Improving the Efficiency of the Polycrystalline silicon cell using linear focus fresnel lens

Assist. Prof. Dr. Ali H.A. Al-hamadany
University of Technology-Renewable Energy Center
Assist. Prof. Dr. Faten Sh. ZainAlabideen
Almustansiriyah University-Education Coll. - Physics Depm.
Abdilmoutalib H. A. Al-Shariefy
Baghdad Governorate

Abstract

In this research , one linear focus Fresnel lens made of PMMA plastic material has been used to increase the incident irradiance on one solar cell by concentrate the sun light ray on it and then to improve the cell performance. It is important to find the appropriate distance between the solar cell and Fresnel lens to reach the maximum power and efficiency.

The distance between a solar cell with dimensions (12.5cm × 12.5cm) made of poly-crystalline Silicon and the Fresnel lens was changed. The results showed that the best distance at which the parameters (I_{sc} , I_{mp} , V_{oc} , V_{mp} , P_{mp} , FF and η) reached their maximum values; was 55 cm. So the output power of this solar cell was (2.25watt) and efficiency (15.18%) before using Fresnel lens. The power reached the maximum value (3.23watt) at (55cm) distance and it its efficiency become (21.77%).

1. Introduction

Solar technology offers great potential in terms of supplying the world's energy needs. Over the last few decades, there has been an increasing effort from governments, industry and academic institutions to find useful way to improve the solar cell or photovoltaic cell efficiency. One of these ways is concentrator photovoltaic systems (CPV), which use a limited number of small, specialized, efficient solar cells and concentrating optics to increase the intensity of sunlight striking the cells [1]. The basic idea of CPV is to save system costs by focusing the sunlight onto solar cells of area (A_c) through an optical devices of area (A_o) that is less costly than the solar cells as shown in figure (1) .The concentration ratio (C_R) is approximately $C_R = A_o / A_c$ and it is clear that the cost saving increases with C_R [2]. Here a Fresnel lens is used to concentrate the sunlight to a small solar cell.

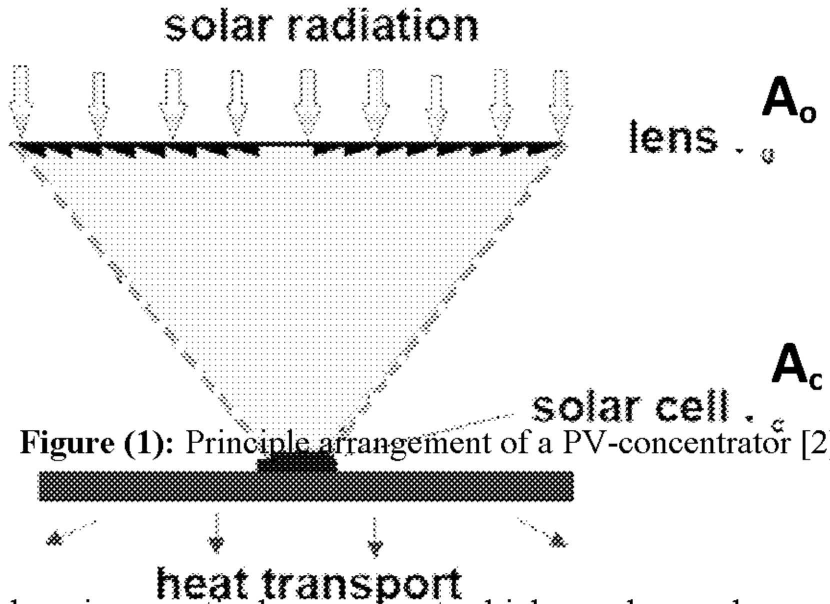

Figure (1): Principle arrangement of a PV-concentrator [2].

A Fresnel lens is an optical component which can be used as a cost-effective, lightweight alternative to conventional continuous surface optics. The principle of operation is straightforward enough: given that the refractive power of a lens is contained only at the optical interfaces (i.e. the lens surfaces), remove as much of the optical material as possible while still maintaining the surface curvature [3].

An optical system in which the goal is to converge light from a relatively large regional area to a significantly smaller aperture can be labeled as a condenser or concentrator. For a concentrator system a Fresnel lens design will be thinner and lighter weight than an equivalent continuous surface optic. The gain is most evident at especially large area applications (200 × 200 mm^2 or larger for example) in which solid core continuous refractive lenses will become very heavy and unwieldy indeed [4].

These concentrators come in two configurations: point-focus and line-focus. Line-focus systems use linear Fresnel lenses to focus sunlight on cells mounted along the focal line [1].

2. Theoretical Part

The conversion efficiency is the most commonly used parameter to compare the performance of one solar cell to another. It is defined as the ratio of energy output from the solar cell to input energy from the sun. The efficiency (η) of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as : [5].

$$\eta = \frac{P_{mp}}{P_{in}} \times 100\,\% = \frac{V_{oc} I_{sc} FF}{P_{in}} \times 100\,\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where (P_{mp}) is the power at the maximum power point, (P_{in}) is the incident power of the sun and can be calculated from multiplying the solar irradiance in (W/m^2) by the area of the solar cell or module in square meter unit, (I_{sc}) is the short-circuit current, (V_{oc}) is the maximum voltage available from a solar cell and (FF) is the fill factor.

P_{mp} is determined from: [6]

$$P_{mp} = I_{mp} \cdot V_{mp} \quad \text{……………………………………………………….(2)}$$

Where, I_{mp} and V_{mp} are the current and voltage at the maximum power point respectively.

I_{sc} is the maximum current through the solar cell when the voltage across the solar cell is zero and V_{oc} is the maximum voltage available from a solar cell, and this occurs at zero current. These four parameters can be determined from the current-voltage characteristic curve (IV-curve) which is shown in figure (2).

The performance of a photovoltaic cell can be characterized by its current-voltage (IV) characteristic. It describes the relationship between the current extracted from a photovoltaic cell and the voltage over the cell as the resistive load connected to the cell changes. It is influenced both by the total irradiation on the cells and on how the light is distributed over the cell [7,8].

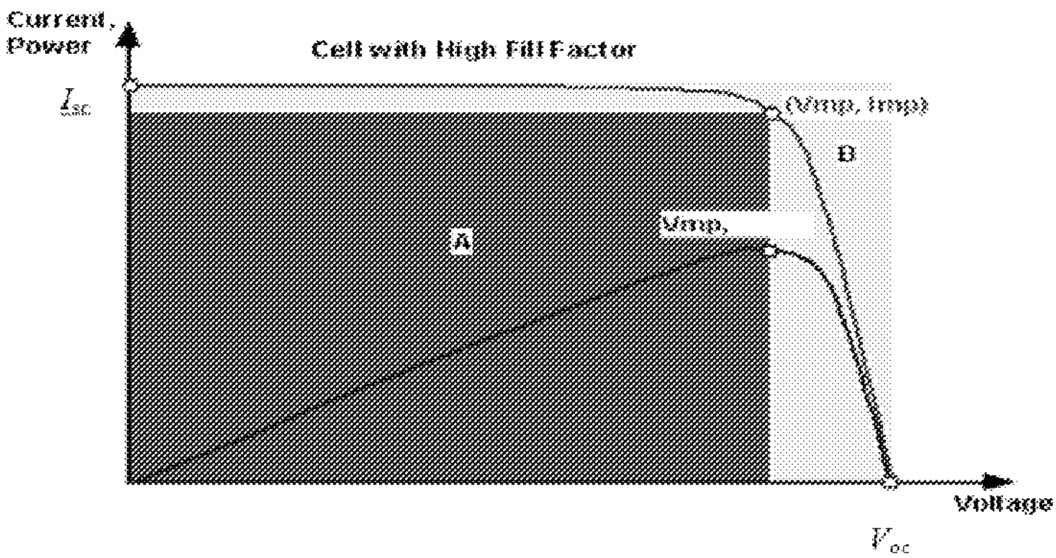

Figure (2): Graph of cell output current (below line) and power (up line) as function of voltage[8] .

The (FF) is the ratio of the maximum power from the solar cell to the product of (V_{oc}) and (I_{sc}). Graphically, it is the measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the current - voltage curve as illustrated in figure (2). It can be determined from the following equation: [6]

$$FF = \frac{I_{mp} . V_{mp}}{I_{SC} . V_{OC}} = \frac{P_{mp}}{I_{SC} . V_{OC}} \quad \text{...} \quad (3)$$

3. Experimental Apparatus

In this research one linear Fresnel lens used with one Poly crystalline Silicon solar cell. The specifications of Fresnel lens was as follows:

Size : 400 × 320 mm
Thickness : 2 mm
Material : PMMA
Groove Pitch : 0.6 mm
Focal Length : 650 mm

Figure (3) illustrates how the collimated light rays become as a cone or pyramid and concentrated to make the linear focus.

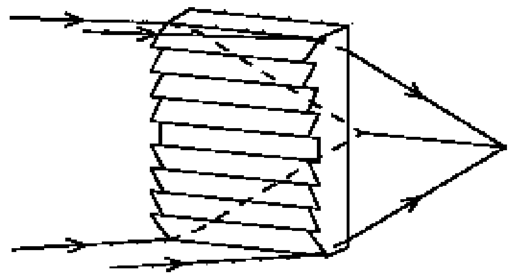

Figure (3): Linear Fresnel lens.

While the solar cell specifications was as followes:

Length : 12.5 cm
Maximum Power : 2.25 watt
Maximum Voltage : 0.46 volt
Maximum Current : 4.83 amp
Fill Factor : 0.746
Efficiency : 15.18 %

Figure (4) shows the (12.5 × 12.5) cm^2 solar cell that used in this research.

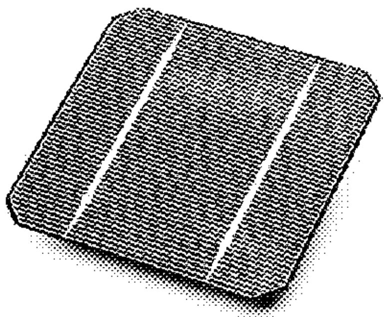

Figure (4): Poly crystalline silicon solar cell of 148.25 cm^2 area .

In order to masher the parameters needed in this research a QuickSun 130CA device was used which is shown in figure (5). It is a versatile manually operated single flash simulator for testing both ordinary and high capacitance crystalline Silicon solar cells. The system is easily customized also up to (32 x 42) cm^2 mini modules manufactured from any thin film or polycrystalline Silicon material. This novel simulator with clear margin, providing enhanced IV graph measurement accuracy and reliability for PV industry. The current – voltage window as appear at the screen of this device has demonstrated in figure (6)

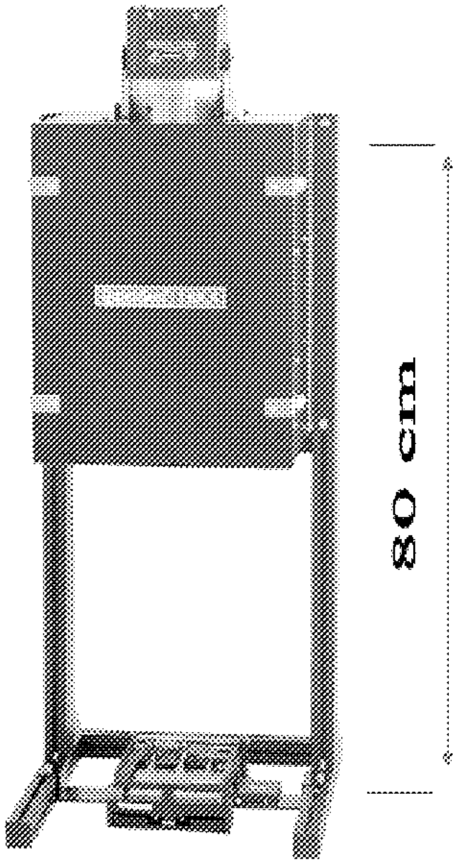

Figure (5): The front side of the QuickSun 130CA device .

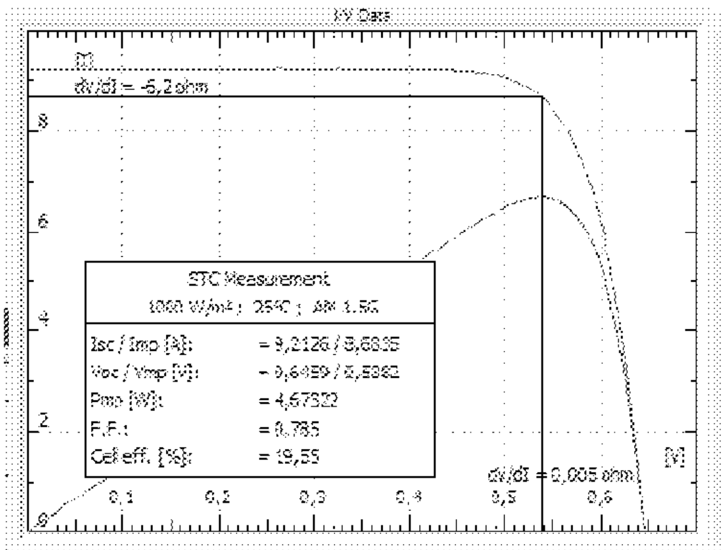

Figure (6): The current– voltage window of QuickSun 130CA screen .

4. Procedures

In order to improve the solar cell performance to make the concentrator photovoltaic , it is necessary to find the fitting distance between Fresnel lens (its focal length (65cm)) and solar cell to see whether the values of the short circuit current(I_{sc}) ,open circuit voltage(V_{oc}) , current at maximum power point(I_{mp}) , voltage at maximum power point(V_{mp}) , the maximum power(P_{mp}), fill factor(FF) and efficiency (η) increase or decrease . For doing this test, the QuickSun 130CA device was used with different distance each time starting from 10cm far from the focal length and getting to 3cm of Fresnel lens i.e. (75-65-55-45-35-27-15-3) cm respectively. Then the fitting distance was (55cm) that means the perfect distance to reach the maximum values of the (voltage , current , power & efficiency) is less than the focal length of Fresnel lens about 10 cm.

5. Results & Discussions

An electronic load controlled by a data logger was constructed for the measurements. The data logger sent control signals to the electronic load that was connected to the cells. The load was able to vary the voltage over the cells from (0) to a specific value of (V_{oc}) in approximately 100 micro second. The current and voltage over the cells are measured simultaneously with the data logger inside the measurement device (QuickSun 130CA). The current and voltage pairs were measured in each measurement. The points were not evenly distributed between 0 and V_{oc} value, the majority of the points were taken around the maximum point of the power on the current-voltage curve. The maximum power point was calculated through a parabolic fit to the three points closest to the maximum power point.

Since the short circuit current is proportional to the irradiation, it is important to measure the incident irradiation during the measurements. The surface of the pyranometer was mounted normal to the sun simulator inside the measurement device.

The efficiency of the cells is proportional to the fill factor, which is calculated at the maximum power point. A high fill factor translates to a high efficiency. The efficiency and the fill factor are calculated from equations (1) and (3) respectively.

The solar cell has been put on the base of the measurement device and connected with it , while Fresnel lens has been put between the light source of this device and the cell , then changing the distance between the cell and the lens starting from 75cm to (65, 55, 45, 35, 27, 15,3) cm and tested by the (Quicksun 130CA) . Whereas the (I_{sc} , I_{mp} , V_{oc} , V_{mp} , P_{mp} , FF and η) parameters of these moves are described in table (1) .

Table (1): The effect of variation the distance between solar cell and Fresnel lens on the (P_{mp} , η , I_{sc} , V_{oc} , I_{mp} , V_{mp} , FF) parameters .

Distance (cm)	P_{mp} (watt)	η %	I_{sc} (amp)	V_{oc} (volt)	I_{mp} (amp)	V_{mp} (volt)	FF
without lens	2.25	15.18	5.282	0.571	4.833	0.465	0.746
3	2.26	15.27	5.310	0.571	4.854	0.466	0.746
15	2.34	15.81	5.502	0.572	5.031	0.466	0.744
27	2.76	18.64	6.527	0.575	5.911	0.467	0.736
35	2.56	17.29	6.058	0.573	5.514	0.464	0.738
45	3.19	21.50	7.671	0.580	6.824	0.467	0.715
55	3.32	21.77	7.792	0.580	6.931	0.465	0.713
65	3.08	20.78	7.420	0.575	6.655	0.462	0.722
75	2.7	17.94	6.529	0.570	5.771	0.460	0.714

As shown from the above table, the maximum value of (I_{sc} , I_{mp} , P_{mp} and η) parameters occurs at 55cm distance .

The IV characteristic which obtained from the measurement device (QuickSun 130CA) for the solar cell without Fresnel lens is shown in figure (7). And the IV-curve for the solar cell at distances (3,15,27,35,45,55,65,75) from Fresnel lens are shown in the figures (8,9,10,11,12,13,14,15) respectively.

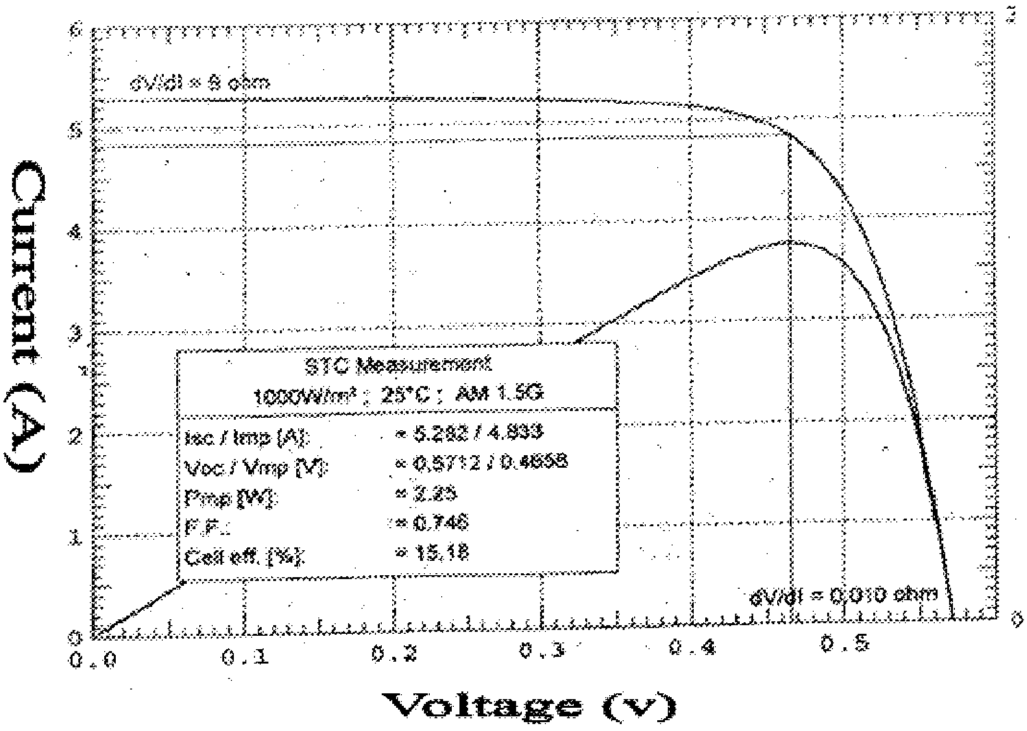

Figure (7): The IV-curve for the solar cell without Fresnel lens.

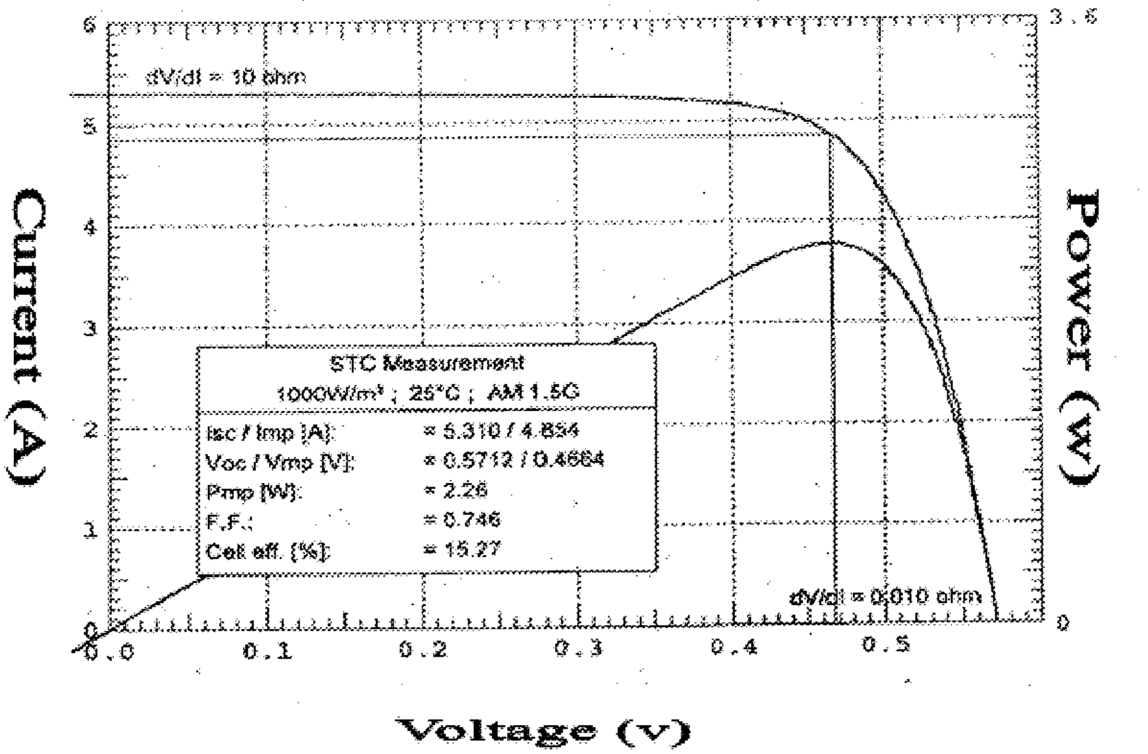

Figure (8): The IV-curve for the solar cell at a distance (3cm) from Fresnel lens.

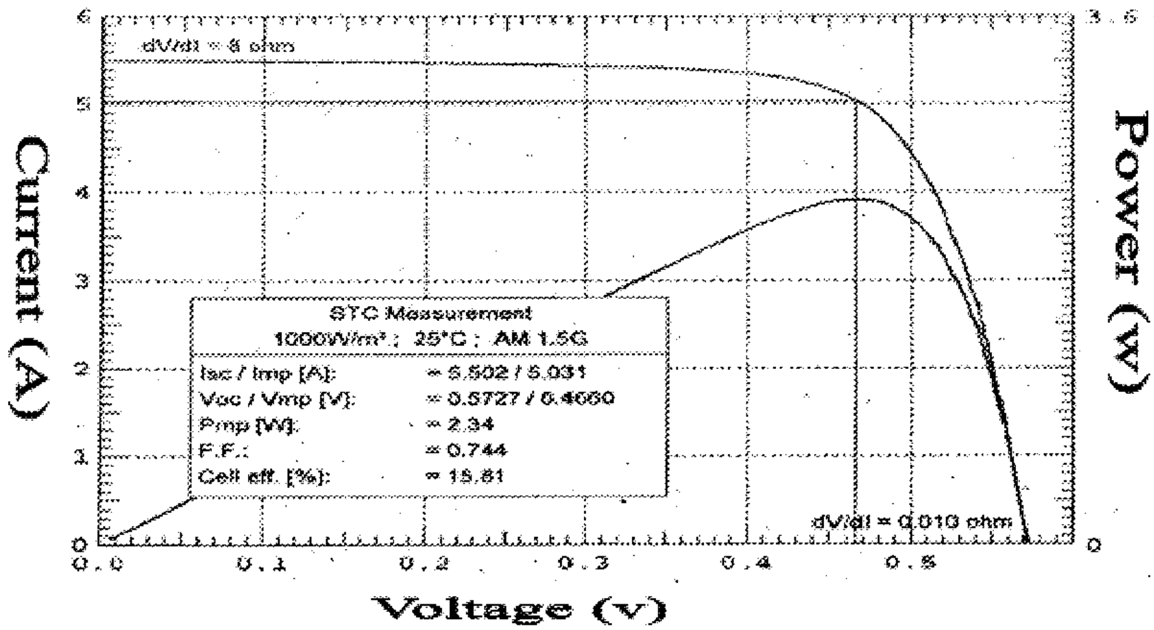

Figure (9): The IV-curve for the solar cell at a distance (15cm) from Fresnel lens.

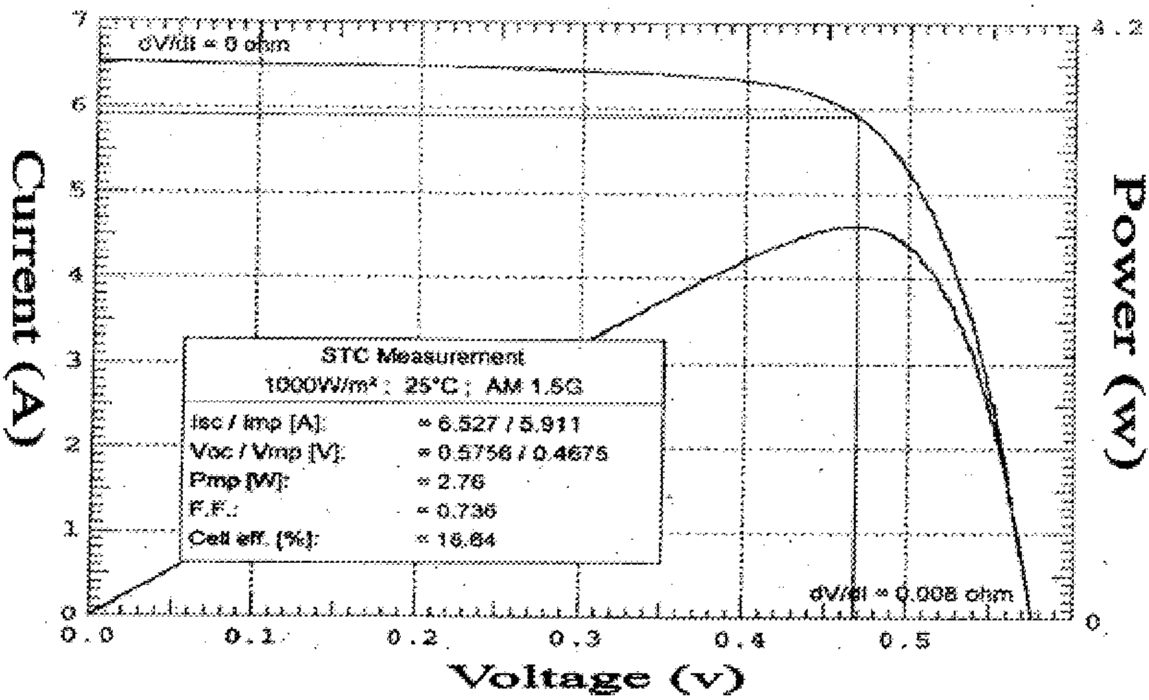

Figure (10): The IV-curve for the solar cell at a distance (27cm) from Fresnel lens.

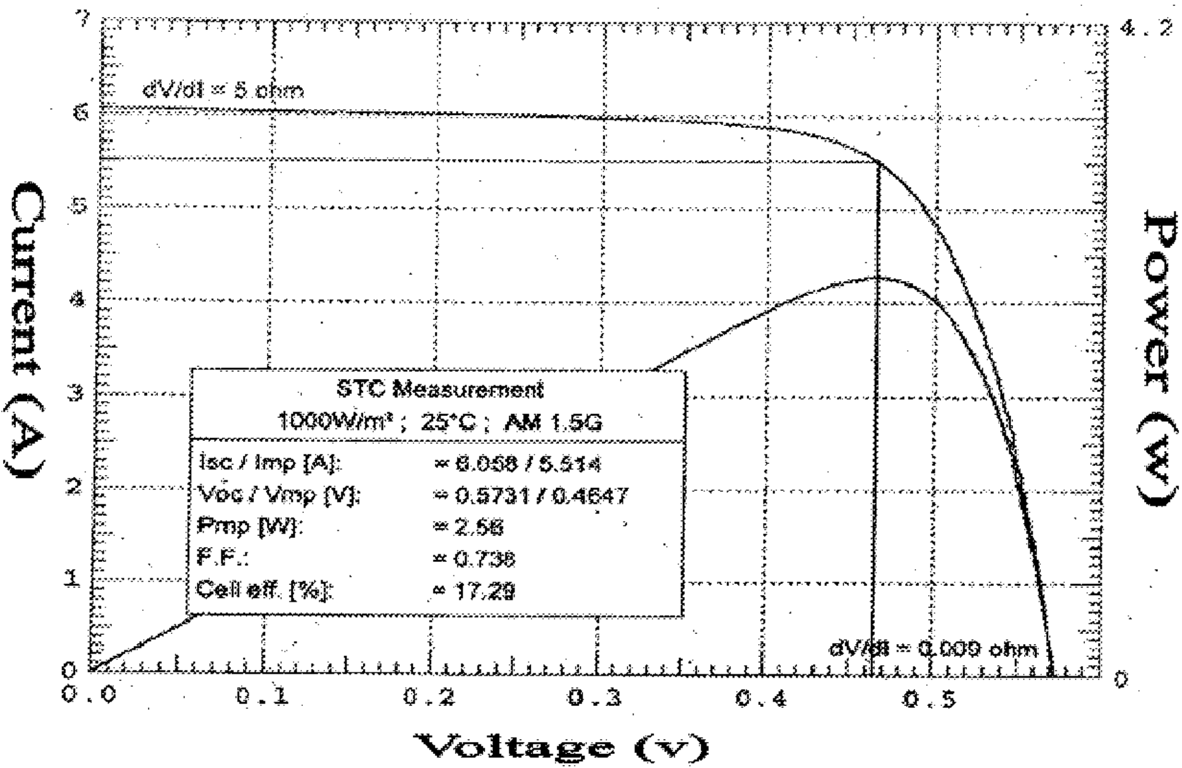

Figure (11): The IV-curve for the solar cell at a distance (35cm) from Fresnel lens.

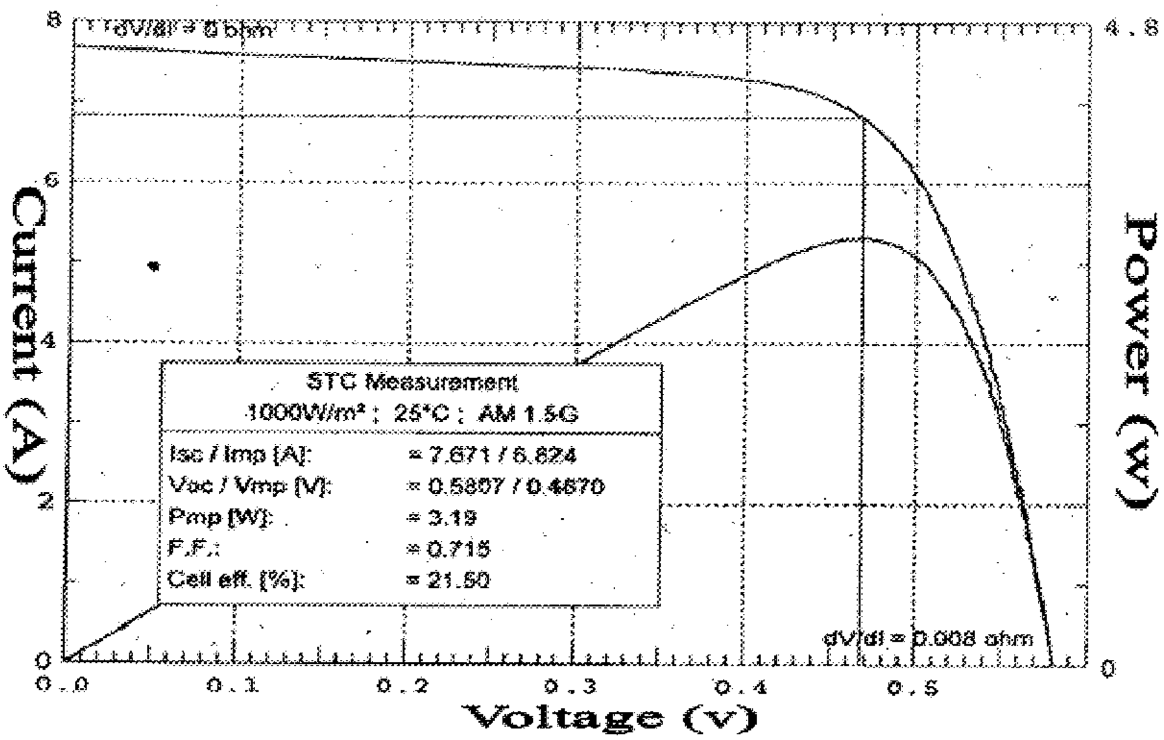

Figure (12): The IV-curve for the solar cell at a distance (45cm) from Fresnel lens.

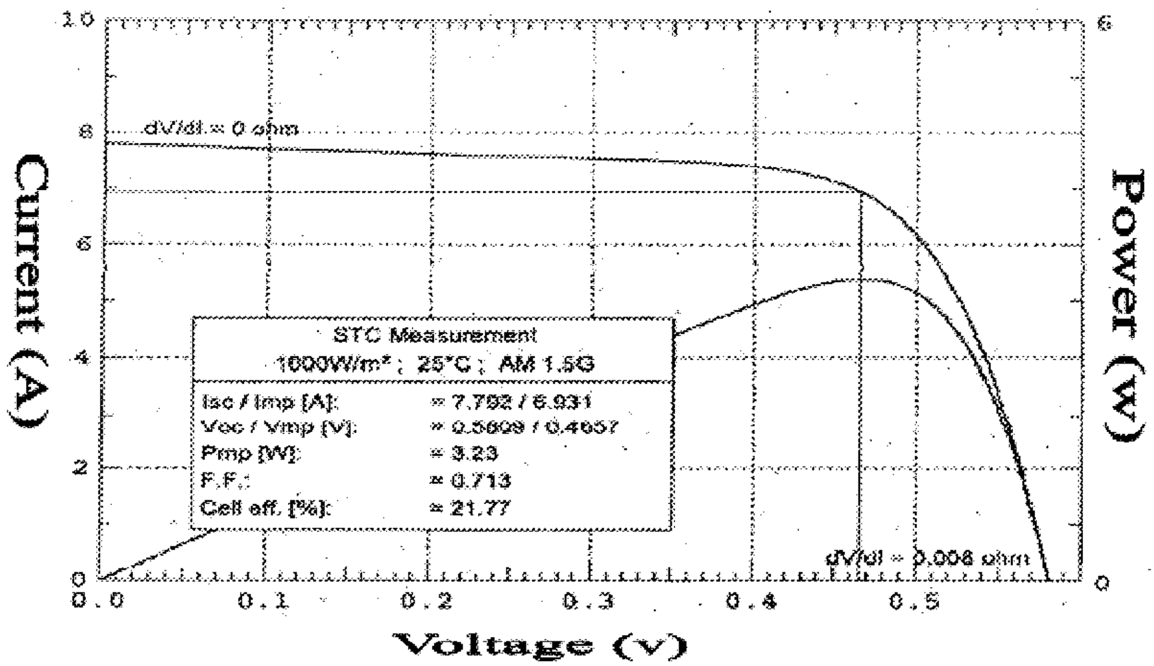

Figure (13): The IV-curve for the solar cell at a distance (55cm) from Fresnel lens.

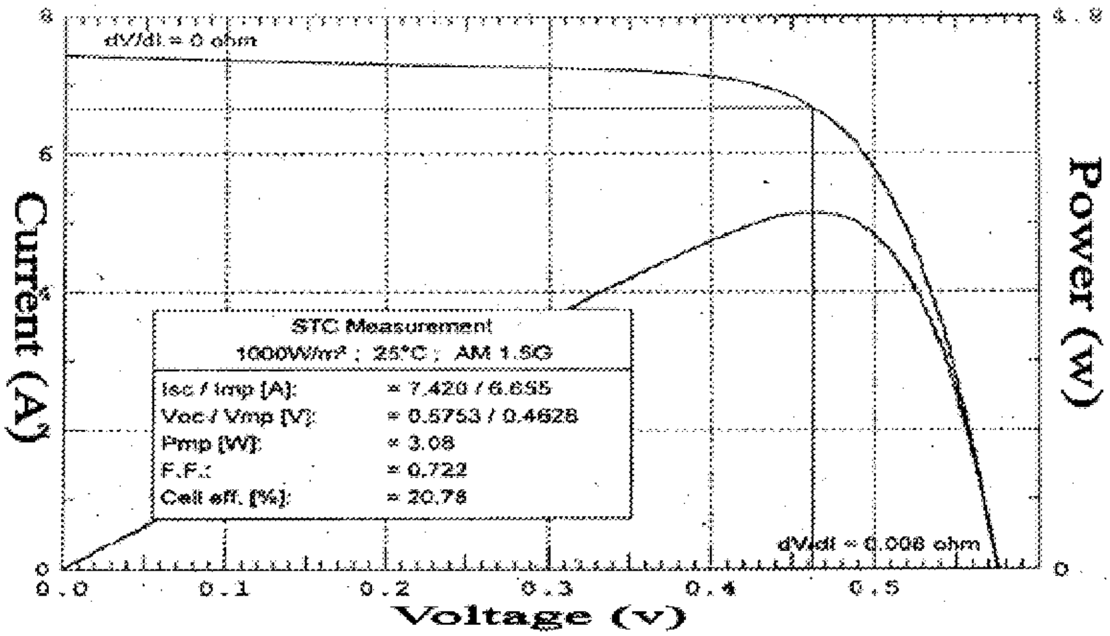

Figure (14): The IV-curve for the solar cell at a distance (65cm) from Fresnel lens.

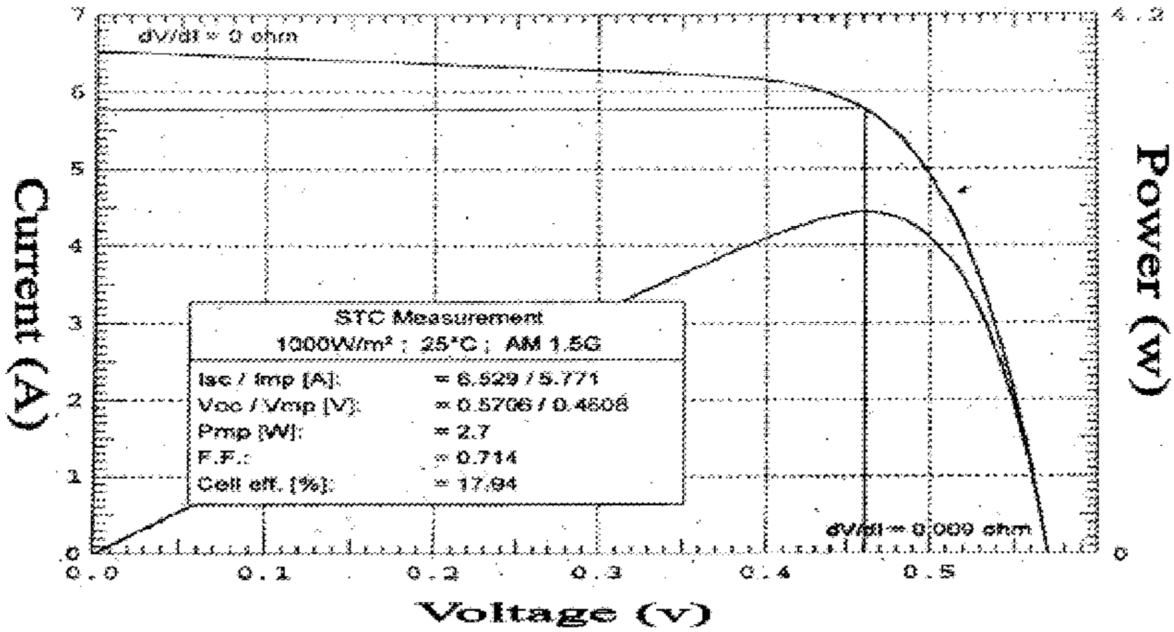

Figure (15): The IV-curve for the solar cell at a distance (75cm) from Fresnel lens.

6. Conclusions

1) Just putting the linear focus Fresnel lens in front of the solar cell it made (I_{sc} , I_{mp} , V_{oc} , V_{mp} , P_{mp} , FF and η) parameters increase .
2) Putting Fresnel lens in front solar cell increase the incident irradiance on it by concentrate the sun light ray on it and then improve the cell performance
3) The best distance between Fresnel lens used in this research and the solar cell at which the parameters (I_{sc} , I_{mp} , V_{oc} , V_{mp} , P_{mp} , FF and η) reached their maximum values; was 55 cm .
4) The fitting distance or the perfect distance to reach the maximum values of the (voltage , current , power & efficiency) is less than the focal length of the linear focus Fresnel lens that used in this research about 10 cm.

References

1 A. B. Rosli, "Development of Solar Concentrating Power System for Green Energy generation", National Conference in Mechanical Engineering Research and Postgraduate Students, p.p.442-456, (2010).

2 A. Bett, , F. Ferrazza, J. Herzog, A. Marti, W. Wettling, " Concentrating Photovoltaic's " , EU Photovoltaic Technology Platform , The Strategic Research Agenda, Working Group 3, April 28th , (2006) .

3 R. John, Egger, "Use of Fresnel Lenses in Optical Systems: Some Advantages and Limitations", Proc. SPIE, vol. 193, pp. 63-68, (1979).

4 R. Leutz, A. Suzuki, A. Akisawa, T. Kashiwagi, " Design of a Nonimaging Fresnel Lens for Solar Concentrators", Solar Energy, vol. 65, p.p. 379-388, (1999).

5 M.A. Green, " The Path to 25% Silicon Solar Cell Efficiency: History of Silicon Cell Evolution " , Journal of Progress in Photovoltaics: Research and Applications , vol.17, p.p.183-189, (2009).

6 M.A. Green, " Solar cell Fill Factors: General Graph and Empirical Expressions ", Journal of Solid-State Electronics, ISSN: 00381101, vol. 24 ,p.p. 788 - 789, (1981).

7 F.A. Lindholm, J.G. Fossum, E.L. Burgess, "Application of the Superposition Principle to Solar-Cell Analysis", Journal of IEEE Transactions on Electron Devices, vol. 26, p.p. 165–171 , (1979).

8 M.A. Green, "Accuracy of Analytical Expressions for Solar Cell Fill Factors", Journal of Solar Cells , vol. 7 , P.P. 337-340 , (1982) .

تحسين كفاءة خلية السليكون متعدد البلورات الشمسية باستخدام عدسة فرينل

*أ . م . د . علي هادي عبدالمنعم الحمداني / الجامعة التكنولوجية- مركز الطاقات المتجددة
** أ . م . د .فاتن شكور زين العابدين / الجامعة المستنصرية- كلية التربية- قسم الفيزياء
*** عبدالمطلب حسن علي الشريفي / محافظة بغداد

تم في هذا البحث استخدام عدسة فرينل واحدة ذات البؤرة الخطية والمصنوعة من مادة (PMMA) البلاستيكية لزيادة شدة الأشعاع الشمسي الساقط على خلية شمسية واحدة من خلال تركيز اشعة الشمس عليها وبالتالي تحسين اداء الخلية.

من المهم ايجاد المسافة المناسبة بين الخلية الشمسية وعدسة فرينل وذلك للوصول الى اعلى قدرة وكفاءة. فتم تغيير المسافة بين الخلية الشمسية ذات الابعاد (12.5سم × 12.5سم) والمصنوعة من السليكون متعدد البلورات وبين عدسة فرينل. اوضحت النتائج ان افضل مسافة والتي اصبحت عندها قيم المتغيرات (I_{sc} , I_{mp} , V_{oc} , V_{mp} , P_{mp} , FF وη) اعظم مايمكن هي (55سم). حيث كانت قيمة القدرة الخارجة لهذه الخلية الشمسية هي (2.25 واط) والكفاءة (15.18%) قبل استخدام عدسة فرينل. وصلت القدرة الى أعلى قيمة لها عند المسافة (55 سم) حيث كانت (3.23 واط) واصبحت الكفاءة (21.77%) .