Performance Improvement of Photovoltaic Module Using an Air-Cooling Micro Finned Heat Sink

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Abstract: In this work, improved PV panel was fabricated by replacing the tedlar layer with aluminum alloy micro pin fin heat sink to increase the heat transfer conduction. Air flow system was designed and implemented to apply force convection on the heat sink, which named MPFHS-PV/T integrated system, to decrease the PV module temperature. The integrated system was tested on 25Jun 2019 in Baghdad climate and the results recorded as flowing: decreasing the PV module temperature by 14.65% along with electrical performance improvement by 13% for the output power and 13.32% for efficiency. The daily averages of electrical efficiency .1102%, thermal efficiency 40.94% and overall thermal efficiency 51.9%.

Keywords: Micro, Heat sink, Photovoltaic module, Air-cooling system, Performance improvement, Micro finned heat sink.

| Symbol | Meaning | Unit |
|--------|---------|------|
| $AB$   | The Fins Base Area | $m^2$ |
| $I_s$  | Solar Radiation. | $W/m^2$ |
| $I_{mp}$ | Maximum Current of The PV Module at the Maximum Power | $A$ |
| $V_{mp}$ | The Maximum Voltage of PV Module at Maximum Power | $V$ |
| $\eta_e$ | Electrical Efficiency | ____ |
| $\eta_o$ | Overall Thermal Efficiency | ____ |
| $\eta_{th}$ | Equivalent Thermal Efficiency | ____ |
1. Introduction

A photovoltaic module represents a band of PV cells arranged together to convert solar energy to electric power, by investing the behavior of semiconductor with solar radiation. High-efficiency photovoltaic panels become a necessity in today's high power demands globally as many countries move toward renewable energy sources. One of the main limitations to photovoltaic panel’s efficiency is temperature toleration, which has a tremendous impact on it, which will lead to deteriorating performance and eventually stop working [1]. The need for thermal management in PV panels becomes imperative to emit this unwanted heat away. Various types of heat sinks have been designed to address this issue in PV panel, radiators, and printed circuit boards. One particular solution which is micro fins has received extensive research. Micro fins aim to increase the heat transfer through the extension of the exchange surface area [2]. Fins cross section can be a square, elliptical, cylindrical, and rectangular or any other shape. Fins attached to the base of a heat sink to increase the heat transfer area, and gather as many fins on the base of the heat sink as possible to provide extra heat transfer area [3]. But for the case of natural fluid flow, increasing fin density can cause obstruction to the fluid flow during fins and reduce heat transfer, [4]. Also, higher fin density at forced fluid flows may lead to increase power consumption, which results in high power consumption, thus reducing the system efficiency, [6]. For these reasons, Engineers have to determine a proper fins density and fins array arrangement that optimally work for a specific system. This leads to an abundance of possible arrangements for the fins.

PV panel cooling system utilizes water and air which is a thermal unit appended to the rear side of the module. However, most preferred is air because of the minimal use of the material and low-cost operation in spite of its thermal physical properties [5]. The thermal performance of an air circulation system to remove heat is spacious used due to air properties such as low viscosity, small density, and a little power fun consumption.

Many research carried out and various technologies utilized to improve the performance of PV panels. The related studies of the heat sinks with various geometries and arrangements of fins, with heat sinks effect on the cooling process and heat flow are reviewed. As well as, it included the outcomes of using micro fin heat sink as a useful technique for cooling and different flows such as free and forced convection. Peles et al., 2005 [6] investigated the phenomenon of pressure drop also heat transfer for flow over the micro pin fins heat sink. The result was that quite low thermal resistances were obtainable at using the pin fin heat-sink. Abel Siu-Hoetetal., 2007[7] carried on an experimental study for heat transfer and pressure drop features for a heat sink of micro pin fin. The measurement of temperature distribution and pressure drop were used to estimate averaged local Nusselt number (heat transfer coefficient) and the average friction factor. The found results were the coefficient of Heat transfer had a higher number near the heat sink entrance and decreased with the flow direction. Mahmoud et al.2011 [8] studied the effects of fin's high for the range of 0.25 - 1.00 mm in thermal performance of copper heat sinks. The results were the rates of convective coefficient improved when decreasing fin height or increasing fin spacing.

The micro-fins heat sink is our focus of an investigation, as a model of micro-fins with a duct attached to the rear surface of the panel developed that allows studying the effect of micro-fin as a cooling system on panel electrical output at a different velocity of fluid flow. The main objective of
this work is to reduce PV panel temperature by employing a micro fins heat sink, and estimating the improvement in heat transfer carried by the introduction of micro fins with forced convection of airflow in the cooling channel.

2. Methodology:

For writing the equation of energy balance for the suggestion improved PV module with a thermal collector system, these assumptions are used: 1. A system is supposed to be at nearly a steady state for any time during their execution, 2. whole thermal characteristic for materials are supposed to be independent on temperature [9]. 3. The EVA (Ethylene-vinyl acetate) transmissivity is close to 100 % [10].

The formulated equation of energy balance is:

\[
\text{Solar energy incident on panel} = \left\{ \begin{array}{l}
\text{Energy loss from upper surface} + \\
\text{Output electric energy} + \\
\text{Heat separated to thermal collator channel}
\end{array} \right. \tag{1}
\]

The electrical efficiency of a module is calculated as follow:

\[
\eta_e = \frac{I_{mp}V_{mp}}{I_s \times AB} \tag{2}
\]

Thermal efficiency is defined as follows [11]:

\[
\eta_{th} = \frac{\Delta \text{Hairflow}}{AB \times I_s} \tag{3}
\]

While, the overall thermal efficiency \(\eta_o\) can be obtained by the following equation [12]:

\[
\eta_o = \eta_e + \eta_{th} \tag{4}
\]
3. System Description

The PV panel has been developed by replacing the Tedlar layer with a micro finned plate, Figure 1 shows the fined plate which was fabricated by CNC machine. The cooling system depended on forced convection for the micro pin fin heat sink (MPFHS). MPFHS was enveloped by an isolated channel (a Perspex plastic channel) for flowing the cooling fluid (air) as a forced convection. This system will name MPFHS-PV/T system and its schematic is presented in Figure 2. It consists of a glass layer, EVA layer, cell layer, EVA layer and a heat sink of micro pin fins as well as an airflow channel. All these components have been described in detail with their physical properties and dimensions in Table 1. The schematic of the submitted MPFHS-PV/T integrated system is displayed in Figure 3. The experiment was performed on the site of Baghdad/Iraq (The latitude of Baghdad, Iraq is 33.3, and the longitude is 44.36), during Jun 2019.

![Figure 1: Micro Finned Plate Heat Sink](image1.png)

![Figure 2: View of Cross-Sectional MPFHS-PV/T System](image2.png)
Table 1: Dimensions and thermal properties of the proposed PVT module component.

| Layer       | Thickness (t), (M) | Thermal conductivity (K), (W/MK) | Absorptivity (α) | Reflectivity (A) | Transmittance (τ) | Backing factor (bc) | Emissivity (ε) |
|-------------|--------------------|---------------------------------|------------------|------------------|-------------------|---------------------|-----------------|
| Cover glass | 0.0032             | 1.0                             | 0.05             | 0.05             | 0.9               | 0.9                 | 0.91            |
| EVA(1)      | 500×10⁻⁶           | 0.35                            |                  |                  |                   |                     |                 |
| PV cell     | 180×10⁻⁶           | 148                             | 0.85             | 0.15             | 0.9               | 0.9                 | 0.9             |
| EVA(2)      | 500×10⁻⁶           | 0.35                            |                  |                  |                   |                     |                 |
| Heat Sink Base | 0.003            | 78                              |                  |                  |                   |                     |                 |

| Tested heat sink Geometry | Fin length (Lfin),mm | Fin width (d),mm | Fin spacing (S),mm | Fin number (Nfin) | Kfin w/mk | AB m² |
|---------------------------|----------------------|------------------|--------------------|-------------------|-----------|-------|
| Tested heat sink Geometry | 1                    | 0.9              | 1.5                | 29150             | 195       | 0.1444|

| Channel Geometry | Channel height(Hch) (m) | Channel length (Lch) (m) | Channel length (Wch) (m) | Material |
|------------------|------------------------|--------------------------|--------------------------|----------|
| Channel Geometry | 0.02                   | 0.38                      | 0.38                      | Perspex plastic |
The photovoltaic panels used in the experimental work are two units of 21.4W, monocrystalline type, manufactured in AL-Mansoor Factory/Ministry of Industry. The layers that constructed these two panels are shown in Figure 4.

Each half-hour, the value of solar radiation, cell temperature, inlet, outlet fluid temperature, the current and voltage related to maximum power and ambient temperature by temperature recorder have measured. Measurements were taken on Jun 25 in Baghdad’s Weather conditions and at a fixed flow rate of 4.5 m/s in the cooling duct. The measurements started at 8:00 AM and ended at the 14:30 PM.
4. Results and Discussion

The PV module temperature during June may reach more than 70°C, due to the influence of hot climate in Iraq. The improved PV module has been tested on Jun-19-2019 and its performance result has been compared with that of the traditional module and without any cooling system or under free convection effect. Figure 5 shows hourly temperatures distribution of improved PV module along with traditional module, ambient temperature and radiation intensity. There was an expected enhancement in average operating temperature about 3.2% due to the existence of micro finned plate at the back side of improved module.

Figure 5: Hourly Temperatures of Improved PV Module Along with Traditional Module and Ambient Temperature

The experimental performances of MPFHS-PV/T integrated system were conducted at Baghdad city on Jun 25 2019 from 8:00 AM to 14:30 PM. The airflow velocity in cooling channel was determined at 4.5 m/s due to its tangible effect on PV module temperature. These data are measured by using solar power meter, digital thermometer and wind speed device, respectively. Figures 6 show hourly solar radiation, wind speed, ambient temperature along the day time on Jun 25.

Figure 7 presents a comparison of hourly PV modules temperatures during the day of measuring with and without cooling. The temperature for the non-cooling solar module varies from minimum values of 53.6 °C at 8 AM to maximum values of 72.4 °C at 12:30 pm, whereas for the cooling module it varies from a minimum values of 44.5 °C at 8 am and a maximum value of 65.3 °C at 12 pm. This figure reveals that the use of the cooling system caused to decrease in the average daily operating temperature of two modules about 13.5.
Figures 8 illustrate output voltage during the testing period. It was found that it was an enhanced of 6.01% in average daily output voltage. This enhances had been achieved due to a reduction in operating temperature of module. Voltage increasing has a positive influence on the productive power and electrical efficiency of improved module, as represented in Figures 9 and 10. The percentage increases are 13% and 13.32%, for output power and efficiency at 12:00 PM respectively.

Figure 6: Climatic condition on Jun 25 2019, modules in Baghdad city temperature

Figure 7: Hourly temperatures for PV in a different state along with ambient

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Figure 8: Hourly maximum voltage cooling for cooling and not cooled PV module

Figure 9: Hourly maximum power for and not cooled PV module
Figure 11 shows the hourly variations of heat energy gained and solar radiation. Thermal energy gained and solar radiation is connected directly to each other, which was the reason for the observed change in airflow temperature difference along with enhancement in module temperature efficiencies. The thermal efficiency variations for each hour during measuring date have been depicted in Figure 12. Solar radiation, panel’s area, and airflow velocity played a main role in evaluating the thermal efficiency. The multiple efficiencies of the MPFHS-PV/T system which converts solar energy into electrical and thermal energy are shown in Figure 13. Cooling the PV module not only recaptures the excess thermal energy, but it also keeps its electrical efficiency during the time operation in hot climatic condition. The daily averages of electric, thermal along with overall thermal efficiency were found to be 11.02%, 40.94% and 51.9% respectively. The air flow rate extracts thermal energy from the Micro fined heat sink at the panel back side also fairly enhances its electrical efficiency.
5. Conclusion

The improved PV module and airflow channel to collect the excess are one of the solutions to tempered module temperature rising. The improved PV module and airflow channel to collect the excess heat are one of the solutions to tempered module temperature rising.

A prototype for a single channel solar collector with micro bin fins heat sink has been made and the performance outputs have been analyzed. The use of the proposed cooling system has the potential to achieve an increase in output power of 13%, and 13% for efficiency when compared with traditional module results. While the decreasing in average daily temperature of module was 14.65%. The daily averages of electrical, thermal and overall thermal efficiency were found to be 11.02%, 40.94% and 51.9% respectively.

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