Indoor Characterisation of a Reverse Truncated Pyramid Concentrator

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***Abstract*—The development of concentrating photovoltaic (PV) started in 1960s and over the years, a variety of concentrator designs have been explored. One of its applications is for use in building integrated photovoltaic (BIPV) with the aim of producing a cheaper alternative to a traditional PV panel. This paper presents the experimental characterization of a low concentrating photovoltaic (LCPV) unit that utilizes a reverse truncated pyramid (RTP) concentrator design. The RTP has a geometrical gain of 3.61 and a total height of 40 mm. The result from indoor characterization shows that the RTP-PV device could achieve an opto-electronic gain of 3.0 with a measured half-acceptance angle of ±23.8°. The RTP-PV can be used as a suitable alternative to traditional solar PV panels.**

Keywords—photovoltaic, reverse truncated pyramid, indoor characterization.

I. Introduction

Solar photovoltaic (PV) application to buildings in urban settlements began long ago, far back as 1970s and has since then, remained a viable research space especially in this era of modern energy-harvesting technology for buildings [1]. This application transforms the energy-efficient buildings from consumers of energy into producers of energy, and the technologies which enhance the integration of solar PV into the building structure are called building applied photovoltaic (BAPV) and building integrated photovoltaic (BIPV). In BAPV application, the PV materials do not replace any part of the building but are mounted on the roofs or facades while in the BIPV system, the PV materials directly replace parts of the conventional building structure like the facades, windows and roofs [2].

The challenge with BAPV and BIPV is the perceived high cost of installation which has made their wide adoption difficult hence, domiciled in urban settings [3]. Primarily, the high installation cost of the solar PV modules has been attributed mainly to the material cost according to some researchers [4]. To remove the cost equation from the costly BIPV materials, researchers have proposed the inclusion of a cheap solar concentrator to the PV module in order to improve its performance and reduce the volume of PV materials. This technology of introducing an optical or solar concentrator into the PV module or cell is called concentrated photovoltaic (CPV) [5].

The CPV is an optical device which redirects incident sunlight from a wider entrance aperture and reflects it to a smaller exit aperture where a solar cell is attached. This increases light intensity and illumination on the solar cell and in turn, increasing its electrical output. The integration of the CPV modules into buildings is known as building integrated concentrating photovoltaic (BICPV) technology. This is more economical, cost effective, more flexible, more efficient and easier to maintain when compared to BAPV and BIPV systems but yet to compete commercially [6].

This paper presents the experimental characterization of a low concentrating photovoltaic (LCPV) unit that utilizes a reverse truncated pyramid (RTP) concentrator design. The indoor characterization evaluates the RTP-PV electrical characteristics and its angular response.

II. RTP Concentrator

Fig. 1 shows the RTP-PV device. It consists of a truncated reversed pyramid concentrator made from BK7 glass, a triple junction solar cell and a bypass diode. The physical dimensions of the RTP concentrator are presented in Table 1.

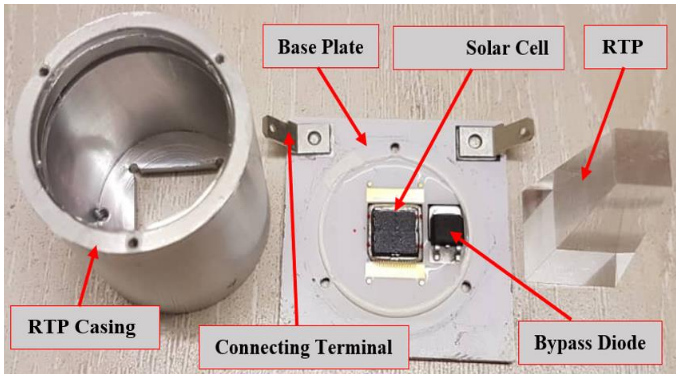

Fig. 1. Components of CPV.

TABLE 1. Parameters of the RTP Concentrator

Parameter	Value	Unit
Concentrator height	40	mm
Entrance aperture length	19	mm
Exit aperture length	10	mm
Entrance aperture Area	361	mm^2
Exit aperture Area	100	mm^2
Geometrical concentration ratio	3.61	

III. Experimetal Setup

The experiments were conducted indoors in Glasgow Caledonian University's laboratory facility. The experimental setup is presented in Fig. 2. It includes an Oriel Sol3A™ Class AAA solar simulator (model 94083A) from Newport Corporation, which provided the needed illumination for the indoor experiments, with an irradiance of 1000 W/m^2. A source meter, 2440 5 A from Keithley Instruments was connected to a computer containing the software package LabTracer 2.0. A reference PV cell with a thermocouple was provided which was used to set the irradiance at standard test conditions (STCs) and measure the room temperature. The solar simulator can be tuned to produce various irradiance levels. A platform for changing the angle of incident of the solar concentrator was also provided called variable slope base. The angular slope of the concentrator is measured with a digital level meter calibrated in degrees.

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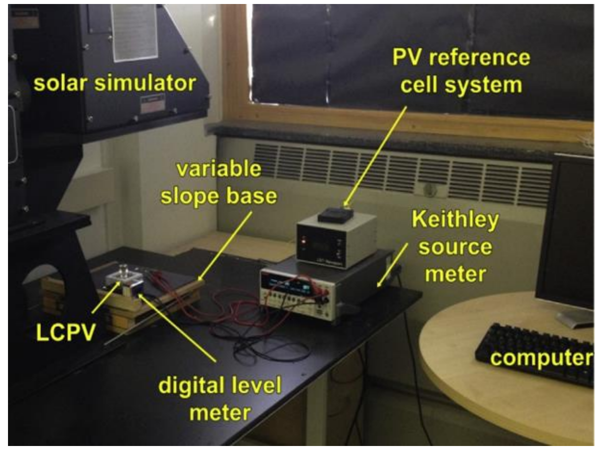

Fig. 2. Indoor experimental setup for RTP-PV characterization.

IV. Results and Discussions

A. Current-voltage (I-V) and power-voltage (P-V) characteristics

The current-voltage (I-V) and power-voltage (P-V) characteristics of the RTP-PV device and the non-concentrating PV cell is shown in Fig. 3. The results show that RTP increased the short-circuit current (Isc) of the bare cell from 13.05 mA to 40.6 mA, the open-circuit voltage (Voc) from 2.6 V to 2.7 V, the maximum power output from 29.3 mW to 95.85 mW, and the fill-factor from 0.864 to 0.874 at STCs. This gives a power gain of about 3.3, indicating an improved performance.

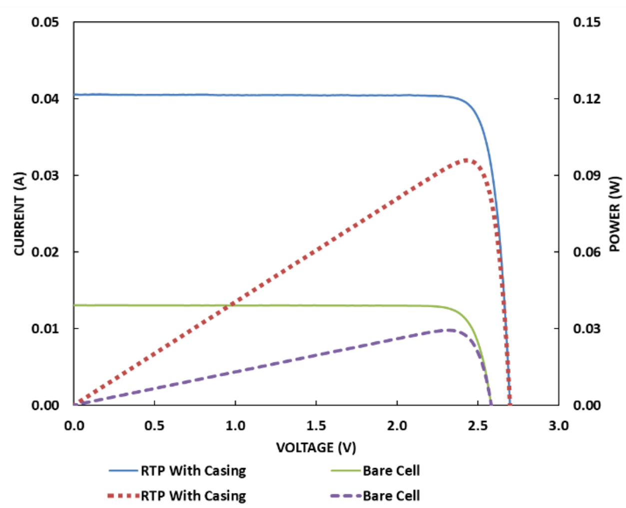

Fig. 3. The current-voltage (I-V) (in solid lines) and power-voltage (P-V) (in dotted lines) characteristics of the RTP-PV device and the non-concentrating PV cell at STCs.

B. Variations in irradiance

The response of the RTP was tested at different flux values as shown in Fig. 4. The results show that as the irradiance was increased steadily, the maximum power increased accordingly. This is typical of solar PV cells [4].

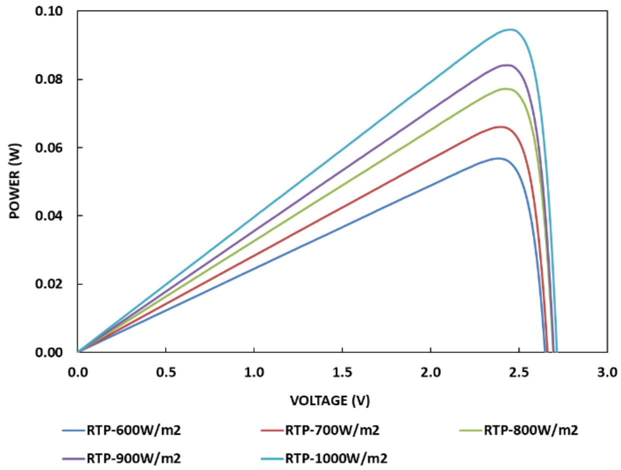

Fig. 4. The maximum power output of the RTP-PV at various irradiances.

C. *Angular response of the RTP-PV device*

Fig. 5 gives the result of the angular response of the RTP-PV concentrator. It shows that the RTP can increase the electrical output by a factor of about 3.0 when compared to the non-concentrating cell. Also, from the angular performance of the CTRP, it shows that the half-acceptance angle is ±23.8°.

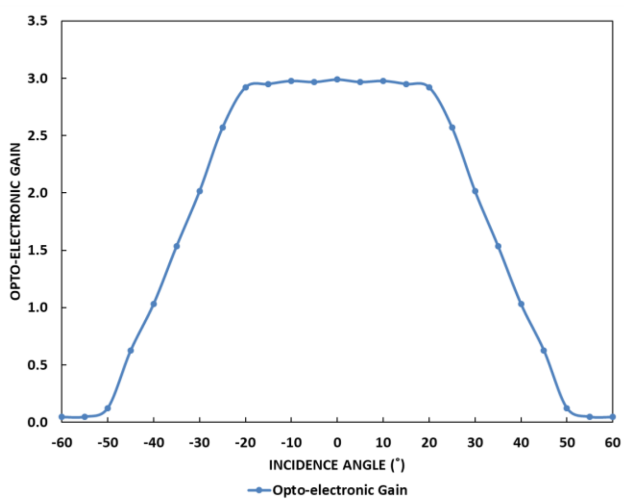

Fig. 5. The angular response of the RTP-PV device.

V. CONCLUSIONS

The characterization of an LCPV that employs an RTP concentrator was carried out. The RTP concentrator, which has a geometrical concentration ratio of 3.61x, was investigated. It was found that the device could achieve an opto-electronic gain of 3.0 and has a measured half-acceptance angle of ±23.8°. The RTP-PV can be used as an alternative to a traditional solar PV panel. The next step would be to study create a small solar window incorporating these RTP concentrators, integrate the CPV window into a building structure, and test its electrical performance.

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