Performance quality of single and two stage solar concentrators

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Abstract

The performance of single and two stage solar concentrator were studied experimentally. The ratio of the primary to the secondary mirrors diameter is taking to be 0.5, depending on the theoretical calculation for the accumulated energy by the concentrator with ratio between 0.0 to 0.9. The design of the systems were designed and examined by using a ray-tracing program. The efficiency of the single and the two stage concentrators are calculated and compared with and without cooling systems.

Introduction

Because of the spherical aberration, the image of the sun is wider when focussed by a spherical mirror than when focussed by a parabolic mirror [1]. The importance of spherical mirror as means to concentrate solar energy, may be emphasized by their low cost in addition, their low concentration may be improved by the introduction of the second mirror at their focal plane.The focus of the primary mirror coincides with the focus of the secondary mirror. The irradiance of a two-stage concentrator without any defects, at a distance r from the center of the sun image is given by [2],

$$I(r,\varepsilon) = \frac{1}{(1-\varepsilon^2)^2}\left[\frac{2J_1(\pi r)}{\pi r} - \varepsilon^2 \frac{2J_1(\pi\varepsilon r)}{\pi\varepsilon r}\right]^2 \quad \ldots\ldots 1$$

Where $J_1(\pi r)$ is the first Bessel function (ε) is the ratio of the secondary to the primary mirror, from this equation, it is shown that for a single stage (ε=0) the irradiant is;

$$I(r,0) = \left[\frac{2J_1(\pi r)}{\pi r}\right]^2 \quad \ldots\ldots 2$$

To compare the performance of a single and two-stage concentrators with different (ε), one could use the accumulated energy by a circle of

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radius (α) which is given by the relation;

$$Accumuated\ energy = \frac{\pi^2}{(1-\varepsilon^2)} \int_0^{\alpha} \left| \frac{2J_1(\pi r)}{\pi r} - \varepsilon^2 \frac{2J_1(\pi \varepsilon r)}{\pi \varepsilon r} \right|^2 r dr \quad \ldots\ldots 3$$

The first term of equation (3) represent the accumulated energy for a single stage concentrator. This equation was solved by using Mathematical Computer Added Design (MCAD) [3], depending on this reference, one conclude that the accumulated energy in two stage concentrator with (ε=0.5) is the best (figure (1)), so this theoretical results was used in the design of the two stage concentrator.

The energy conversion efficiency can be calculated using the equation;

$$\eta = \frac{I_m V_m}{P_i A_i} \quad \ldots\ldots 4$$

Where (Im, Vm) are the maximum current and voltage point, P_i is the incident solar power density and A_i is the receiving area of the solar cell [4].

The design procedure for a concentrator involves the choice of a basic geometry followed by an analysis of the shape using the yearly solar radiation data, the most convenient method for examine three- dimensional module structure is computer ray tracing [5].The primary and the secondary mirror , the diameter of each mirror, the distance between the mirrors (Th) and the refractive index of the spacing between the mirrors. An optimization for these input parameters to give the best-accumulated energy was done by using least square method which find the design after an optimization. Figure (2) shows this optimized system.

Experimental arrangement

Silicon solar cell of diameter (10 cm) was used (SZ100-0) of a surface (78.5±1.5 cm), thickness (0.5±.15 mm), and with refractive index for the antireflective coating (n=2.2). The applied base material of solar cell is a single -crystalline silicon, which is n-doped n sensitized face. The cell was supplied with tin-plated connections, which can solder using all usual soldering process. The short circuit current (I_{sc}) and the open- voltage (v_{oc}) are measured using (7045 digital multimeter supplied by (Electro plan company). Solar intensity meter (118 from Instruments Haenni Mesgerate) was always used to give the radiation incident on the solar cell. The temperature of the solar cell is measured by digital thermometer module (2754-PT100), and a cooling system was used with flow rate water (0.006l/sec). The I-V characteristic behavior of the cell is drawn in figure (4,5). The efficiency of the solar cell is calculated using equation (4), where Pi=300 W/m^2, 3000 W/m^2 for single and two-stage concentrator respectively.

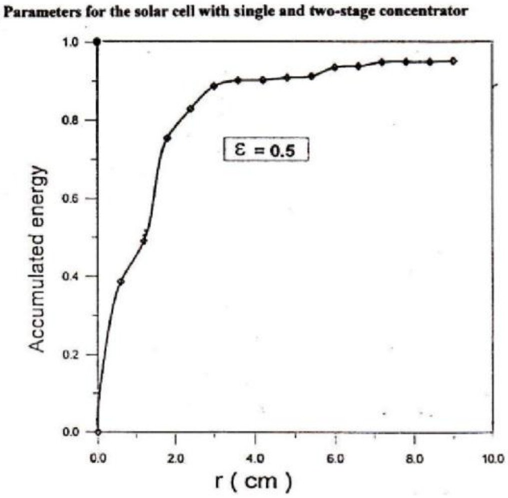
Results & Discussion

The I-V characteristic of the solar cell with and without cooling was measured using simple electric circuit shown in figure (3). Without cooling and at Pi=300W/m^2 the cell efficiency and output power were 5.08% and). 0.119 watt respectively. With cooling the efficiency of the cell and output power are improved and become 6.8% and 0.162 watt respectively (at a cell temperature=306 K) Voc is also improved (table 1). When the one stage concentrator was used, the irradiance on the cell is increased to 1200 W/m^2, the efficiency also increased to 14.7% and the output power has increased to 0.382 watt and the temperature of the cell become T=333 K while when the cooling was used, the efficiency increased to 16.7% and output power to 0.433 watt while the cell temperature (T=308 K) (Figure (4).

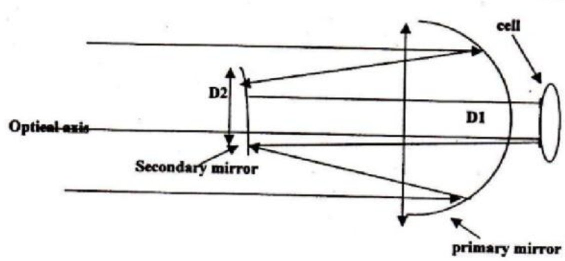
Using two-stage concentrator increased the irradiance to 3000 W/cm^2 so the temperature of the cell was raised to 366 K$^{\circ}$; the efficiency increased to 16.2% and output power to 0.3496. So that cooling is necessary to improve efficiency and output power, which increased, to 21.7% and 0.5132 watt. Voc also increased to 0.475 with cooling (T=333 K$^{\circ}$) as shown in figure concentrator will increased the output power of the solar cell. Moreover it is more efficient with low cost, and its manufacturing is easy than the other concentrators.

Parameter	Cell only		Single-stage		Two-stage	
	Without cooling	With cooling	Without cooling	With cooling	Without cooling	With cooling
η%	5.082	6.8	14.7	16.7	16.	21.7
Output power watt	0.119	0.162	0.382	0.4333	0.3946	0.5132
Cell Temp. (Kelvin)	318	306	333	308	369	333
Isc (mA)	565	660	1116	1173	1139.9	1481.86
Voc (volt)	0.468	0.525	0.435	0.4942	0.454	0.475
Incident power w/m	300	300	1200	1200	3000	3000
Concentra-tion ratio	1	1	4	4	10	10

Table (1) Parameters for the solar cell with single and two-stage concentrator



Fig(1) : The accumulated and out put energy for different r and (ε=0.5) .



Fig(2): Two stage concentrator

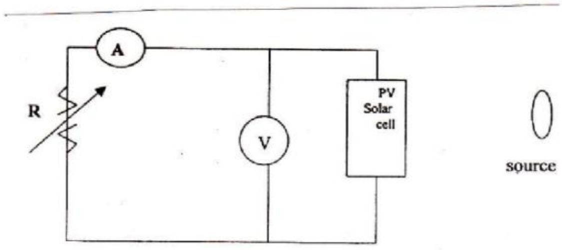


Fig.(3) : Electrical circuit for solar cell

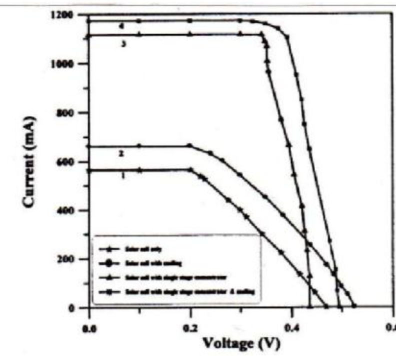


Figure (4):I-V characteristics of silicon solar cell using single –stage concentrator with cooling.

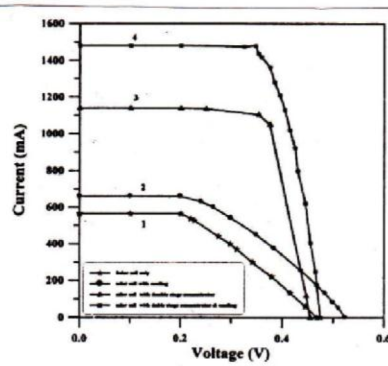


Figure (5): I-V characteristic of silicon cell using double stage concentrators with cooling.

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المستخلص

درس أداء مركز المرحلتين عمليا واستخدمت أفضل نسبة بين قطر المرآة الثانوية والابتدائية مساويه الى ٠,٥ وذلك اعتمادا على الحسابات النظرية للطاقة المتجمعة على الخلية الشمسية . تم تصميم وتقييم المنظومة المركزة باستخدام برامج تتبع المسار البصري. حسبت كفاءة أداء مركز المرحلة الواحدة والمرحلتين ومقارنتهما بوجود وعدم وجود منظومة تبريد.