Evaluation the Performance of CPV with Different Concentration Ratio

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Abstract

The present work aims at decrease the cost of the photovoltaic (PV) solar system by decreasing the area of expensive solar cells by low cost optical concentrators that give the same output power. Output power of two types' monocrystalline and polycrystalline silicon solar cells has been measured with and without presence of linear focus Fresnel lenses (FL) with different concentration ratios. Cooling system has been used to decrease the effect of temperature on solar cell performance. The results indicated that the increase in the output power is about 5.3 times by using Fresnel lens concentrator without using cooling system in comparison with solar cell without concentrator, while it is about 14.6 times by using cooling system. The efficiency of monocrystalline solar cell without cooling system is about 11.2% for solar irradiance 0.698 kW/m^2, this value decrease to 3.3% for solar irradiance 12.4 kW/m^2 and concentration ratio 17.7 by using Fresnel lens concentrator, while when using cooling system the efficiency enhance to 12.9% and 8.8% for solar irradiance 0.698 and 12.4, respectively.

Keywords: solar cell efficiency**,** CPV systems, Fresnel lens concentrator

1. Introduction

The use of traditional resources of energy in the world leads to many disadvantages because of its high cost, limited resources and it cause to emit the greenhouse gases that contribute to environmental pollution and global warming. These reasons represent the main motivation for the use of alternative energy sources. Nowadays, the world has turned to the use of renewable energy sources to get rid of the disadvantages of using traditional sources as well as this topic has become a concern of scientific researchers. One of the important type's renewable energy is solar energy, it can be harnessed mainly in three different ways which are Photochemical, Photothermal, and Photovoltaic [1]. Today, the industry of photovoltaic is growing rapidly, however, the expensive semiconductor material for solar cells make the use of photovoltaic systems is limited. The combination of concentrating optics with solar cells is an effective way to cut down the amount of semiconductor material and thus reduce the cost of photovoltaic systems. Sandia National Labs proposed the first photovoltaic integrating concentrator in the late 1980s [2]. Refractive or reflective optical approach or a combination of both can be employed as PV concentrators (CPV). recently, Fresnel lenses (FL) have been one of the best choices of refractive concentrated solar energy applications because of it has light-weight, small volume, low cost with mass production as well as effectively increase the energy density. The FL can either be linear focus lens to concentrate the solar radiation on a row of cells as shown in figure 1, or circular focus lens to concentrate the solar radiation on a single cell [3].

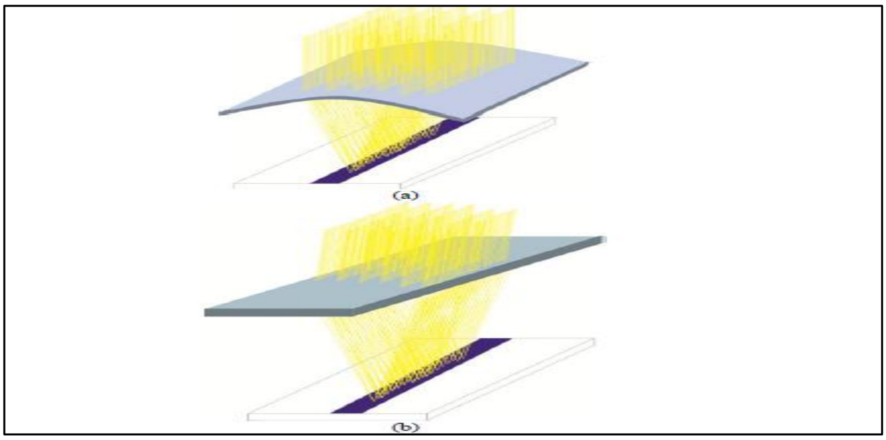


Figure (1) Line-focus concentrating Fresnel PV module [4]

The high concentration ratio of CPV system cause to increase the temperature of solar cell that makes its efficiency decrease significantly because the photons not converted to electricity are dissipated as heat in the cells which lead to drop the solar cell efficiency [5]. Thus, an essential requirement is cooling system for a successful photovoltaic concentrator that can efficiently remove the heat dissipated from solar cell and keeping it at the desired temperature [6]. There are several studies which have focused on reducing the cost of photovoltaic systems using Fresnel lenses by increasing the amount of solar radiation falling on the cell. David et al in 2014 used nine monocrystalline solar cells, one facing the sun without lens serving as the control and eight with Fresnel lenses which had been placed above the cells with different heights (0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, and 1.8 times the lenses' focal lengths). The results indicated that the best case was 0.8 times the lenses' focal lengths (0.8F) which generate 14.93% more energy than the control, while in the other experimental groups the net increases in energy outputs ranged from 1.25% to 9.53% [7]. Maike et al used a method to determine the optimal cell-lens distance, In addition, they investigated the dependency of the focal length on the temperature. The measured short circuit current was then normalized to the illumination intensity measured with a pyrheliometer. The results showed that an increase of the optimal cell-lens distance with lens temperature by 0.74 mm per 10 K. This result agrees with the results of indoor measurements [8]. Muhammad et al used four different cooling techniques for enhancement of solar cell output power under concentration which were closed loop method, passive heat sink method, active air fan method, and water sprinkling system. The results indicated that cooling systems with the water sprinkling system being the most efficient (8–13.14%) than others, while the active air-cooled fan system and closed loop system are comparatively more efficient that the heat sink-based passive cooling [9]. The object of the present work is to use linear focus Fresnel lens optical concentrator with solar cell in order to increase the input solar radiation by increasing the concentration ratio and thus increase the output power from solar cell. In addition, cooling system has been used to decrease the effect of temperature on the efficiency of solar cell.

2. Experimental Part

2.1 Assembling of the CPV system

Mono and poly crystalline Silicon solar cells with dimensions of (15.39 cm ×15.39 cm); from Al Mansour Factory has been used (see figure 2). Table 1 shows the characteristics of these solar cells.

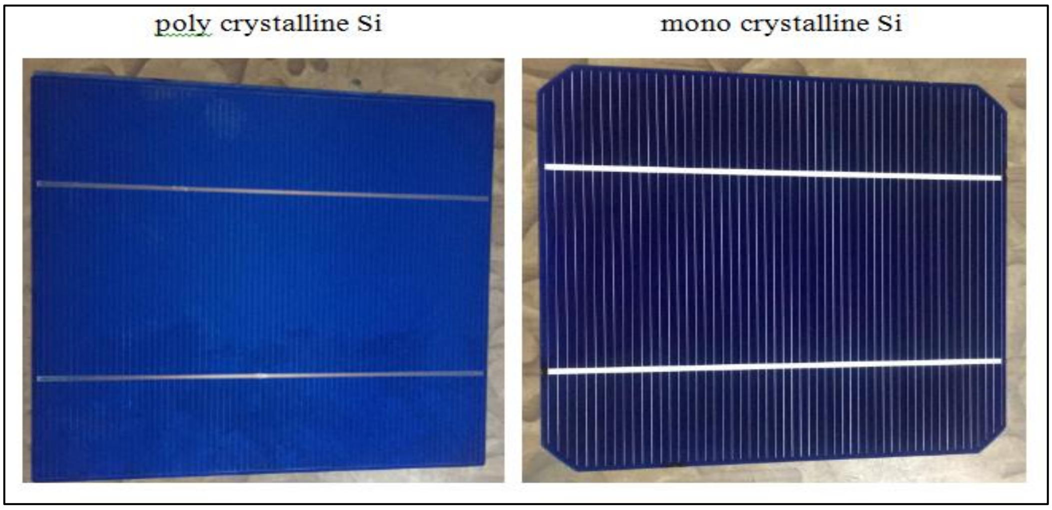


Figure (2): mono and poly crystalline types Silicon solar cells

Table (1): Technical specification of solar cells as measured in Al-Mansour factory under standard conditions (Irradiance=1000W/m^2, Air mass=1.5, cell temp.=25 ^oC)

parameter	Value (monocrystalline)	Value (polycrystalline)
Short circuit current (I_{sc})	8.93 A	8.37
Open circuit voltage (V_{oc})	0.639 V	0.607 V
Maximum current (I_m)	8.27 A	7.74 A
Maximum voltage (V_m)	0.526 V	0.495 V
Maximum power (P_m)	4.35 W	3.84 W
Fill factor (FF)	0.762	0.754
Efficiency (η)	18.2 %	16.1 %
Voltage temp. coefficient	-2.1	-2.1
Series resistance (R_s)	6Ω	6Ω

These cells were cutting into small pieces (2 cm ×1cm) and the electrodes was welded using caustic as shown in fig (3)

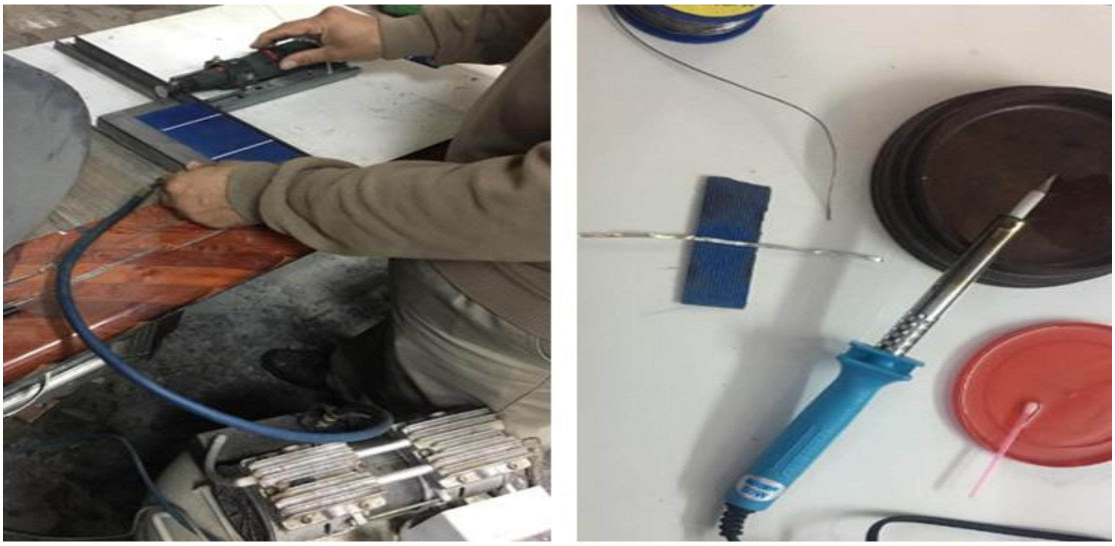


Figure (3): Method of cell cutting and welding electrodes

In the present work linear focus Fresnel lens were used. It made from polymethylmethacrylate (PMMA), polycarbonate (with dimensions of (30 cm ×30 cm), focal length (33 cm), relatively flat lens used to concentrate incident sunlight by using of concentric refractive facets known as Fresnel zones (see fig 4). Fresnel lens was installed on the top of the structure in front of the solar cell. The distance of Fresnel lens and solar cell has been changed in order to measure the effect of solar radiation intensity or concentration ratio on the output power of solar cell.

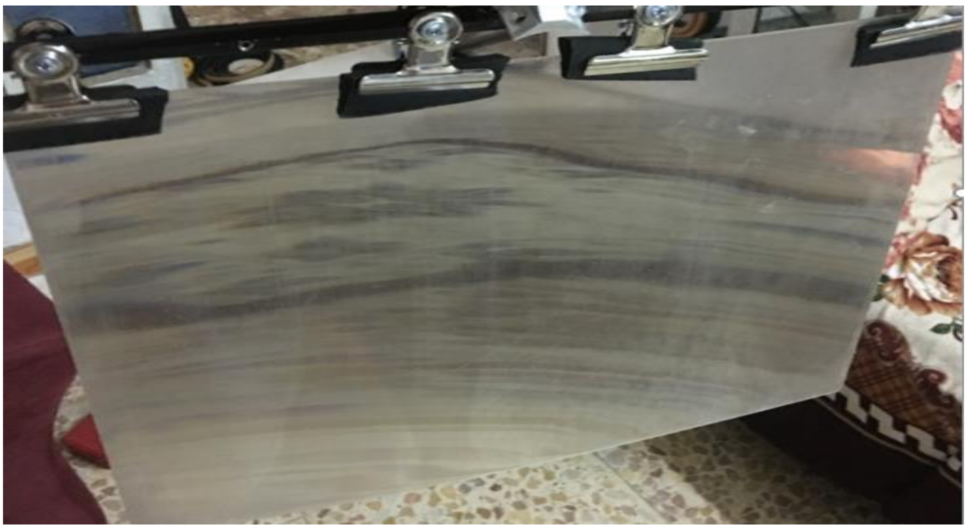


Figure (4): Line focus Fresnel lens

A central processing unit (CPU) Deep cooler with fan 2.4 W that operate in 12 V has been used as heat sink cooling system to cool the solar cell as shown in figure 5.

Figure (5): CPU Deep cooler

Each of the solar cell and FL were placed on a suitable structure as demonstrated in figure 6.

Figure (6): The CPV system

2.2. Measurements

Two types of solar cells, monocrystalline and polycrystalline cells under different rates of solar radiation, were tested using linear focus Fresnel lenses. The practical procedures are summarized as following:

1. In the first case the solar cell characteristics have been tested in Al-Mansour factor under standard test conditions (solar radiation=1000 W/m^2, AM=1.5, solar cell temperature=25^o).
2. Linear focus Fresnel lens is placed at a specific distance from the solar cell. The set-up was placed on the manual tracker structure. The open

circuit voltage (V_{oc}), short circuit current (I_{sc}), solar cell temperature (T_c), ambient temperature (T_a) and the value of concentrated solar radiation has been measured for different concentration ratio.

3. Repeat all previous measurements in point (2) under the effect of cooling process.
4. The output power (P_m) and the efficiency of the solar cell can be calculated by using the following equations:

$$P_m = I_{SC} V_{OC} FF \quad (1)$$

$$\eta = \frac{P_m}{H_{SR} A_{SC}} \quad (2)$$

   Where FF is the fill factor, A_{SC} is the area of solar cell and H_{SR} is the solar radiation intensity
5. The parameters of concentrated solar cells were compared with a solar cell without concentrator.

3. Results

Figure 7 illustrates the effect of increasing the solar irradiance on the temperature of solar cell with and without using cooling system. It can be seen that the solar cell temperature increase with increasing solar irradiance but this effect decrease by using cooling system for both monocrystalline and polycrystalline solar cells.

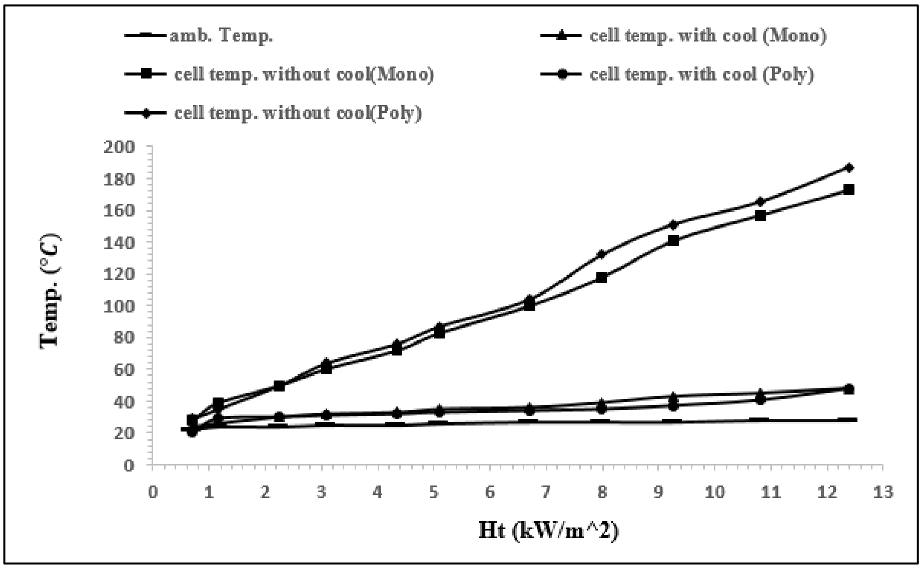


Figure (7): Effect of increasing the solar irradiance on the solar cell temperature with and without cooling system.

Effect of increasing the solar irradiance on the output power and efficiency is tested for two different types monocrystalline and polycrystalline solar cells under concentration by using linear focus Fresnel lens, with and without using of cooling system that are shown in Figures 8-11, respectively.

The current increase gradually with increasing the solar irradiance, thus the current produced from monocrystalline solar cells without using of cooling system increase from 39 mA for solar irradiance 0.698 kW/m^2 to 251 mA for solar irradiance 12.4 kW/m^2, while it increase from 35.9 mA to 230 mA for polycrystalline solar cell as shown in figure 8(a). on the other hand the use of cooling system enhance the performance of solar cell, thus the current produced from monocrystalline solar cell increase from 39mA for solar irradiance 0.698 kW/m^2 to 553 mA for solar irradiance 12.4 kW/m^2, while it increase from 34 mA to 540 mA for polycrystalline solar cell as shown in figure 8(b).

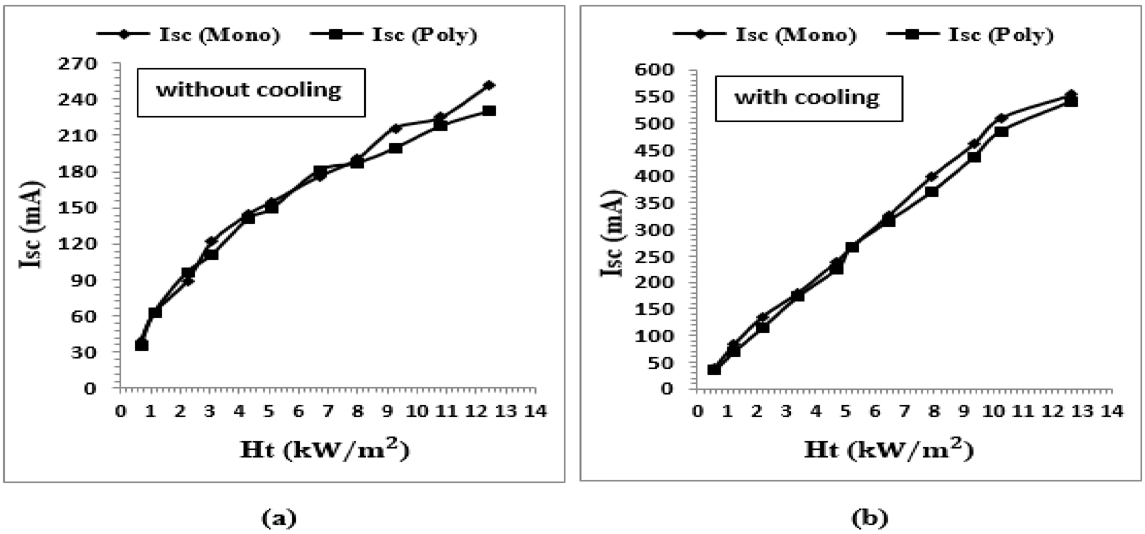


Figure (8): Effect of increasing the solar irradiance on the current produced by solar cell under concentration

The effect of solar irradiance on the voltage of solar cells under the forced convective cooling conditions are shown in Figure 8, it can be seen from figure 9(a) that the cell voltage decrease with increasing solar irradiance because of increase the cell temperature. But the temperature is significantly reduced by using forced convective heat transfer cooling that lead to increase the voltage as shown in figure 9(b). This behavior occurs in both types of solar cells.

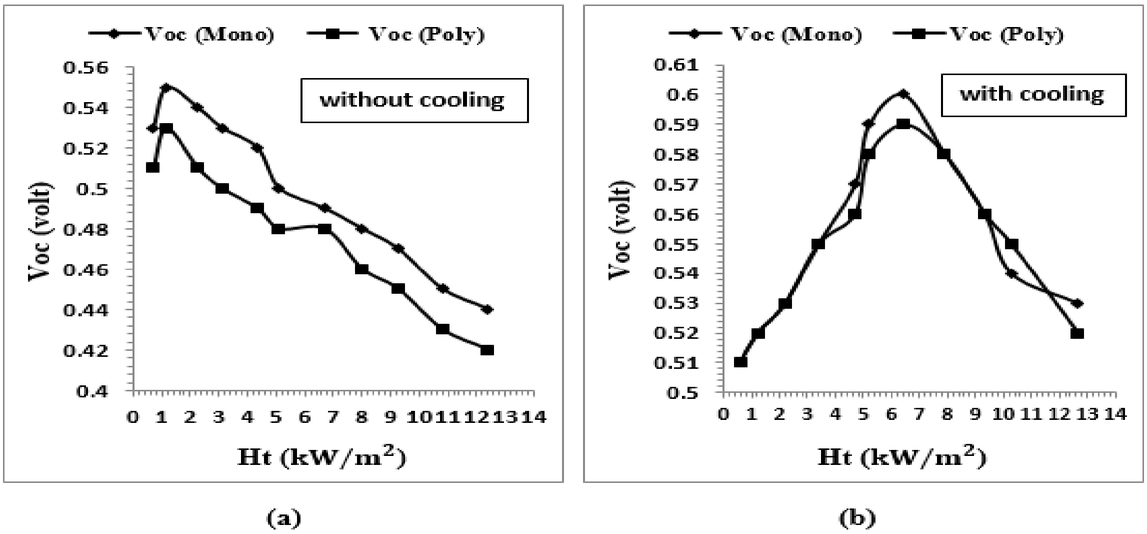


Figure (9): Effect of increasing the solar irradiance on the voltage produced by solar cell under concentration

Figure 10 illustrate the output power from solar cell as a function of solar irradiance. When the solar irradiance was 0.698 kW/m^2, the measured output power was 0.015 W for monocrystalline solar cell, and 0.013 W for polycrystalline solar cell. These values increase and reach to 0.08 W and 0.07, respectively when the solar irradiance becomes 12.4 kW/m^2. It is concluded that the increase in the output power is about 5.3 times by using Fresnel lens concentrator without using cooling system. At solar irradiance 12.4 kW/m^2 the output power reach to 0.22 W and 0.21 W for monocrystalline and polycrystalline solar cell with cooling system, respectively, in other words the increase in the output power is about 14.6 times.

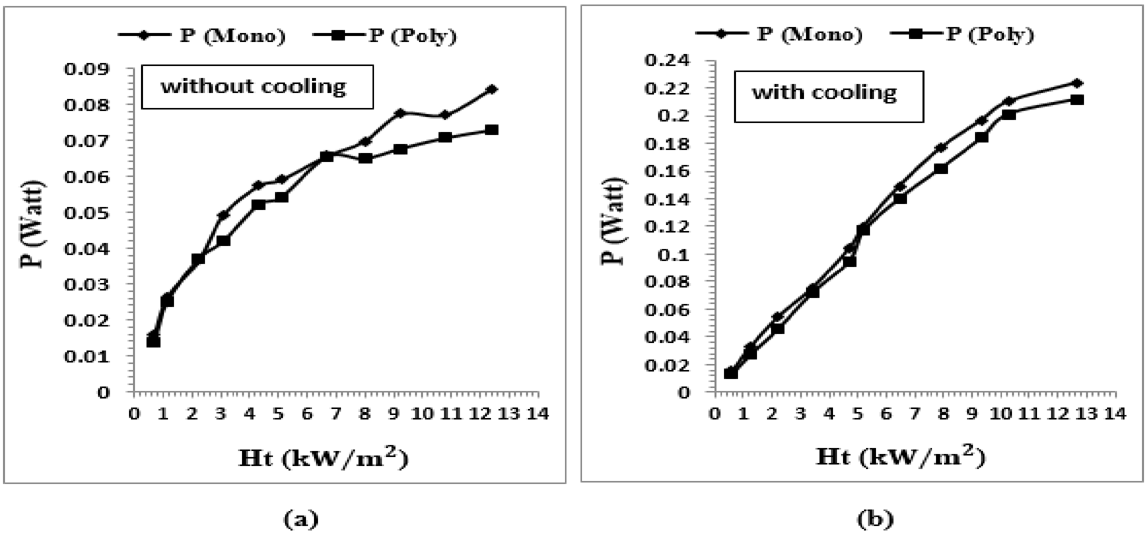
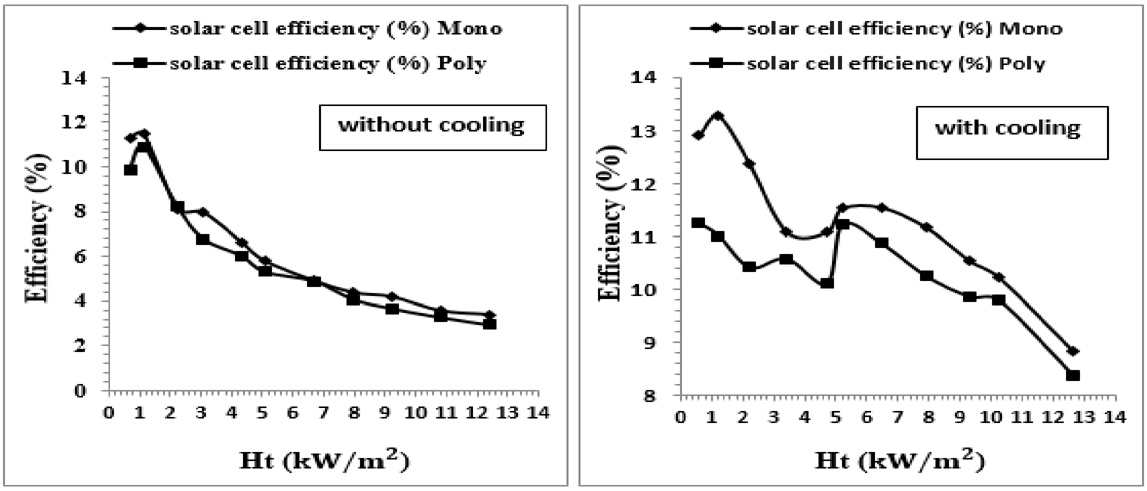


Figure (10): Effect of increasing the solar irradiance on the output power of solar cell

The increase in solar irradiance by increasing in the concentration ratio lead to increase the temperature of solar cell which effect to decrease the solar cell efficiency. This can be shown in figures 11. While the efficiency has been enhanced by using cooling technique. The efficiency of monocrystalline solar cell without using cooling system decrease from 11.2% for solar irradiance 0.698 kW/m^2 and concentration ratio 1 to 3.3% for solar irradiance 12.4 kW/m^2 and concentration ratio 17.7, while when using cooling system the efficiency enhance to 12.9% and 8.8% for solar irradiance 0.698 and 12.4, respectively. On the other hand the efficiency of polycrystalline solar cell without using cooling system decrease from 9.8% for solar radiation 0.698 kW/m^2 and concentration ratio 1 to 2.9% for solar radiation 12.4 kW/m^2 and concentration ratio 17.7, while when using cooling system the efficiency enhance to 11.2% and 8.3%, respectively.



(a) (b)

Figure (11): Variation of solar cell efficiency with irradiance

4. Conclusions

It is concluded from this research that:

1. The behavior of the two types monocrystalline and polycrystalline is the same for all test measurements but monocrystalline is better than polycrystalline in its efficiency and output power under concentration.

2. The output power increase about 5.3 times by using Fresnel lens concentrator without using cooling system and 14.6 times with cooling system.
3. Fresnel lens concentrator is a feasible application in photovoltaic system specialy when using cooling system.

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