Efficiency Enhancement by Using a Solar PV Module Free Channel Rectangular Aluminum Fins

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***Abstract:* -** The performance of PV modules decreases with a rise in temperature and the cooling techniques can increase the capacity and effectiveness of PV modules. In order to increase and improve the effectiveness of electrical output by lowering the PV module's exterior surface temperature, rectangular Free Channel Aluminum fins are attached to the PV module's backside surface. The primary objective of this research effort is to look into passive cooling performance of a silicon-based polycrystalline PV module. It was shown that fins had a good chance of lowering PV module temperature and improving efficiency. The work on the use of different geometries of the fin is limited and the effect of their weight, thickness, and type of fin has not been studied extensively. In this work, the rectangular fins with open ends that form a free channel have been explored. The channel allows for airflow, which can ultimately improve the cooling impact of the panel. The experiment was conducted on entirely bright days, with an average ambient temperature of 35.5 °C, solar irradiance ranging from 100 to 1000 W/m2, and non-uniform fluctuations in wind speed with a mean value of 1.5 m/s. The effect of wind speed was also studied in the work. The heat transfer from the PV module after the installation of fins is 3.29 times the heat transfer without fins, and as a result, the maximum temperature drops on the back and front surfaces by 7.3 °C on the experimental day with an average solar radiation value of 646.32 W/m2 and a maximum value of 892.8 W/m2. For the entire day, the average temperatures for the back and front surfaces of PV modules with and without fins are (Tavg) back 3.94 °C and (Tavg) front 4.04 °C, respectively. As a result, it can be said that over the course of a day, the PV module with aluminum fins placed is 3.94 °C cooler than the one without. Electrical output efficiency was increased by up to 6.11% with cooling effect caused by the fins. Fin-induced cooling produced an improved cooling effect i.e. Electrical output efficiency by up to 6.11%. As a result, it is determined that passive cooling of PV modules, especially with rectangular free-channel aluminum fin designs, is the most suitable approach. So, the system can be designed with the use of free channels made up of aluminum to boost the electrical performance of solar power panels and it is recommended to use passive techniques simultaneously to get better results.

Keywords: *PV Module cooling, Passive cooling, Fins, solar cells, renewable energy.*

1. Introduction

Today’s world is inconceivable without electricity and it has been an inseparable part of life. Nowadays, using fossil fuels to produce power is less attractive, and the world is moving towards the use of innovative and renewable electricity generation. Renewable energy is the best alternative to fossil fuels and it has the potential to meet the world's needs for energy both now and in the future. [1]. As a result, greenhouse gas (GHG) emissions have decreased of the increased usage of renewable energy over conventional fuels. As per the latest report, India is in 8th position out of 63 in the climate change performance index (CCPI) 2023. Many countries have already taken the initiative to promote renewable energy resources. In India, the breakthrough occurred with a slight modification in energy policies and the availability of subsidies for commercial and household use of solar energy [2]. The International Energy Agency recently reported that in 2020, the generation of renewable energy will grow at the quickest rate in twenty years. About 278 gigawatts of capacity were added last year, a 45% jump and the largest year-on-year increase since 1999 [3]. Because energy consumption is rising and the consumption of conventional sources of electricity changes the climate, researchers and governments from all over the world are interested in the use of renewable energy. [4]. The Corporate renewables market is coming of age. From being on the fringes of the Power sector it is moving center stage. In recent years one of the fastest-growing sectors in India has been solar energy. The Jawaharlal Nehru National Solar Mission has been launched by the government of India under the Ministry of New and Renewable Energy to produce 20 GW of clean energy by 2022. Still, as of 20th November 2020, the installed capacity is 36.9 GW, with 42 solar parks across India. A total of 2.1 GW of energy is produced using a rooftop PV panel. Presently 34.627 GW of energy is produced using solar energy, including rooftop & ground mounted grid-connected solar power.

Solar energy is utilized by two important methods: photovoltaic (PV) and photothermal. Solar stills, drying, and solar air warmers are only a few of the uses for photothermal systems' usage of heat from sun radiation. Using solar cell technology, solar photons from the photovoltaic (PV) system are immediately converted into electrical energy [5]. For harnessing solar energy to generate electricity, the photovoltaic (PV) panel is a promising technology. Solar PV has the ability to reach the Sustainable Development Scenario level by 2030, which would require an increase of 15% per year in power production from solar PV. By 2030, this growth trend would increase the generation capacity from 720 TWh in 2019.

There are certain external and internal factors which determines the performance of PV Panels. The external environment factors may be intensity of solar radiation, dust over the panels, wind speed and others. The current and output voltage of the module are significantly affected by the operating temperature. [6]. In the PV panel, less than 20% of the incident energy is transformed into usable electrical energy, with the remaining being lost as heat. This heat loss significantly raises the module's effective temperature above the ambient temperature, and higher ambient temperatures exacerbate this effect. Consequently, a substantial portion of energy is wasted as heat in the PV panel [7]. Many correlations are available in the literature that reflect the dependence of electrical conversion efficiency of the module on the working temperature, and most of them have reported a linear relationship [8]. It has been reported in the literature that for every degree of surface temperature increase in PV Cell, the panel efficiency decreases 0.4-0.65% [9].

Consequently, in order to improve the PV module's electrical efficiency and performance, the researchers have discussed various cooling techniques. The cooling techniques can be categorized into passive and active cooling. In order to power mechanical elements like pumps and fans, active approaches need to utilize more electricity. Passive cooling of air, water and conductive cooling are the main categories. It frequently includes additional parts, such as a heat pipe, sink, or exchanger, to facilitate natural convection cooling. There are many techniques used for passive cooling like a fin, PCM, heat pipe fixed to the below of the PV module [11]. The primary focus of this research is passive cooling approaches, which have been proposed to be more efficient in lowering PV cell temperatures while at the same time more cost effective to manufacture.

Active cooling not only increases the power output but may impact economically [12]. While passive cooling does not require a fan or pump, active cooling uses air or water and often requires one.[13]. Implementation of an active cooling technique for a Photo voltaic panel as compared to a passive cooling technique is more difficult and expensive because the passive cooling technique does not need external power for the cooling process [14]. Installing metallic materials with fins on the back surface of the PV panels will improve the cooling of the panels. This installation promotes increased air circulation around the panels, thereby improving their cooling efficiency [15].

By incorporating a heat sink with high thermal conductivity as extended surfaces, the heat transfer area from the solar cell to the ambient environment is significantly increased. This enhanced surface area facilitates more efficient dissipation of heat, leading to improved cooling of the solar cell. [16]. an outdoor experimental study was conducted, comparing the performance of PV panels with and without evaporative cooling. The results revealed a significant 12oC reduction in the PV panel temperature during peak insolation when evaporative cooling was applied. Additionally, the average electric power generation efficiency exhibited a notable 7.7% increase under the influence of evaporative cooling. These findings demonstrate the potential benefits of utilizing evaporative cooling techniques to enhance the performance and efficiency of PV panels in outdoor conditions [1].

The efficiency of a PV module is influenced by several environmental parameters, including sunlight intensity (solar radiation), ambient temperature, PV module surface temperature, humidity, wind speed, dust, shading, and the installation height of the system. Among these variables, solar irradiance and temperature play the most significant roles in affecting the performance of the PV module. The combined effect of high solar irradiance and elevated PV module temperature can lead to overheating of the panel. This overheating adversely impacts the overall performance and conversion efficiency of the PV module. Additionally, it can accelerate cell degradation, leading to a reduction in the cell's lifespan [17].

2. Effect of solar irradiance and ambient temperature

The short circuit current (Isc), which is correlated with light intensity, is influenced by the quantity of photons absorbed by the semiconductor material. [15]. There is very little relationship between the open-circuit voltage (Voc) and light intensity [16-17].

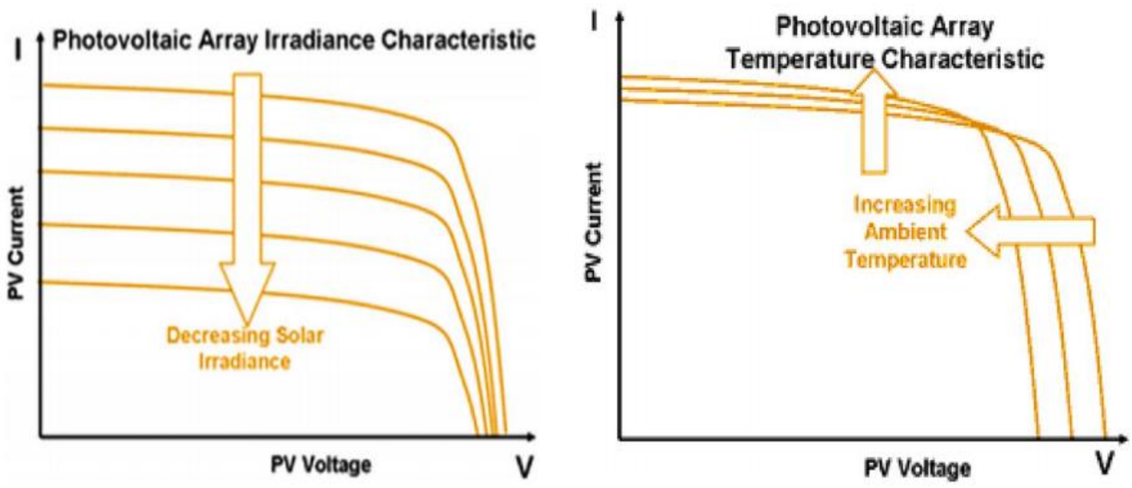


Fig. 1 Effect of solar irradiance and ambient temperature [17]

When the temperature of the PV module rises over 25 oC, the open-circuit voltage (Voc) decreases significantly, while the short-circuit current (Isc) slightly changes. Since these systems' performance is predicated on a Standard Test setting of 25 oC, a one-degree Celsius increase in temperature results in a 0.5% reduction in electrical output and a loss of electrical performance and PV module life. [15-17].

Experimental analysis using passive cooling technique method on flat PV panel by attaching heat sink and wick structure back side of the panel results in the efficiency is 12.03% and average operating temperature is 47.41°C without fin and with fin, it was 12.29%, 44.41°C respectively [16]. The thermodynamic and environmental assessment was done by mounting the aluminum fin at the back surface of the PV module therefore the 7°C reduction in the cell temperature by aluminum fin & entropy generation was also 3.5% lower than the conventional one [2]. The review work presented various cooling techniques and in conclusion, the most proper solution is to reduce module cell temperature [17]. A M Elbereki et al [18] in their research work made a combined technique of planar reflector and backplate finned surface to the PV module and worked on optimization of efficiency. The results reveal an increase of electrical efficiency from 9.81% to 11.2% with a temperature difference of 24.57 °C at 1000 W/m2. The thickness above 2 mm of aluminum fin showed a minor effect on the PV Electrical Performance and efficiency [18]. Another investigation was carried out by attaching a heat sink to the rear of the PV module and employing the passive cooling method. Efficiency improved by 2.74% and temperature dropped by 10.2 C, respectively [19]. Another researcher in his experimental study worked on PV modules with and without fin. It was observed that the open- circuit voltage and electrical efficiency increases up to 12.97% and 2.08% respectively [20]. The aluminum fin was mounted to the rear surface of the PV module for the thermodynamic and environmental assessment, which resulted in a 7°C decrease in cell temperature. & entropy generation was also 3.5% lower than conventional ones [21]. Micro-channel Heat Sink with V-Ribs Using Nanofluids used for Micro photovoltaic Solar Cells, therefore, the MCHS with V-ribs raises the heat transfer rate of the system because of inserted V-Ribs fins [22]. In one of the study, fins and aluminum mesh were attached to a PV Module which reduced the module temperature by 4.35oC and 6.56◦C, respectively [23]. In another study, MPFHS-PV/T integrated system was utilized and it reduces the module temperature by 14.65% and enhanced the electrical performance by 13% [24]. The study presents the reduction of the temperature by heat sink cooled by air the operating temperature was found 56 °C, without fin and maximum produced power was 86% therefore with fin temperature reduced by 10℃ and maximum power produced was 6.97% to 7.55% [25].

3. Need for PV panel cooling with Fin

The surface temperature of PV modules increases due to environmental conditions such sunshine, humidity, wind speed, ambient temperature, and dust. Reducing the operating temperature of the solar panel can increase its effectiveness. [17]. Solar radiation is treated as an uncontrollable parameter as it is quite difficult to modify or control the other parameters. The passive cooling technique using fins could be possible solution and more reliable as the initial cost is low and easy to behind PV panel. The arrangement will ensure convective heat transfer from air to PV Module [15-19]. It has been established that high thermal conductivity heat sink improves the heat transfer area from the solar PV cell to the ambient environment [16]. Temperature decrease was achieved in one study utilizing an aluminum plate heat sink with perforated fins. The arrangement also utilizes the cooling system with air and the temperature got reduced from 85.3 ℃ to 72.8 ℃. This brought an increase in the VOC & MPP by 10% and 18.6% respectively [19]. From the research, it was observed that fin is having enough potential in reduction of PV panel temperature in order to enhance efficiency but the geometry of fins are limited and weight, thickness and type of fin affect the temperature and efficiency. The present paper gives stress on the use of free aluminum Channel rectangular fins instead of solid rectangular, hollow rectangular plate fins. The free channel rectangular shape of fins with open ends improves the cooling effect of the panel.

4. Climatic data of the experimental site

The experimental research was carried out in Nagpur Location with 21.123° Latitude & 79.0021° Longitude. The experiment was conducted during the daytime as shown in Fig. 2 with an average ambient temperature of 35.5 ℃.

Average Solar radiation= 646.32 W/m2 & Average wind speed= 1.5 m/s.

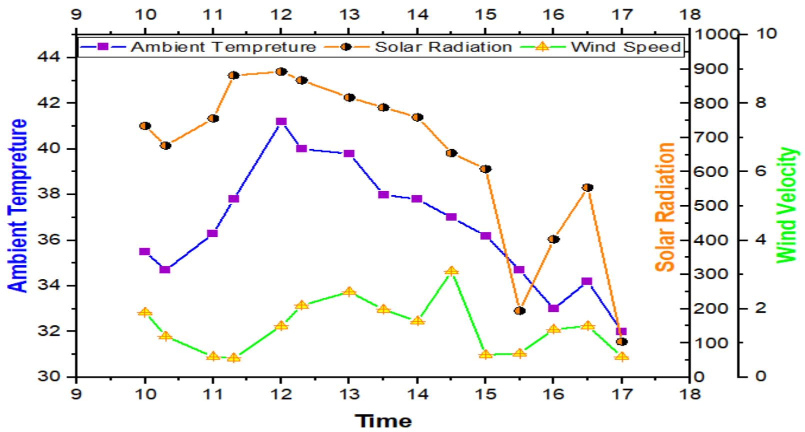


Fig. 2 Variation of climatic factors with time interval

5. Methodology

The grid-connected solar photovoltaic (SPV) power plant which consists of polycrystalline solar PV modules is shown in Fig 3. The said power plant has been in operation since 31st March 2016 and having a total installed capacity of 112.5KW

Fig. 3 Solar Power plant

Table 1. Modules specifications at standard test conditions.

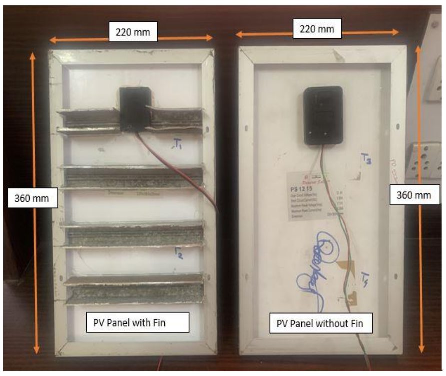
Type of cell	Polycrystalline	Module efficiency	15.3%
Peak power output (Pmax)	15 W	Module area	1584 cm2
Maximum voltage (Vmax)	17.4 V	Open-circuit voltage (Voc)	21.6 V

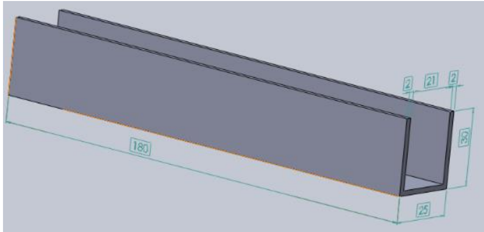
The main aim is to study the thermal behavior of the PV modules, and a comparative analysis has been made with and without rectangular Free Channel as a fin. The experimental arrangement consists of flat PV Panel, multimeter, stand, heat sink, thermal grease, pyranometer, thermocouples and other accessories.

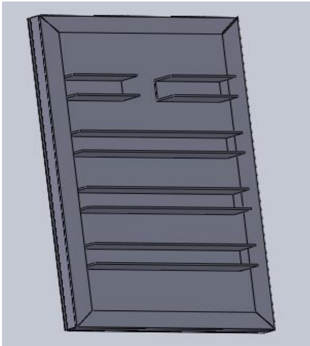
Heat sink

Fig. 4(a) represents the schematic of PV modules. The PV panel's back was covered with aluminum fins and prepared from Hollow Aluminum Rectangular Pipe. Thermal grease is used to attach the heat sink to the solar panel and the properties of Aluminium are shown in Table II.

Table II: Properties of aluminum fin	
Length	180 mm
Wall thickness	2 mm
Density	2.7 g/cm3
Thermal conductivity	204.2







4(a) 4(b)

Fig. 4 Using Free Channel attached at the backside

Figure 5 shows the two PV modules mounted on an aluminum frame at a real solar power plant with a 172.5 KW capacity that is oriented south-east and has a 16° slope to the ground. Six thermocouples are used, which measures the surface temperatures on both sides. In order to measure the surrounding temperature, one thermocouple was positioned in front of each module. A pyranometer and an anemometer were used at the experimental site to detect solar radiations and wind speed every 15 minutes. The temperature was recorded by thermocouple as well as by infrared temperature gun at every 15 min.

Fig. 5 (a) Experimental setup at Lab **Fig. 5 (b) Experimental setup at Roof Top**

6. Thermal analysis of the PV modules

In this part, the associated equations that are utilized to determine the heat transfer rate from the PV modules' finned and unfinned surface area have been described.

The experimentation has been performed on the average ambient temperature of 35.5oC and solar irradiance varying from 100 to 1000 W/m2. If the lower surface of the panel is at a temperature Ts, and the fluid (surrounding air) has a temperature T∞ that is lower than the surface temperature, then according to Newton's law of cooling

$$Q_{convection} = hA_S(T_s - T_a) \tag{1}$$

Where h is the film coefficient, "Ts" and "As" are the surface's temperature and area for heat transfer, respectively. There are two different ways to increase the rate of heat transfer, according to Eq. (1). The first strategy, which is frequently used in active cooling systems, is to increase the convection heat transfer coefficient (h). Active cooling methods actively manipulate the fluid flow or the environment around the system to augment the heat transfer coefficient, thereby facilitating efficient heat dissipation

On the other hand, the second approach centres around expanding the heat transfer area, a characteristic typically associated with passive cooling methods. Passive cooling relies on enlarging the surface area exposed to the surroundings, allowing for enhanced heat dissipation through convection and radiation without actively manipulating the fluid flow.

By understanding these two distinct pathways for increasing the heat transfer rate, engineers and designers can tailor their cooling strategies to suit specific application requirements, striking a balance between active and passive cooling methods based on efficiency, cost, and system constraints.The current study is motivated for the domain of passive cooling. Eq. (2), represents the total heat transfer for finned and unfinned area [19].

$$Q_{totalfin} = nQ_{unfin} + n\eta_{fin}Q_{fin} \qquad (2)$$

$$Q_{totalfin} = nh_{unfin}A_{unfin}(T_{s.unfin} - T_a) + nh_{fin}(T_{s.fin} - T_a) \qquad (3)$$

Where, fin efficiency is represented by

$$\eta_{fin} = \frac{\tanh * m * L_c}{m * L_c} \qquad (4)$$

$$L_c = L + \frac{t}{2} \qquad m = \sqrt[2]{\frac{2h}{kt}} \qquad A_{fin} = 2w(L + \frac{t}{2})$$

Average of wind speed "U" measured during the experimentation = 1.5 m/s, Average Ambient temperature of experimentation location = 36.5 °C, the width of fins "b" is 0.18 m

$$\mathrm{Re} = (\frac{Ub}{v})$$

Where; v = kinematic viscosity of air is 1.5 x 10-5 m2/s

$$h = 0.664 * (\frac{K_{air}}{b}) * (\mathrm{Pr}^{0.3}) * (\mathrm{Re}^{0.5}) \qquad (5)$$

$$h = \frac{Nu * Lc}{Ka}$$

The effectiveness of fin is given by the below equation:

$$\varepsilon = \frac{Q_{fin}}{Q_{no\ fin}} = \frac{nhA_{unfin}(T_s - T_a) + nhA_{fin}\eta_{fin}(T_s - T_a)}{hA_{no\ fin}(T_s - T_a)} \qquad (6)$$

Aunfin= 64878-mm2, Afin=5400-mm2, Ano fin= 79200-mm2, n=4, and Efficiency of fin =0.22 from Eq. (4)] are substituted for these values in Eq. (6) to compute the effectiveness of fins in the current research, which is greater than one, i.e., ε = 3.29. As a result, the amount of heat transferred from the PV module has increased to 3.29 times more than it was before the fins were installed. This indicates that using fins will increase the heat transfer.

$$\varepsilon = \frac{n(A_{unfin} + \eta_{fin} A_{fin})}{A_{no\ fin}} \tag{7}$$

7. Results and discussion

The experimental study has been done to obtain the performance of solar-power module under the condition with and without fins. Several parameters were recorded which includes temperature of the front and back surfaces, open circuit voltage, short circuit current, and further PV panel efficiency have been calculated. As shown in Fig. 5 (b), the four temperatures of solar panels First, the surfaces' (Tfin)back, (Tfin)front, (Tno fin)back, and (Tno fin)front are calculated by averaging the readings from the respective thermocouples mounted to the PV module's two sides.

The greatest temperature reduction following fin installation is shown in Fig. 6. At 7.3 °C, the maximum temperature decreases on the front and back surfaces. For the whole day, the average temperatures for the rear and front surfaces of with and without fins, PV modules are (Tavg)back 3.94 °C and (Tavg)front 4.04 °C, respectively. By averaging the temperatures from 10:00 to 17:00, the values of the average temperature gradient for the whole day are computed. As a result, The PV module with integrated aluminum fins is 3.94 °C cooler than the one without.

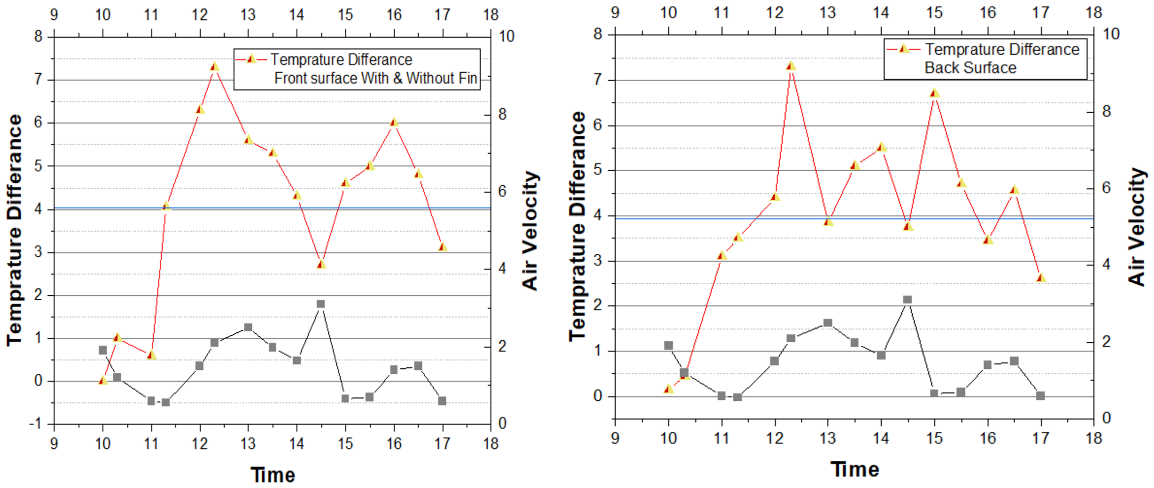


Fig. 6 The difference in surface temperatures between the PV module with fins and without fins on its back and front

The temperature gradient at 10:00 and 17:00 is shown in Fig. 6 to be (T 10:00) back is 0.1 °C and (T 17:00) back is 2.6 C, and on the front surface is (T 10:00) front is 1 °C and (T 17:00) front is 3.1 °C, confirming the lower fin effect at 10:00 and 17:00 as compared to noon. During the hours when solar radiation is less intense and less likely to alter the temperature of the module, the temperature gradient between the surface of the PV module and the ambient temperature is on the lower side as shown in Fig. 6

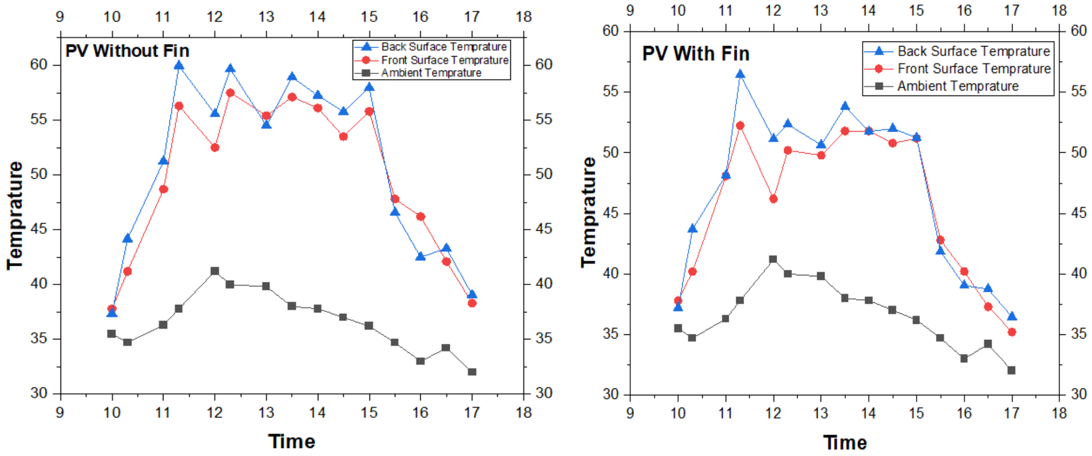


Fig. 7 Temperature of a PV module compared to the ambient temperature with and without fins

Fig. 7 illustrates The PV module's hourly surface temperatures, or Tfin and Tno fin. The figure shows that there is a consistent difference between the two curves of hourly surface temperatures for both the front and rear surfaces.

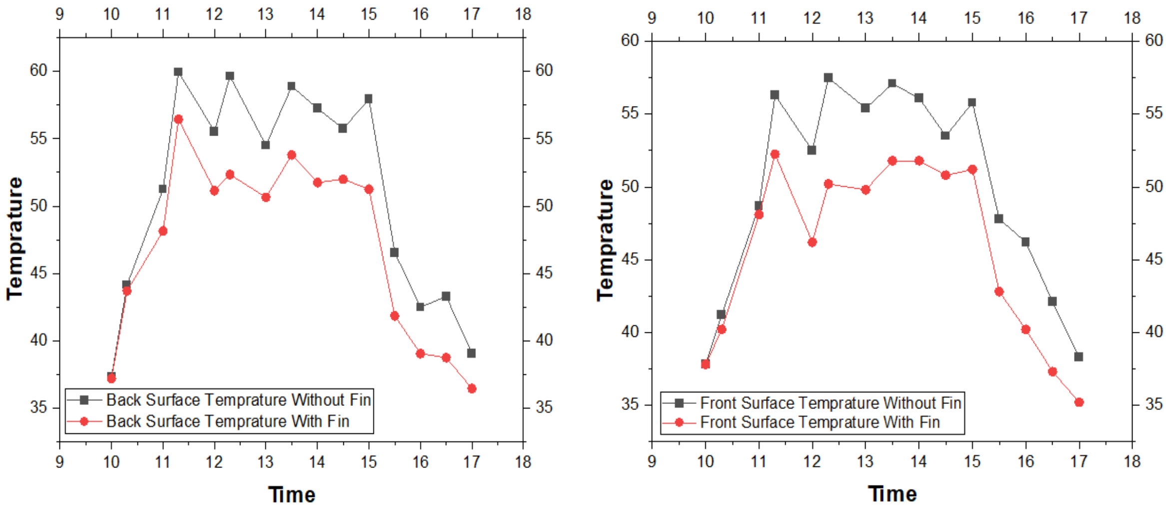
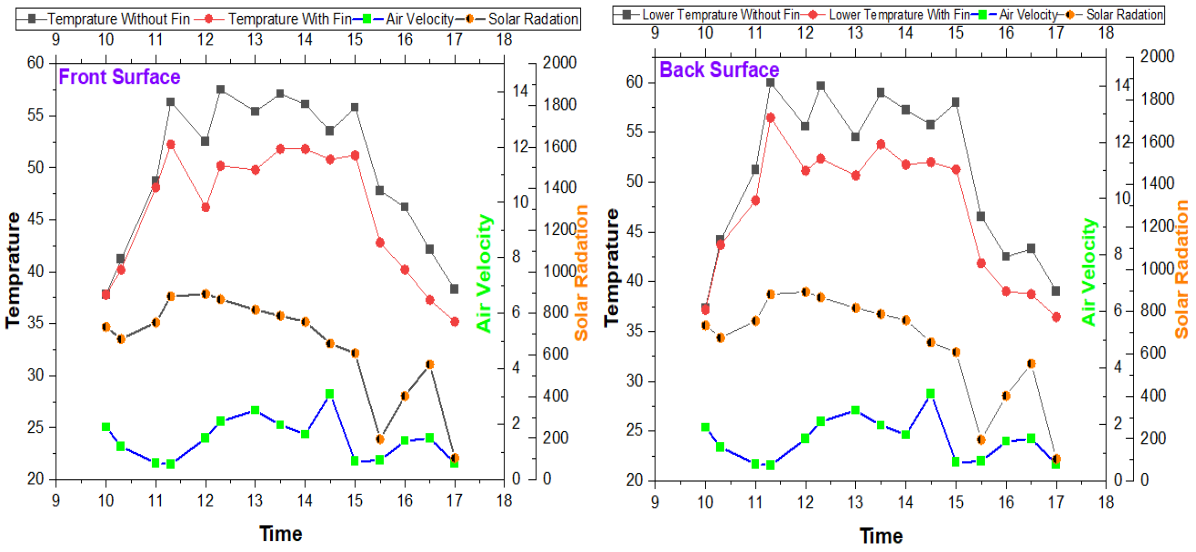


Fig. 8 PV module's exterior surface temperature

Passive cooling technique by using Aluminium free channel reduced the temperature of front and back surface of PV panel Fig. 8 (a) shows temperature difference at the back surface of PV panel with fin and without fin and it found that the temperature of Panel without fin is having higher temperature as compared to panel without fin. From 11:00 h to 15:30 h we get the maximum temperature difference similar results found at the front surface of Panel with and without fin from 11:00 h to 15:30 h we get the maximum temperature difference.

Wind speed variation on the PV module surface temperature

Due to the rise in the convection heat transfer coefficient, changes in wind behavior from laminar to turbulent might result in a reduction in the temperature of the PV module.



(a) (b)

Fig. 9 Wind speed's impact on the PV module

In Fig. illustrates the temperature curves of the PV module surfaces as a result of the effects of wind speed and solar radiation. The temperature of the PV module surface rises from 10:30 to 11:00 when the wind speed decreases. Because the front surface of the PV module is more affected by wind speed than the rear surface, a spike in wind speed around 12 o'clock can be seen, which lowers the temperature curves of the front surface. After 1:00 a.m., the wind's velocity varies between 1.5 and 2.5 m/s. The curves of the surface temperatures begin to deteriorate around 03:00 h due mostly to a drop in solar intensity and wind velocity, which also occurs at that time. These relationships between wind speed and the surface temperatures of the modules on the front side demonstrate how the wind speed also affects the PV module's surface temperature.

Fin effect on PV module's electrical output efficiency

Solar cells, which usually consist of crystalline silicon, activate by absorbing photons from sunshine and releasing them as the electrons, which produces an electric current. The link between the solar cells' current and voltage characteristics may be observed in the I-V curve. A variable resistor is used to acquire I-V data. The voltage (V) is influenced by variations in solar cell temperature, whereas the current (I) is influenced by the intensity of solar radiation.

Direct current (DC) power is generated by solar cells. The Open Circuit Voltage (Voc), Short Circuit Current (Isc), Efficiency (η), and Fill Factor (FF) are important metrics that may be determined by measuring the I-V curve. Isc stands for the maximum electric current in a circuit with no resistance, whereas Voc represents the greatest voltage capacity in a circuit with no current flowing.

A specific point on the I-V curve is known as the maximum power point (PMPP). The fill factor (FF), which is represented in the equation, may be calculated by comparing PMPP with VOC and ISC, as shown in the equation..(1).[2][18]

$$FF = \frac{P_{MPP}}{I_{SC} * V_{OC}} = \frac{I_{MPP} * V_{MPP}}{I_{SC} * V_{OC}} \quad (8)$$

$$\eta = \frac{P_{MPP}}{P_{LIGHT}} = \frac{P_{MPP}}{I_{RAD} * A} = \frac{I_{SC} * V_{OC} * FF}{I_{RAD} * A} \quad (9)$$

Heat sinks are commonly used cooling devices that have fins of various sizes and shapes that are intended to effectively disperse heat. The size and form of the fins have an impact on a heat sink's efficiency, which is determined by the difference between the actual and ideal heat transfer rates.

The entire fin surface has an uniform starting temperature under the ideal heat transfer rate condition. The method described by Gardner [26] and shown in Equations (2) and (3) can be used to calculate the magnitude fin's efficiency. These equations enable a comprehensive assessment of the heat sink's performance based on the fin's characteristics and the temperature distribution along its surface.

This equation describes PV module efficiency as a function of temperature. [16][21]

$$\eta_{pv} = \eta_0[1-\beta_0(T_c - 298.15)] \quad (10)$$

The following are the assumptions for the thermal analysis in this work:

- At 25 °C (298.15 K), the standard PV cell efficiency is 15%.
- Every property of a substance is isotropic.
- The surrounding temperature (ambient temperature) is the same everywhere.
- The temperature of the ground and sky is assumed to be the same as the surrounding air.
- The surrounding temperature (ambient temperature) is between 35°C.
- The range of solar irradiation is 100 to 1000 W/m2.
- The convection heat transfer coefficient ranges from 5 to 12 W/m2 K.

The solar panel efficiency (η) is the ratio of the solar panel's (Plight's) maximum power to the power it receives from solar radiation. Sunlight intensity (Irad) and the solar panel's active area (A) are combined to form solar radiation power. The amount of power generated will rise since solar panels are more effective at producing power. Equation (10) can be used to determine the efficiency of the panel.

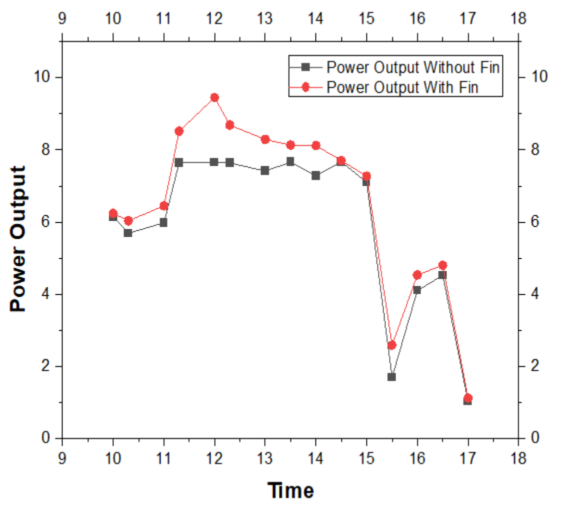


Fig. 10 (a) Power output

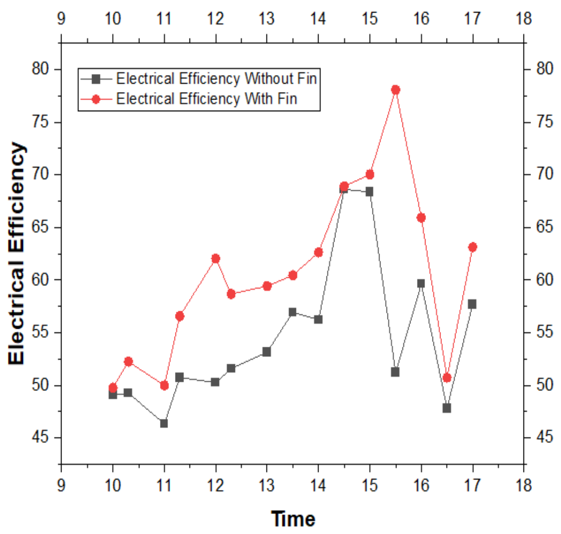
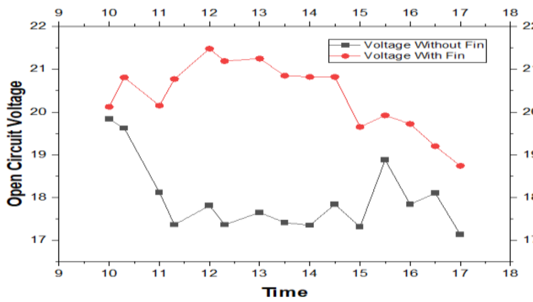


Fig. 10 (b) Efficiency

Open circuit voltage (Voc) and short circuit current (Isc) Effect on the PV module

• The amount of photons absorbed by the semiconductor material has an impact on the short circuit current (Isc), which is correlated with light intensity [9]. There is very little relationship between the open-circuit voltage (Voc) and light intensity. [10-11]. The impact of temperature on open circuit voltage and short circuit current is depicted in Figures 12(a) and 12(b).

• The open-circuit voltage (Voc) reduces in large amount when the panel temperature increases above 25 degree Celsius but the rise in short-circuits current (Isc) hardly noticeable. The Electrical performance and Panel life affect and degraded above 45 degree Celsius, Performance of these systems is based on a 25 °C STC condition. so electrical output decreases by 0.5 % with a one degree Celsius rise in temperature. [9-11]. fig 11(a) and 11(b) shows the Open Circuit Voltage (Voc) and short circuit current (Isc) with fin and without fin, the temperature of PV Panel without fin is higher than the temperature of the panel with fin therefore the short circuit voltage is decreased with rising in temperature and open circuit current increased marginally



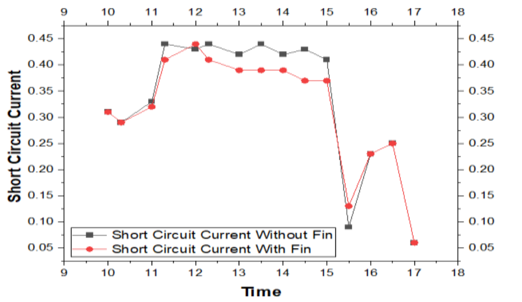
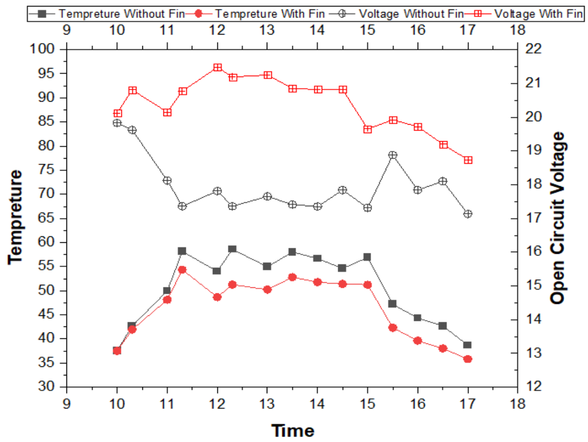


Fig. 11 (a) Open Circuit Voltage (OCV) **Fig. 11 (b) Short Circuit Current (SCC)**

From 11:00 h top 3:00 h maximum temperature difference occurred, at 12:00 the temperature without fin was 51 ℃, the open-circuit voltage was 17.81 and with fin 48℃ open circuit voltage was 21.48 similarly short circuit current was found 0.43 and 0.44 respectively.



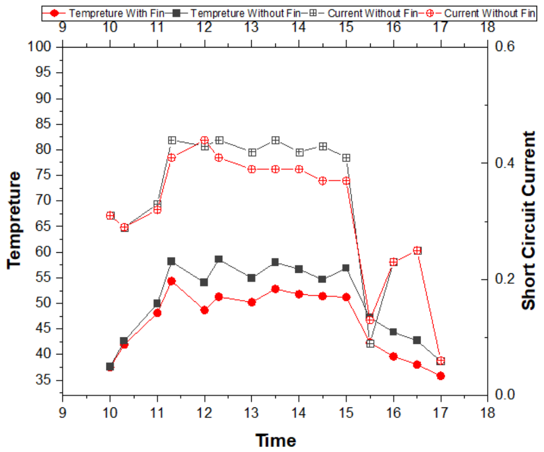


Fig. 12(a) Effect of Temperature on OCV **Fig. 12(b) Effect of Temperature on SCC**

8. Conclusion

By lowering the back-surface temperature of polycrystalline photovoltaic (PV) modules, this experimental study aimed to increase their efficiency. While passive cooling techniques are easier and less expensive, active cooling methods require additional mountings and accessories like pumps and fans that come with maintenance and operational costs. In this experiment, free channel aluminum fins have been added to the PV panel's rear surface to improve the heat transmission area. The weight rise of the modified PV module is prevented by this free channel. The weight of the PV module is a crucial factor that might affect the cost of the module's installation, portability, and shipping. The free channel rectangular shape of fins with open ends provides the airflow through the channel.

It is observed that fin is having enough potential to reduce the temperature of the PV module and enhance efficiency. The geometry of fins, weight, thickness and type of fin affect the temperature and efficiency and in this work free aluminium Channel rectangular fins have been utilized instead of solid rectangular and plate fins. The PV module's increase in weight is prevented by this free channel. The weight of the PV module is a crucial factor that might affect the cost of the module's installation, portability, and shipping. The airflow through the channel is provided by the free channel rectangular shape of fins with open ends, which can ultimately boost the cooling impact of the panel. The effects of ambient temperature, wind speed, and global horizontal irradiance (GHI) on the surface temperature of the finned and unfinned PV module were also discussed in the article. Additionally, the effects of the PV module's efficiency and open-circuit voltage on the temperature decrease caused by the fins were investigated. The module temperature may rise as solar irradiation increases, but efficiency will decrease. On the other side, a greater convective heat coefficient might result in a lower PV module temperature, which raises the PV module's electrical efficiency. The study discovered that the solar cell temperature influences the electrical efficiency of PV cells, the fins on the rear surface of PV modules had a substantial impact. The following conclusions have been made as a result of the findings:

- Study of different variable parameter (Dust, Shading, Height, Thickness, Temperature, Solar radiation etc.) affecting cell temperature and use of passive cooling to control it.

- Designing a PV system is crucial since it depends on a number of variables, including location, module orientation, and cooling system components.

- Any cooling method that works must be affordable. The PV module temperature might be lowered concurrently via a hybrid method, which would be more impressive by controlling the larger initial cost with better efficiency.

- A simple and affordable way to lower the temperature of the PV cells is to mount aluminium fins on the back surface of the PV module.

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