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Prototype of dense-array concentrator photovoltaic system using non-imaging dish concentrators and cross compound parabolic concentrator

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Abstract

The paper presents a novel dense-array concentrator photovoltaic prototype system consisted of primary non-imaging dish concentrator and secondary concentrator (an array of crossed compound parabolic lenses). The secondary optics has a geometrical concentration ratio of 5.998 but the average measured concentration ratio is only 4.07 suns. The losses are mainly attributed to both the Fresnel reflection at the interfaces and absorption of the dielectric material. The preliminary measured power conversion efficiency of the system is 17% due to significant optical loss incurred by the secondary concentrator.

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Keywords: Non-imaging dish concentrator; concentrator photovoltaic; solar flux distribution; cross compound parabolic concentrator; solar power generation; power conversion efficiency

1. Introduction

Power conversion efficiency of multi-junction solar cell as high as 46% had given huge boosts to the development of concentrator photovoltaic (CPV) system [1]. The idea of replacing the solar cell material with cost-effective solar concentrator to focus solar energy to thousand folds on multi-junction solar cell can reduce the cost of solar electricity. Many different types of solar concentrator system had been develop in the past 30 to 40 years to achieve this target, but there is still more improvement can be done to the existing system for achieving a better outcome.

Recently, non-imaging focusing technologies have been widely deployed in the application of concentrator photovoltaic system and can be categorized based on the nature of sun-tracking methods: on-axis tracking design [2-12], and off-axis tracking design [13-23]. The merits of using non-imaging optics as primary concentrator with segmented mirror facets are many and we just mentioned a few points here. Firstly, the non-imaging optical device does not form perfect image but provides a great flexibility to

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form the focused image with different shape and dimension on the receiver. Secondly, the design of non-imaging solar concentrator consisted of multi-facets allow adjustment of the focal point and pattern of the focused spot so that the solar flux distribution profile can be tailored towards specific need. Thirdly, non-imaging optical device can form uniform illumination that is highly required by CPV system. Chong et al. invented a computer generated non-imaging dish concentrator (NIDC) that is constituted of many flat facet mirrors aimed to produce uniform focusing spot [4-5]. Dense-array CPV (DACPV) receiver is placed at the receiver to convert the concentrated sunlight to electricity. The assembling of DACPV module requires small gap among solar cells for interconnection both in parallel and series and thus there is significant physical area illuminated by the concentrated sunlight without active solar cell material. Furthermore, the present of build-in bus bars on the surface of CPV cell (about total of 1 mm in both sides of CPV cell) has further increased non-active area of the incident surface. As a result, it is impossible to achieve 100% packing factor. Packing factor of the DACPV module is defined as the ratio of usable active area of solar cells to the total illumination area on the incident surface. Low packing factor will affect overall power conversion efficiency of CPV system since those concentrated sunlight fallen on non-active area of the receiver will not be productive. A method to increase the percentage of incident rays that impinge on the active area of solar cells had been proposed by the introduction of a secondary concentrator. The solar cell is attached directly to the exit aperture of the secondary concentrator, which acts as optical funnel tailored to guide the concentrated sunlight from primary concentrator to solar cells. In addition, the introduction of secondary concentrator can provide more space for the interconnection among solar cells that allow more flexibility in the ways to connect solar cells in both series and parallel for minimizing the current mismatch in the circuitry of DACPV cells. Each CPV cell can also have individual by-pass diode for protecting the cell and improving the fill factor of the CPV system.

2. Methodology

A prototype of DACPV system has been set-up in the campus of Universiti Tunku Abdul Rahman, Malaysia as shown in Figure 1. The primary concentrator of DACPV system is a NIDC intending to produce uniform solar flux distribution across rectangular receiver. The NIDC is comprised of ninety-six identical flat facet mirrors acting as optical apertures to gather solar irradiance from the sun and to superimpose all the facet images at the focal plane to form a primary focused image. The geometrical configuration of the facet mirrors is determined using a newly developed computational algorithm, which is capable to eliminate blocking and shadowing effects among the adjacent facet mirrors [5-7,10-11]. It can be done by gradually increasing the height of facet mirrors located from the central to peripheral regions. Due to the gradually elevation of the facet mirrors from central region to outer ring of the concentrator, the final optical configuration of facet mirrors forms a reflective surface of dish contour.

The simulation was performed with only considering solar disc effect but slope error and circumsolar effect were omitted. Figure 2 depicts the simulated result of primary focused image cast by NIDC without pointing error, with pointing error of 0.3° counter-clockwise rotation about Y-axis, with pointing error of 0.3° counter-clockwise rotation about X-axis, with pointing error of 0.3° counter-clockwise rotation about both X-axis and Y-axis. The simulated solar flux distribution is consisted of flat top region with maximum concentration ratio of 88 suns located in the central region covering the area of 18.2 cm × 18.2 cm and surrounded by steep decrease from 88 suns to 0 within 2 cm near the edge to form a total primary focused image size of 22.6 cm × 22.6 cm. The percentage of energy within the uniform illumination area is 79%. With such uniformity, it can minimize current mismatch problem that has made it suitable for DACPV application.