Sun Tracking Method for Fractal Concentrator Panels

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Abstract

The transmittance of Fractal Concentrators (FC) exhibits a slow and steady decline for incidence angles beyond the acceptance angle. This feature can be employed to track the Sun by the FC solar panel itself without the need of additional tracking devices which is the subject of this work. Of specific interest are FC solar panels at relatively high geometrical concentrations C_g and, hence, with relatively small acceptance angles.

1. Introduction

FC concentrators have been recently proposed [1,2] for concentrating sunlight. Such concentrators consist of an array of refractive optical elements (OE) of conical shape and separated by small gaps of a lower refractive index material. Consequently, rays entering an OE initially propagate through total internal reflection until they eventually lose forward component and start bifurcating through concurrent refraction/reflection events at the interfaces creating in the process a cascade of fractal rays. Thus most generally, such concentrators operate under the principle “one ray in – more than one ray out” which results in a spatially homogeneous exit flux[3] amongst other advantages. At low geometrical concentrations FC concentrators are shown to have a sufficiently large acceptance angle eliminating thus the need for sun tracking. This is not the case at high concentrations. Thus, the acceptance angle θ_a of the concentrator is given by:

$$\theta_a = \arcsin \left[\frac{n_1}{n_2 \sqrt{C_g}} \right] - \varepsilon = \theta_{th} - \varepsilon \quad (1)$$

where n_1 is the refractive index of the OEs, n_2 is the refractive index of the gaps, ε is a function of the angular aperture of the concentrator and the acceptance angles of the OEs, while θ_{th} represents the theoretical limit. Strictly speaking, the angular acceptance aperture of the concentrator represents the common intersection between the angular acceptance apertures of the individual OEs. In practice, θ_a is readily calculated numerically for any specific geometry. Further, it has been also shown[3] that the transmittance of an FC concentrator at 100X declines slowly and steadily for incidence angles θ in the interval:

$$\theta_a < \theta < \theta_{th} \quad (2)$$

as illustrated in Figure 1.

Figure 1. Typical behaviour of the transmittance.

Specifically, it shows a typical behaviour of the FC transmittance as a function of the incidence angle θ . Notably, the transmittance is flat for incidence angles smaller than θ_f beyond which it declines steadily.

2. Method for sun tracking

FC concentrators are typically to be used in a flat panel configuration as schematically illustrated in Figure 2.

Figure 2. Flat panel configuration of FC concentrators.

Specifically, the FC concentrators are arranged tightly in a planar array with their axes n_c parallel to the normal n_p to the panel plane. Solar cells are optically connected to the exit apertures of each concentrator. As noted above each FC concentrator consists in turn of an array of OEs but in view of eq. (1) we limit the number of OEs to six in order to maximize the acceptance angle (minimize ε). Assuming also that the OEs represent truncated triangular pyramids results in a hexagonal periphery of the FC concentrators. Figure 3 represents a top view of a solar panel with such FC concentrators.

Figure 3. Top view of an FC solar panel.

We now tilt the axes n_c of concentrators 1 through to 6 in Fig. 3 by bringing their exit apertures closer to the central FC concentrator denoted as “0” such that the axis n_c of any of the six concentrators lies in a plane containing the normal n_p . Finally, the tilt angle is chosen to be θ_f while the azimuthal separation between two neighbouring concentrators naturally is 60° . Figure 4 illustrates the definition of the tilt angle where only two of the six concentrators are illustrated for clarity.

Figure 4. Illustration of the tilt angle θ_f .

It is clear from the above construction that the FC concentrators 1 through to 6 will be operated at the edge of the flat region of the transmittance at perfect alignment. Hence, any misalignment will produce a decreasing voltage signal by the solar cells whose FC concentrators are misaligned by an angle exceeding θ_f . Hence, from knowledge of the positions of the six concentrators in the plane of the solar panel one can readily calculate the gradient vector of the output voltages (voltage gradient) in the same plane and which vector

together with the normal n_p determine the plane of rotation. The actual angle of rotation is obtained from a standard calibration procedure. Hence, the angular positioning of the solar panel is achieved by first positioning it from prior knowledge of geo-position and time of the year followed by fine tuning using the above method. In this way the panel stays aligned at all times without needing additional tracking devices. As a matter of fact, the panel in this way stays locked onto the Sun more or less at the centre of the angular acceptance aperture of the panel itself since any disbalance (voltage gradient) greater than a predefined margin is immediately detected and subsequently compensated. Note that compensation is always possible as long as the misalignment of at least two of the 6 concentrators is smaller than θ_{th} .

The concentrators 1 through to 6 were intentionally chosen to be clustered together in order to minimize the chance of false readings produced by partial shadowing from clouds and the like. Several such clusters may be distributed over the panel surface to further minimize this probability. Any loss of efficiency due to the misalignment of tilted FC concentrators is negligible since the areal aperture of the individual FC concentrators is much smaller (by orders of magnitude) than the total area of the panel.

3. Conclusions

The inherent behaviour of the transmittance of FC concentrators has been employed to devise a method for indirect tracking of the Sun by monitoring the output voltages at selected solar panel concentrators tilted appropriately for maximum response. The overall performance of the solar panel is not affected.

References

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