Experimental Investigations on the Performance of PV Modules with/without Module Cooling

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Abstract: Temperature effect on the performance of a photovoltaic module is one of the main concerns facing the effective utilization of solar energy for electrical power generation. Such effects can lessen the overall output of the Solar panel for a given level of solar insolation. Cooling of the solar panels is thus necessary. In the literature, this issue has been addressed by different researchers using passive and active means. Some of the methods suggested use water cooling, liquid cooling, air cooling, use of cooling fins, air ducts, hybrid PV/T systems etc. However, the authors of this paper feel that a simple cooling arrangement consisting of a small D.C. operated fan and a suitable heat sink can help to reduce the loss in the PV efficiency. This paper attempts to investigate experimentally the changes in the system characteristics and performance with and without such a cooling system. The results of the study indicate that some degree of improvements can be expected in system outputs and efficiency when a cooling fan is introduced.

Keywords— Solar PV modules, Cooling system, Solar performance Characteristics, Experimental study, Fan Cooling.

I. INTRODUCTION

Solar Photovoltaic cells convert solar radiation into electricity. A combination of several solar cells constitutes a module. A module is necessary because the voltage and current output of a single Photo Voltaic (PV) cell is not sufficient to meet requirements of a practical system. Several such modules are grouped to make up an array when a specific voltage and current output is desired.

Despite the simplicity of the operation, a solar cell is able to produce only around 15% of electricity from the solar radiation that falls on it. The rest is converted into heat that increases the cell temperature and overheats the panel. It has been shown that this will result in a lowering of the cell efficiency [1]. Increment in cell temperature also causes significant reduction in open circuit voltage (Voc) that leads to reduction in the electrical efficiency. Another reason for maintaining low temperatures in solar cells or modules is that at high temperatures, the light induced degradation of a PV module gets accelerated this causes a deterioration in the performance of a PV module which needs to be minimized. Temperature reduction in solar PV modules can be achieved by extracting out the extra heat, associated with it. For best results, a solar PV panel needs to be operated within a temperature band recommended by the cell manufacturer who generally specifies a temperature degradation coefficient and a maximum operating temperature for the cell [2].

The thermal energy can be extracted in several ways. In the literature various means are suggested. These include: using heat sinks [3], water passive cooling [4]-[7],use of special coolants [8], Heat pipe cooling , (which is a combination of phase change cooling together with convection of cooling medium)[9]-[12] and thermo-electric cooling [13].

Sometimes, the thermal energy extracted from the PV module can also be utilized for low temperature applications e.g. water and air heating. Such types of systems are known as hybrid photovoltaic- thermal (PV/T) systems [14]-[20].

In all such cases, decreasing the temperature of PV module can boost the electrical efficiency since the whole PV characteristics change.

These methods are usually elaborate and expensive. For domestic PV systems with small outputs, a simpler cooling system is suggested. It has been observed that a simple DC fan used for cooling a personal computer can provide sufficient cooling to the heated hardware. It was felt worthwhile to apply the same strategy for cooling a small rated PV system delivering load with a heat sink. Hence the present scheme has been conceived. However, the degree of effectiveness of the proposed cooling scheme has not been tested. The purpose of the present paper is to highlight the findings of an experimental study on the same.

II. THEORY OF COOLING

The heat is transferred from solar radiations to the PV cell. The heat due to current flow in the junction (due to external load) will be also added. A cooling system is required to extract this heat and dissipate it suitably, so that the temperature of the panel cabinet remains within the limits as prescribed by the manufacturer for best results.

The amount of heat transfer in a PV module with air cooling is given by-

$$Q = C_p * W * D$$

Where Q=Amount of heat transfer

= Specific heat of air

W= Mass flow

D_T= temperature rise within the cabinet

Under thermal equilibrium the heat added to the system will equal to the heat extracted from the system. The temperature at which this equation gets satisfied will be the prevailing steady state temperature of the solar PV module. The study was conducted to examine the PV performance characteristics without cooling and with cooling.

III. EXPERIMENTAL SETUP

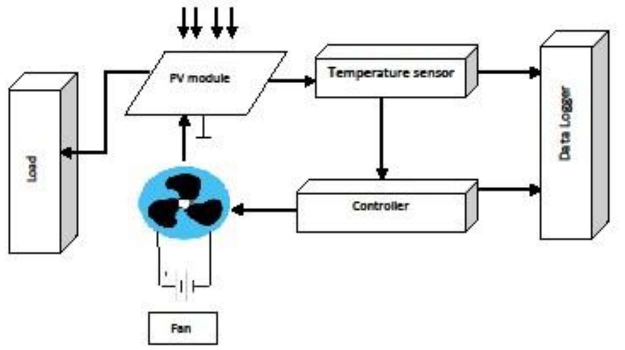


Fig. 1: Schematic layout of the Experimental Setup

Fig. 1 shows the schematic layout of the experimental setup designed for the study. The various components of the setup are described as under:

A. *The PV Module:*

The PV module chosen for the study has the specifications as given below in Table 1:

Table 1: Specifications of Solar Module used for study

Parameter	Symbol	Value
Maximum Power	P_m	12.75 W
Voltage at Max Power	V_m	18.023 V
Current at Max. Power	I_m	0.707 A
Open circuit voltage	V_{oc}	21.752 V
Short circuit current	I_{SC}	0.768 A
Fill Factor	FF	76.29%

It is a mono crystalline solar cell module. A solar meter was used to measure the direct and diffused (global radiation) of the radiations incident on the module. For this purpose, the solar meter has a dark surface which absorbs the radiations falling on it.

B. *Temperature Sensor*:

An integrated circuit temperature sensor device (LM 35) was used to record the temperature of the solar module cabinet. The device is calibrated for temperature in degrees Centigrade. The range of the temperature measurements possible is -55°C to 150

°C with an accuracy of ±0.75°C. The temperature sensor is used for activating a microcontroller to turn on the cooling fan when the temperature of the module cabinet rises above 40º C. To obtain a continuous record of the temperature changes during the observations, temperature sensor is attached at the back of the panel.

C. *The Micro Controller:*

Arduino UNO R3 microcontroller employing the ATmega 328 chip has been used for automatic switching of the temperature control cooling fan. This device has 14 digital inputs with output pins available on the board. It has additionally 6 analog inputs. A 16 MHz quartz crystal is used. USB connections and power jacks are provided.

Fig. 2 shows the basic layout of parts of this microcontroller.

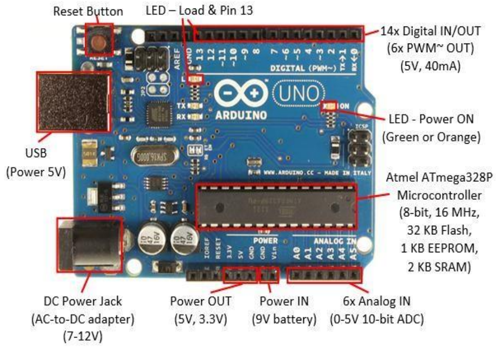


Fig. 2: Layout of Arduino Uno microcontroller parts

D. *Data Logger:*

A Micro SD card adapter was used for data logging. The Micro SD card adapter has 6 pins, ground, supply terminal V_{CC}, Master In Slave Out (MISO) pin, Master Out Slave In (MOSI) input pin, SCK, CS pins that are interfaced to the microcontroller. Additionally, the data logger receives the temperature inputs.

E. *Cooling Fan:*

A small DC fan normally used in the cooling of a computer. CPU is used for providing the needed cooling of the module cabinet. The fan is fitted on a heat sink which has a hole of appropriate size cut within it to house the fan .The heat sink is attached to the back of the solar module cabinet. The DC fan is turned ON by the microcontroller whenever the module cabinet temperature rises above 40º C.

The rating of the DC fan is 12V, 0.13±10% A and it displaces 53 CFM (cubic feet per minute) of air in contact with the heated solar PV module. The fan receives a voltage supply through a power transistor activated at its base by the microcontroller programmed to send a turn -on signal at a temperature exceeding 40º C.

F. *Load:*

A laboratory rheostat was used for loading the PV module in order to obtain the I–V and P-V characteristics at particular temperature value

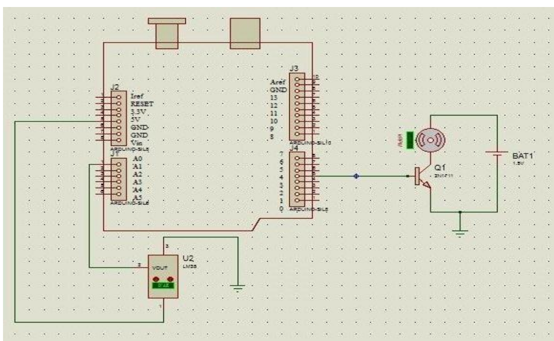


Fig. 3: Control circuitry for fan cooling

IV. EXPERIMENTAL METHODS

The setup described in III above was employed for obtaining experimental observations with and without cooling of the solar PV module cabinet.

A halogen lamp setup illuminated the solar panel. The intensity of illumination was recorded. Experiments were performed at two levels of radiation, namely 500 W/m^2 and 1000 W/m^2. It has been observed that the radiations result in heating of the panel, thereby raising the temperature of the solar cells. A preliminary test run showed that it takes approximately 10 minutes for the temperature to rise by 5ºC. This means, that on an average, it takes 2 minutes to raise the temperature of the cabinet by 1ºC. Within this period of 2 minutes, the PV cell is assumed to operate at virtually constant temperature. Hence, readings of current, voltage and power were noted for the 2 minute period against the temperature level at the start of the 2-minute interval. In this way, the performance curves were obtained at different temperature levels.

The experiments were initiated when the temperature of the panel rose to 40 ºC. At this temperature, the cooling fan is activated by the microcontroller system. Separate readings were recorded for the cases of performance of the PV panel without cooling and with cooling. The I-V and P-V curves at the different temperatures without cooling and with cooling are shown in Fig.s 3-8.

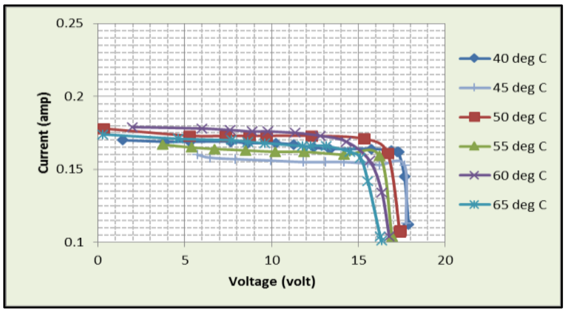


Fig. 3: I-V Curves at various temperatures without cooling with radiation at 500W/m^2

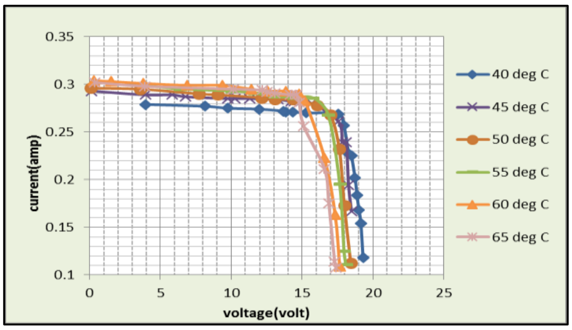


Fig. 4: I-V Curves at various temperatures with cooling with radiation at 500W/m^2

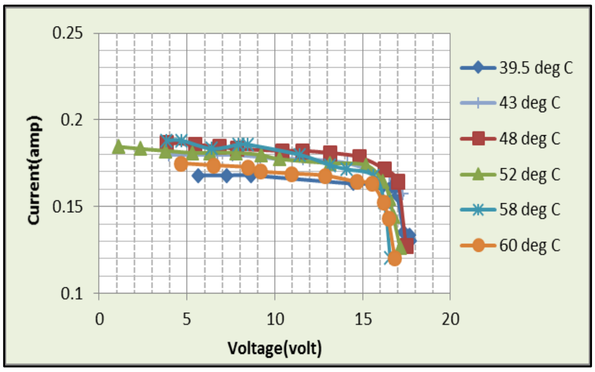


Fig. 5: I-V Curves at various temperatures without cooling with radiation at 1000W/m^2

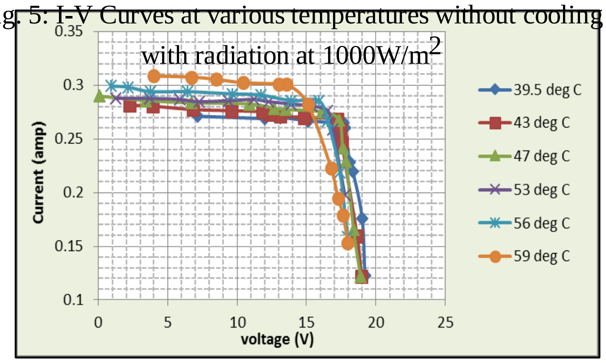


Fig. 6: I-V Curves at various temperatures with cooling with radiation at 1000W/m^2

The experimental curves so obtained agree satisfactorily with the simulated results on similar lines as reported in [21]-[25]. The improvement in the open circuit voltage is however marginal in all these cases when the temperature is lowered with cooling. Nonetheless, even this low magnitude of change in the voltage can improve the power gain at lowered temperatures. This is seen in Fig.s 7 & 8.

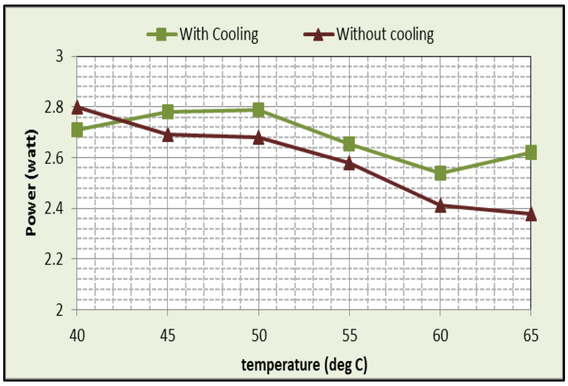
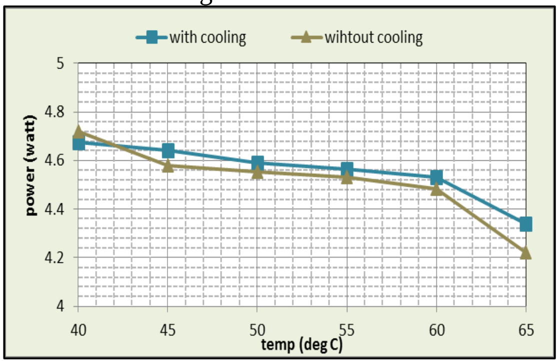


Fig. 7: Power vs Temperature Curves at various temperatures with cooling with radiation at 500W/m^2

Figure 8: Power vs Temperature Curves at various temperatures with cooling with radiation at 1000W/m^2



V. DISCUSSION OF RESULTS

When the temperature of the PV module is allowed to fall, there is an increase in the open circuit voltage. It was observed that in the present experimental study, the increase is very marginal. With increased temperature, the short circuit current increases, while the open circuit voltage falls. However, the net effect is that the power output falls with rise in temperature. The results obtained from the experimental observations show that these trends are in agreement with the simulated results reported in the literature.

Table 2 and 3 indicate the efficiency of the cooling scheme in terms of the fall in temperature with cooling as against the temperature fall without cooling for the two cases of radiations i.e. 500 W/m2 and 1000W/m2. Observations are recorded at 2 minute intervals.

Table 2: Fall in temperature with respect to time at start of record of observations (at 500W/m2)

S. No.	Time of observation record (w.r.t starting time at t=0) (mins)	Cabinet temperature without cooling (natural cooling) [ºC]	Cabinet temperature with cooling (using Fan arrangement) [ºC]	Change in temperature (+implie fall;_implies rise in temp) [ºC]
1.	2	40	39.5	+0.5
2.	4	45	43	+2.0
3.	6	50	48	+2.0
4.	8	55	52	+3.0
5.	10	60	58	+2.0
6.	12	65	60	+5.0

Table 3: Fall in temperature with respect to time at start of record of observations (at 1000W/m2)

S. No.	Time of observation record (w.r.t starting time at t=0) (mins)	Cabinet temperature without cooling (natural cooling) [ºC]	Cabinet temperature with cooling (using Fan arrangement) [ºC]	Change in temperature (+implies fall; _ implies rise in temp) [ºC]
1.	2	40	39.5	+0.5
2.	4	45	43	+2.0
3.	6	50	45	+3.0
4.	8	55	53	+2.0
5.	10	60	56	+4.0
6.	12	65	59	+6.0

A t

VI. CONCLUSIONS

The effect of cooling of a PV module was examined in the present paper using an experimental setup constructed for the purpose. The results show that the lowering of the temperature by a simple cooling fan arrangement can result in a reduction of temperature by 5 to 6º C, depending on the radiation levels on the PV module. However, the cooling is not instantaneous and some degree of improvement in cooling performance can be observed only after a few minutes after the cooling fan is activated by the control circuitry. The performance of this system demonstrates the possibility of achieving temperature reduction in a heated PV module with a simple cost effective strategy. It is expected that with a larger cooling fan, the results will be improved. Future studies in designing the optimal size of the cooling fan in terms of efficiency and power consumption will be of much value.

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