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# Fresnel Lens Concentrated Solar Photovoltaic and Thermal Module

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**ABSTRACT:** Solar irradiation is concentrated to a small area of solar photovoltaic (PV) cell to generate electricity by using a Fresnel lens made of Poly Methyl Meth Acrylate (PMMA) and has a positive focal length and higher transmittance. The primary advantage of concentration is reduction in area of solar cell, the main cost driver in a flat plate unit. Since the concentration ratio of the system is on the higher side, the temperature generated at the focus of the lens is very high. Rather than at the focal plane of the lens, the PV cell is placed at different distances defined in terms of focal length. Panel immersed cooling system is used to tap the thermal energy generated along with the electrical output. The hot water produced can be considered as a by-product and is available at useful temperatures so it can be utilized for applications like building heating, domestic water and other commercial applications that require low grade heat. A 3W water cooled miniature panel is used for the study and because of the reduced acceptance half angle manual tracking is done so as to accept more amount of direct beam radiation. A frame work design of a commercially viable system combining both electrical and thermal energy generations is also proposed which may find its application on space circumscribed areas and on rooftops.

**KEYWORDS:** Fresnel lens, Solar Concentrated, Photovoltaic, Panel Immersed Cooling, Electrical and Thermal Power.

## I. INTRODUCTION

By 2050 the demand for energy could double or even triple as the global population grows and developing countries expand their economies. All life on Earth depends on energy and the cycling of carbon. Energy is essential for economic and social development and also poses an environmental challenge. We must explore all aspects of energy production and consumption, including energy efficiency; clean energy, the global carbon cycle, carbon sources, and sinks and biomass, as well as their relationship to climate and natural resource issues. Knowledge of energy has allowed humans to flourish in numbers unimaginable to our ancestors.

The world's dependence on fossil fuels began approximately 200 years ago. Though we are not running out of oil, we certainly are running out of the affordable oil that has powered the world economy since the 1950s. Recent International Energy Agency (2001) estimates are that oil will be depleted by 2100. We know how to recover fossil fuels and harvest their energy for operating power plants, planes, trains, and automobiles; this leads to modifying the carbon cycle and additional greenhouse gas emissions. The result has been the debate on availability of fossil energy resources; peak oil era and timing for anticipated end of the fossil fuel era; price and environmental impact versus various renewable resources and use; carbon footprint; and emissions and control, including cap and trade and emergence of "green power." The challenge is to replace fossil fuel to achieve sustainable energy generation. By the end of the twenty-first century, clean-energy sources will dominate the landscape.

## II. LITERATURE REVIEW

Arthur Davis & Frank Kuhn Lenz (December 2007) stated the different applications of Fresnel lenses. A Fresnel lens being an optical component can be used as a cost-effective, lightweight alternative to conventional continuous surface optics. The various parameters governing the properties of Fresnel lenses were also discussed. The paper defines focal length as the distance from the lens to where an idealized collimated input beam converges to a point. A Fresnel can hence be used for diverse applications like as a magnifier to magnify an object, as a collimator for a confined beam of light and also as a concentrator. [1]

Ralf Leutz et al, (May 2001) clarifies the role of colour aberrations in a novel non-imaging Fresnel lens of moderate concentration, intended for photovoltaic applications where homogeneous illumination is imperative.

They pointed out that Fresnel lenses offer more flexibility in optical design, thus allowing for uniform flux on the absorber, which is one of the conditions for efficiency in photovoltaic cells. [2]

Isao Oshinda (May 1961) stressed the pre-eminent properties of a plastic Fresnel lens as a solar collector, especially owing to the fact that the economic feasibility of such a material is very good and can be produced in masses. The various merits using such a lens included possibility of supply at reasonable prices, light weight, density is about half of that of a glass, mould ability in any shape and size, high durability, high resistance for weathering etc. the paper also listed the various demerits of such a type of lens, prominently existence of scattering of light, inconvenient mechanical properties common to plastic materials, weakness for heat, large absorption of infrared rays above 2 microns in wavelength etc. [3]

Abraham Kribus et al, (April 2006) invented a novel miniature concentrating PV (MCPV) system. The system is producing both electrical and thermal energy, which is supplied to a nearby consumer. In contrast to PV/thermal (PV/T) flat collectors, the heat from an MCPV collector is not limited to low-temperature applications. A miniature concentrating PV (MCPV) system that can be installed on any rooftop, as close as possible to the energy consumer was developed. [4]

Saurabh Mehrotra et al, (June 2014) developed a technique to immerse solar panel in a heat absorbing liquid in-order to cool the panel. PV cell was submerged in water so as to maintain its surface temperature and provide better efficiencies at extreme temperatures. The electrical parameters of solar cell were calculated by monitoring solar panel placed at different depths while controlling the surface temperature from 31°C to 39 °C. The main problem faced with water used as a coolant is its conductivity. It is a conductive liquid which when decomposes into its ions may affect electrical efficiency as the ions will also have a current. De ionized water can be used instead as it has high thermal capacity and low viscosity. [5]

E. Skoplaki et al, (October 2008) found out that operating temperature plays a central role in the photovoltaic conversion process. Both the electrical efficiency and hence the power output of a PV module depend linearly on the operating temperature, decreasing with Temperature. The various correlations that have been proposed in the literature represent simplified working equations which apply to PV modules or PV arrays mounted on free-standing frames, to PV/Thermal collectors, and to BIPV arrays, respectively. [6]

M. Hasan Nia et al, (May 2014) utilized Fresnel lens and thermoelectric module (TE module) in order to concentrate solar beam and generate electrical power, respectively. The energy of concentrated sunlight on the heat absorber of TE module is transferred to cold water reservoir. Heat transfer in TE module leads to temperature difference in its both sides and finally electrical power is generated. The main components of this system consist of a mono-axial adjustable structure, a thermoelectric generator (TEG) and a Fresnel lens with an area of 0.09 m<sup>2</sup>. Results revealed that matched load output power is 1.08W with 51.33% efficiency under radiation intensity of 705.9 W/m<sup>2</sup>. In order to apply TE module capacity optimally for electrical generation, it is recommended to employ an array of Fresnel lenses which transfer heat to TE module by an intermediate fluid. [7]

### III. PROBLEM IDENTIFICATION

The aspects of a novel solar concentrating photovoltaic / thermal collector can produce both electricity and hot water. The hot water can be produced at useful temperatures for applications such as building heating and domestic hot water, as well as many commercial and agricultural applications that require low-grade heat. The motivation for the development of the project is in twofold: in the short term, to produce photovoltaic power and solar hot water at a cost which is competitive with other renewable energy technologies and within the long run, at a price which is less than possible with current technologies. To be capable of achieving this aim, the collectors must have an inherent advantage over other photovoltaic and thermal technologies. Most photovoltaic and thermal collectors used for similar applications are flat plate collectors. The primary advantage of the this system is that concentrating light allows a significant reduction in the area of solar cell coverage, the main cost driver in a flat plate system. The thermal energy generated could be considered as a by-product due to the necessity to cool the cells, but in appropriate applications the thermal energy is equally valuable. A secondary advantage of this system is the efficient use of space inherent in combining electrical and thermal energy generation, which may be advantageous on rooftops or in other applications where space is limited. The challenge in the development of this system is to design a robust collector with a clear pathway to more rapid cost reduction than the incumbent flat plate technology, and to optimize the performance within the cost constraints.

IV. SYSTEM DESIGN

A. The Fresnel Lens

Optical quality acrylic is that the most generally applicable material, and may be a good general-purpose material in the visible. Its transmittance is nearly flat and almost 92% from the ultraviolet to the near infrared; acrylic may additionally be specified to be UV transmitting (UVT acrylic) or UV filtering (UVF acrylic). Hence a Fresnel lens made of acrylic was procured.

B. Focal length measurement

When the lens was placed in front of an object, it gave a virtual image. The distance between object and lens along with distance between image and lens on the focal plane was noted as shown in Fig4.1. The focal length  $f = 60.09\text{mm}$  was measured using the Lens.

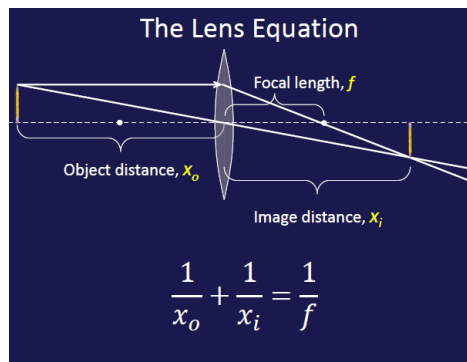


Fig. 4.1 The lens equation

Table 1. Fresnel lens Specifications

Length	61.20 cm
Width	46.60 cm
Width of Outer Frame	1.00cm
Measured Focal Length	59.40 cm
Calculated Focal Length	60.09 cm
Material	Acrylic
Type	Imaging
Magnification	1.42 X
F Number	1.2882

C. Height adjustable Support stand for Lens

In-order to vary the equivalent distance between Photovoltaic panel and Fresnel lens, a height adjustable support stand was fabricated. With the help of support stand the lens and photovoltaic panel relative distance can be varied in terms of focal length (say  $0.2f, 0.4f$  etc.).

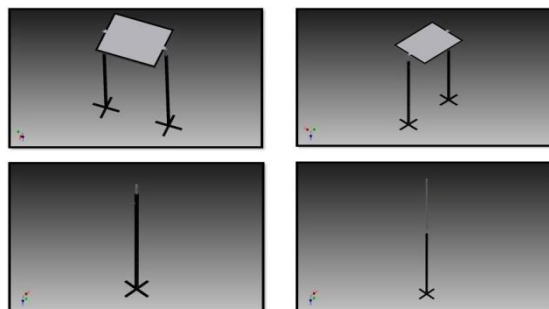


Fig 4.2 Three-Dimensional drawing of support stand mounted with Fresnel lens.

D. The Photovoltaic Panel

Two identical Solar Photovoltaic panel of 3 Watt rated output was used for the work. The PV module is 185 mm wide and 185 mm long. The specifications are as shown in the Table 2.

Table 2. Photovoltaic panel Specification

Rated Power, $P_{max}$	3 W
Open circuit Voltage, $V_{oc}$	11.00V
Short Circuit Current, $I_{sc}$	0.40 A
Voltage at Maximum Power, $V_{mp}$	8.70 V
Current at Maximum Power, $I_{mp}$	0.35 A
Tolerance	$\pm 10\%$

E. Panel Immersed Cooling

The PV module will be immersed in a solution of non-conducting liquid to dissipate the immense temperature when subjected to concentration. Since the temperature of PV module greatly affects its efficiency it must be closely regulated. A sophisticated container with a glass lid and a tilt able support stand is designed for this purpose. The stand consists of two square tubes made from mild steel. The container is also made of mild steel material and is covered with the help of a 6mm glass lid. The entire container and glass lid assembly is air and water sealed with the PV panel placed inside it. The container was provided with an inlet outlet port for the smooth flow of water. Provision for allocating temperature sensor inside the container and a hole for extracting the PV panel output line was also provided. Inlet and outlet ports were connected to an 8 litre capacity water inlet tank and an outlet tank of 20 litre capacity governed by a flow control valve and set of hoses.

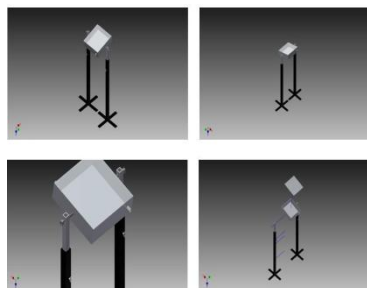


Fig 4.3 Three-Dimensional drawing of support stand mounted with glass container

H. Thermal and Electrical Efficiency

The thermal output  $Q_{th}$  and electrical output  $Q_{ele}$  of the collector can be calculated from the measured data as follows

$$Q_{th} = C_p \cdot M_w \cdot (T_{in} - T_{out})$$

$$Q_{ele} = I_{mp} \cdot V_{mp}$$

Where  $C_p$  is the specific heat at the average fluid temperature,  $M_w$  is the mass flow, and  $T_{out}$  and  $T_{in}$  are the outlet and inlet temperatures respectively of the Fluid.  $I_{mp}$  and  $V_{mp}$  are the current and voltage of the receiver at the maximum power point. The thermal efficiency  $\eta_{th}$  and electrical efficiency  $\eta_{ele}$  are calculated based on the following definitions. System efficiency accounts for the overall efficiency of the system over the course of an entire day.

$$\eta_{th} = \left( \frac{Q_{th}}{I \cdot A} \right) \times 100\%$$

$$\eta_{ele} = \left( \frac{Q_{ele}}{I \cdot A} \right) \times 100\%$$

Where  $I$  is taken as direct beam radiation and  $A$  is the area of receiver. Electrical efficiency of the module can be calculated from the maximum power point. The electrical output  $P_{max}$  can be calculated from measured maximum voltage and maximum current. The area selected to calculate the electrical efficiency depend up on the surface area. For Flat plate photovoltaic module surface area is taken and only electrical efficiency is calculated. In the case of Fresnel lens based concentrated photovoltaic module the aperture area is considered and both electrical and thermal efficiency can be calculated giving totalefficiency.

### V. EXPERIMENTATION

Experimentation was done by setting the distance between the Fresnel lens and photovoltaic module initially at  $0.2f$  (i.e. at  $0.2 \times 60.09 = 12.018\text{cm}$ ) for two consecutive days followed by placing it at  $0.4f$ ,  $0.6f$ ,  $0.8f$ ,  $1.2f$  and  $1.4f$  on a series of sunny days. To facilitate the flow of water to carry away the excess heat from inside the glass container the inlet port was connected to an 8 litre capacity water tank and the outlet port was connected to the collection tank. The collection tank had a capacity of 20 litres. The flow of water inside the system was adjusted with the help of a flow control valve. Temperature of fresh water in, temperature inside the glass container and temperature of the water inside the collection tank was reordered every hour from morning to evening. In-order to compare the results with a Flat plate system an identical 3 Watt module was placed horizontally on the ground and its characteristics were also studied. The short current  $I_{sc}$  and open circuit voltage  $V_{oc}$  along with  $I_{mp}$  and  $V_{mp}$  values under a load was recorded for the entire day of the experiment for the Fresnel lens concentrated module and flat plate module from time to time. The PV module containing glass container was also mounted on the height adjustable stand. The relative distance between Panel Box and Lens was varied during the course of the experiment. Manual tracking was employed throughout the experiment to make sure a perfect square image of the concentrated solar irradiation lens was incident on the PV panel.

### VI. EXPERIMENTAL RESULTS

#### A. PV Module Characteristics

If no load is connected with solar panel which is facing the sun, an open circuit voltage  $V_{oc}$  will be produced but no current flows. If the terminals of the solar panel are shorted together, short-circuit current  $I_{sc}$  will flow but the output voltage will be zero. In both cases, no power is delivered by the solar panel. When a load is connected, we need to consider the I-V curve of the panel and the I-V curve of the load to figure out how much power can be delivered to the load. The maximum power point (MPP) is the spot near the knee of the I-V curve, and the voltage and current at the MPP are designated as  $V_m$  and  $I_m$ . For a particular load, the maximum point is changing as the I-V curve is varying with the temperature, insolation, and shading. Fig 6.1 Shows the I-V characteristics of both flat plate panel and Fresnel lens concentrated panel at  $0.2f$ ,  $0.4f$ ,  $0.6f$ ,  $0.8f$ ,  $1.2f$  and  $1.4f$  during the peak insolation hour. With the decrease in voltage the current increases initially and then current remain constant for further decrease in voltage. We can easily observe that when panel is kept at  $0.8f$  the  $V_m$  and  $I_m$  values are at the peak compared to flat plate panel and other corresponding locations in Fresnel lens concentrated system.

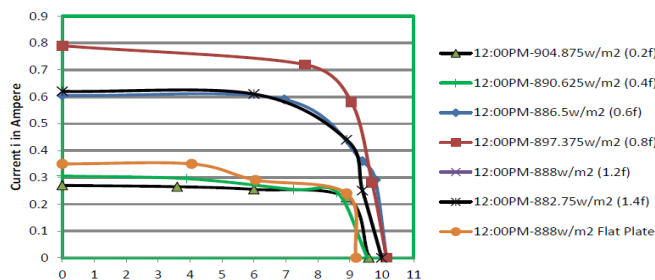


Figure 6.1. I-V Characteristics of Panel at 12:00 PM

Fig 6.2 Shows the P-V characteristics of both flat plate panel and Fresnel lens concentrated panel at  $0.2f$ ,  $0.4f$ ,  $0.6f$ ,  $0.8f$ ,  $1.2f$  and  $1.4f$  during the peak insolation hour. The P-V Characteristics shows that power increase to a maximum value and then decreases. The peak values are obtained at when the panel is placed at  $0.8f$  with respect to the lens.

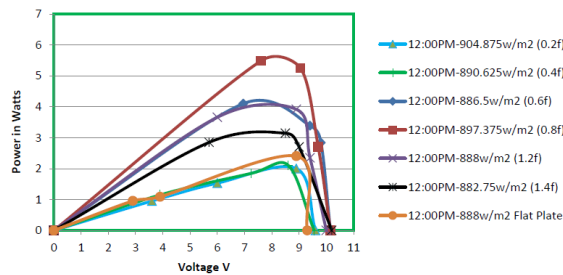


Figure 6.2. P-V Characteristics of Panel at 12:00 PM

B. Power and Temperature Comparison

Fig 6.3 shows the variation maximum power over the course of a day for each position of PV panel placed. The figure also shows the  $P_{max}$  values of Flat Plate panel. At 0.8f the peak values are obtained. The maximum value of peak power obtained is 5.8355W

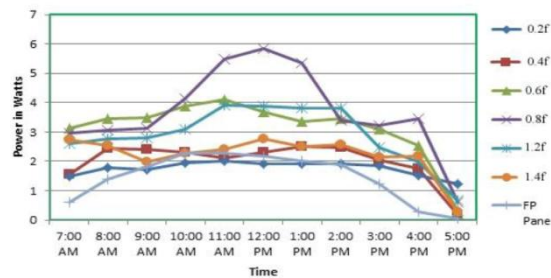


Figure 6.3. Variation of  $P_{max}$  vs Time

Fig 6.4 shows the variation of temperature of the flat plate panel and the panel placed at 0.2f, 0.4f, 0.6f, 0.8f, 1.2f and 1.4f. Although the concentration of oncoming radiation is supposed to increase the temperature of Fresnel lens concentrated panel there is a considerable decrease in temperature of the panel compared to the flat plate panel because of the fact that excess heat was carried away by the cooling water. The flat plate panel surface reached a temperature of 58.33°C. This rise in temperature has reduced the flat plate panels overall efficiency.

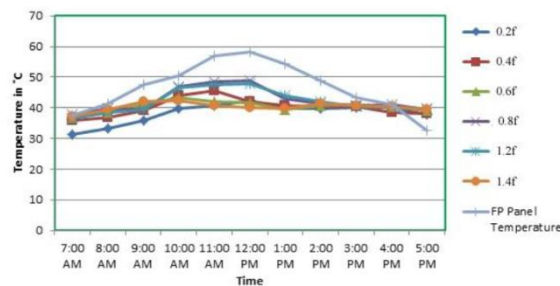


Figure 6.4. Hourly variation of Panel temperature

Fig 6.5 shows the temperature of hot water obtained at the outlet tank in the Fresnel lens concentrated system compared to the ambient water temperature. The hot water obtained from the outlet of the glass container can be used for heating purpose like bathing. Average Indian bathing temperature is 40 - 41 °C. Around 40 liters of hot water was used to circulate in the system over the course of a day while conducting the experiment.

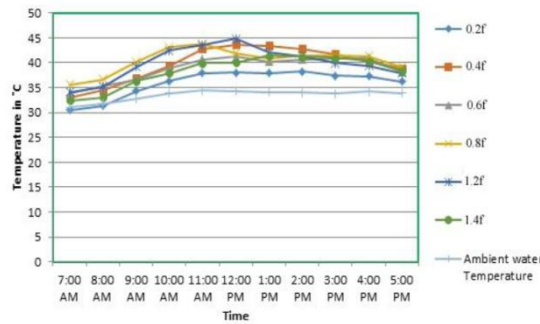


Figure 6.5. Hourly variation of outlet water temperature

### C. Electrical and Thermal Efficiency

The Fresnel lens concentrated system has contributed quite well in affecting solar panel electrical efficiency. Fig 6.6 shows the variation of electrical efficiency over a day. The maximum value obtained was around 33.05% which was obtained when the panel was placed at 0.8f to the lens. On other thing to be noted here is the fact that, the Fresnel lens concentrated panel showed fairly good efficiency even during off peak hours. Hence on daily output bases Fresnel lens concentrated system can achieve more in-terms of output.

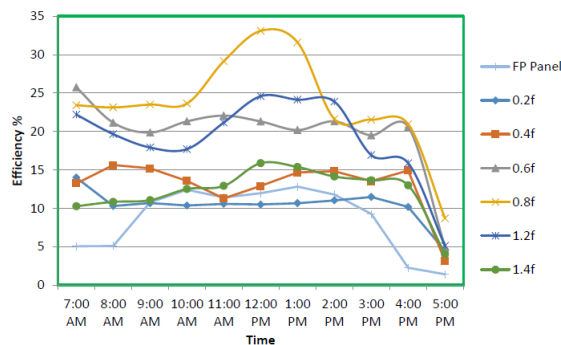


Figure 6.6. Electrical Efficiency vs Time

## VII. CONCLUSION

The Fresnel lens concentrated system with thermal module showed excellent characteristics. Although placing the panel at 0.2f, 0.4f, 0.6f, 1.2f and 1.4f showed excellent figures compared to flat plate panel, the peak values of thermal and electrical output was obtained at 0.8f. Around 40-45 liters of water was obtained each day during the course of the experiment at a temperature of around 38.5°. The average water temperatures obtained over a day's time was about 38.5°C which can be used for domestic hot water purposes

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