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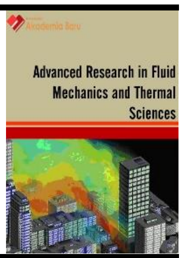

A Numerical Approach to Study the Performance of Photovoltaic Panels by using Aluminium Heat Sink

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ABSTRACT

The increase of operating temperature of photovoltaic (PV) panels due to excess heat from solar irradiance leads to a decrease in efficiency and the lifespan of PV panels. In this paper, a numerical model of temperature reduction of the photovol-taic panels by using air-cooled heat sink with Re = 13100 was studied. The heat sink was devised as an aluminum baseplate with perforated fins attached to its surface. The cooling efficiency was determined by comparing the simulation of the photovoltaic panel's performance with heat sink and without heat sink using ANSYS-Fluent software. The simulation results were presented by temperature distribution contour of the PV module and velocity profile of air moving through the heat sink. An average decrease of 13.1°C in temperature and increase of 0.8% in efficiency of the PV module was achieved on the model with heat sink, provid-ing a promising solution to overcome overheating PV panels.

1. Introduction

The ever-increasing global energy demand is amongst the biggest challenges for mankind in the 21st century [1]. Renewable energy, especially solar energy, could be the solution for the growing demand of energy consumption. According to the 2000 World Energy Assessment by the United Nations Development Programme, the annual potential of solar energy was 1,575 – 49,837 exajoules (EJ) [2], several times larger than the annual global energy consumption, which was 567 EJ in 2013 [3].

Solar energy can be converted into electricity directly using devices based on semiconductor materials, such as photovoltaic (PV) panels. The working principle of PV panels is based on the photovoltaic effect, which is the generation of voltage and electric current in the semiconductor

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material upon exposure to light [4]. This phenomenon happens when sunlight – which carries packets of energy called photon – hits the semiconductor material. Photons with certain level of energy, known as the "bandgap energy", excites the electrons within the material, so that the electrons freed from its covalent bond and produces electricity [5].

However, photons which have more energy than the bandgap energy exerted the extra amount of energy as heat when freeing electrons. Furthermore, ordinary PV panels could only convert 6 – 20% of solar radiation into electricity, depending on the solar cell type and the climate conditions where the module is used [6]. The excess solar radiation becomes heat which could increase the temperature of the PV module and decrease the efficiency significantly.

The operating temperature of a PV panel has a crucial impact to the efficiency [7]. For every degree of temperature rise, crystalline silicon solar cells experienced a reduction in conversion efficiency of ~0.4 – 0.5% [8]. The operating temperature of a PV module could reach up to 80°C in summer, causing a drastic reduction of efficiency [9]. Such extreme temperature increment caused by inefficient waste heat dissipation could even lead to irreversible damages to the solar cells such as delamination, micro-sized cracks, and deformation due to thermal stress [10].

There are two methods of PV module cooling, namely the active and the passive cooling method. Active cooling method utilizes mechanical and electrical devices, such as fans or pumps to drive the coolant, such as water or air that absorbs heat from PV module. There is additional power required to make the mechanical and electrical devices work in active cooling, which does not provide obvious benefit in the net gain of PV module efficiency [8].

On the other hand, passive cooling method does not require additional power since there are no mechanical and electrical devices involved. This method may uses additional parts which relies fully on the principles of convection heat transfer to direct the coolant flow to the PV module, such as thermosiphon or heat sink [11].

Passive cooling method developed by Ali *et al.,* [12] to lower the operating temperature of PV module was based on the installation of aluminum heat sink to the PV module. The study was conducted by fabricating two heat sinks of different dimensions, a large one of 150 mm × 100 mm × 95 mm and a small one of 100 mm × 100 mm × 95 mm. A temperature difference of 4.1°C and 2.73°C were noticed for the large and small heat sink, respectively.

Araki *et al.,* [13] had designed a passive and simple heat sink consisted of a copper sheet on a heat-conductive epoxy-printed aluminum baseplate for cooling concentrated photovoltaic (CPV) modules. The experiment was conducted by mounting the solar cell on the heat sink and evaluating the cooling performance. Results of the experiment showed a difference of temperature between the ambient air and the solar cell of only 18°C for heat flux of ~600 W/m^2.

Natarajan *et al.,* [13] had numerically investigated the passive cooling performance of fin-attached aluminum heat sink for CPV modules. The module was modelled in 2D with the heat sink attached beneath the solar cells. The simulation resulted in a reduction of solar cell temperature of 14.8°C under heat flux of 1000 W/m^2.

An experiment of passive cooling on PV module conducted by Gotmare *et al.,* [14] proposed an aluminum heat sink attached to the back side of a PV panel. The heat sink was consisted of fins with different sizes, number of perforations and perforation distance. The installation of fins resulted in a reduction of the panel temperature by 4.2%. Moreover, an average power output increase of 5.5% was observed in the case of PV panel with fins.

Perforation influence on passive cooling for PV module has been studied by Abd-Elhady *et al.,* [15] by drilling through holes on the free area of a PV panel and observing the performance through experimental and numerical methods. It had been found from the study that addition of holes assists in cooling the PV panel and decreased the overall surface temperature of the PV panel. An increase in the number of holes also decreases the PV panel temperature until a certain number of holes, where the average panel temperature decrease becomes marginal. Moreover, there is a critical diameter for the through holes, after which cooling of the panel decreases and the temperature increases.

Popovici *et al.,* had numerically examined a passive cooling method with fin-attached copper heat sink for PV module [16]. In a 3D simulation model, the heat sink was attached beneath a layer with thermal characteristics of the PV cells. The study was conducted using ANSYS Fluent software, using variation of fin height, number of perforations, and fin inclination towards vertical axis. Results of simulations showed a temperature difference of 10°C and a 6.97 – 7.55 % rise of maximum power produced by the PV panel, as compared to the base case.

The objective of this research is to solve the problem of overheating of PV panels by means of passive cooling using heat sink. A numerical model is developed to simulate the temperature distribution on the PV panel and velocity profile of the air passing through the heat sink. The model is realized by using ANSYS Fluent software which could provide accurate results with ease of use and modification before building a prototype product.

It is crucial to understand the structure of a PV panel to acquire accurate results and realize correct simulations. PV panels could have different configuration of layers, depending on the manufacturer and the technology for fabrication. A typical example of the structure was provided by Bayu *et al.,* [17]. The main layers of a PV panel are: exterior glass, ethylene-vinyl acetate (EVA), PV cells, another layer of EVA, and polyvinyl fluoride (PVF) film. Table 1 provides the thermo-physical properties of the layers of a PV panel.

Table 1
Properties of the layers of a photovoltaic panel [17]

Layer	Thickness (m)	Thermal Conductivity (W/m·K)	Density (kg/m^3)	Specific heat capacity (J/kg·K)
Glass	0.0032	0.7	2450	790
EVA	0.0005	0.311	960	2090
PV Cell	0.0002	130	2330	677
PVF	0.0003	0.15	1200	1250

2. Research Methodology

This paper examines the influence of heat sink on the operating temperature of a PV panel during a clear day in the summer. A unique layer with the thermal characteristics of PV cells was considered as the PV panel. The panel was oriented vertically, with the heat sink attached to the rear surface of the panel. An air channel with a width of 0.1 m was situated on the back of the module to extract heat from the heat sink by means of convection heat transfer.

Aluminium was selected as the heat sink material due to its high thermal conductivity [18]. Furthermore, its lightweight, ease of machinability, and low cost would be advantageous if a prototype would be realized in further studies. The heat sink was composed of a number of fins attached to a baseplate. The fins were perforated to improve air circulation around the heat sink and to absorb more heat from the panel [19].

Figure 1 shows the proposed geometric design. The heat sink model was created using SolidWorks 2018 and then converted into IGES (.igs) file format before being imported into ANSYS DesignModeller. Circular holes on the fins were placed at a distance of 0.03 m one to another. Table 2 describes the dimensional characteristics of the heat sink. Fluid domain was created using ANSYS Design Modeller after the heat sink geometry was added. The hydraulic diameter of the air channel was 0.166 m.

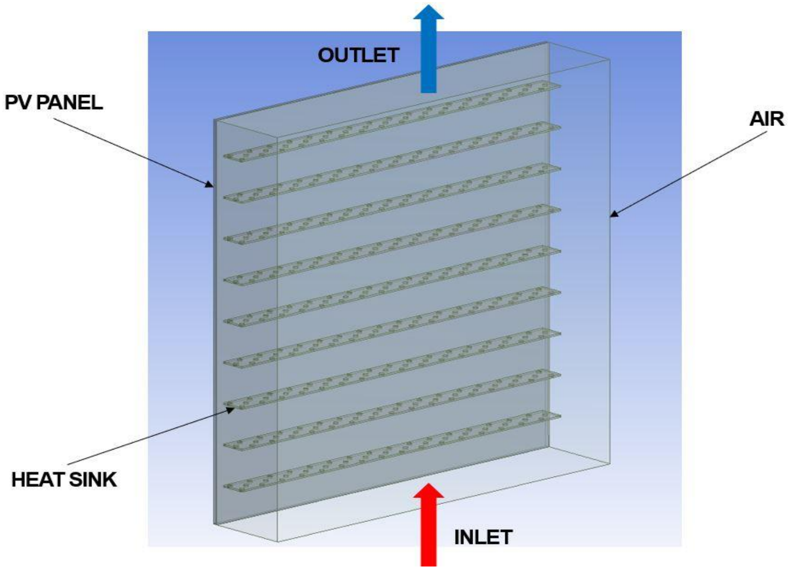

Fig. 1. Heat sink design

Table 2
Dimensional characteristics of the heat sink

Specifications	Size (m)
Fin height	0.03
Fin length	0.48
Fin thickness	0.002
Fin holes diameter	0.003
Distance between fins	0.05
Heat sink base length	0.5
Heat sink base width	0.5
Heat sink base thickness	0.002

Meshing was done with cell size of 1 mm and 2 mm for the heat sink and 4 mm, 6 mm, and 8 mm for the fluid domain. Mesh independence study was conducted to obtain simulation results which were independent of the number of cells [20] (Figure 2) Different refinements of the mesh are displayed in Figure 3.

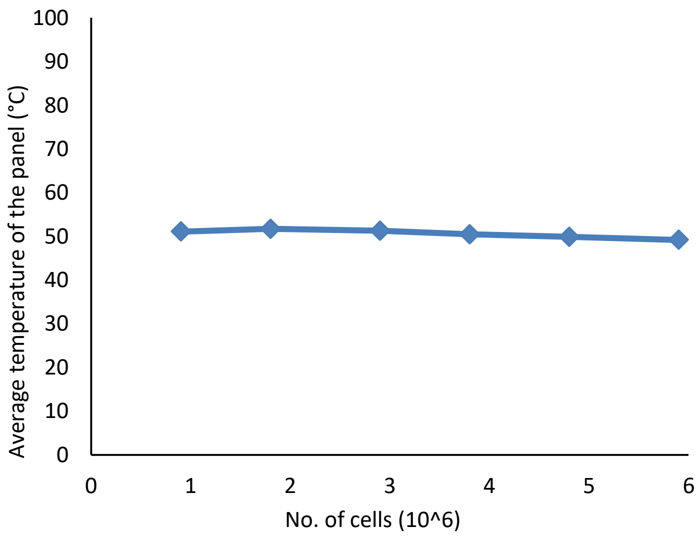

Fig. 2. Mesh independent study

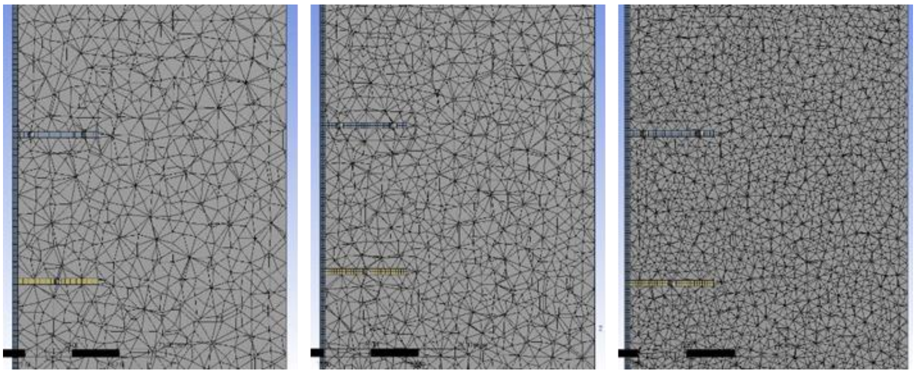

Fig. 3. Different refinements of the mesh, 2 mm and 8 mm (left), 1 mm and 6 mm (middle), 1 mm and 4 mm (right)

Steady-state condition with control volume was assumed for the simulation. Inlet velocity was set at a constant value of 1.5 m/s. The corresponding Reynolds number for the imposed velocity was 13100 [21], obtained from the equation

$$Re = \rho \frac{VL}{\mu} \tag{1}$$

For the Reynolds number, turbulent flow regime was considered. Re-Normalization Group (RNG) k-ε turbulence model was applied, recommended for air flow inside channels [22]. Turbulence intensity of 4.8% was estimated using the equation

$$I = 0.16 \cdot Re^{-\frac{1}{8}} \tag{2}$$

Inlet temperature was set to 25°C, with the normal component of solar radiation applied to the outer surface of the panel using heat flux was varied from 300 – 1000 W/m^2. Semi-Implicit Method for Pressure-Linked Equation (SIMPLE) scheme was applied for the pressure-velocity coupling, with Second Order Upwind discretization to improve accuracy of the final solution [22]. Convergence criteria of 10^{-6} for energy equation and 10^{-3} for pressure, velocity and continuity equations was configured for the iterative calculations.

3. Results and Discussions

Results of the simulation are presented as contours of temperature distribution across the whole domain and velocity profile of the airflow. Figure 4 represents the base case's temperature spectrum without fins attached. The average temperature reached 38.4°C, 47.2°C and 69.4°C for heat flux of 300 W/m^2, 500 W/m^2, and 1000 W/m^2, respectively.

Temperature range of the case with heat sink installation is shown in Figure 5. Average temperature decreased to 32.3°C, 37.1°C and 49.2°C for heat flux of 300 W/m^2, 500 W/m^2, and 1000 W/m^2, respectively. This shows an improvement of the heat transfer performance from the panel to ambient air. Velocity profiles of the airflow are presented in Figure 6 for cases with fins and without fins under applied heat flux of 500 W/m^2.

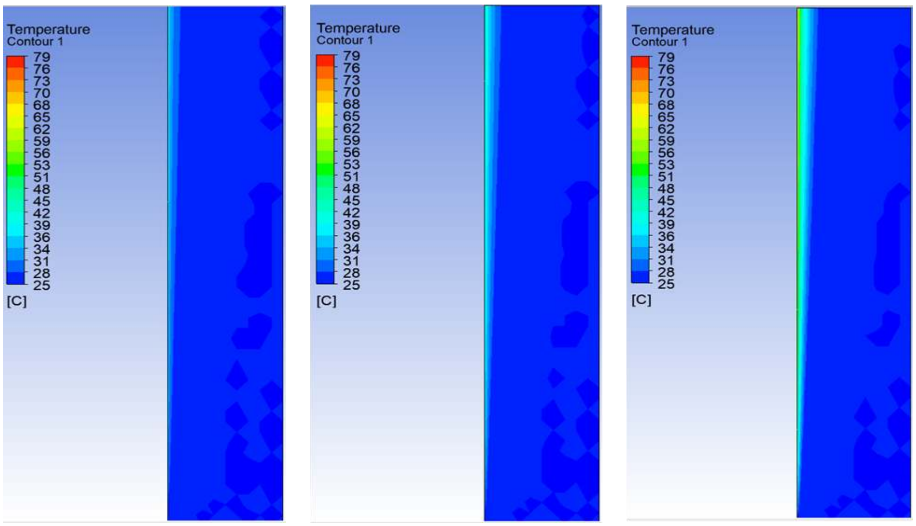

Fig. 4. Base case temperature spectrum for heat flux of 300 W/m^2 (left), 500 W/m^2 (middle), and 1000 W/m^2 (right)

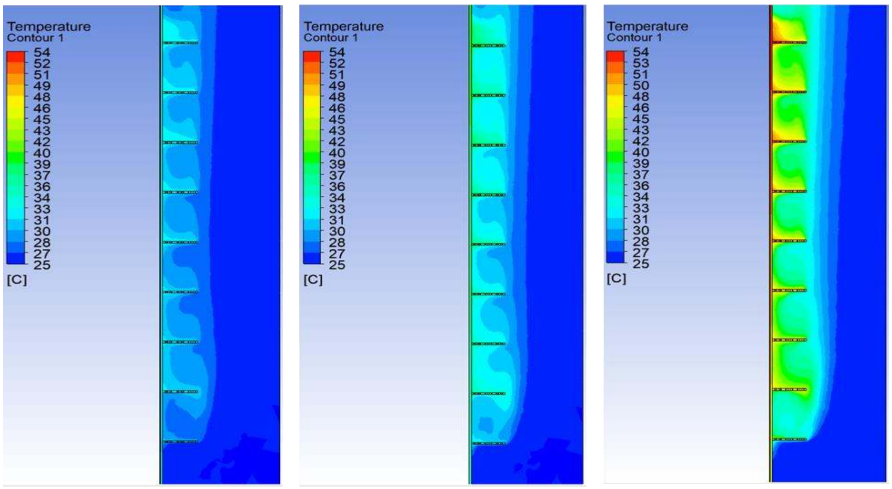

Fig. 5. Temperature spectrum of the case with heat sink for heat flux of 300 W/m^2 (left), 500 W/m^2 (middle), and 1000 W/m^2 (right)

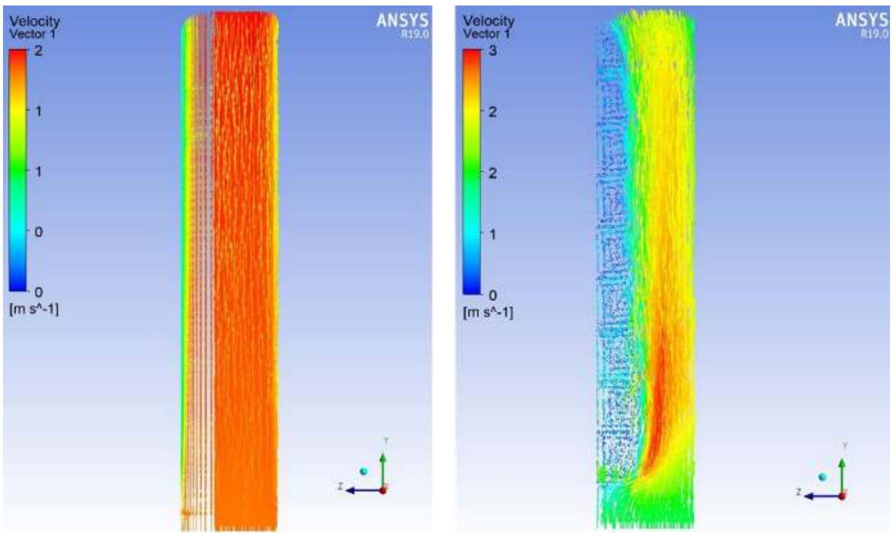

Fig. 6. Velocity profile of the airflow for the base case (left) and case with heat sink (right)

Figure 7 shows the average temperature of the panel under variable heat flux with heat sink and without heat sink. The increasing amount of heat flux contributes to the rise of the panel's average temperature. Overall average temperature for the case with heat sink is lower than the case without heat sink due to the heat sink provided better rate of heat transfer. The influence of heat sink in reducing the PV panel operating temperature is presented in Table 3. The temperature coefficient is -0.004%/°C, according to [23].

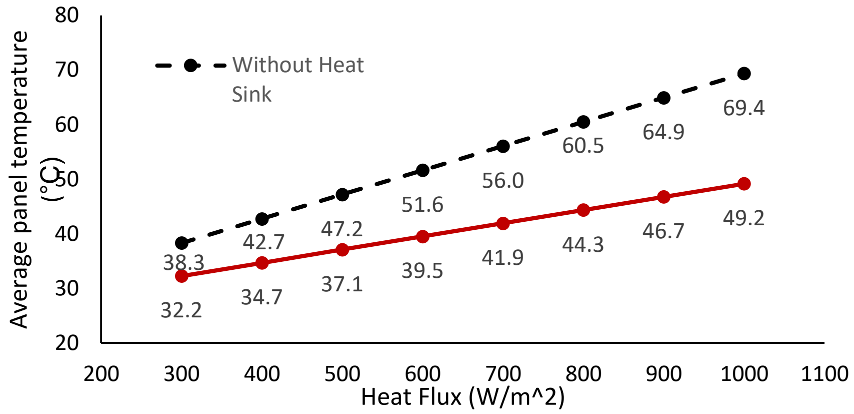

Fig. 7. Average panel temperature under variable heat flux

Table 3
Influence of average operating temperature to PV panel performance

Case	Heat flux [W/m2]	t_{ave} [°C]	[%] of P_N	η	P_S [W/m^2]	P_{el} [W]	Raise over case without heat sink [%]
Without heat sink	300	38.3	94.7	0.151	45.4	11.4	-
	400	42.7	92.9	0.149	59.5	14.9	-
	500	47.2	91.1	0.146	72.9	18.2	-
	600	51.6	89.4	0.143	85.8	21.4	-
	700	56	87.6	0.140	98.1	24.5	-
	800	60.5	85.8	0.137	109.8	27.5	-
	900	64.9	84	0.134	121	30.3	-
	1000	69.4	82.2	0.132	131.6	32.9	-
With heat sink	300	32.2	97.1	0.155	46.6	11.7	2.58
	400	34.7	96.1	0.154	61.5	15.4	3.44
	500	37.1	95.2	0.152	76.1	19.0	4.43
	600	39.5	94.2	0.151	90.4	22.6	5.42
	700	41.9	93.2	0.149	104.4	26.1	6.44
	800	44.3	92.3	0.148	118.1	29.5	7.55
	900	46.7	91.3	0.146	131.5	32.9	8.66
	1000	49.2	90.3	0.145	144.5	36.1	9.82

where t_{ave} – average temperature of PV panel [°C], P_N – nominal power produced at 25°C [W], η – conversion coefficience, P_S – specific electric power [W/m^2], and P_{el} – electrical power produced by the studied PV panel [W]

4. Conclusions

The performance of aluminium heat sink as a cooling system for PV panel was studied. Heat sink installation increased the heat transfer area on the back of the PV panel so that the rate of heat transfer from the panel to the ambient air increased. Perforations of the heat sink's fins also aided the air circulation around the fins and created air vortices which increased the heat transfer as well.

For the case without heat sink, maximum produced power could reduce into 82.2% of the nominal (STP) one when the panel receives heat flux of 1000 W/m^2. For the case with heat sink, maximum produced power could be maintained at 90.3% of the nominal (STP) one when the panel receives heat flux of 1000 W/m^2, which showed better electrical power output and efficiency, compared to the case without heat sink.

The usage of heat sink could reduce the average operating temperature, ranging from 6 – 20°C. The proposed method could represent a cheap and flexible solution for cooling of PV panels. The simulations conducted could also provide valuable insight if an actual prototype or experiment would be realized in the future.

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