Enhancement the Output Power from Solar Cell Using Lens

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Abstract- In this work, a hemispherical lens was used as a solar concentrator to concentrate solar light components (direct normal and diffused direct normal radiation) on the solar cell to increase the electrical output power from the solar cell. Optical properties of the hemispherical lens, electrical parameters of the polycrystalline Si-Solar cell, solar radiation components (direct normal and diffused direct normal radiation) with and without a lens, and output power from used a solar cell with and without lens were measured. Some conclusions are obtained; the hemispherical lens was used practically to concentrate sunlight components on solar cell where the concentration was found to be about 2x solar light components, the used hemispherical lens was found to increase the electrical output power from the solar cell about 25 % for direct normal plus diffused solar light intensity which relates to the action of used hemispherical lens and properties of the used solar cell.

Index Terms- Hemispherical lens, Solar cell, Output power.

I.INTRODUCTION

As a result of increased need for energy use and related requirements and limited of available resources, it is noticed that there is much dependence on the fossil fuels for the fulfillment of energy needs. This gives a wide range and field to find new ways of renewable and alternative ways of energy. Solar energy is one of the most economic and freely available source of energy today [1].The development of photovoltaic (PV) concentrator innovation started adequately in 1976 at national Sandia laboratories. This early work determined and attempted to solve problems linked to concentration systems and gave satisfactory responses to a considerable lot of them. The basic idea of a photovoltaic (PV) concentrator is to utilize optics such as mirror or lenses to concentrate sunlight radiation on a small delivering solar cell. In the present, the standard of concentration photovoltaic (CPV) is the use of cost-efficient concentrating optics that severally diminish the cell area, taking into consideration the utilization of more costly, high-efficiency cells and possibly a leveled cost of electricity competitive with concentrated solar oriented power and standard flat-plate photovoltaic (PV) technology in certain sunny zones with high direct normal irradiance (DNI) [2].Using optical concentrator to concentrate solar radiation reduce the area of the used solar cell, increase the intensity of solar radiation on the solar cell, and may reduce the cost of concentration system [3].

In this paper a hemispherical lens was used as a solar concentrator, the solar radiation components (direct normal and diffused direct normal radiation) were measured practically with and without lens and the output power from the poly-crystalline silicon solar cell was measured with and without lens and the results were compared where the aim is to increase the output power from the solar cell.

II. THEORY

1. Solar Irradiation Equation

The total solar irradiation $I_{t\theta}$ of a terrestrial surface of any orientation and tilt with an incident angle θ is the amount of the direct normal componentsI_{DN} Cos θplus the diffuse element$I_{d\theta}$coming from the sky plus the element of reflected shortwave radiation $I_r$that can reach the surface from the earth or from adjacent surfaces [4]:

$$I_{t\theta} = I_{DN} \cos\theta + I_{d\theta} + I_r \qquad (1)$$

Where:

$I_{t\theta}$:is the amount of radiation and the diffuse solar radiation on a surface also called as global radiation on the surface (W/m^2) [5].

I_{DN}: is the direct normal radiation (W/m^2).

θ: is the angle between the beam radiation that incident on a surface and the normal to that surface [5].

$I_{d\theta}$: is the diffused radiation on a horizontal surface (W/m^2).

I_r: is the reflected radiation (W/m^2) which is neglected in this work.

Stephenson [6] displayed that the intensity of the direct normal irradiation I_{DN}at the surface of the earth on a clear day can be calculated by [4]:

$$I_{DN} = A\ e^{\frac{-B}{\sin\beta}} \qquad (2)$$

Where

β = The solar altitude angle between the horizontal surface and the line to the sun that is the complement of the zenith angle [5].

Both A and B are functions of the date and take into account the seasonal difference of the earth-sun distance and the air's water vapor content[4]. This equation can be utilized to estimate the value of diffuse radiation$I_{d\theta}$that arrives a tilted or vertical surface [4] that is a sun-oriented radiation got from the sun after its direction has been altered because of diffusing by the environment (atmosphere). Diffuse solar light radiation is alluded to in some meteorological literature as sky radiation or sunlight based sky radiation [4]:-

$$I_{d\theta} = C\ I_{DN} F_{ss} \qquad (3)$$

Where

C: is the ratio of the diffuse radiation on a horizontal surface to the direct normal irradiation [5].

F_{ss}: is the angle factor between the surface and the sky.

$$F_{ss} = \frac{1+\cos\Sigma}{2} \qquad (4)$$

And $$\cos\theta = \cos\beta\cos\gamma\sin\Sigma + \sin\beta\cos\Sigma \qquad (5)$$

Where:-

γ :The Surface azimuth angle that is deviation of the projection on a horizontal surface of the normal to the surface from the local meridian, with zero to the south, east negative, and west positive; $-180° \leq \gamma \leq 180°$ [5].

Σ: The tilt angle. Without further discussion, the solar angles and the equation of time that translate time from solar to local time can be found in ASHRAE standard [4].

2. Ideal Geometrical Optics Concentrator

Different systems have been formulated that work in the n^2Limit for focusing [7]. One system is the optical hemispherical lens of diameter (NW), where (W) is known as the width of the attached absorber (solar cell) and (n) is known as the refractive index of the dome, seefig.1. Solar light enters to the dome and is refracted to the exit plane. This concentrator has a variable entrance aperture in that various portions which are utilized at various incident angles. For any input angle, the rays that can intercept the dome that would also have crossed the diameter area of the optical hemisphere face of the lens will reach exit aperture [7].

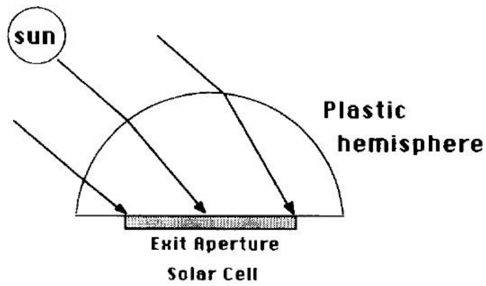

Figure 1: Hemispherical lens that used to generate a concentration ratio of n^2[7].

This system is one of the only few imaging systems that works close to perfect or ideal concentration limits. Actually, if one views the solar cell through the dome at any angle, one sees a 2x magnified image. The optical hemisphere lens has properties of no spherical aberration or coma and is identified with the aplanatic lens used in microscopy [7]. When light incident on the spherical face of hemispherical lens with incident angle θ_i , light will be refracted with refracted angle θ_r and therefractive index of the hemispherical lens can be found from following equation [8]:

$$n = \frac{\sin \theta_r}{\sin \theta_i} \qquad (6)$$

And the focal length of the hemispherical lens can be found from the following equation [8]:-

$$\frac{1}{f} = (n-1)(\frac{1}{R_1} + \frac{1}{R_2}) \qquad (7)$$

Where:-

f: Focal length of lens (cm).

The refractive index and reflectivity of used hemispherical lens were measured using experimental setup consists of diode laser (Wavelength 632 nm) incident on spherical face of used hemispherical lens that is placed horizontally on axis with different incident angles $20°$,$40°$ and $60°$ laser beam refracted with different refraction angles, laser traveled from medium of less density (air) to medium of more density (polymer), so the

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n: Refractive index of hemispherical lens.

R_1, R_2: - radiuses (with a sign) of spherical surfaces of a lens (cm).

III. EXPERIMENTAL WORK

1. Optical properties measurements of hemispherical lens

The optical properties of used hemispherical lens (polymer) such as focal length, refractive index, and reflectivity were measured using a laser. The diameter and height of lens are 6 cm and 3.5 cm respectively. The focal length of the hemispherical lens was measured using an experimental setup that consists of He-Ne laser (power 0.38 mW and wavelength 632 nm) incident on the spherical face of the hemispherical lens at distance 8 cm and screen at 28 cm from He-Ne laser. The clear focal length of the hemispherical lens was found to be 6.2 cm as shown in Fig. 2.Theoretically using eq. (7) the error in determining focal length was found to be equal to 4%.

refractive index of used hemispherical lens was calculated using Snell's law, and it is found to be equal to 1.49 as shown in fig. 3a,b,c. Also, the reflectivity of the lens is tested by subjecting known source power of laser on the lens at different angles of incident ($20°, 40°, 60°$) and the reflecting laser power is tested.The reflectivity is found to be equal to 0.2, as shown in fig. 3a, b, and c.

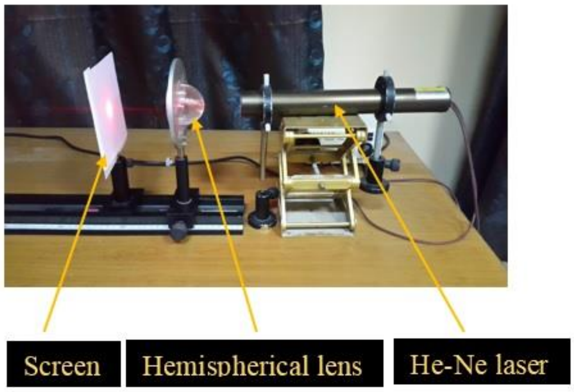
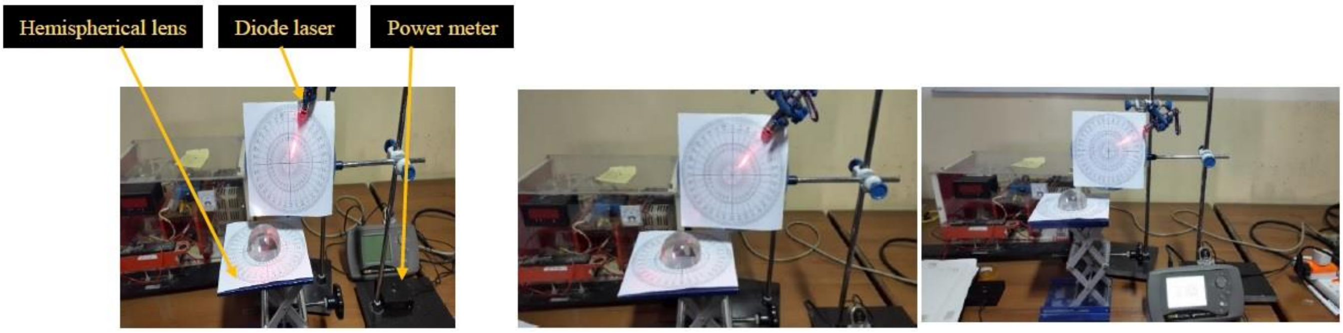


Figure 2: Experimental setup using He-Ne laser to measure focal length of hemispherical lens



(a) **(b)** **(c)**

Figure 3 a, b, c: Experimental setup of diode laser (Waveleght 632 nm) at different angle of incident to measure refractive index and reflectivity of the hemispherical lens.

2. Output parameters measurements of used solar cell

Electrical output parameters of solar cell such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), output power (P_{out}), maximum output power (P_m) were measured. Experimental setup that consists of solar cell (poly-crystalline silicon solar cell) placed horizontally and illuminated vertically with light source at different intensities from zero to 2000 W/m^2 which is measured using solar power meter (TES 1333R, Taiwan, ranging from 0-2000 W/m^2) that placed horizontally under light source is as shown in fig. 4. The solar cell was connected in series with an ammeter (UNI-T, UT61A) and a variable resistor (0-100KΩ) and parallel with a voltmeter (ASWAR, DT830D).The short circuit current (mA) and open circuit voltage (V) were measured for each variation in variable resistance and intensities, where the current-voltage characteristic of the used solar cell was obtained. The variable resistance was set to its maximum value, where the output voltage of the solar cell is equal to open circuit voltage and output current is equal to zero. Variable resistance is decreased until it reaches its minimum value (no-load), at this value the output current of the solar cell is equal to short-circuit current, and the output voltage is equal to zero. The output power (mW) of used solar cell was calculated by multiplying the output current (mA) with the output voltage (Volt).

3. Solar radiation Components measurements with and without lens

Solar radiation components (direct normal and diffused direct normal radiation) were measured from the sunrise to sundown in Baghdad for specific days during the year 2016 (23 March, 13 May, 26 June, and 8 August) every 15 min. and the local time was converted to solar time based on ASHRAE standard [4].Direct normal light intensity was measured using solar power meter (TES 1333R, Taiwan, Ranging from 0-2000 W/m^2) fixed at the end of a pipe ,1 cm in diameter and 50 cm in length,coated with black color from inside so as to absorb the diffused and reflected components of sunlight and allow only direct normal light intensity to pass through [9].Diffused direct normal light intensity was measured using solar power meter (TES 1333R,Taiwan,Ranging from 0-2000 W/m^2) which is fixed at the end of the pipe of 6 cm in diameter and 8 cm in length coated with white color from inside to reflect all the incoming diffused solar component [9]. The other end of the pipe is shaded to avoid direct sunlight. The output intensity from hemispherical lens was measured using the previously mentioned solar power meter (TES 1333R,Taiwan, Ranging from 0-2000 W/m^2) which is fixed at the end of a pipe of 6 cm in diameter and 8 cm in length coated with white color from inside to reflect all the incoming diffused sun ray back to the pipe, the setup is shown in fig. 5.It is to be noted that every reading has been repeated for ten times by following chauvenent's criterion [10] and some extreme bias readings were dismissed to obtain the average values which were regarded as the acceptable reading.

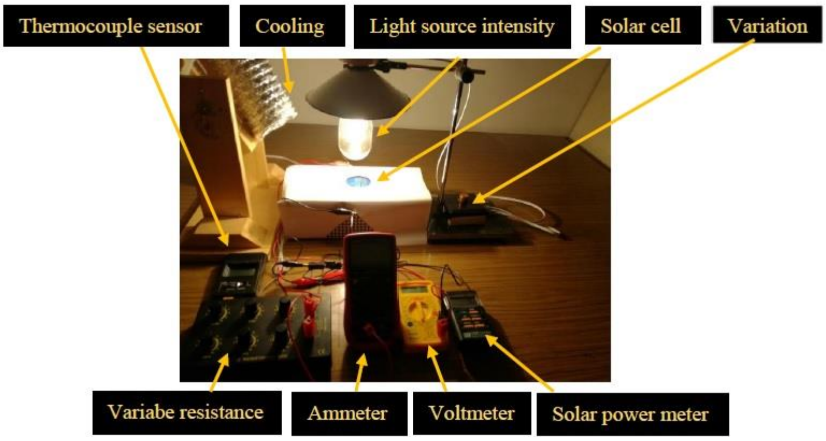


Figure 4: Experimental setup to measure output parameters of the used solar cell

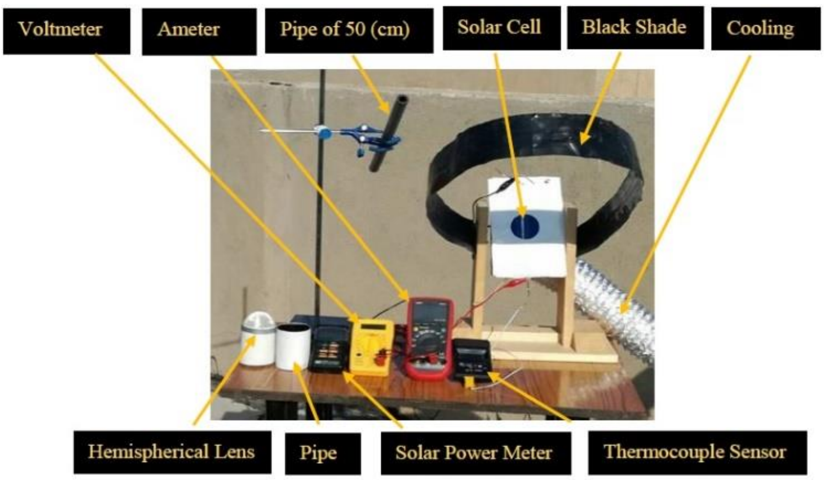


Figure 5: Experiment setup to measure and concentrate solar light component (W/m^2) using the hemispherical lens.

4. Output power measurements from solar cell with and without lens

Electrical output power from the solar cell with and without hemispherical lens was measured using ammeter (UNI-T, UT61A) connected in series with a solar cell to measure current (mA) and voltmeter (ASWAR, DT830D) connected in parallel with a solar cell to measure voltage (Volt), see fig. 5. The cooling system has been placed behind the used solar cell to avoid boost in its temperature and to fix its temperature at 25 °C to standardize the solar cell performance [11].

IV. RESULTS AND DISCUSSION

1. Optical properties measurements of the hemispherical lens

The optical properties of used hemispherical lens were measured in this work as shown in fig. 2 and 3. The focal length is equal to 6.2 cm, the refractive index is equal to 1.49, and the reflectivity is equal to 0.2.

2. Output parameters measurements of used solar cell

The output parameters of used polycrystalline silicon solar cell were measured. The maximum output power that could be obtained from the cell at intensity 1000 (W/m^2) is as shown in fig. 6. The characteristic curve is drawn between I-V which match the result that obtained from [12]. The maximum power of 1 sun (1000 W/m^2) is obtained which is close to that obtained from reference [12].

The variation of maximum output power from the used solar cell with different intensities were measured and plotted, see fig. 7. It shows a sharp increase at low intensities and a slow increase in the output power from solar cell as intensities increased beyond 200 (W/m^2) which is also become less steply as the intensity increased toward 2000 (W/m^2), this is due to that, the intensity becomes closer to that of solar cell saturation.

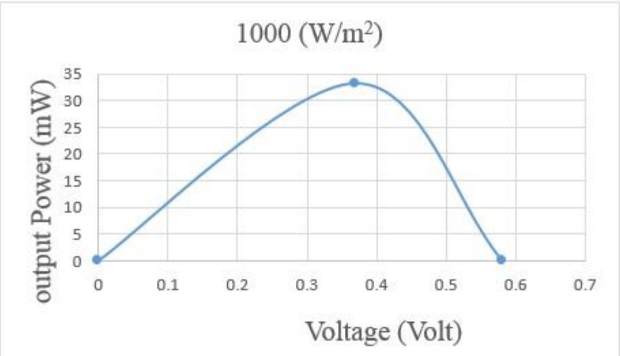


Figure 6: Maximum power of the used solar cell at 1000 (W/m^2) intensity.

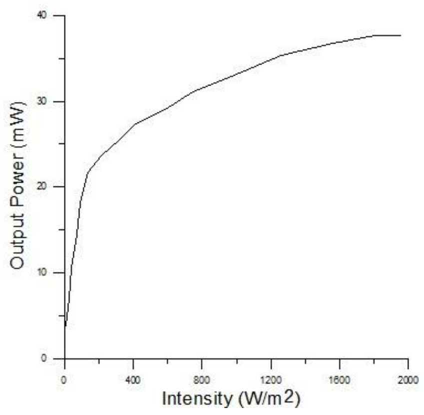


Figure 7: Variation of maximum output power from the solar cell with intensity.

3. Solar radiation components measurements and comparison with and without lens

The sunlight components (direct normal and diffused direct normal radiation) with and without hemispherical lens were measured using the setup shown in fig. 5.The readings of solar light intensity with and without lens are shown in fig. 8assuming the input intensity is the direct normal plus diffused direct normal component of sunlight. An average concentration of 2x is observed due to the action of the lens. The experimental and theoretical sum of direct normal components is shown in fig. 8, with and without a lens. It shows experimental values of sunlight components as the lens is used to concentrate them. It is found to have the maximum sum of the sunlight components where more power is expected as a solar cell is directed normal to the sun.

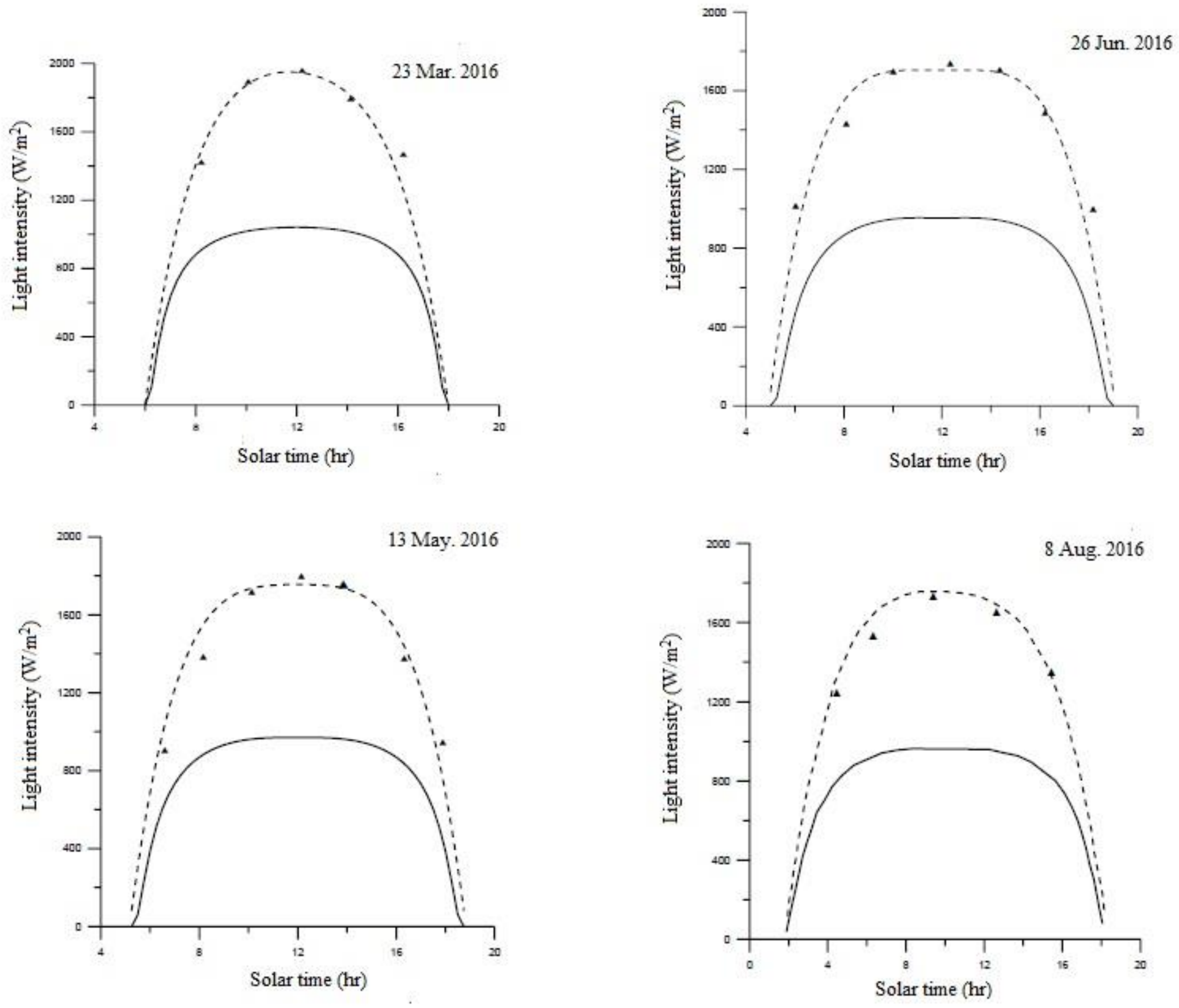


Figure 8: Solar light intensity without lens (solid line) and with hemispherical lens (dashed line) that best fit experimental data (solid triangle) at 23 Mar., 13 May, 26 Jun., and 8 Aug.

4. Output power measurements from used solar cell with and without lens

A polycrystalline silicon solar cell was used which is shown in fig. 5. The maximum output power of used solar cell with and without hemispherical lens was measured using ammeter (UNI-T,UT61A) that measuring current (mA) and a voltmeter (ASWAR, DT830D)to measure voltage (Volt). The output power in (mW) produced by solar cell was calculated by multiplying current and voltage. Assume the input solar intensity was the sum of direct normal and diffused direct normal components that shown in fig. 8.Where March seems to produce the maximum output power due to the fact that the maximum sum of solar light components is happening at this month.An increase of about 25 % in the output power of the solar cell is observed as the lens is used which is the main goal of this work.

V. CONCLUSIONS

The optical properties of used hemispherical lens were measured experimentally using lasers and verified theoretically whenever available. The hemispherical lens was used practically to concentrate sunlight components on the solar cell. The electrical output parameters of the used solar cell were measured practically where the used hemispherical lens was found to increase the electrical output power from the solar cell which was related to the action of used hemispherical lens and properties of the used solar cell. An increase in the output power is observed (about 25 % for direct normal plus diffused solar light). The used lens was approved to concentrate solar irradiation by a factor of about 2x due to the action of the lens and the characteristic properties of the solar cell. March seems to produce maximum input power to solar cell which consistently produces more power from solar cell.

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