Parabola Dish and Cassegrain Concentrators to Improve Solar Cell Conversion Efficiency

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Abstract:

New designs of solar using ray tracing program, have been presented for improved the performance and the out put power of the silicon solar cell, as well as reducing the cost of system working by solar energy. Two dimensional solar concentrator (Fresnel lenses) and three dimensional concentrators (parabola dish and cassegrain) were used as concentrator for photovoltaic applications (CPV). The results show that the performance efficiency and out power for crystalline silicon solar cells are improved.

Key words: Solar energy, Luminescent, Fresnel and Hybrid concentrators.

Introduction:

In an era of steadily increasing population and increasing world energy consumption we are faced with a series of problems limiting our future energy supplies. All of these problems combine to place increased emphasis on alterative energy source such as solar energy which is available internationally, safe, and relatively free environmental impact.

Solar cells are capable of converting sunlight directly into electricity by photovoltaic affect; its long life, reliability, and low maintenance are well established. The major factor preventing widespread terrestrial use of solar cells is the price at which they deliver electricity to the user. [1-2].

One approach to the reduction of the effective energy cost of photovoltaic (PV) systems is to increase the solar cell output power density by concentrating sunlight on the cells. Many methods were adopted to improve the utilization ratio of sunlight for solar cell. , Fresnel lenses, mirrors, and luminescent solar concentrators [3-5], and coating of fluorescent coloring agents on the surface of solar cells to increase the energy conversion efficiency of the cells by reducing the reflection of the incident light [6]. Also micro concentrators were used to improved solar energy conversion efficiency [7-9]. The energy conversion efficiency can be calculated using the equation:

$$\eta = \frac{I_m V_m}{p_i A}$$

where (I_m,V_m) are the maximum power points, p_i is the incident solar power density and A is the receiving area of the solar cell [10].

Materials and Methodes :

Silicon Solar cell of diameter (10) cm was used of a surface (78.5$\pm$1.5)cm^2 thickness (0.5$\pm$0.15)mm. The applied base material of solar cell is a single – crystalline silicon which is n – doped on sensitized face. The cell was supplied with tin-plated connections,

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which can be soldered using usual soldering process.

Three types of two dimensional concentrators, Fresnel lenses with different grooves density. The first lens made of glass, it has a focal length of 60cm, width (across the prisms) of 35 cm and a length (parallel to the prisms) of 38cm. There were 20 prisms on each side of the center section, their widths decreasing monotonically from 1.8 to 0.4 cm at the outer edges. The second circular lens has a diameter of 49 cm, the groove density is 20 grooves/mm. The third lens has high – density grooves, more than 40 grooves/mm. Grooves of the three lens are used down for two reasons: first to reduce the transmission losses and to reduce the accumulation of dust and dirt on the lens side exposed to the sun, this dust and dirt reduce the transmitted light towards the focus, thereby reducing the performance of lens [11,12].

Three-dimensional concentrators were design by using a special ray tracing program ZEMAX[13]. The radius of curvatures, distance between the primary and the secondary mirrors were evaluated.

In three-dimensional concentrator,(parabola dish and cassegrain) concentrators the primary and secondary mirrors, made from stainless –steel material with high reflectivity. An obscuration ratio (the ratio of the diameters of the secondary mirror to the primary mirror) and its effects on the acumulated energy on the solar cell were studied. Equations are solved using MCAD program for different obscuration ratio (0 0.9) and from the result the best ratio (0.5) was selected. Auto cad program was used to draw, cut and manufacture the system. Figure 1, show the parabola dish and concentrator used in this work.

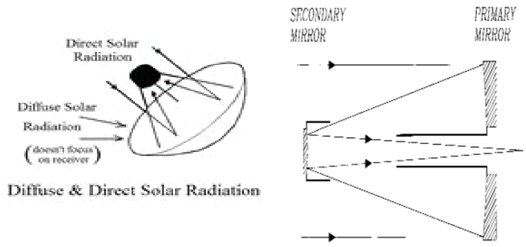

Fig.1, Parabola dish and concentrators.

The water cooling system was used to reduced the effect of the temperature on the output power and performance efficiency of the parabola and cassegrain [12].

Indoor and outdoor testing were used . For indoor measurements, Xenon lamp was used as artificial source of light supplied by Pasan Company (Flasher test- Rev 181/ 86), it gives intensity of 1-sun (1000W/m^2). The (I-V) characteristic of the panels were measured and drawn by a special program using computer (Hp-HEWLFT, PACKARD 85B). Outdoor measurement was also done, the intensity of the sun radiation in (537 W/m^2) measured using solar intensity meter.. The short –circuit current (I_{sc}) and open –voltage (V_{oc})are measured using (7045) digital multimeter supplied by (electron plant company). Solar intensity meter (118 from instruments Haeni Mesgerte) was used to give the radiation incident on the solar cell. The temperature of the solar cell is measured by digital thermometer model (2754-PT100).

Result and Discussion:

Two dimensional concentrators (Fresnel lenses):

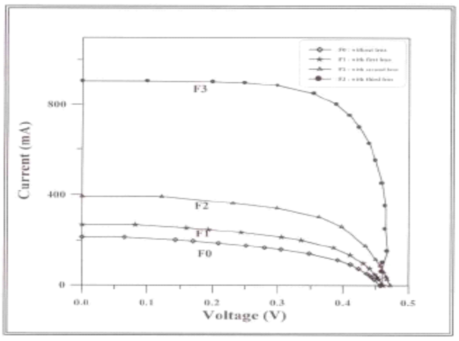

Fig.2, Solar cell I-V characteristic with and without Fresnel lenses. Indoor

- Indoor Testing (laboratory): for indoor testing, I-V characteristic of the solar cell with and without Fresnel lens concentrators is shown in figure (2).

Table 1, show that the efficiency of the system (cells and Fresnel lenses) increased from 6.259 (without concentrator) to 8.585, 13.998 and 33.857 with Fresnel lens (concentrator) of the first, second and third type respectively. Percent increment in peak power output and the efficiency from the first Fresnel lens (37.14%) to the third Fresnel lens (440.85%) is due to increasing of the grooves density, which cause a high intensity concentrated on the panel.

Table 1: Indoor parameters of the solar cell with and without Fresnel lenses.

Parameters	Without lens F0	First lens F1	Second lens F2	Third lens F3
$I_{Sc}(mA)$	214	269	293	912
$\Delta I_{Sc}(mA)$	-	55	179	698
$V_{oc}(V)$	0.4572	0.4617	0.4721	0.462
$\Delta V_{oc}(mV)$	-	4.5	14.9	-4.8
$\%\eta$	6.259	8.585	13.998	33.857
$\%\Delta\eta$	-	37.16	123.65	440.897
P_m(W)	0.04914	0.0674	0.10989	0.265
$\%\Delta P_m(W)$	-	37.14	123.63	440.858
P_{mn}/P_{mo}	1	1.371	2.236	5.408
C	1	1.257	1.836	4.261

- Outdoor Testing: Figure 3 shows the effect of field (environment) on the characteristics of Si solar cell with Fresnel lens concentrators.

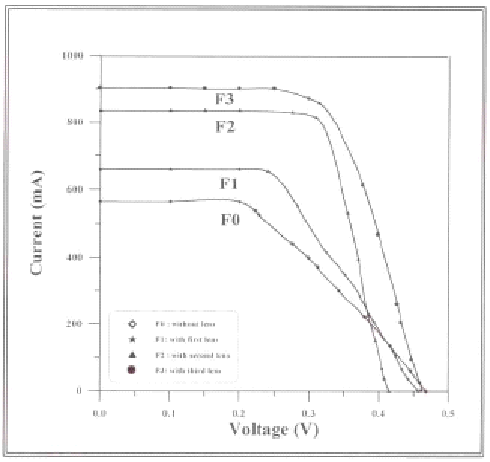

Fig.3, Solar cell I-V characteristic with and without Fresnel lenses. outdoor

Table 2 indicates that efficiency of the cell is increased from 5.082 (without concentrator) to 6.713, 10.92, and 11.458 with Fresnel lens concentrators (1st, 2nd and 3rd type respectively). It is shown that this increment is less than the indoor testing which indicates the effect of field high temperature on the performance of the solar cell. Although the short circuit current is increased with the irradiance (see figure 4), while figure 5 shows that as of environment temperature is increased, the open circuit voltage is decreased which reduce the cell conversion efficiency of the cell. So cooling system was suggested.

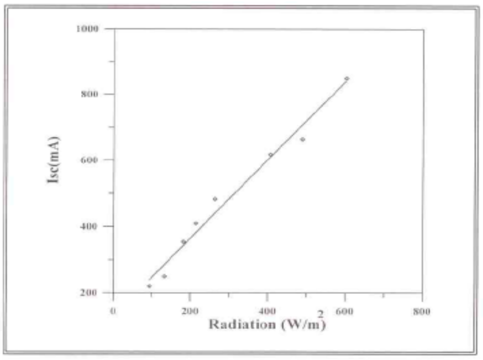

Fig.4, Short circuit current with irradiance on the cell

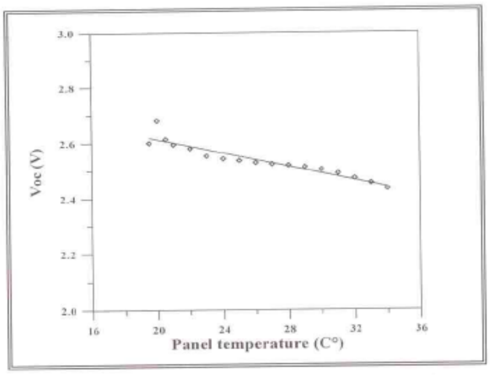

Fig.5, Open circuit Voltage with cell temperatures.

Table 2: outdoor parameters of the solar cell with and without Fresnel lenses.

Parameters	Without lens (0)	First lens	Second lens	Third lens
$I_{Sc}(mA)$	564.8	660	835	902.7
$\Delta I_{Sc}(mA)$	-	95.2	270.2	337.9
$V_{oc}(V)$	0.4682	0.4491	0.4149	0.4631
$\Delta V_{oc}(mV)$	-	19.1	53.3	5.1
$\%\eta$	5.082	6.713	10.92	11.458
$\%\Delta\eta$	-	32.093	114.876	125.462
$P_m(W)$	0.11969	0.158098	0.257397	0.2698
$\%\Delta P_m(W)$	-	32.10	115.21	125.58
P_{mn}/P_{mo}	1	1.372	2.16	2.33
C	1	1.168	1.478	1.598

Three dimensional concentrators (Parabola and cassegrain);

Parabola concentrator: Parabola concentrator was used, the intensity radiation increased from 300 W/m^2 to 1200 W/m^2 without and with parabola concentrator respectively. The I-V characteristics is shown in figure 6

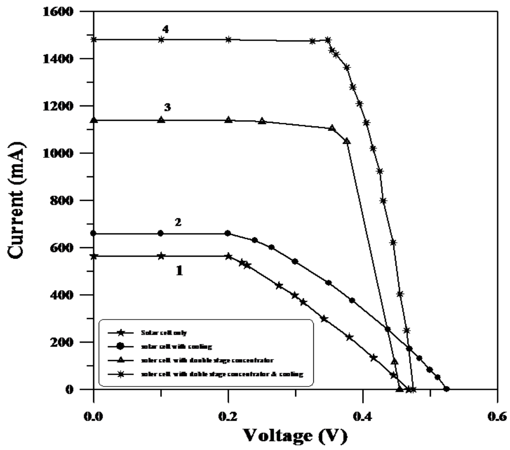

Fig.6, I-V characteristics of silicon solar cell using parabola concentrator with cooling.

while table 3, indicate that the efficiency and output power also increased to 16.2 and 0.382 watt respectively. While when the cooling is used, the temperature is decreases from 60°C to 35°C and due to that, the efficiency increased to 18.3% and output power to 0.433 (watt).

Cassegrain concentrator: Intensity of the radiation is increased to 3000W/m^2 when Cassegrain concentrator was used, and efficiency and output power (table 3, figure 7 are improved when the cooling in used, they increase to 21.7% and 0.531 (watt) as shown in table 3.

Table 3, Characteristics of Si solar with and without the parabola and cassegrain concentrator, effect of cooling is shown also.

Parameters	Cell only		Parabola concentrator		Cassegrain concentrator	
	Without cooling	With cooling	Without cooling	With cooling	Without cooling	With cooling
$I_{Sc}(mA)$	656	660	1116	1173	1139.9	1481.86
$I_i(W/m^2)$	300	300	1200	1200	3000	3000
$V_{oc}(V)$	0.4688	0.525	0.435	0.4942	0.454	0.475
$\%\eta$	5.082	6.8	16.2	18.3	16.7	21.7
$P_m(W)$	0.119	0.162	0.382	0.4333	0.3946	0.5132
$\%\Delta P_m(W)$	-	36.13	221	264.1	231.5	331.2
P_{mn}/P_{mo}	1	1.36	3.21	3.641	3.317	4.312
C	1	1	4	4	10	10

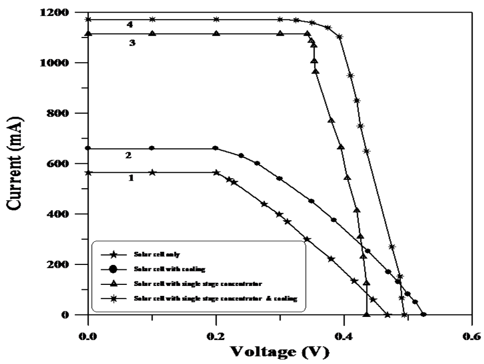

Fig.7, I-V characteristic of silicon cell using cassegrain concentrators with cooling.

The use of cassegrain concentrator increase the output power by factor four which reduced the Si material size which reduce the size of all system . Also one of the great advantage of cassegrain concentrator is increased the depth of focus of the system which simplified the tracking system and reduce the total cost of the solar energy system.

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استخدام المركزات ذو القطع المكافئ والكاسكريني لتحسين اداء الخلايا الشمسية

علي هادي الحمداني ***بتول درعم بلاوة *****

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الخلاصة:

يستخدم في هذا البحث برامج التصميم البصري لاستنباط نوع جديد من الخلايا الشمسية وذلك لتحسين كفاءة الخلية الشمسية وزيادة الخرج الناتج منها, استخدم المركز ثنائي الابعاد (عدسات فرينيل)ومركزات ثلاثية الابعاد (ذو القطع المكافئ الكاسكريني) لتركيز الاشعة الشمسية. اوضحت النتائج زيادة ملحوظة ومهمة في كفاءة الخلية الشمسية وخاصة عند استخدام منظومات تبريد بسيطة كما ان استخدام مركز الكاسكريني يقلل من الحاجة الى استخدام منظومات المعقب الشمسي المعقدة التركيز والغالية الكلفة.