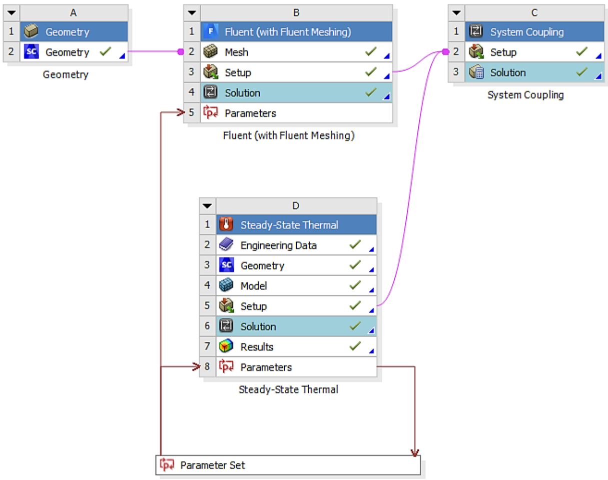

Figure 5. Setup from ANSYS workbench.

3 Results

In order to perform the experimental and numerical analysis, days with different weather conditions were selected. The numerical analysis was validated by comparing the PV panel temperature obtained experimentally with the numerically one. Then, the temperature difference for the PV1 (reference) and PV2 (with the passive cooling system) was analyzed. Figures 6 to 8 show the average temperature of the PV panel with and without fins obtained by the numerical analysis and experimentally for different days in December 2021.

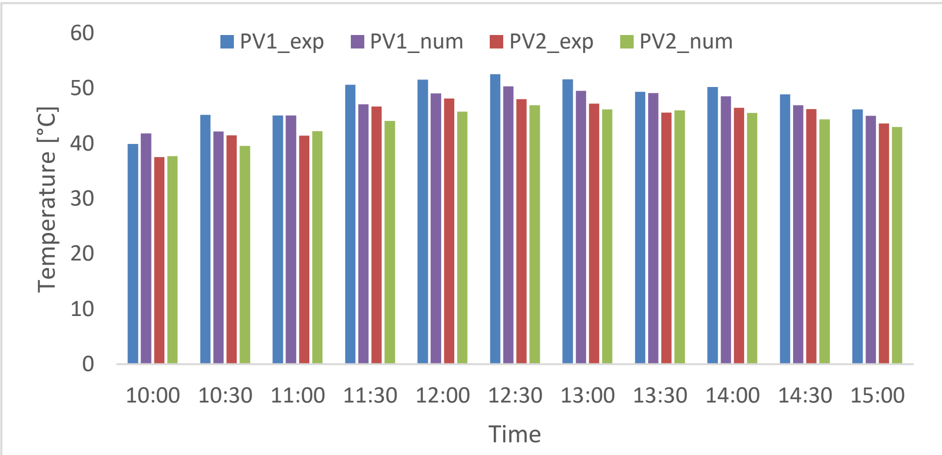

Figure 6. Average temperature of the PV panel with (PV2) and without fins (PV1) for Day 1.

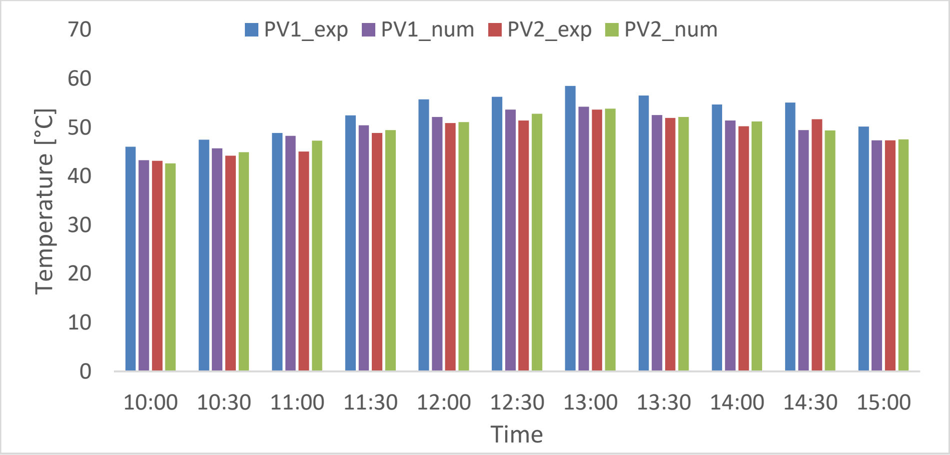

Figure 7. Average temperature of the PV panel with (PV2) and without fins (PV1) for Day 2.

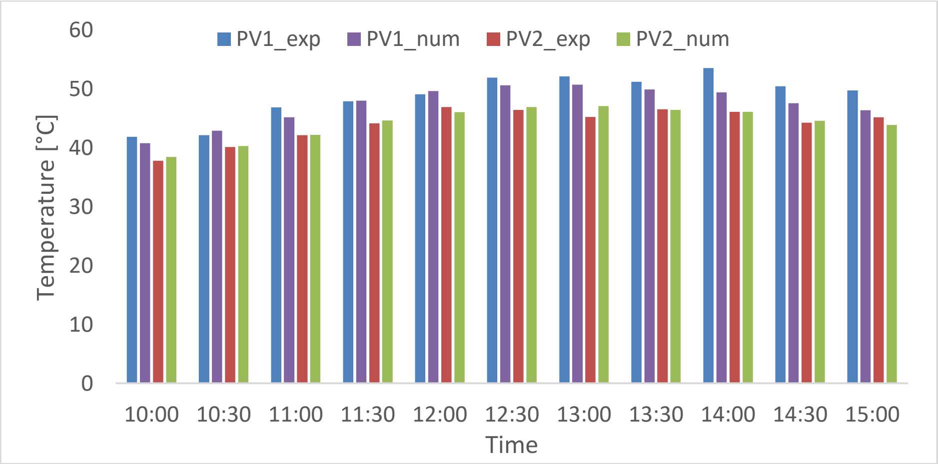

Figure 8. Average temperature of the PV panel with (PV2) and without fins (PV1) for Day 3.

For the PV1, the so-called reference PV panel, the temperatures obtained experimentally are close to those obtained numerically (the mean absolute error was around 4%). In addition, for PV2, the results from the numerical analysis agree well with the experimental data, with a mean absolute error of 2.7%. Therefore, the numerical procedure described in section 2.2 is appropriate and capable of predicting the temperature of the PV panel with and without the passive cooling system. The deviations in such results can be explained by assumptions made for the numerical approach, such as the heat transfer through the PV panel is in steady-state conditions; the thermal conductivities of the materials are constant; the thermal contact resistances at the interfaces are negligible; and, the cell thickness is negligible.

From Figures 6 to 8, one may observe that the use of fins in the rear surface of the PV panel (PV2) as a passive cooling method leads to a reduction in the PV panel temperature compared to the reference panel (PV1); for the experimental data, it was found a maximum decrease of 4.7 °C, and for the numerical approach, it was found a maximum decrease of 4.1 °C. Such temperature reduction can improve the PV panel's efficiency and lifespan.

4 Conclusion

This work aimed to develop a numerical approach to predict the temperature of a PV panel coupled with a passive cooling system. The passive cooling system consists of 4 segmented L-shaped aluminum fins arranged in the central region on the rear surface of the PV panel. The numerical approach was validated by comparing it with the experimental data; the simulation can predict the recorded temperature satisfactorily. Then, the temperature of the PV panel using fins cooling technique was analyzed experimentally and numerically; the presence of the passive cooling system reduces the PV panel temperature by up to 4.7 °C and 4.1 °C, respectively. Moreover, the results from the numerical analysis agree well with the experimental data, with a mean absolute error of 2.7%.

Therefore, implementing the proposed passive cooling system (L-shaped aluminum fins arranged on the backside of a PV panel) can decrease the panel's operating temperature, improving its energy efficiency and lifespan.

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