

Researches on the development of an optical system for improving the efficiency of photovoltaic panels

Dana Rizescu¹, Ciprian Ion Rizescu¹, Cristian Gabriel Alionte^{1,*}

¹University POLITEHNICA of Bucharest, Mechatronics and Precision Mechanics Department,
Splaiul Independentei no. 313, sector 6, Bucharest, Romania.

Abstract. The paper aims to create a unit using Fresnel lenses. This module consist of an arrangement of planar-convex Fresnel lenses, made of methyl polymethacrylate, mounted in a hexagonal raster and bent to form a dome for collecting and amplifying solar radiation at several focal points and with the possibility of adjusting the focal distance. The module has three aluminum alloy legs that are vertically adjustable. This construction using Fresnel lenses mounted in a hexagonal raster will increase the energy collected by a photovoltaic panel, thus significantly reducing energy losses and long-term costs. Compared to normal lenses, these lenses are considerably lighter because the material in the center of the lens is reduced, and for manufacturing can be used methyl polymethacrylate or polycarbonate, thus greatly reducing manufacturing costs. To show the functioning of the unit the authors presents in the paper a MATLAB simulation of the Fresnel lens model and a ray propagation.

1 Introduction

The energy of solar radiation is an inexhaustible source of energy, which we can use to replace known fossil fuels or uranium ore, having an annual energy of 23,000 times greater than the actual energy consumption produced by them.

Solar power is the conversion of this energy given by the sun into electricity by using photovoltaic systems, concentrating solar power or a combination of the two. Solar panel concentrators use lens systems, mirrors, or sun tracking devices to focus a wide area of sunlight in a small radius (area).

Advantages of using a solar power concentration system:

- Increase the amount of solar energy received;
- Replacement of pollutant fossil fuels;
- Recovery of the investment in a relatively short time;
- It is environmentally friendly;
- They can be accessed by a considerable number of people for both personal and professional purposes.

* Corresponding author: cristian.alionte@upb.ro

In the literature exist some new approaches [1] which use Fresnel lenses to collect and focus the sunlight rays onto very high efficiency tandem-junction solar cells. By using a relatively inexpensive Fresnel lens to collect the sunlight and to focus it onto much smaller solar cells, the cost and weight of the cells are dramatically reduced. By using very high efficiency cells, the required array area is minimized, reducing overall system weight and launch volume. The advantages of the new Fresnel lens concentrating solar electric power supply are now being widely recognized [2].

In [1,3,4] are presented some solar energy systems with Fresnel lenses solar concentrators, used for space applications, for the satellites power feeding. More specifically, this patent relates to for space power. These systems are high-efficiency, extremely light and robust. For example, in Fig. 1 [1] is shown a Fresnel flexible lens attached to the end supports, in which the end supports extend the lens to maintain their proper position and shape on orbit in space. The main part of the system is the flexible, stretched Fresnel lens optical concentrator fastened on a curved spring sustained by a vertical support and two structural elements of compression that support the pillars and springs. Solar energy is focused on receiver / converter which is fastened on the surface of the radiator for the dissipation of waste heat in space. In this embodiment of this concentrator, before the deployment, the lenses flexible and the end brackets are folded into a flat, low volume package for launch efficient in space.

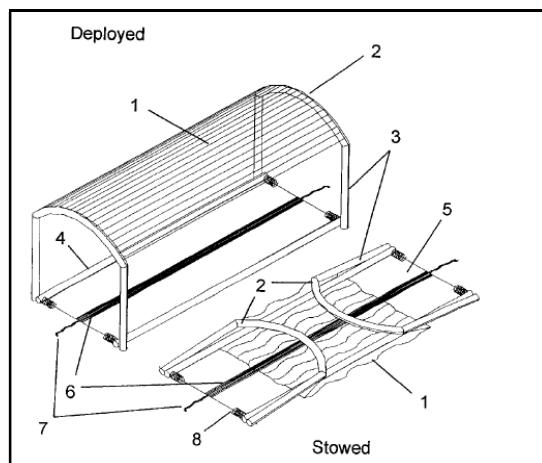


Fig. 1. High efficiency Fresnel lens: 1. Fresnel lens optical concentrator; 2. Curved spring attached to Fresnel lenses; 3. Vertical support posts for the arch structure; 4. Structural elements of compression that support the pillars and springs; 5. The surface of the radiator for the dissipation of waste heat in space; 6. The receiver / converter; 7. Wires for electricity transport generated by the receiver.

The current paper is focused on the Fresnel lenses configuration which are part on a new stationary photovoltaic system. This system does not have any mobile parts and through a complex mirror system that surround the dome, oriented so that the solar rays are normal on the surface of each lens. This system will be presented in another paper.

2 Unit construction

Following the detailed research developed by the authors regarding the solution for the concentration of the light beam, the following constructive solution was reached. An arrangement of planar-convex Fresnel lenses, made of methyl polymethacrylate, mounted

in a hexagonal raster, bent so as to form a dome for collecting and amplifying solar radiation at several focal points and with the possibility of adjusting the focal length with three attached aluminum alloy legs that are vertically adjustable. The aim is to increase the energy collected by a photovoltaic panel, thus significantly reducing energy losses and long-term costs, but also the consumption of other polluting energy sources.

The series of hexagonal Fresnel lenses of the dome is inclined at an angle that allows the incident beam of solar radiation to be inclined on the surface of the solar cell, on the surface of the solar panel, Fig. 2. The reason why the solution was chosen for the lenses to be twice as large in diameter than the size of the solar panel is so that there is no loss of light and the concentration is on the entire surface of the panel. This theory of overlap can be properly implemented if the inclination of each illumination lens is in the normal direction of the vector and this can be achieved by using the inclination angle of each illumination area. The system consists of:

1. Fresnel lens arrangement which formed a dome using hexagonal lenses;
2. Adjustable foot to tilt and dome orientation;
3. Photovoltaic panel on which the solar rays are concentrate.

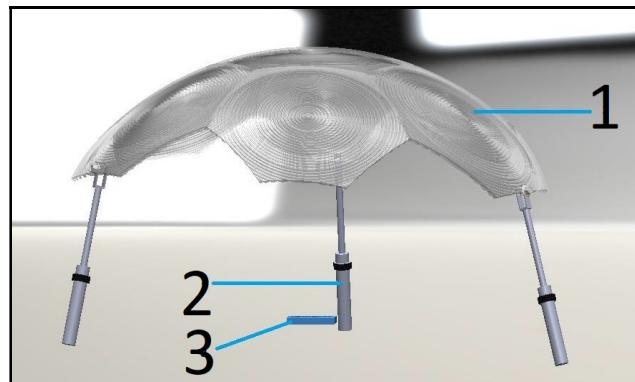


Fig. 2. Designed Fresnel lens unit: 1. Fresnel lens arrangement; 2. Adjustable foot; 3. Photovoltaic panel.

The hexagonal concentration form of the Fresnel lens resembles the beehive and it is more resistant due to the shape and allows an easy detachment or attachment of other lenses, thus increasing assembly much easier, reducing costs [6]. The designed model was developed in Solidworks and is shown in Fig. 3.



Fig. 3. The Fresnel lenses placed in hexagonal arrangement

3 Materials for Fresnel lenses

This method of concentration was chosen using Fresnel lenses, because of the advantages they offer over conventional lenses. Compared to normal lenses, these lenses are considerably lighter, the material in the center of the lens being reduced, using only its faces for the collection and concentration of light.

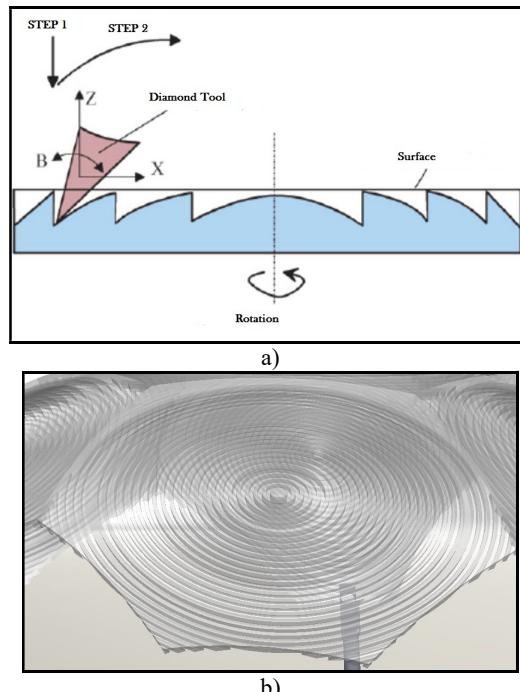


Fig. 4. The manufacturing of the Fresnel lens: a) the manufacturing process; b) hexagonal Fresnel lens

Fresnel lenses can also be made of glass, but most are made of acrylic or polycarbonate, thus greatly reducing manufacturing costs. At the same time, Fresnel lenses can be easier to handle compared to ordinary lenses, having greater flexibility and being more durable [5]. They are several manufacturing possibilities for Methyl polymethacrylate plate (PMMA). One solution is using a numerically controlled machine based on a CAD model. In the process can be used a diamond tool to lower and raise the corners of the future Fresnel lenses, while the PMMA plate is rotated, as can be seen in Fig. 4a. Another solution is the injection molding of PMMA, as can be seen in Fig. 4b.

4 Design of Fresnel lens and ray propagation simulation

To design the experimental setup, it was developed a Fresnel model using MATLAB environment.

Through the Fresnel of the dome will pass those “useful” rays which has an angle of incidence below the limit values bellow the total reflection of the lens surface. In the Fig. 5 can be seen that these rays (represented with red color) are distancing from the normal rays (represented with blue color). These rays are influencing the dimensions of the solar cell.

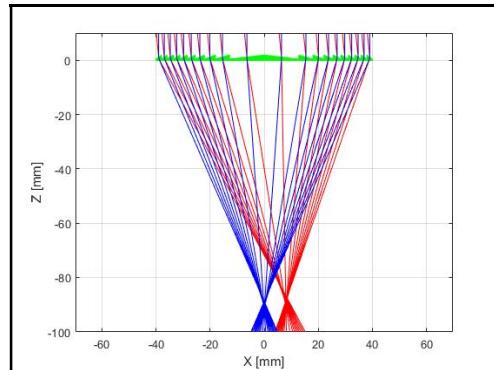


Fig. 5. MATLAB simulation: normal rays (represented with blue color) versus “useful” rays (represented with red color)

To have a minimum dimension of the solar cell, it was considered in the simulation only the normal rays. To achieve this scope, we are currently researching and building a complex mirror system around the dome and will be presented in another paper.

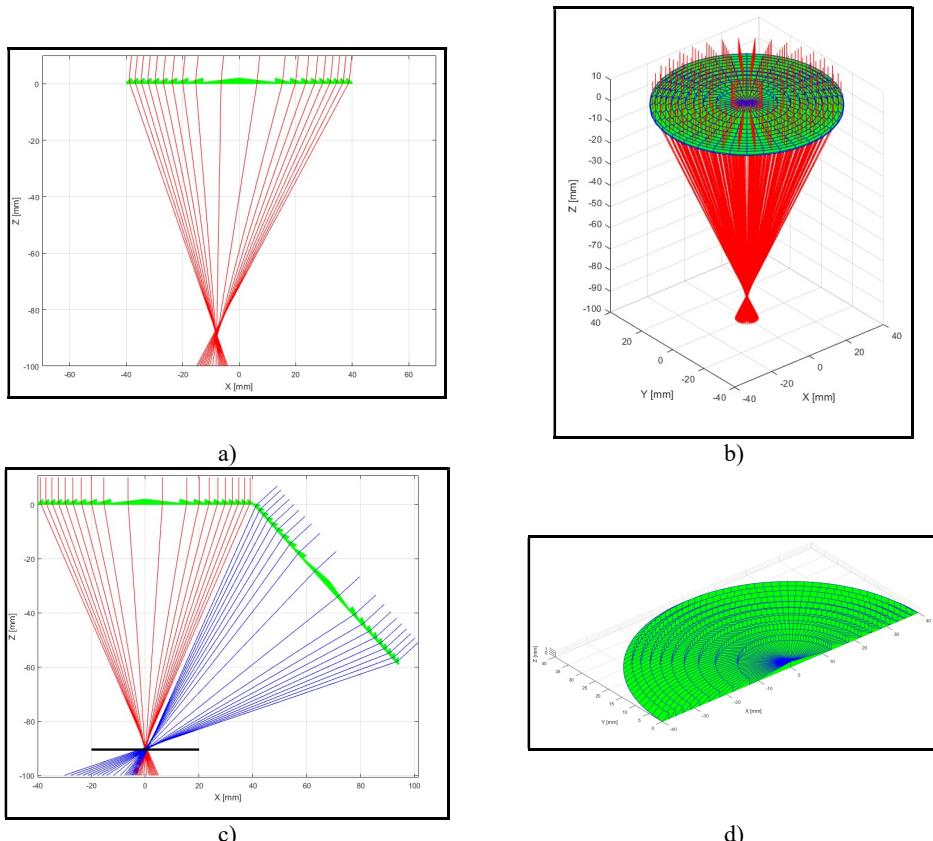


Fig. 6. MATLAB simulation: a) the Fresnel lens ray propagation simulation 2D; b) The Fresnel lens ray propagation simulation 3D; c) The two Fresnel lenses ray propagation simulation 2D; d) The Fresnel lens 3D model

The simulation has the following steps:

- design the Fresnel lens with a proper geometry, as can be seen in fig. 6a;
- simulate a ray propagation simulation, as can be seen in fig. 6b;
- simulate the ray propagation for the dome using a hexagonal arrangement according to [7], as can be seen in fig. 6c.

5 Conclusions

In the paper is presented a new solution which proves that there are:

- long-term financial advantages, because is an alternative to creating electricity and replacing fossil fuels in order to help the environment by using photovoltaic panels;
- by using Fresnel lens the structure has:
 - a reduce the cost;
 - lighter weight due to the material;
 - more compact structure;
 - flexible structure;
 - easy to manufacture and to assembly
 - by using polymethylmethacrylate instead of glass for a lower refractive index, cost reduction and a half weight;
- the structure is adjustable due to the supports which has the possibility of adjusting them vertically to change the focal length.

The way of obtaining normal beams on the surfaces of the Fresnel lenses that make up the dome is a continuation of the research theme. Also, the relative orientation of the Fresnel lenses that make up the dome, the characteristics of the lenses, the geometry of the profile of the Fresnel surfaces in order to increase the number of useful rays for different orientations of the Sun are further research directions.

References

1. M. J. O'Neill, *Stretched Fresnel Lens Solar Concentrator for Space Power* (US Patent, US6075200, 2000)
2. L. L. C. Chen, *Stationary Photovoltaic Array Module Design for Solar Electric Power Generation Systems* (US Patent, US6653551 2003)
3. V. Shaoulov, J. Rolland, *Compact relay lenses using microlenslet arrays*, in International Optical Design Conference 2002, Proc. SPIE **4832** (2002)
4. N. Lindlein, *Simulation of micro-optical systems including microlens arrays*, Journal of Optics A: Pure and Applied Optics **4** (2002)
5. J. P. Rolland, V. Shaoulov, F. J. Gonzalez, *The art of back-of-the-envelope paraxial raytracing*, IEEE Trans. Educ. **44** (2001)
6. K. Mersereau, C. R. Nijander, W. P. Townsend, R. J. Crisci, A. Y. Feldblum , D. Daly *Design, fabrication, and testing of refractive microlens arrays*, IOP Short Meeting, **30** (1991)
7. A. E. Bruno, S. Barnard, M. Ehrat, R. Völkel, P. Nussbaum, H. P. Herzig, *Optische Detektionsvorrichtung für chemische Analysen an kleinvolumigen Proben* (European patent application no 96810341.6. 1996)