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Development and Simulation of Concentrated Photovoltaic Systems (CPV)

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Abstract **-** Concentrated Photovoltaic Systems (CPV) use optical components to collect large area of solar radiation and transfer its energy to small high performance PV cells. The development of CPV is seen as the future of solar energy. The objective of our work is to reduce the cost of peak power watt photovoltaic origin. Concentration photovoltaic generators use less amount of silicon for higher yield compared to conventional generators. Therefore, we have developed a simulator to optimize longitudinal Fresnel concentrators that uses a series of prisms with different dimensions interspersed between cells and solar radiation. The simulation of a luminous flux allows a three-dimensional concentrator PV. A program developed under WinDev enables mapping the concentrator according to different parameters (n= refractive index, F = focal length, L= width of PV cells… etc). Experimental measurements have shown an increase in power output of PV modules using this type of concentrators.

Keywords**:** Photovoltaic, Solar energy, Silicon, Watt peak, Simulation, Prism**.**

1. Introduction

Photovoltaic energy, as part of renewable energy is faced to increase prices of their operating, particularly in developing countries which is around 0.25$ to 1.60$/kWh (WEC,2007) (El Mnassri and St Leger, 2010). This increase of price is mainly due to the cost of Silicon process (purification crystallization, etc ...) (Miquel and Gaiddon, 2009). In order to have alternatives to conventional methods, a number of solutions are designed to increase the efficiency of PV modules including the amplification of the light flux entering the PV module, where the concentrated photovoltaic widely known CPV system. This method is the subject of several research programs (Chikouche, 2013). In this work, we present the Fresnel longitudinal concentrator, studying the influence of the focal length and its thickness on the concentration ratio.

2. Prismatic Concentrator

The prismatic concentrator, also called Fresnel lenses is based on the principle of refraction of the incident light under the Descartes' law:

$$D(i,A) = i + Arcsin(n * sin(A - Arcsin(\frac{sin(i)}{n}))) - A. \quad (1)$$

D: deflection angle, *A* : apex angle of prism, *i* : angle of incidence and *n* : refractive index.
In the case of normal incidence (*i*=0°), equation (01) becomes:

$$D = -A + Arcsin(n * Sin(A)) \quad (2)$$

The focal length *F* depends on the width of PV cell (or light flux collector) and the deflection angle of the last facet (Fig. 1 b), which is limited by the apex angle *A* as: $A + D < \pi/2$ (Fig.1).

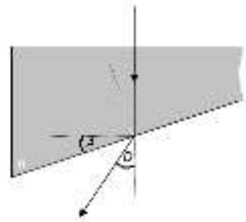

Fig.1. Limit angle between *D* and *A*.

2. 1. Concentration Ratio

In this work we consider only the direct sunlight.

The optical concentration ratio is estimated at first, as the ratio of the area of the incident light flux by the active surface of the PV module:

$$R = \frac{S_{in}}{S_{PV}} \tag{3}$$

Where S_{in} is the incident light flux section and S_{PV} is the surface of the PV cell receiving the concentrated light flux.

This value must be corrected by the estimation of losses of the incident light flux at its crossing of the medium of the concentrator (polymer, glass, ect ...).

2. 2. Estimated Losses of Incident Light Flux

Assuming homogeneous and isotropic media and that the solar radiation is monochromatic, the Fresnel coefficients of transmission energy is given by:

$$T = \frac{4 * n * Cos(i) * Cos(\theta_t)}{(n * Cos(\theta_t + Cos(i))^2} \tag{4}$$

i and θ_t are respectively, the angle of incidence and the angle of transmission at the 2nd plane of the concentrator (at lower).

At the first plane of separation (air-concentrator), the normal incident luminous flux loses 4% of its amplitude due to the phenomenon of reflection, so only 96% of the luminous flux is spread. At the 2nd plan, the 96% of the luminous flux undergo a second reflection before projecting on the PV cell with a new transmission coefficient. The surface of the PV cell receives 0.96 T_2 from the initial luminous flux. T2 depends on the apex angle of the prism.

R is given by integrating the concentrated light flux on the PV cell area using this formula:

$$R = 1 + 2 * \sum_{i=1}^{N_f} \tag{5}$$

$T_i=0.96T_{2i}$.

N_f: number of different facets.

R is implicitly depending on *L* and *F*.

2. 3. Distribution of Concentrated Luminous Flux

The diopter in front of the apex angle *A* is not transmissible of luminous flux (due to the limitations of the Descartes' law eq 1), so the image received on the PV cell is not homogeneous (Fig. 2). The ratio of upper and lower for the j^{h} facet surfaces is given as follows:

$$C_j = \frac{S_1}{S_2} = 1 + \frac{(jL/F)^2}{(1+(jL/F)^2)(n*(1+(jL/F)^2)^{-1/2} - 1} \tag{6}$$

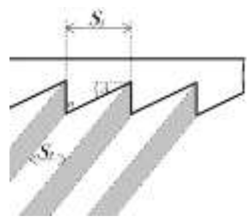

Fig. 2. Inhomogeneous density distribution of concentrated luminous flux on the surface of the PV cell.

3. Results

We have developed a computer program using *Mathematica* language in order to systematically determine *R*(*F*,*L*) and $R(N_f)$ (Fig.3). The program is used to optimize the focal length corresponding to a width of PV cell.

Another program developed under *WinDev*® language can diagram the optical concentrator in real time.From the equation (5) and (6) we calculated the distribution of the concentrated luminous flux on the Pv cell surface, as shown in (Fig.4). This calculation was made for a PV cell of 56mm of width and a concentrator with 3 different facets.

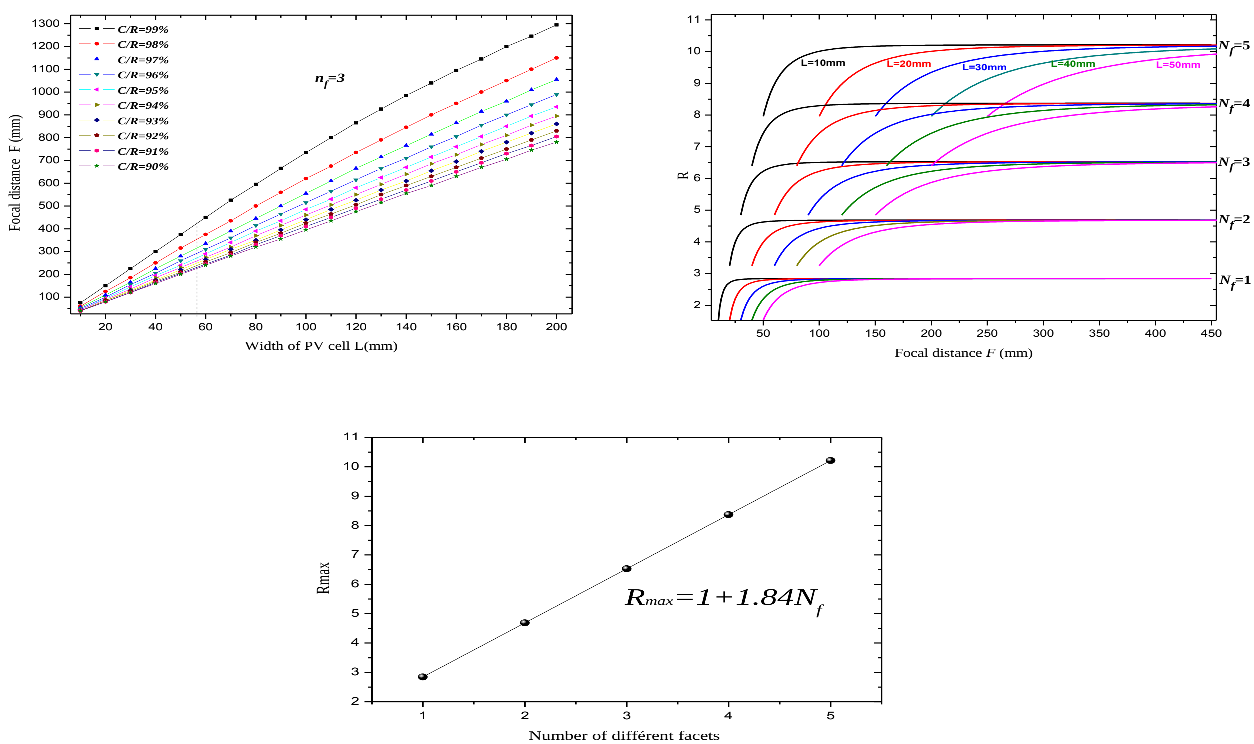

Fig. 3. Variation of the concentration ratio in function of *F*, *L* and N_f.

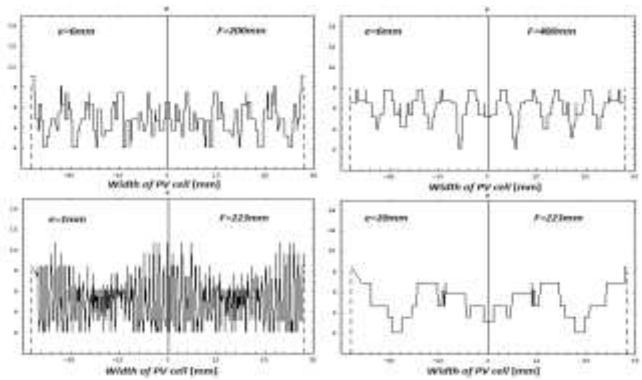

Fig. 4. Variation of the intensity distribution of concentrated luminous flux in function of the focal length *F* and of the thickness of the concentrator *e* (*The prisms are carved at e/2*).

The above figures show that the concentration ratio is more important for large focal lengths (also shown in Fig.3-a). The intensity distribution of the light flux is more homogeneous for low concentrator thicknesses

3.1. Concentrator Design

For a PV module which is a series of PV cells made of polycrystalline Si with a width of 56 mm, and a concentrator of three different facets, the concentration ratio can reach 90% of maximal concentration ratio for a focal distance F = 223mm with a series of 3 different prisms: A_1 = 24.68°, A_2 =36.51° and A_3 = 40.63°.

With a concentration ration of 5.76, the new configuration of the concentrator is shown on Fig. 5.

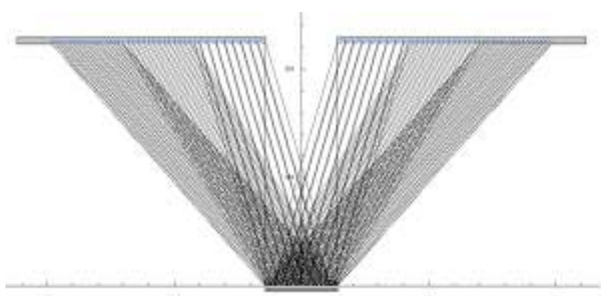

Fig.5. Longitudinal-plan concentrator optimized at F=223mm, R=5.76.

We can compare, at the same focal distance, both longitudinal-plan concentrator and cylindro-longitudinal concentrator made by Hihi (Hihi,2004) (Fig.6), which is at F=310mm, with 3 different facets. The concentration ration for the 1st one is R=6.67 while in (04) is about 5.34 (an increase of 24.91%).

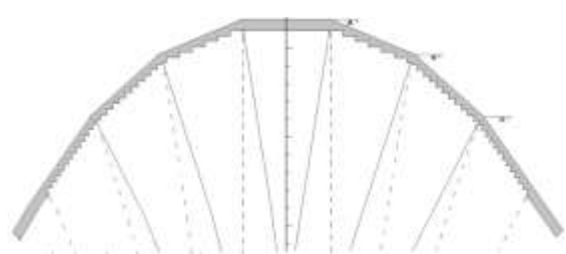

Fig.6. Cylindro-Longitudinal concentrator at F=310mm, R=5.34.

4. Conclusion

We studied the impact of different optical parameter (F,L,N_f) on the concentration ratio for PV concentrator based on Fresnel lens.

The thickness of the concentrator should be minimized to ensure a good homogeneity of the concentrated light flux.

The major problem encountered in the CPV systems is the decrease in the efficiency of PV cells due to the increase in temperature (Robert McCon-nell and Vasilis, 2012) (Ling and Ping, 2011).Experimental measurements envisaged in the future will validate our calculation.

The use of rare-earth doped polymeric media as materials optically active will protect the PV cell by dividing the UV waves into visible (Miller et al., 2012).

A study of the polarimetric distribution of the solar light flux is in progress to get a more real estimate of the transmission coefficients.

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