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Performance Monitoring of Polycrystalline and Monocrystalline Solar Modules

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ABSTRACT

Solar Energy has been acknowledge as a free and infinite source of energy and provides an alternative energy where there is no pollution of the environment and its use will decreases the rate of depletion of energy reserves. Solar photovoltaic technologies provide an attractive renewable energy solution for growing world energy demands. Photovoltaic cell is often referred to as PV and is a technology for converting light directly into electricity. Solar cell properties can be altered by changes in environmental conditions such as temperature. The objective of research work is to show behavior of commercially available solar modules at different temperature. The commercially available polycrystalline and mono-crystalline solar modules are used for their performance monitoring. The solar photovoltaic training and research kit is used to obtain I-V characteristics of solar modules. The samples were illuminated by halogen lamps which are inbuilt in solar photovoltaic training and research kit and illumination power is measured with solar power/illumination meter. The measurement was performed at 25°C, 30°C, 35°C, 40°C, 45°C and 50°C temperatures and Maximum power, fill factor and efficiency of both modules is measured and compared at each level of temperature. The Maximum Power (Pm) of polycrystalline module has maximum value of 0.584 at 25°C and Maximum Power (Pm) of mono-crystalline at 25°C is 0.679 has maximum value of Pm = 0.75 at 50°C. The fill factor of polycrystalline module has maximum value of 0.706 at 25°C and the fill factor of mono-crystalline has maximum value of 0.749 at 50°C. The efficiency of mono-crystalline is higher than the polycrystalline at each level of temperature. The efficiency of polycrystalline module has maximum value of 7.11at 25°C and efficiency of mono-crystalline has maximum value of 7.65 at 25°C.

Keywords: *Solar Energy, Photovoltaic Cell, Polycrystalline Solar Cell, Mono-crystalline Solar Cell*

1. INTRODUCTION

In recent years, the harmful effects of global warming due to heavy dependence on fossil fuels are becoming more and more visible. The phenomenon of global warming is appearing much earlier and much more widespread than initially expected [1]. This forced the global community to initiate corrective steps to check the trend. The need of developing clean, sustainable and secure energy resources is being increasingly realized [2]. Also, the cost of fossil fuels especially oil is ever increasing. The era of cheap and secure availability of oil is over [3, 4]. Therefore an attention is being focused to develop and utilize renewable and non-conventional energy sources which have been largely neglected so far due to unhindered and cheap availability of oil [5]. Renewable energy is a natural source available in large quantity and is sustained.

Energy consumption pattern of nation changes with passage of time. Because of the crisis in fossil fuel the developing countries postponed their important programs to keep their economy operating with petroleum products [6, 7]. It was concluded that world oil production if likely to level off very shortly and that alternative fuels will have to be meet growing energy demand. The task is now to increase the share of renewable energy sources to meet energy crisis [8]. Photovoltaic Cell is the basic electronic device made from silicon material which is used to convert sunlight directly into electricity [9]. The term “photo” means light and “voltaic,” electricity. A photovoltaic (PV) cell, also known as “solar cell, “is a semiconductor device that generates electricity when light falls on it [10, 11]. While most PV cells in use today are silicon-based. The solar cell is the basic element of Photovoltaic (PV) system [12]. It is also called PV cell. A number of cells are interconnected together in a sealed weatherproof package called Module or Panel. To achieve the desired voltage and current, modules are wired in series and parallel which is called an Array [13].

The efficiency of solar cells is one of the most important variables to be determined. It is largely depend upon the material of solar cells. The module efficiency determines the power output of a panel per unit of area [14], knowing the efficiency of a panel or module for the selection of correct panels of photovoltaic system. Research is still going on to modify the materials of solar cells for better output efficiency. The performance of solar modules varies from one material to another [15]. Most commonly and commercially available solar modules in the market of Punjab are polycrystalline solar module and mono-crystalline solar modules. The objective of this research is to investigate the performance monitoring of polycrystalline and monocrystalline solar modules.

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2. METHOD AND STUDY

The performance of Mono crystalline and Poly crystalline solar modules analyze data of different temperature with the help of indoor experimental setup by using solar photovoltaic training and research kit. The experimental kit is divided into three main parts. The first part of the experimental kit is power conditioning unit. It is a rectangular shaped electronic device which consists of various voltmeters and ammeters with led display. These meters measure the voltage and current of modules, inverter, battery, and load in volts and current in volts and ammeter respectively. At back side of this device ports are made for connecting the solar modules electrically. The second part of the experimental kit is logger and plotter unit. The input of this unit is connected with the PCU and output is connected to the computer for creating real time curves by using the readings from display of voltmeters and ammeters inbuilt in PCU.

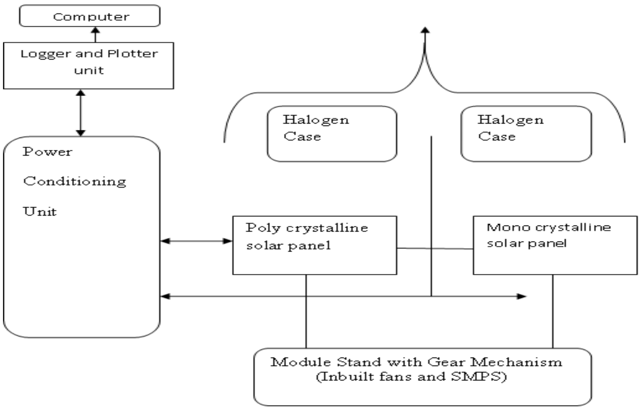

Fig.1. Block diagram of indoor experimental setup

A. Basic Circuit for Evaluation of I-V Characteristics

The basic circuit diagram for evaluating I-V curves of solar module consists of solar panel, Ammeter, Voltmeter and potentiometer. The potentiometer in circuit acts as a variable resistive load. Solar module is a combination of solar cells. A solar cell is a semiconductor device that generates electricity when Light falls on it. When sunlight strikes a PV cell, the photons of absorbed sunlight eject the electrons from the atoms of the cell. The free electrons then move through the cell, creating and filling in holes in the cell. It is this movement of electrons and holes that generates electricity. This physical process in which a PV cell converts sunlight into electricity is known as the photovoltaic effect.

The basic equation for solar cell is

$$I = I_l - I_O(e^{\frac{qv}{mkt}} - 1) \qquad \text{------------------} \qquad (1)$$

Where I_l is the light generated current [A], Io is the reverse saturation current [A], V is the cell voltage [V],T is the cell temperature [K], q = electric charge 1.6^{e-19} [C], k = $1.38e^{-23}$ [j/K] Boltzmann's constant,
m is the ideality factor (m=1 for an ideal cell)

Fig. 2. Real time circuit of indoor experiment.

Fig. 2 shows the real time circuit of indoor experimental setup. The performance of each type of module is measured by using equation of fill factor and efficiency of solar cell.

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$$Fill\ Factor = \frac{V_m I_m}{V_{oc} I_{sc}} \quad \text{-------------------} \quad (2)$$

V_{oc} and I_{sc} are the open circuit voltage and short circuit current. V_m and I_m are the voltage and current at a maximum power point.

$$Efficiency = \frac{V_m I_m}{Pin\ A_c} \quad \text{---------------------} \quad (3)$$

Table 1 shows the performance of Mono-crystalline solar module and poly crystalline solar module at different temperature and illumination level and at ambient temperature 19°C.

Table 1. Voltage and Current of polycrystalline and mono-crystalline at different temperature and illumination.

			Poly crystalline solar module		Mono crystalline solar module	
Sr. No	Illumination in Watt/m^2	Temperature on module surface/Ambient Temperature in ° C	Voltage V(Volts)	Current I(Ampere)	Voltage V(Volts)	Current I(Ampere)
1.	240	25 / 18	0	0.09	0	0.10
			7.0	0.09	7.7	0.09
			7.5	0.08	8.5	0.05
			8.0	0.07	8.8	0.03
			8.5	0.04	9.0	0.02
			8.8	0.02	9.5	0.00
			9.2	0.00		
2.	325	30 / 18	0	0.09	0	0.11
			7.0	0.08	7.5	0.10
			7.8	0.06	8.0	0.09
			8.0	0.05	8.2	0.07
			8.5	0.03	8.5	0.05
			9.1	0.00	8.8	0.02
					9.5	0.00
3.	610	35 / 18	0	0.10	0	0.11
			7.5	0.07	7.5	0.09
			8.0	0.05	8.5	0.06
			8.5	0.02	8.8	0.04
			8.8	0.01	9.0	0.02
			9.0	0.00	9.2	0.00

4. RESULTS AND SIMULATIONS

A. Effect of variation of temperature on the electrical parameters of polycrystalline and mono-crystalline solar module

As temperature and insolation keeps on varying throughout the day, it is important to observe its effect on I-V characteristics of solar module. The solar modules are used at temperature range between 25°C to 50°C and at illumination level between 240 to 700W/m^2 to determine the I-V characteristics. The measurements were performed at 25°C, 30°C, 35°C, 40°C, 45°C and 50°C temperature by highly accurate measuring equipment.

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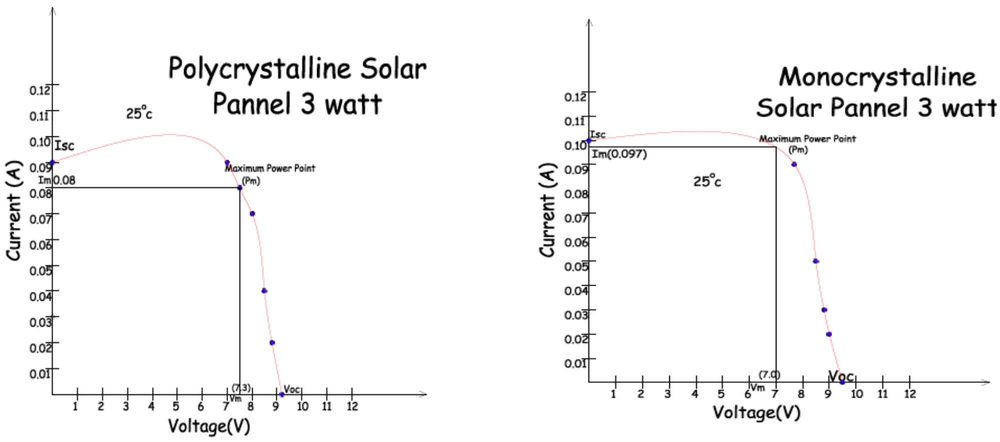

Fig. 3. I-V characteristics of Polycrystalline and Mono-crystalline solar module at 25°C.

Table 2. Electrical parameters of polycrystalline and mono-crystalline at 25°C

Sample	V_{oc} (V)	I_{sc} (A)	V_m (V)	I_m (A)
Polycrystalline	9.2	0.09	7.3	0.08
Mono-crystalline	9.5	0.10	7.0	0.097

Fig. 4, 5, 6, 7 and 8 shows current-voltage characteristics of solar modules at 30°C, 35°C, 40°C, 45°C and 50°C respectively. Table 2, 3, 4, 5, 6 and 7 shows the effect of temperature on electrical parameters of polycrystalline solar module at 30°C, 35°C, 40°C, 45°C and 50°C respectively.

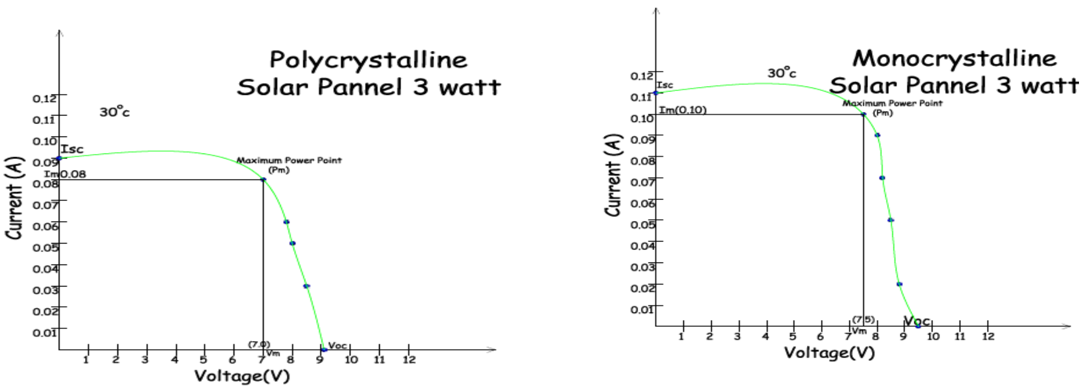

Fig. 4. I-V characteristics of Polycrystalline and Mono-crystalline solar module at 30°C.

Table 3. Electrical parameters of polycrystalline and mono-crystalline at 30°C

Sample	V_{oc} (V)	I_{sc} (A)	V_m (V)	I_m (A)
Polycrystalline	9.1	0.09	7	0.08
Mono-crystalline	9.5	0.11	7.5	0.10

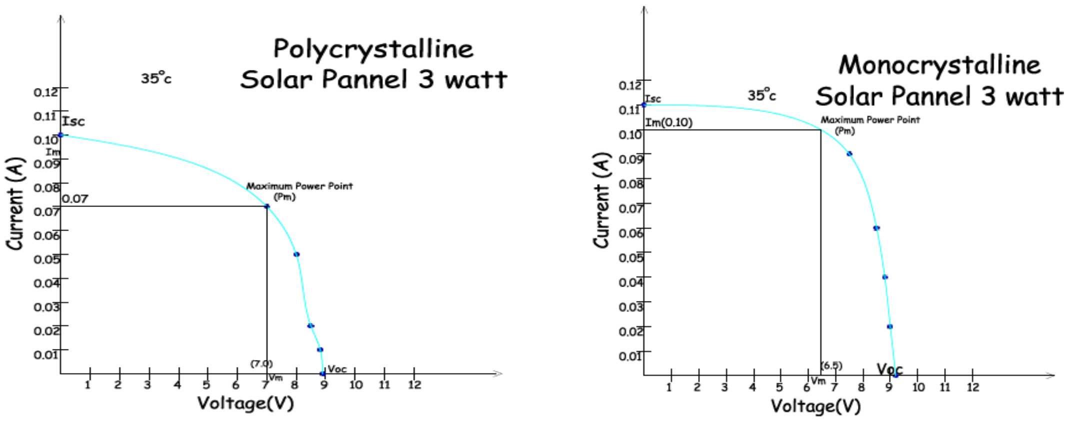

Fig. 5. I-V characteristics of Polycrystalline and Mono-crystalline solar module at 35°C.

Table 4. Electrical parameters of polycrystalline and mono-crystalline at 35°C

Sample	V_{oc} (V)	I_{sc} (A)	V_m (V)	I_m A)
Polycrystalline	9.0	0.10	7	0.07
Mono-crystalline	9.2	0.11	6.5	0.10

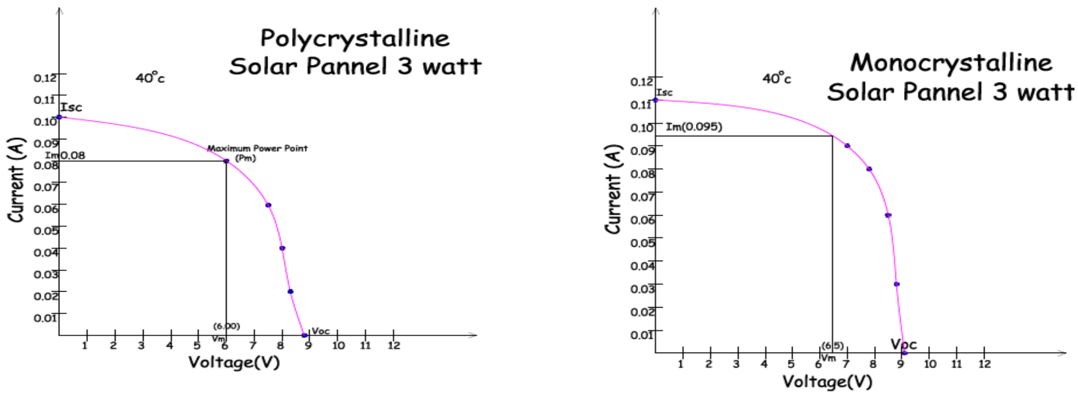

Fig. 6. I-V characteristics of Polycrystalline and Mono-crystalline solar module at 40°C.
Table 5. Electrical parameters of polycrystalline and mono-crystalline at 40°C

Sample	V_{oc} (V)	I_{sc} (A)	V_m (V)	I_m (A)
Polycrystalline	8.8	0.10	6	0.08
Mono-crystalline	9.1	0.11	6.5	0.095

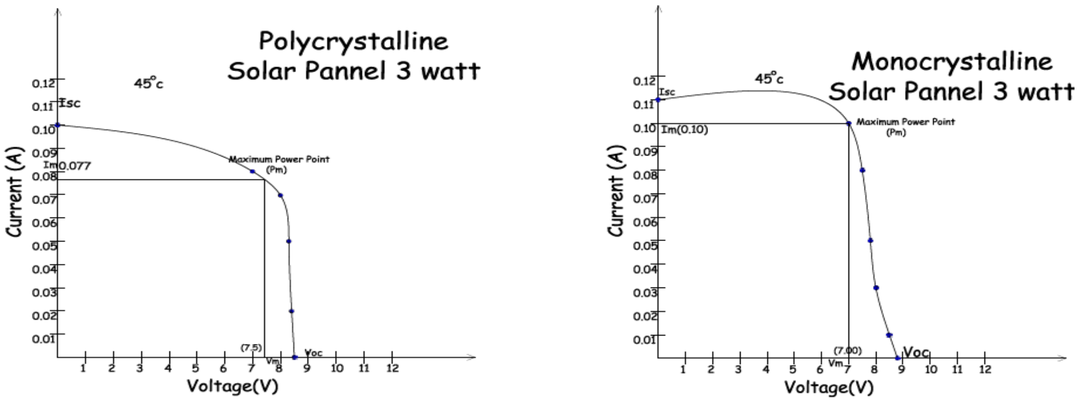

Fig. 7. I-V characteristics of Polycrystalline and Mono-crystalline solar module at 45°C.

Table 6. Electrical parameters of polycrystalline and mono-crystalline at 45°C

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Sample	V_{oc} (V)	I_{sc} (A)	V_m (V)	I_m (A)
Polycrystalline	8.5	0.10	7.5	0.07
Mono-crystalline	8.8	0.11	7.0	0.10

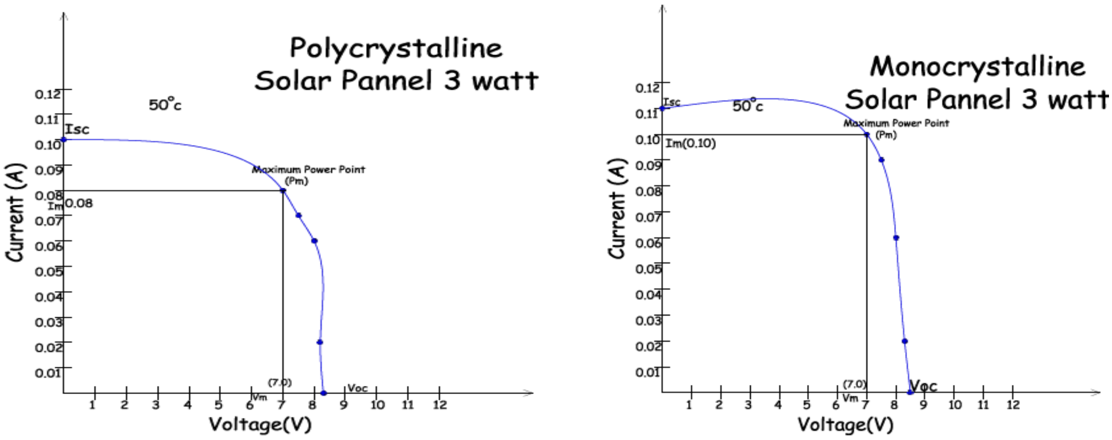

Fig. 8. I-V characteristics of Polycrystalline and Mono-crystalline solar module at 50°C.

Table 7. Electrical parameters of polycrystalline and mono-crystalline at 50°C

Sample	V_{oc} (V)	I_{sc} (A)	V_m (V)	I_m (A)
Polycrystalline	8.3	0.10	7	0.08
Mono-crystalline	8.5	0.11	6.5	0.095

Table 8 shows the effect of temperature on electrical parameters of polycrystalline solar module and Table 9 shows the effect of temperature on electrical parameters of mono-crystalline solar module.

Table 8. Effect of Temperature on electrical parameters of polycrystalline solar module

	POLYCRYSTALLINE							
Temp. (°C)	Voc (V)	Isc (A)	Vm (V)	Im (A)	Pm =Im×Vm	Pin (W/m^2)	Fill Factor(FF) $= \frac{Vm \times Im}{Voc \times Isc}$	η (%) $= \frac{Vm \times Im}{Pin \times Ac} \times 100$
25°C	9.2	0.09	7.3	0.08	0.584	240	0.706	7.11
30°C	9.1	0.09	7	0.08	0.56	352	0.684	5.04
35°C	9.0	0.10	7	0.07	0.49	610	0.544	2.35
40°C	8.8	0.10	6	0.08	0.48	650	0.545	2.16
45°C	8.5	0.10	7.5	0.07	0.525	670	0.618	2.29
50°C	8.3	0.10	7	0.08	0.56	700	0.675	2.34

Where V_{oc} is open circuit voltage and I_{sc} is short circuit current., Vm is maximum voltage and Im is maximum current.

P_m is maximum power and Pin is incident light power., FF is fill factor., η (%) is efficiency.

For polycrystalline, Area of collector (A_c) = 0.034225 m^2

For monocrystalline, Area of collector (A_c) = 0.036975 m^2

Table 9. Effect of Temperature on electrical parameters of mono-crystalline solar module

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	MONO-CRYSTALLINE							
Temp. (°C)	Voc (V)	Isc (A)	Vm (V)	Im (A)	Pm =Im×Vm	Pin (W/m²)	Fill Factor(FF) = $\frac{V_m \times I_m}{Voc \times Isc}$	η (%) = $\frac{Vm \times Im \times 100}{Pin \times Ac}$
25°C	9.5	0.10	7.0	0.097	0.679	250	0.715	7.65
30°C	9.5	0.11	7.5	0.10	0.75	352	0.718	6.24
35°C	9.2	0.11	6.5	0.10	0.65	610	0.642	2.88
40°C	9.1	0.11	6.5	0.095	0.618	650	0.617	2.57
45°C	8.8	0.11	7.0	0.10	0.7	670	0.723	2.83
50°C	8.5	0.11	7.0	0.10	0.7	700	0.749	2.70

B. Comparison of effect of temperature on maximum power (pm) of polycrystalline and mono-crystalline solar modules

Fig. 9 the represents the maximum power (P_m) of poly-crystalline and mono-crystalline solar module. At 25 °C the values of Pm for poly-crystalline module is 0.584 and of mono-crystalline module is 0.679. As temperature increase to 30 °C the maximum power (P_m)of poly-crystalline module decreases to 0.56 and of mono-crystalline module increases to 0.75. When temperature reaches to 35 °C the maximum power (P_m) of poly-crystalline module further decreases to 0.49 and maximum power (Pm) of mono-crystalline module is decreases 0.65.When temperature is further increases to 40 °C the maximum power (Pm) of poly-crystalline module again decreases slightly to 0.48 and maximum power (Pm) of mono-crystalline module also decreases slightly to 0.6175. At temperature 45°C the maximum power (Pm) of poly-crystalline module increases slightly to 0. 525 and maximum power (Pm) of mono-crystalline module also increases slightly to 0.7. At temperature 50°C the maximum power (Pm) of poly-crystalline module increases slightly to 0.56 and maximum power (Pm) of mono-crystalline module is again 0.7.This represents that Maximum power of both modules varies with the temperature.

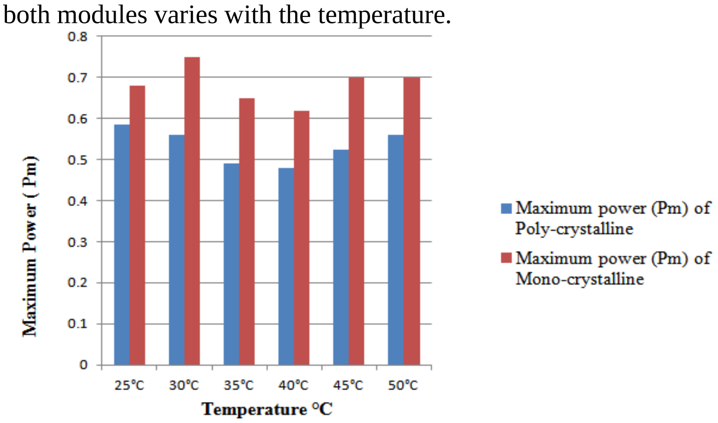

Fig. 9. Maximum Power of Polycrystalline and Mono-crystalline solar module at 25°C, 30°C, 35°C, 40°C, 45°C and 50°C.

C. Comparison of effect of temperature on fill factor of polycrystalline and mono-crystalline solar modules

Fig. 10 represents the Fill Factor of polycrystalline and mono-crystalline solar module. At 25 °C the values of fill factor (FF) of polycrystalline module is 0.706 and fill factor of mono-crystalline module is 0.715, but as temperature increase to 30 °C thefill factor of polycrystalline module decreases to 0.684 and fill factor of mono-crystalline solar module increases slightly to 0.718. As temperature reaches to 35 °C the fill factor of polycrystalline module decreases to 0.544 and fill factor of mono-crystalline module starts decreasing and has value 0.642. At 40 °C fill factor of polycrystalline slightly decreases to 0.545 and fill factor of mono-crystalline decreases to 0.617 at 45°C the fill factor of polycrystalline module increases to 0.618 and fill factor of mono-crystalline module increases to 0.723. At 50 °C the fill factor of polycrystalline module is increase slightly to 0.675 and fill factor of polycrystalline module increases slightly to 0.749.

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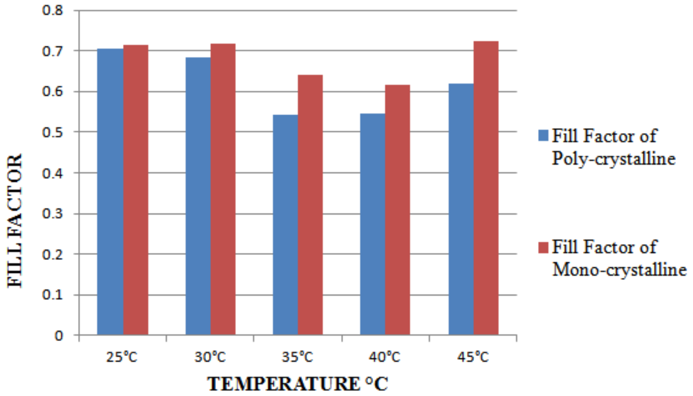

Fig. 10. Fill Factor of Polycrystalline and Mono-crystalline solar module at 25°C, 30°C, 35°C, 40°C, 45°C and 50°C.

D. Comparison of effect of temperature on efficiency of polycrystalline and mono-crystalline solar modules.

In Fig. 11 the graph represents the efficiency (η %) of poly-crystalline and mono-crystalline solar module. At 25 °C the values of efficiency for poly-crystalline module is 7.11% and of mono-crystalline module is 7.65%. As temperature increase to 30 °C the efficiency of poly-crystalline module decreases to 5.04% and of efficiency mono-crystalline module decreases slightly to 6.24%. This again shows that at 30 °C mono-crystalline module is more efficient than polycrystalline module. When temperature reaches to 35 °C theefficiency of poly-crystalline module further decreases to 2.35% and efficiency of mono-crystalline module is decreases 2.88%. This again shows that at 35 °C mono-crystalline module is more efficient than polycrystalline module. When temperature is further increases to 40 °C the efficiency of poly-crystalline module again decreases slightly to2.16% andefficiency of mono-crystalline module also decreases slightly to 2.57% again this shows that at 40 °C mono-crystalline module is much more efficient than polycrystalline module. At temperature 45°C the efficiency of poly-crystalline module increases slightly to 2.29% and efficiency of mono-crystalline module also increases slightly to 2.83% this again shows that at 45°Cmono-crystalline module is much more efficient than polycrystalline module. At temperature 50°C the efficiency of poly-crystalline module increases slightly to 2.34andefficiency of mono-crystalline module is 2.70 but this again shows that at 50 °C mono-crystalline module is more efficient than polycrystalline module.

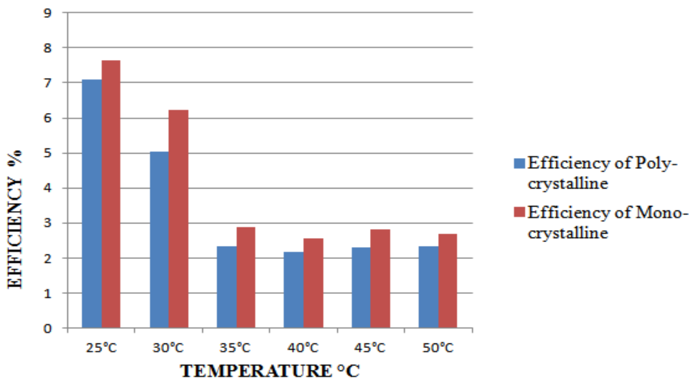

Fig. 11. Efficiency of Polycrystalline and Mono-crystalline solar module at 25°C, 30°C, 35°C, 40°C, 45°C and 50°C.

4. CONCLUSIONS

A performance test of polycrystalline and mono-crystalline solar module has been carried out in this research. The experiment was carried out and the maximum voltage, maximum current, fill factor and efficiency was, measured attemperature 25°C,30°C, 35°C ,40°C, 45,°C, and 50°C respectively and at illumination 240W/m^2, 325 W/m^2, 610 W/m^2, 650 W/m^2, 670 W/m^2 and 700 W/m^2 respectively.

(1) The results shows that the cell temperature has a significant impact on photovoltaic parameters and it controls the quality and performance of solar module. The Pm of polycrystalline module has maximum value of 0.584 at 25°C, as compare to polycrystalline the value of Pm of mono-crystalline at 25°C is 0.679 has maximum value of P_m = 0.75 at 50°C.

(2) The fill factor of polycrystalline module has maximum value of 0.706 at 25°C, as compare to polycrystalline the fill factor of mono-crystalline has maximum of 0.749at 50°C.

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(3) The findings indicate that efficiency of mono-crystalline is higher than the polycrystalline at each level of temperature. The efficiency of polycrystalline module has maximum value of 7.11at 25°C, as compare to polycrystalline the efficiency of mono-crystalline has maximum value of 7.65 at 25°C.
(4) The findings also indicate that the polycrystalline module has efficient performance at 25°C and at 30°C, as compare to polycrystalline module the mono-crystalline module perform efficiently between 25°C to 50°C.
(5)The best performance of solar modules in proper illumination and at less temperature has been suggested. The mono-crystalline solar module is suggested to be installed rather than polycrystalline solar modules for solar power applications as the efficiency of this module is high at various temperatures.

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