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Investigating the Effect of Forced Cooling of Polycrystalline Silicon Solar Photovoltaic Module on Power Output

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Abstract: The operation of photovoltaic module is dependent mainly on the incident solar irradiation and the module temperature. PV module temperature tends to rise during field operation. The effect of applied cooling on polycrystalline photovoltaic using electric fans is investigated. The fans are on the rear of the module which is mounted on a roof and it is connected to a fixed load for a period of seven weeks. A simple algorithm is implemented to control the process. Cooling is applied on some days followed by days where cooling is not applied. The result, which was obtained for air-mass condition (AM $\leq$ 2), show a 5.68% improvement in performance for days when cooling is applied over days where cooling is not applied.

Keywords: Photovoltaic module, solar irradiation, PV module temperature, efficiency.

Introduction

The Photovoltaic (or PV) systems are becoming quite common especially with the need to explore non-fossil fuel sources of energy. The challenge with silicon PV cell technology is associated with the conversion efficiencies of such cells. Researchers have developed methods of improving the conversion efficiency of silicon solar cells. Azzouzi and Tazibt (2013) carried out a study using numerical approach to investigate the potential of the impurity photovoltaic (IPV) effect in crystalline silicon solar cell doped with a new IPV impurity to improve cell characteristics such as short circuit current density, open circuit voltage, conversion efficiency and quantum efficiency. The operational conditions of PV depend mainly on available solar radiation, cell/module temperature, wind speed, location of the PV module, and its capacity to dissipate the heat generated. It is therefore important to take in account the temperature coefficients (CT) of the solar cell in order to predict the real power that can be produced in an installation under operating conditions (Ponce-Alcantara et al., 2014). The solar module performance varies with location and prevailing environmental conditions to which they are subjected. (Ettah *et al*., 2009).

Although the advantages PV technology are clearly identified, PV conversion systems do have some general problems associated with their location of installation such as hail, dust and surface operating temperature; these can negatively affect the efficiency of the conversion system (Da Silva and Fernades, 2010**).** Common natural factors which influence the surface temperature of a PV module are wind speed, ambient temperature, relative humidity, accumulated dust and solar radiation intensity (Elbreki, *et al.,* 2016). According to Kumar et al. (2007), every one degree Celsius rise in temperature of the PV module leads to a reduction in efficiency of 0.5%. Heat is generated in the module arising from the law of conservation of energy. The consequence of this wasted heat is a reduction in module efficiency. This condition can be managed for a positive outcome by collecting this heat and putting it to use. However, the PV module output can be improved by implementing a process that prevents the module temperature from rising significantly above the ambient temperature. PV module temperature can be controlled through passive or active means. Hussam *et al*. (2020) investigated experimentally the effects of passive cooling on the performance of PV module using an optimized plate fins heat sink. They determined the efficiency and maximum power output with and without heat sink and compared the results. They found that cooling the module with heat sink led to an average reduction of the front and back temperature by 4% and 6.5% respectively which led to improvement in the efficiency and power output of the PV module. They reported a maximum increase in the solar to electrical conversion efficiency of 35% and approximately 55% in the power output with the use of a heat sink.

Although the option of natural cooling may be explored in some cases, hybrid solar photovoltaic system cooled by forced air circulation provides better cooling and higher energy conversion efficiency in comparison to natural air circulation (Pandey *et al*., 2019). Akbarzadeh and Wadowski (1996) designed a hybrid solar photovoltaic – thermal (PV-T) system and discovered that cooling the PV panel with water increases the solar cells output power by almost 50%. They also found that cooling the PV panel does not allow the solar cells surface temperature to rise above 46 degree Celsius on exposure to solar radiation for a period of 4hours. Moreover, Chaniotakis (2001) designed a hybrid solar photovoltaic – thermal (PV-T) system, where water and air were both investigated in the combined system as cooling agents. The water based cooling system was found to increase the solar cells efficiency than the air based cooling system.

Dubey and Tiwari (2008) designed an integrated solar PV-T solar water heater. They measured the efficiencies of the solar PV modules under three different cases, namely Case A where the absorber of the solar collector is fully covered by the PV module while in Case B, the absorber is 50% covered by the PV module and in Case C, the absorber is 30% covered by the PV module. They observed a significant increase in the instantaneous efficiency of the solar collector from 33% to 64% moving from Case A to C respectively.

The increase in the efficiency was due to an increase in the glazing area. Li *et al*. (2020) reported a new strategy for photovoltaic panel cooling that is based on harvesting atmospheric water as an effective cooling component. They reported a reduction in temperature of 10°C under controlled conditions in the laboratory and a 13 – 19% increase in electricity generation in field tests during the winter and summer periods in Saudi Arabia.

Mawoli *et al.* (2017) studied the effect of cooling on temperature coefficient of a polycrystalline silicon solar photovoltaic module. They achieved a reduction in heat on the surface of solar module of 4.08% from the effect of cooling.

Photovoltaic modules are affected by their temperature. The objective of this study is to investigate the effect of forced cooling on temperature and hence performances of polycrystalline PV module. The temperature of interest is that of the rear surface and the module is connected to a fixed load.

Methodology

Materials

The PV module employed in this study is a 20W polycrystalline solar module connected to a fixed load. The load is derived from the data provided for this module (table 1) using the maximum current and voltage. The cooling unit consists of fans installed at the back of the module which sits on a stand that is mounted on a roof at the location of the study. There is a space of about 0.1m between the rear of the module and the roof surface. Temperature sensors were located appropriately to measure the temperature of the back of the module as well as ambient temperature. A pyranometer installed at the site provides solar irradiation data. Load current and voltage are recorded with a data-logger. Logging interval for all logged data is one minute.

Table 1. Technical Information of Solar Module

Maximum power (P_{MAX})	**20W**
Voltage at maximum power (V_{MP})	18.0V
Current at maximum power (I_{MP})	1.12A
Open circuit voltage (V_{OC})	22.32V
Short circuit current (I_{SC})	1.28A
Temperature at STC	25°C
Solar irradiance at STC	1000W/m^2

Methods

The operation of the system is based on the stand-alone configuration without storage. The purpose of studying temperature effect on the PV module is achieved by implementing an algorithm that directs the processes required. These include alternating the days when the fans will be switched on and the condition that will require that the fans be switched on. The flowchart below in figure 1 is a representation of the process. The period considered for each day is that for air-mass (AM) which satisfies the condition (AM ≤ 2) and the module is placed in the horizontal position.

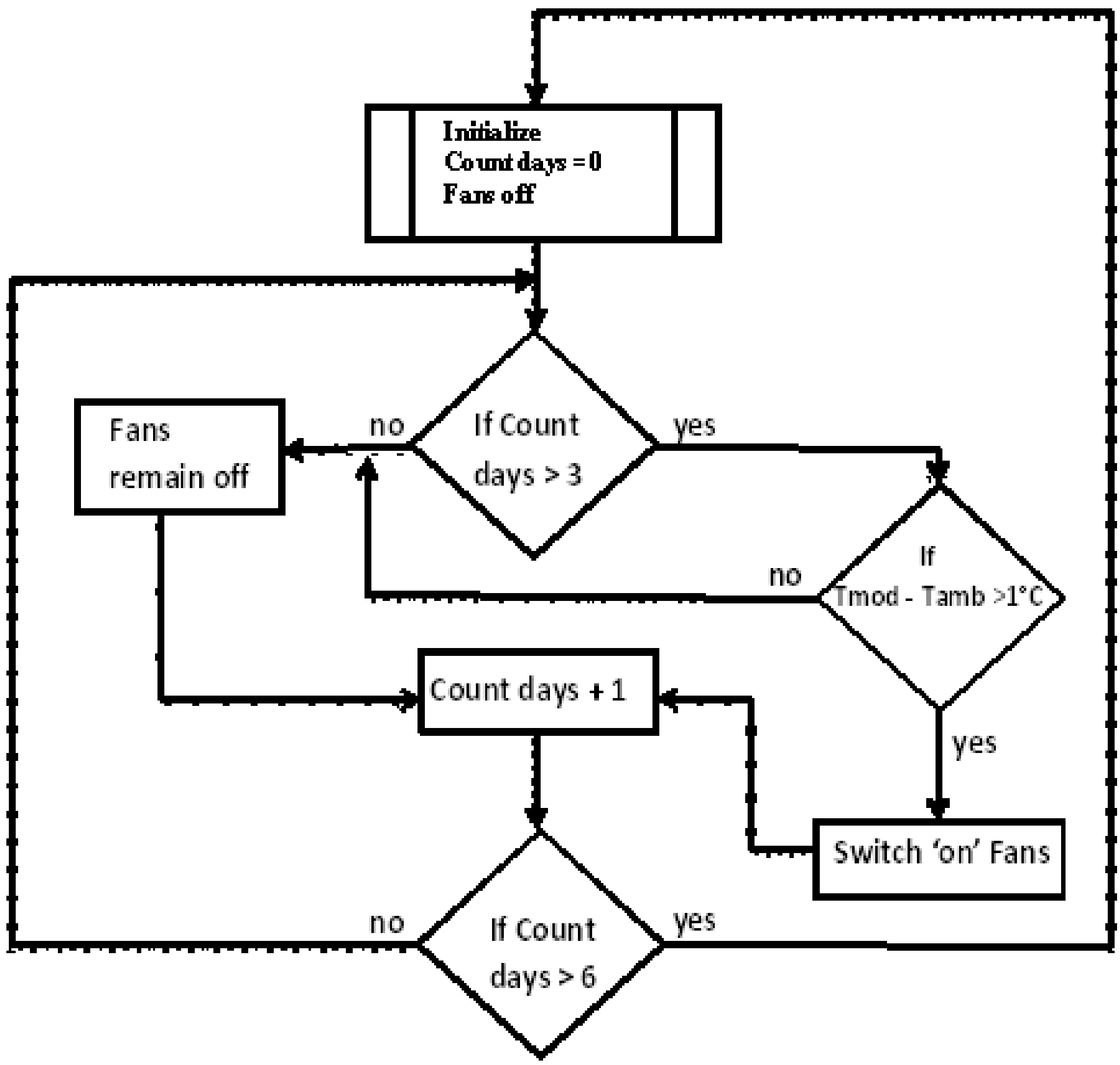

Figure 1. Flowchart for implementation of cooling of module. Note: Tmod and Tamb are module temperature and ambient temperature respectively.

Theory

The power developed across a load by the PV module at maximum power point is:

$$P_{\max} = V_{mp} I_{mp} \quad (1)$$

where V_{mp} = Voltage at maximum power and I_{mp} = Current at maximum power.

Module efficiency can be defined as the ratio of PV module output power, (P_O) to solar irradiance input power, (P_i) expressed as follows:

$$Efficiency = \frac{P_O}{P_i} \quad (2)$$

given that A = Area of PV module in m^2 and, P_i = Solar irradiance, *I*, in (W/m^2), efficiency becomes:

$$Efficiency = \frac{P_{\max}}{A \times I} \quad (3)$$

The efficiency may also be expressed in terms of the field factor (FF) as follows:

$$Efficiency = \frac{V_{OC} \times I_{SC}. \times FF}{A \times I_{STC}} \quad (4)$$

The open-circuit voltage can be determined from physical parameters of the cells that make the module and, by extension, the module as follows (Smets et. al., 2016):

$$V_{OC} = V_T \ln\left(\frac{I_{ph}}{I_o} + 1\right) \quad (5)$$

V_T is thermal voltage of the cell expressed as .

$$V_T = \frac{nkT}{q} \quad (6)$$

where k is Boltzmann constant, T is Cell absolute temperature, q is electronic charge and n is ideality factor of the cell material. Equation (7) shows the dependency of open-circuit voltage on temperature.

$$V_{OC} = \frac{nkT}{q} \ln\left(\frac{I_{ph}}{I_o} + 1\right) \quad (7)$$

The linear relationship that usually exists between PV cell parameters (*Voc*, *Isc*, *FF*) and temperature makes the separation of temperature sensitivity of the device performance into the sum of their temperature coefficients possible (Dupré et al., 2015):

$$P_{MAX}(T) = V_{OC}(T) \times I_{SC}(T) \times FF(T) \quad (8)$$

and

$$\beta_{PMAX} = \beta_{VOC} \times \beta_{ISC} \times \beta_{FF} \quad (9)$$

where β_{PMAX} , β_{VOC} , β_{ISC} and β_{FF} are the temperature coefficients of PV cell with respect to maximum power, open-circuit voltage, short-circuit current and fill-factor respectively. This suggests that Bpmax may be computed from the temperature coefficients of open-circuit voltage, short-circuit current and fill-factor.

Ponce-Alcantara et al., (2014) stated that for a nominal operating temperature of T = 45°C the temperature dependence of maximum power output (Pmpp) can be linearly parameterized in terms of its temperature coefficient (CT Pmpp) and the power output in standard test conditions as follows:

$$P_{MAX}(T) = P_{MAX}(25^0)\left(1 + CT.P_{MAX}\left(T - 25^0\right)\right) \quad (10)$$

This maximum output power of a standard silicon PV module increases by 0.66% if the CT Pmpp changes from -0.45%/°C to -0.42%/°C.

For continuous operation, the efficiency is obtained by computing the energy from the terms in equation 3 for both the module output and incident solar irradiance in the time interval of data logging and summed up for the day.

Results and Discussion

The current – voltage characteristics of the module was obtained at the location of installation as shown in figure 1 while figure 2 shows the power – voltage curve. The module temperature was 47°C and solar irradiance was 813W/m^2. The temperature coefficient (Pmpp) obtained for this module is -1.40% / °C. This value is out of range when compared with results in literature (Ponce-Alcantara et al., 2014). quite high based.

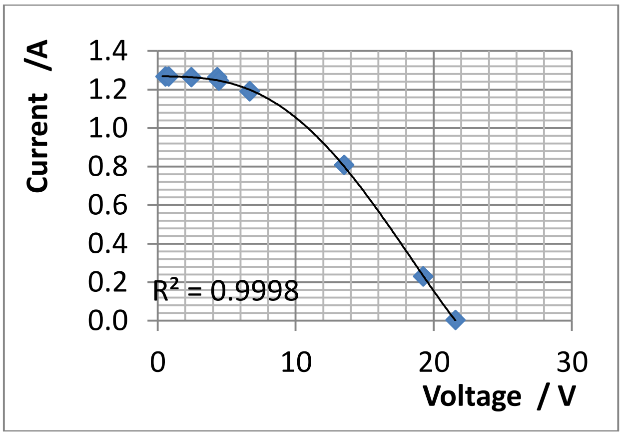

Figure 2: Current - voltage characteristics of the module at solar irradiance of 813W/m^2 and temperature of 47°C.

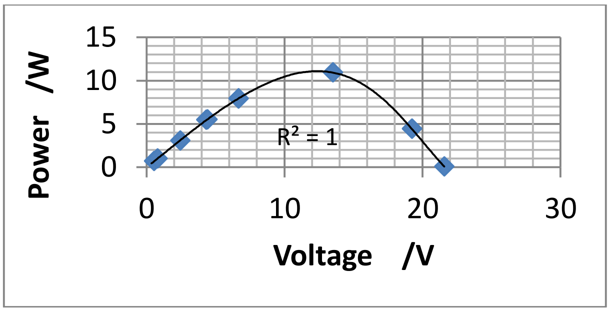

Figure 3: Power - voltage curve for module characteristics of figure 2

Figure 4 shows the module and ambient temperature profile. The reading are for period of the day defined by air mas 2 (AM2). The mean ambient and module temperatures are 36.9°C and 41.3°C.

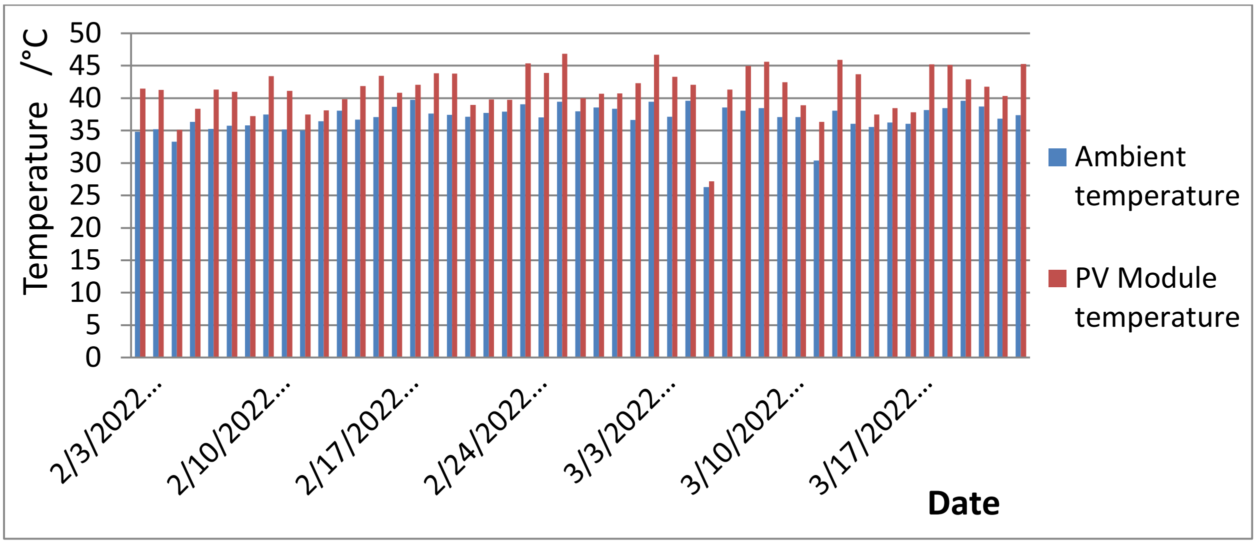

Figure 4: Profile of daily ambient and PV module temperatures.

Figure 5 shows the profile for the difference in PV module temperature and ambient temperature and the status of the fan (whether it is ‘on’ indicated with the presence of the blue bar or not ‘on’ indicated by the absence of the blue bar). The days when the fan is ‘on’ produce lower values for the difference between PV module temperature and ambient temperature.

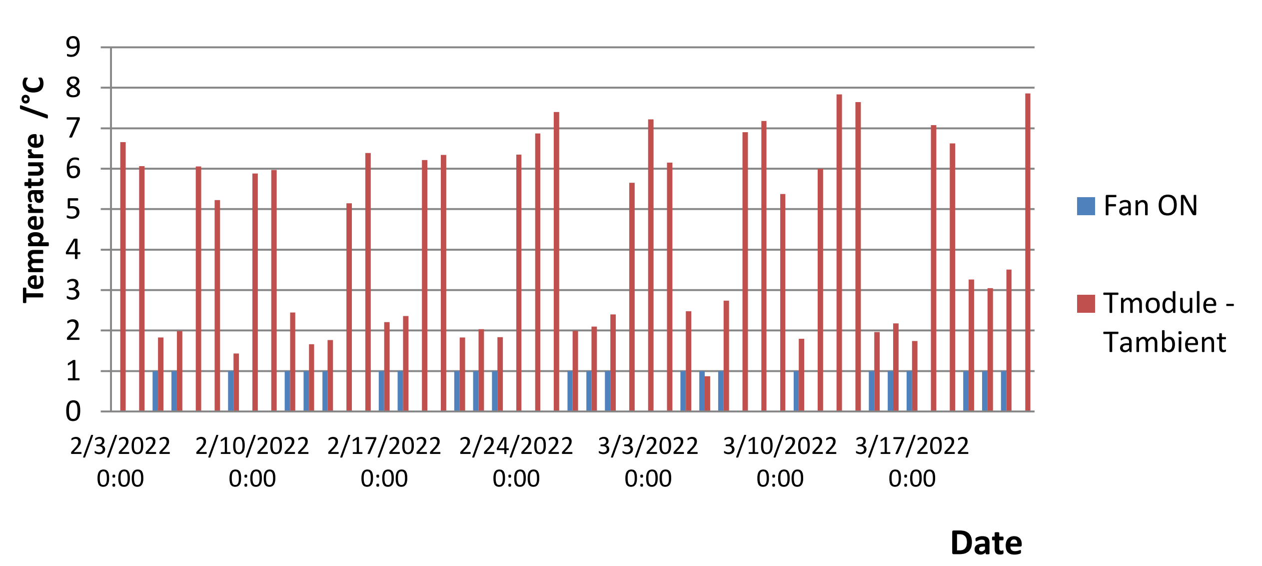

Figure 5: Profile of daily difference between PV module and ambient temperatures (Tmodule –Tambient) when fan is on and off. Days when fans are on present with lower values of Tmodule –Tambient

The profile for daily energy output from the PV module is shown in figure 6 while the percentage daily efficiency is shown in figure 7

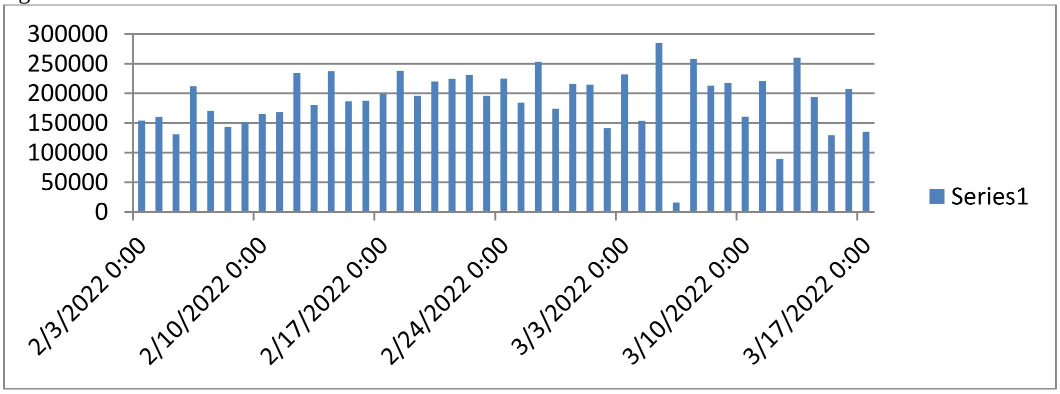

Figure 6: Profile of daily energy output to load.

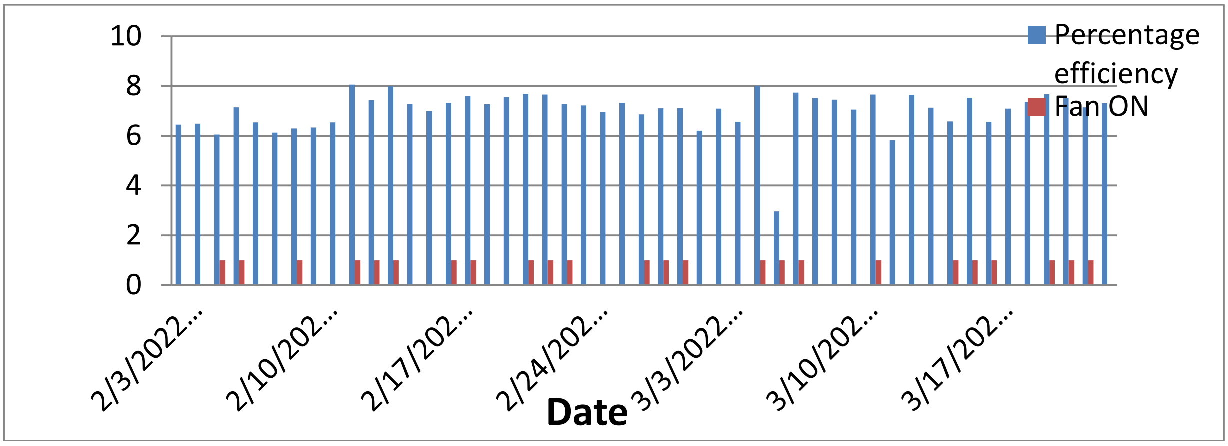

Figure 7: Profile of efficiencies for days when fans are on and when they are off.

The trend in the module efficiency indicates higher values for days where the fans are switched on with an improvement in efficiency of 5.8% when compared with days where the fans are not operated. This suggests an inherent benefit of implementing the cooling of the module at the location of the study though the value may not be significantly high. The significance of this becomes apparent for large array of modules where natural cooling my not be effective at maintaining all the modules at a close temperature value. The period of this study falls within the dry season of the location where high ambient temperatures are recorded. PV generators are expected to benefit from any scheme to prevent temperatures from rising too high. The mean day temperature for days with the fans switched on is 39°C while it is 43.2°C for other days. Optimization methods such as inclining the module to receive more solar irradiation have not been considered; if implemented, this would lead to higher module temperatures than those observed in figure 4.

Conclusion

In this work, the effect of cooling of polycrystalline solar PV module was investigated. The performance of a polycrystalline PV module was observed for days where cooling through fans, mounted on the back side of the module, were switched on as well as other days where the fans were not switched on. It was observed from the result that, for the same module, the efficiency of the module was higher on the average for days where cooling was carried out. The result suggests that large array installed at this location would benefit from the implementation of a cooling process.

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