ENHANCED LONGITUDINAL AND LATERAL FLUX UNIFORMITY FOR LINEAR FRESNEL REFLECTORS IN CONCENTRATING PHOTOVOLTAIC SYSTEMS

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ABSTRACT: This paper presents an overview of the particular optical features of a novel linear Fresnel concentration system that are designed to maximise the uniformity of the longitudinal and lateral flux distribution in the ANU-Chromasun hybrid CPV-Thermal Micro-concentrator (MCT) system. The MCT's unique enclosure has freed the optic and tracking systems from the complexities of dealing with wind loading and the thermal expansion mismatch of composite mirror structures. The ultra light-weight reflectors are free to deal with optical considerations alone, and are mounted with independent closed loop tracking systems at each end. This has reduced system cost, improved longitudinal flux uniformity and increased the expected lifetime system yield.

1 INTRODUCTION

The application of linear Fresnel reflector arrays for linear concentrator photovoltaic (CPV) technology enables low-to-medium concentrations (10-30X) to be readily achieved. Linear CPV systems require highly uniform longitudinal flux distribution in order to maximize their performance efficiency. Reduction in the peak lateral flux intensity by more uniformly spreading the flux distribution across the CPV receiver also has the capacity to significantly improve solar cell efficiency. The Centre for Sustainable Energy Systems at The Australian National University (ANU) and Chromasun, a Silicon Valley company, have developed a new Fresnel reflector optic system to resolve these challenges, with the express target being the application of CPV products for domestic and industrial rooftop installations [1]. The micro-concentrator (MCT) product, as shown in Figure 1., is a low-to-medium concentration, low visual impact, linear Fresnel hybrid CPV-Thermal system producing electrical and thermal energy. The MCT unit features innovative designs that make significant progress in resolving the longitudinal and lateral flux requirements of an efficient CPV system.

Figure 1: The MCT enclosure

The MCT design incorporates an array of linear Fresnel reflectors designed to achieve a concentration of 15X at the receiver. This concentration level reduces silicon requirements by almost 95% whilst still achieving module efficiencies greater than 19.0% using modified 1-sun mono-crystalline silicon cells. The linear design of the system also enables the integrated capture of the thermal energy for use in domestic or commercial water heating, space heating, and solar cooling. By operating at this modest concentration ratio, single axis tracking can be employed, significantly reducing system complexity when compared with comparable dual-axis tracking systems.

With stationary-target, moving-mirror tracking systems, astigmatism becomes a significant problem as the mirror incidence angle increases. The optimized Fresnel reflector optical design, developed by Chromasun, uses differential width reflectors where the reflector width is inversely correlated to the focal length, or the distance of the mirror from the receiver.

The focal characteristic of each reflector is also varied in order to limit the extent of flux peaks while still minimizing light spill, and astigmatism is actively harnessed to improve lateral flux uniformity. While the total number of reflectors required increases with concentration, tolerance to tracking inaccuracy was a significant factor in the system optimisation matrix used for this design.

The CPV receiver incorporates a strip of highly reflective material extending vertically down each inner side of the receiver extrusion in order to form an internal secondary reflector. This means that the focal target of the Fresnel mirror array is shifted forward from the concentrator cell surface to the outer surface of the receiver body, such that the physical surface becomes the effective optical aperture of the receiver.

The optical result is that, instead of the typical Gaussian-Bell distribution resulting from the focus of an array of Fresnel reflectors onto a flat target, this innovation significantly flattens the distribution and improves the flux uniformity across the cell.

The electrical result of more uniform lateral flux distribution is an increase of cell efficiency of approximately 0.5 percentage points; realised directly by reducing localised series resistance. At 20X sun concentration the effective cell efficiency of the CPV receiver can be significantly enhanced through improving longitudinal and lateral flux distributions.

2 OPTICS/TRACKING INTERFACE

The MCT tracker drives an array of ultra light-weight, highly reflective aluminium mirrors tensioned to provide a consistent and uniform image profile along the length of the reflector. The ultra-lightweight, highly reflective, front-surface reflector mirror design can be incorporated because of the environmental protection offered by the MCT enclosure. An additional feature of this design is that the mirrors are perfectly balanced, with negligible gravitational loading, and can therefore be driven by a very low power tracking system

In the MCT system, the focal length is independent of the azimuthal angle. Consequently, the concentrating otpics have been designed so that the reflectors are mounted to individual hubs, with each hub in each receiver array ganged at each end of the mirror so that each element of the mirror array rotates at the same angular velocity while tracking. The practical result of this feature is that it allows a single stepper motor to drive all reflectors in unison, significantly reducing parasitic power losses. Figure 2 shows the reflector mountings in a prototype MCT system.

In addition, each mirror is mounted with varying angular connectivity. This “clocks”, or sets the angular orientation of each mirror in relation to all other mirrors in a particular receiver array during assembly. Consequently, the target vectors of each of the reflectors in the clocked array are all in perfect alignment. This approach reduces the manufacturing time required to assemble the Fresnel mirror array; ensures perfect alignment of the reflector images on the receiver target; and increases the number of identical components which further reduces manufacturing cost and complexity. Identical component count favourably influences manufacturing costs through improving the economies of scale advantages, thus reducing the overall manufacturing cost of the MCT.

Figure 2: Detail of ganged reflectors in the prototype MCT, showing focal performance at the end-plane.

The mirror tracking concept is designed with a geometric layout, where the relationship between the pulse count of the stepper motor as a function of angular position is not linear. Likewise, the angular rotation of the mirror hubs, as a function of angular rotation per pulse count of the stepper motor, is also non-linear. The geometry of the hub, the length of the minor link, and the vertical displacement of the horizontal motion of the major link from the reflector axis of rotation, all contribute to producing this angularly-varying level of non-linearity. An optimisation process has been performed on the geometric design to ensure that the maximum resolution of the tracking system and mirror focus occurs during a tracking excursion which is oriented within ±70 degrees centred on a sector rotation incident in the plane, and symmetrically distributed about a perpendicular aligned to the length of the mirrors.

The effective tracking through 140 degrees of sun motion in the above-mentioned plane only requires half the angular excursion, amounting to 70 degrees of mirror rotation, given that each degree of sun rotation is shared between the angle of incidence and the angle of reflection about the local mirror normal. A lower level of tracking motion resolution is acceptable outside this central region, and is applied to a further 43 degrees of mirror angular rotation so that mirrors can be placed into a safe stow position where no sunlight can be reflected from the MCT enclosure, or onto the receiver. The speed of rotation is designed to increase through this second region of motion which benefits a STOW command made in the event of a system fault. The total angular range of motion for the mirrors is therefore 113 degrees about the normal to the plane of the mirror array.

2. CLOSED LOOP TRACKING FOR LATERAL FLUX UNIFORMITY

The unique capability of the reflector mountings to provide, and compensate for, torsional tolerance along the length of the reflector allows correction for twists inadvertently introduced during assembly and installation. The new reflector design also eliminates image instability arising from the differential expansion of composite mirror structures which is a common problem in conventional linear concentrators.

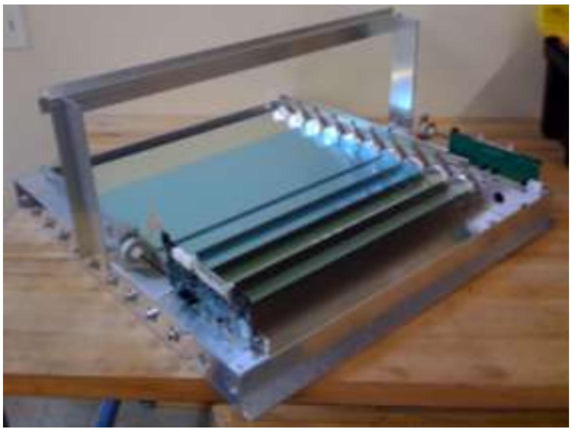

Figure 3: Prototype MCT test-rig system

Rather than employing ephemeris data, the MCT incorporates closed loop sensors located near each end of the receiver. This closed-loop feedback is used to independently track each end of the Fresnel reflectors based upon active assessment of the accuracy of the concentrator focal point. This tracking concept has been demonstrated to produce a uniform flux distribution along the length of the receiver. Longitudinal flux uniformity is critical for the series-connected cell strings that constitute the PV array in each receiver. Figure 3 illustrates a prototype MCT test-rig system, which includes production-standard optics and tracking control systems.

3 LATERAL FLUX UNIFORMITY

The receiver employs secondary 'winglet' optics, which smoothes the lateral light flux distribution across the cell, shown below in Figure 4, flattening the distribution from the typical Gaussian curve as is the case with conventional parabolic trough systems. The 'peak' of the flux profile is undesirable for its contribution to localised series resistance and localised cell heating. By avoiding these effects, cell efficiency is improved by approximately 0.5% absolute [IEEE].

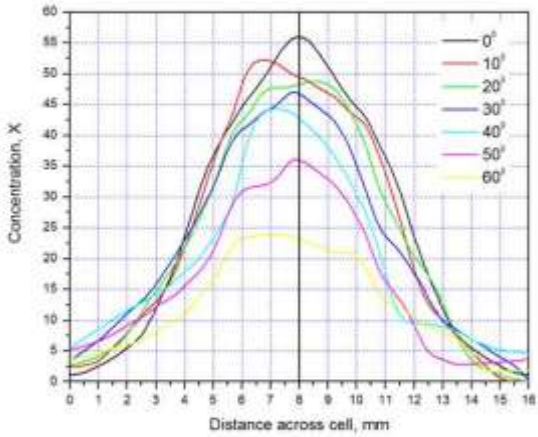

Figure 4a: The light flux distribution without side-wall reflectors

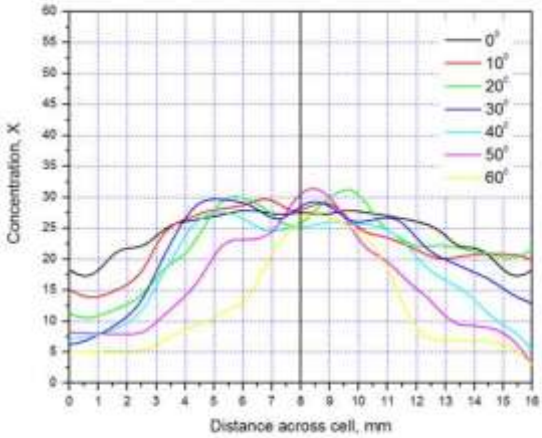

Figure 4b: The change in light flux distribution as a result of side-wall reflectors

An important observation is that 'spillage' of light that falls outside the cell in the distribution shown in Figure 4a is typically lost to the system, whereas some light outside the cell area in Figure 4b is captured and re-distributed by the secondary mirrors. This results in a significantly improved lateral flux distribution uniformity and increased light capture. The winglet arrangement also serves to increase the optical aperture of the receiver, further relaxing the demands on tracking precision.

The modeling used for determining the flux distribution does not use ray tracing for the simulation. Rather, the particular segments of the mirrors are analysed and the light reflecting onto the receiver aperture from each mirror segment is integrated and projected onto the receiver. This leads to a much more accurate total illumination estimate and a more accurate flux distribution model; all with fewer calculations.

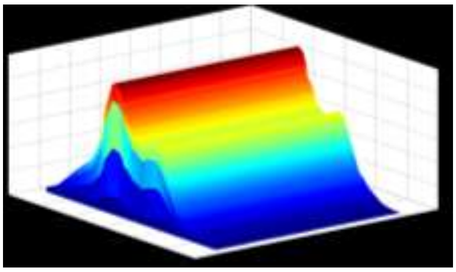

Figure 5: Modeled longitudinal light flux distribution incorporating side-wall reflectors; but using a non-optimised mirror array.

4 CONCLUSION

The unique implementation of the ANU-Chromasun Micro-concentrator has allowed for the use of an array of ultra light-weight, independently tensioned Fresnel reflectors. In conjunction with a low-cost secondary reflector system and a closed-loop tracking system, marked improvements in longitudinal and lateral flux distributions are expected. Future work will focus on optimising the mirror array to improve on-sun results.

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6 REFERENCES

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