INO-CNR ISTITUTO NAZIONALE DI OTTICA

Consiglio Nazionale delle Ricerche

SECONDARY OPTICS DESIGN FOR MITIGATING TRACKING ERRORS IN A LINEAR CPV SYSTEM

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Maximizing the optical efficiency of a linear CPV system implies to provide an appropriate illumination over the cells, even when an off-axis sun tracking angle δ_y occurs. Moreover the small cells size imposes severe requirements on the dimensions of the linear sun image produced by the collector. In contrast, optical aberrations and solar divergence effects contribute to spread the concentrated light. A preliminary study based on ray-tracing simulations has been performed to characterize a model of an existing system. Then a secondary optical device has been especially designed to guarantee a suitable lighting of the cells in a range of tracking angle misalignment $-0.5° < \delta_y < 0.5°$. With secondary optics, the optical system has a lower collection efficiency working in focus, but it is more stable in many more realistic operating situations.

Keywords: Concentrators, Optical design, Ray tracing

SUNLIGHT CONCENTRATION AND DISTRIBUTION ON PV CELLS

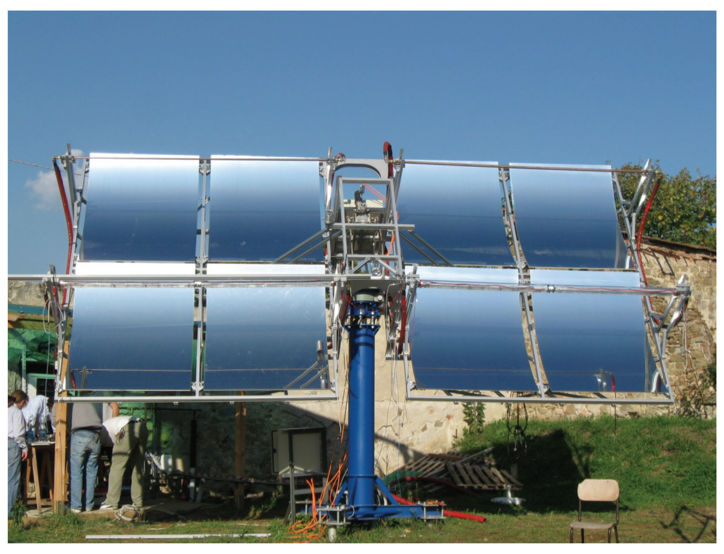

Fig. 1: The Cesare System

The proposed ray-tracing analyses are based on experimentations performed on a prototype of a linear CPV (Concentrating PhotoVoltaic) system. Both theoretical and practical studies were realized in the framework of the "CESARE" project (Concentrated pv combinEd SolAR Energy system).

The system is composed of eight modules with a parabolic profile primary mirror, realized in high reflecting metal, and a receiver consisting in an array of high efficiency PV cells (Fig. 1)

Our studies were addressed at minimizing system sensitivity to tracking angular misalignments δy. Referring to Fig. 2, this parameter is defined as the angle formed by solar rays and normal axis (z) of collector aperture.

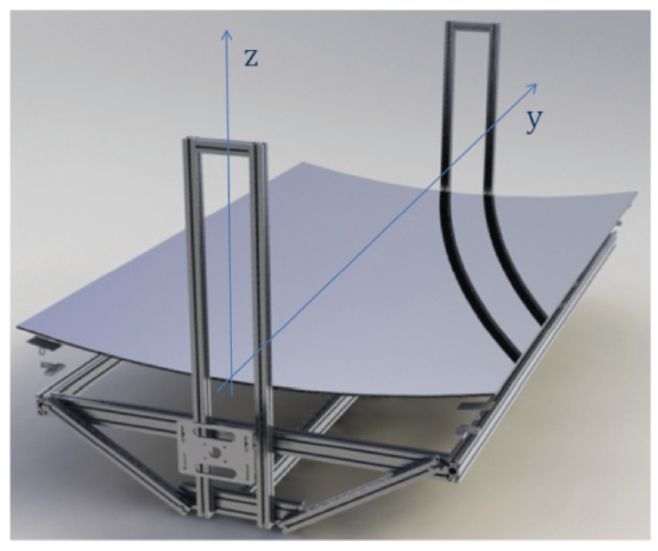

Fig. 2: Collector shaded model

EFFECTS OF ANGULAR MISALIGNMENTS

Some preliminary studies assessed that in our trough system most of sunlight was focused in an area of 9.1 mm width, which was covered by a PV cells array (Fig. 3).
A cells array of 9.1 mm width, placed at the focal distance, received about 90% of the total power concentrated on the linear image on the focal plane.
Collection efficiency was calculated as ratio between the light focused on the absorber and the light captured by collector entrance aperture.

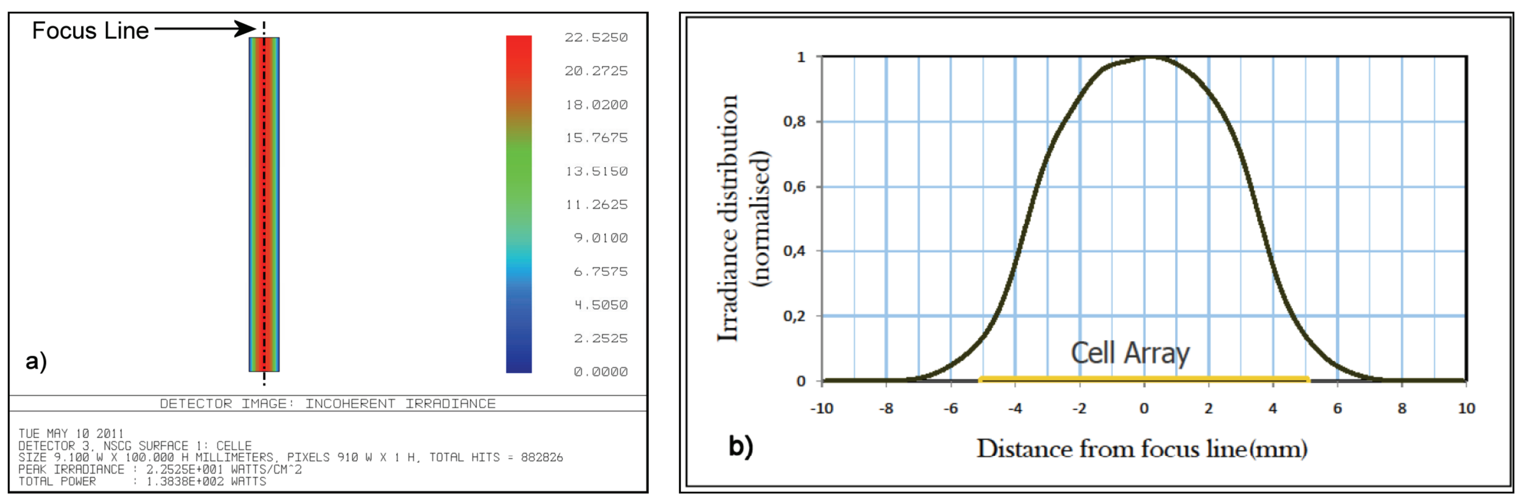

Fig. 3: Light spot in the focal plane:
a) Image on a detector intercepting most rays coming from the mirror.
b) Irradiance distribution versus the distance from focus line; the 90% of the power falls into a spot 9.1 mm width.

For an angular misalignment δy of 0.5°, the solar rays were focused outside the cells array (Fig 4).
The possible causes were intrinsic optical aberrations of the parabolic mirror combined with solar divergence effects. Although our trough prototype was supplied with an accurate two-axis tracking system, occasionally the sun rays could not impinge perpendicularly to the collector entrance aperture.
The consequences were that the sunlight was concentrated outside the cells array. So we obtained a collection efficiency of 3.2%, which was considerably lower with respect to the ideal condition of on-axis tracking.

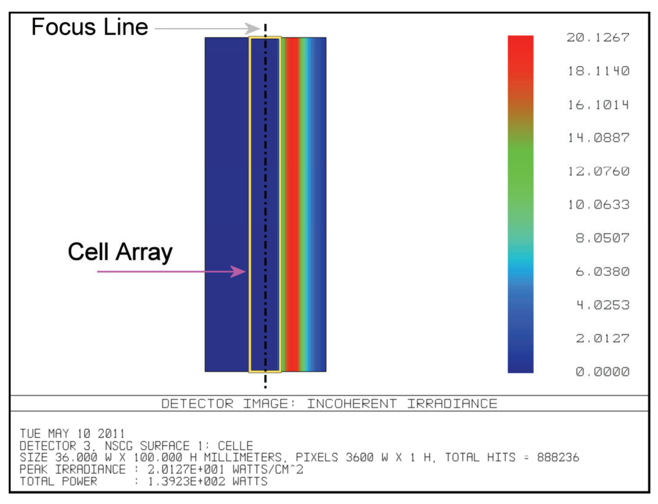

Fig. 4: Image on a detector placed in the focal plane for δ_y=0.5°.
The rays fall far away from the cells zone.

SECONDARY OPTICS DESIGN AND COLLECTION EFFICIENCY

To correct the effects of a possible angular misalignment, parameterized by δy, a secondary non-imaging optical component was optically designed for our trough collector.
Its optical parameters must take into account cost limitations and constraints introduced by the primary mirror itself, whose dimensions and optical features are fixed.

The idea was to create a two-stage concentrator with a secondary device obtained combining several axially symmetric CPC profiles.
This approach allowed us to progressively reduce the transversal dimension of the light spot formed in the focus zone.
The final solution is shown in Fig. 5: it represents the easiest approximation to be realized, with only slight collection performance reductions.

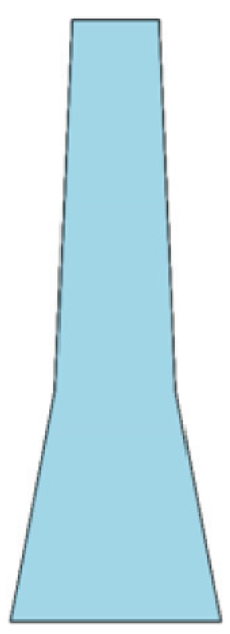

Fig. 5: Cross section of the final configuration for the secondary optics .

The analysis was completed assessing the collection efficiency obtained introducing in the original collecting system the secondary optics.
A synthesis of the results is presented in Fig. 6, comparing the collection efficiency with the secondary optics to the values obtained only with the primary mirror. They are expressed as collection efficiency versus tracking misalignment angle δy. The defocus position of the secondary optics along the parabola axis is parameterized by the coordinate z.
The secondary optics considerably improves the angular stability of sun tracking, slightly reducing the collection efficiency level. In particular, the efficiency curve becomes smoother when the secondary optics is placed with the entrance aperture exactly positioned on the primary mirror focus F (green line in Fig. 5). The most interesting result was that the collection efficiency maintained a quite elevated level (> 50%) within a tracking misalignment range of 1° in tilt angle (-0.5° < δ_y < 0.5°).

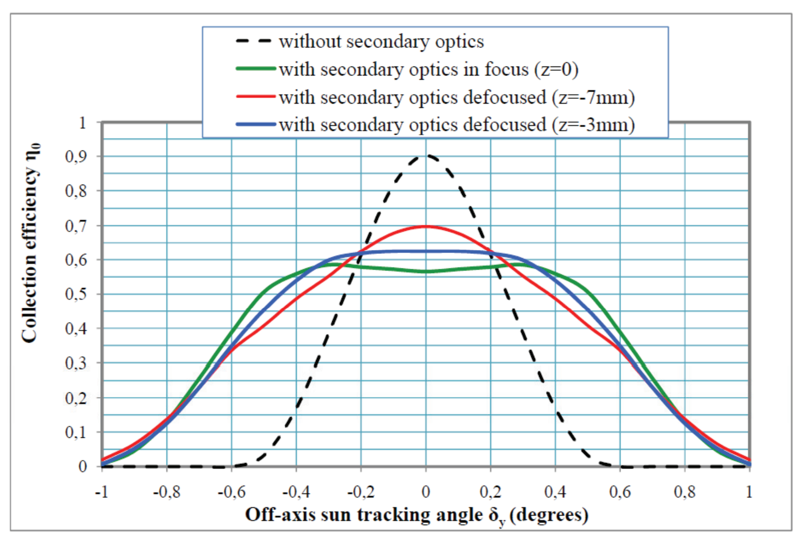

Fig. 6: Collection efficiency for different positions of secondary, vs tracking misalignment angle δ_y.

26th EU PVSEC – Hamburg (5-9 September 2011) - Paper 1DV.4.39