Analysis and Performance improvements of Photovoltaic system by using fins for heat reduction by CFD

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Abstract. The efficiency and power output of the solar PV panel decreases with an increase in temperature. The efficiency of a monocrystalline photovoltaic panel decreases around 0.3\% for every degree rise in temperature after 30°C. By using different techniques we can reduce temperature. A heat sink made up of aluminium plate with fins attached to the PV panel which enhances heat rejection. The analysis of the system was done in computational fluid dynamics (CFD). The static and transient analysis was done and an optimal heat sink was designed. The silicon plate which is designed to simulate the PV panel was maintained at a temperature of 60°C for the analysis. It was found that the optimal fins of heat sink have 1.5 mm thickness and each of 40 mm height and 30 mm spacing between the fins and the natural air flow is maintained through the fins which is parallel to fins. There is a reduction in temperature of panel by 4°C in static conditions by natural convection.

1. Introduction
The production of electricity through photovoltaics was one of the most prominent and eco-friendly as compared to fossil fuels. Solar modules will absorb energy from the sun to produce electricity. They have very less efficiency. Commercially at present they are producing around 13\% to 18\% which was at standard temperature of around 25°C at lab conditions which depends on the type of the cell. As the temperature increases above 30°C there was a decrease in efficiency of solar module. The increase in temperature of solar cell reduces the efficiency of solar panel. The decrease in solar cell temperature results in increase in the efficiency of solar cell. There are many ways to decrease the temperature of solar cells. Different types of heat sinks where placed at different lengths and angles and analysed the overall performance of PV cells and there output through experimentally and CFD analysis [1]. The Photovoltaic modules are analysed by installing air conditioners which shows that 7.2\% of electrical efficiency and 6\% of the performance ratio of the module was increased when compared with cooling and without cooling [2]. The researchers investigated the possible method to decrease the temperature of module for house hold purposes and for different radiation conditions the variation of output P,V,I and efficiency and analysed a setup for household system which increases at 47\% with cooled condition and efficiency by 35\% and hot water to 107\% and payback period is reduced [3]. PV module cooling by placing fins in which water passes which are angled perpendicular through the pipe in fins and analysed the 250 Watts and found an increase of 20.96 Watts [4, 5]. Energy efficiency of PV panels under normal conditions in Greece which shows 18\% lower than lab conditions [6]. Thermal and electrical performances of 25 Watts PV modules integrated with heat spreaders and cotton wick structures for cooling panel which results in 12\% increase in electrical efficiency [7]. Very low amount of energy efficiency was produced by PV
modules and remaining was absorbed by the PV panels which increase the temperature of cells which results in redetection of Voc and Fill factor. And also increases in recombination of charge carriers which decrease the efficiency [8, 9]. Temperature increase effects the production in short term and degradation and aging of the cells takes place which results in decrease in performance [10, 11]. The energy produced by PV panel that was mainly depends on factors environment and tested under nominal lab conditions which does not have any losses and panel does not produce its lab performances under external climatic conditions [12]. Many losses may occur when it is used in external environmental factors like corrosion, hot spots, electrical circuits between modules and glass rupture helps in reducing the efficiency of PV panel [13]. Crystalline silicon PV cell modules are the most broadly utilized around the world, due to the expense and demonstrated dependability. Be that as it may, the proficiency of this innovation depends on its working temperature, particularly in hot situations where, for each 1 °C increment in the sun based module, lost electrical intensity of 0.5% could influence the framework [14, 15]. A successful method to check the pace of warm corruption of a PV module is by decreasing its surface temperature. This can be accomplished by cooling the framework (or then again keeping it from warming up) during activity. As per distributed contemplates, for their application in PV modules, cooling frameworks can be named dynamic or latent. Past work has demonstrated that dynamic frameworks can be powerful [16, 17].

2. Construction of System for validation
The experimental setup was a portable solar PV system which consists of one 63Wp monocrystalline module and two 30Wp monocrystalline modules. Portable solar PV system in which comparative analysis was made between two 30Wp. One module was placed at right side of 63Wp panel and another which was placed with fins was at the left side of 63Wp panel. Aluminium was used for heat transfer because of its high thermal conductivity and weight. Aluminium Heat sink with 10 fins, made up of then aluminium sheet of 1.5 mm attached to the aluminium plate of module length and the fins at equal distance of 30mm by tig welding. The length of fin is 40 mm. Thermal paste is applied between the module and heat sink and gap between plate and fins for reducing the convective losses and for good thermal conductive and electrically insulated. The both panels are placed at a height of 35cm at a tilt angle of 13 degrees facing south in order to maximize the solar radiation utility. Thermocouple was placed on the top of 30Wp module and two thermocouples was used for module with fins. One was at the top of 30Wp module and another thermocouple at the fins.

![Figure 1. Experimental Setup](image_url)

3. Design of Heat Sink
In order to maximize the heat transfer the fin should have the length of having the property to convective resistance should be larger than the increase in conductive resistance. The length of the can be calculated by using biot number.
Grashof number:
\[ Gr = g \cdot L^3 \cdot \beta \cdot (T_p - T_a) \cdot \frac{\rho^2}{\mu^2} \]
Prandtl number:
\[ Pr = \mu \cdot C_p / k \]
Rayleigh number:
\[ Ra = Gr^* Pr \]
Nusselt number:
\[ Nu = 0.54 \cdot Ra^{0.24} = h \cdot L / k \]
g - Acceleration due to gravity
L - length
\( \beta \) - Thermal expansion coefficient
T_a - ambient temperature
T_p - Panel temperature
Pr - Prandtl no
k - Thermal conductive of aluminium 204W/m-K
C_p - specific heat capacity 1005 J/Kg-K
By taking properties at 60°C for aluminium we get \( h = 8.291304 \) W/m2-K.

Biot number:
\[ Bi = hL / 2k \]
If \( Bi = 1 \), then minimum heat flow
If \( Bi < 1 \), the heat flow rate will increase as Biot number is not decreasing.

### Table 1. Variation of Biot number with height of the fin

| Length(cm) | Biot number     |
|------------|-----------------|
| 0.01       | 0.000144        |
| 0.02       | 0.000121        |
| 0.03       | 0.000109        |
| 0.4        | 0.0000102       |
| 0.05       | 9.61E.^-5       |
| 0.06       | 9.18E.^-5       |
| 0.07       | 8.83E.^-5       |
| 0.08       | 8.54E.^-5       |
| 0.09       | 8.3E.^-5        |
| 0.1        | 8.08E.^-5       |

Table 1. show the variation of Biot number with height of the fin. Biot number less than 0.0001 show very low conduction heat transfer and so adding fin height above 0.4 cm will not show any effect on this system and increasing fin height above 0.4 cm is not necessary because only material consumption increase adding to weight of heat sink but with little effect on the heat transfer system. The spacing between the fins is optimised at 28 mm.

By taking the area of the fin with dimensions as length and breadth as 0.55m and 0.45m respectively. Air Velocity as 1.5 m/sec density as 1.06 at 60°C and specific heat as 1.399 at 60°C and the average temperature difference is taken as 4°C.
The amount of heat removed from the fin is:

\[ Q = m \cdot C_p \cdot \Delta T \]
\[ = \text{area} \cdot \text{velocity} \cdot \text{density} \cdot C_p \cdot \Delta T \]
\[ = [(0.55 \cdot 0.45) \cdot 1.5 \cdot 1.06] \cdot 1.399 \cdot 4 \]
\[ = 2.2 \text{ KJ} / \text{sec} \]

4. CFD analysis of the system

Computational fluid dynamic analysis has been made on to the above system in which the design of the system has been imported from CATIA with a measurement of 450 mm x 350 mm for silicon plate an extended thickness of 10mm and aluminium sheet of 450 mm x 350 mm and thickness of 2 mm and fins of 2 mm thickness and 40 mm height. Fine mesh has been generated and given boundary conditions with an air (fluid) inlet and output as pressure outlet with a given fluid input velocity of 2m/sec and having ambient temperature which is parallel to the fins. The temperature at the top of the silicon plate was maintained at 60°C and analysis of transient state mode for 10 seconds and steady state mode of analysis has been made. The temperature contours has been analysed for the given input in steady and transient conditions as in figure 2 and figure 3 respectively.

![Figure 2. Temperature contour for Steady state mode of analysis](image1)

![Figure 3. Temperature contour for Transient mode of analysis](image2)
In this system when maintained at a temperature of 60°C and input fluid velocity of 2 m/sec and at centre of the panel fin temperature on the panel was measured as 50.6°C.

5. Results and Discussion
In this comparative analysis the comparison was made between the nominal fin temperature and fin temperature in CFD. The CFD analysis was done with different boundary conditions for individual results.

The results in figure 4 shows that for the temperature of the panel was maintained at 60°C and at different input fluid velocity was maintained at 1 m/sec, 1.3 m/sec, 1.5 m/sec, 1.8 m/sec, 2 m/sec on an average the temperature difference between Numerical data and experimental data was found to be 0.35°C-0.55°C for increase in fluid velocity of 0.1m/sec.

Figure 4. Fin temperature for silicon plate maintained at 60°C with different input fluid velocity

![Figure 4](image)

Figure 5. Silicon plate with different temperature with fluid velocity of 1.5m/sec

![Figure 5](image)
The results in figure 5 shows the panel temperature was maintained at 50°C, 52°C, 54°C, 58°C, 60°C and maintained at a constant air/fluid velocity of 1.5 m/sec. And on an average for 1°C the temperature difference between Numerical and experimental results found to change in temperature around 0.55°C to 0.85°C.

![Figure 6. Variation of Temperature and Radiation vs. Time](image)

The experiments recorded for ambient temperature, temperature of PV without fins, temperature of PV with fins and solar radiation. Figure 6 gives the plot of these factors for a time interval of 15 min.

![Figure 7. Power output vs time](image)

The experimental results show that the power output panel with fin is greater than the power output without fin. The above plot was made for power output with a time interval of 15 min.
6. Conclusion
The decrease in temperature of solar panel tends to increase in efficiency of PV panel and by the experimental data it was found that the increase in percentage of power output was around 11% and in numerical analysis it was found to be around 8%. The error for the CFD model was found to be around 3%. The increase in the power output of the system was an average of 2.4 Watts for 30 Wp panel by addition of the heat sink. Numerically calculated results show that 2.2KJ-k/sec by taking a temperature difference of 4°C on an average. But in CFD results shows the temperature contours of heat flow and energy contours and shows that 0.5 KJ-k/sec of energy was dissipated by heat sink in 1 second in transient mode. During experiment, the maximum power output was at 12:30 pm for a radiation of 1100 W/m² is 26.18 W without fin and 28.08 W with fin at ambient temperature of 32.8°C with air velocity 1 m/sec. Maximum improvement in power was 3.18 Watts at 3:30PM. Fins are one of the simplest and easily designable heat sinks which can be attached to any existing PV systems to improve their performance in high temperature environment. Further improvements can be made by varying the design for enhanced heat transfer at low cost and weight of the heat sink.

7. References
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