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Performance analysis of a solar window incorporating a novel rotationally asymmetrical concentrator

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A B S T R A C T

The race towards achieving a sustainable zero carbon building has spurred the introduction of many new technologies, including the BIPV (building integrated photovoltaic) system. To tackle the high capital cost of BIPV systems, LCPV (low-concentration photovoltaic) technology was developed. Besides the reduction of cost, the LCPV technology also produces clean energy for the building and promotes innovative architectural design. This paper presents a novel type of concentrator for BIPV systems. This concentrator, known as the RADTIRC (*rotationally asymmetrical dielectric totally internally reflecting concentrator*), was incorporated in a small double glazing window. The RADTIRC has a geometrical concentration ratio of 4.9069x. A series of experiments were carried out to evaluate the performance of the solar PV window both indoors and outdoors. It was found that the RADTIRC-PV window increases the short circuit current by 4.13x when compared with a non-concentrating solar PV window. In terms of maximum power generation, the RADTIRC-PV window generates 0.749 W at normal incidence, 4.8x higher than the non-concentrating counterpart.

1. Introduction

Solar PV (photovoltaic) – a technology that converts solar energy directly into electricity – has the capability to meet the global energy needs. The 2014 report [1] published by the IEA (International Energy Agency) emphasises that this technology will possibly be the “dominant power source by 2050”. Governments and private sectors have invested a huge amount of money on solar PV technology [2]. In 2014 alone, solar technology attracted approximately USD150 billion[1] (GBP94.5 billion)[2] worth of investment [2] for funding technology research, development, commercialisation, manufacturing and new projects. To further accelerate the uptake of solar PV, several governments have introduced a number of measures. One of the most effective ones is identified to be the feed-in tariff (FiT) scheme [3–7]. An FiT scheme pays a consumer a specific tariff per kWh of electricity generated from

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[1] 1 billion is equivalent to 1 thousand million, i.e. 10^9.
[2] Based on the conversion rate carried out on 10/11/2014, USD1.00 is equivalent to GBP0.63 [34]. This value is used throughout this paper.

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solar PV technology for a duration of time [8]. The FiT scheme has now been implemented in more than 80 countries [2]. The investment and policies have had a positive effect on solar PV installations worldwide, which propelled the cumulative installed capacity to reach 177 GW by the end of 2014 [2]. From this figure, approximately 49% of these installations were carried out in Europe (see Fig. 1) [2]. It is reported that solar PV was considered as the fastest growing renewable technology in 2014 [2], with an average annual growth rate recorded at 30% when compared with the growth in 2013 [2]. To date, solar PV technology has created approximately 2.5 million jobs around the globe [2].

Despite the rapid growth in terms of installed capacity, solar PV only supplied around 1% of the world's electricity requirement in 2014 [9]. One of the reasons is the high capital cost of installing a solar PV system, which ranges between USD1200 (GBP756) and USD24000 (GBP15120) per kWp according to the recent data from the IEA [10]. The largest proportion of the cost is from the PV module (around 40%) [10], and the PV material contributes up to 73% of the module cost [11], i.e. 29.2% of the overall installation cost. By reducing the usage of PV material in a PV module, it is possible to achieve a cheaper PV system which could further attract more consumers in opting for and installing this technology.

One of the solutions suggested by several researchers to reduce the cost of a solar PV module is to incorporate an optical concentrator into the solar PV design [12]. A concentrator works by focusing the solar radiation incident on a wide entrance aperture area to a smaller exit aperture area to which a solar PV cell is attached [12]. The corresponding increase in irradiance can be used to offset the displacement of expensive PV material while maintaining the desired level of electrical output, as the concentrator can be fabricated using inexpensive materials such as plastic [12]. The PV technology that includes a low gain concentrator (gains < 10x) in the design is known as LCPV (low-concentration photovoltaics).

Researchers have proposed various designs of LCPV in the past 40 years. Pei et al. [13] demonstrated that a dielectric CPC (Compound Parabolic Concentrator) extrusion in an LCPV design was capable of increasing the electrical power by 73% when compared with a bare solar PV cell. Another study conducted by Goodman et al. [14] showed that a rotationally symmetrical dielectric CPC design increased the short circuit current of the LCPV system by a factor of 5.7x when compared with a similar non-concentrating PV cell. Muhammad-Sukki et al. [15] simulated the performance of an extrusion of a DTIRC (dielectric totally internally reflecting concentrator) and concluded that the design could boost the electrical output by nearly 5 times when compared with a non-concentrating system. From their analysis, their LCPV design could reduce the cost by 41% [16]. On the other hand, Sarmah et al. [17] showed that an LCPV design employing a dielectric extrusion of asymmetrical CPC generated 2.27 times more electrical power when compared with a system without a concentrator. Their LCPV design could bring the solar panel cost down by 20% per kWp [17]. Abu-Bakar et al. [18] proposed an LCPV system based on a rotationally asymmetrical CPC which could potentially increase the short circuit current by as much as 6.18 times than the non-concentrating counterpart.

This paper evaluates an LCPV design incorporating a novel concentrator known as the RADTIRC (rotationally asymmetrical dielectric totally internally reflecting concentrator). The authors have recently investigated a new RADTIRC prototype which was created from the PMMA (polymethyl methacrylate acrylic) material by using an injection moulding method and its performance was compared with the old prototype that was created from an acrylic type material known as ‘6091’ by using a silicon moulding technique [19]. The study [19] concluded that the injection moulding technique enables the prototype to achieve a much closer dimension to the desired design than one created from silicon mould, with an area deviation of 0.8%. In terms of the selection of material, the concentrator created from PMMA material provides a much better performance than the ‘6091’ material, an increase of 13.57% in terms of the short circuit current generated at normal incidence [19].

This paper aims to demonstrate that an LCPV system could be created (in this case a small solar PV window) by incorporating an array of 12 new RADTIRCs for use in building integration and at the same time could provide substantial electrical output when compared to a similar non-concentrating PV window. The electricity generated can be utilised in the building, stored in a battery

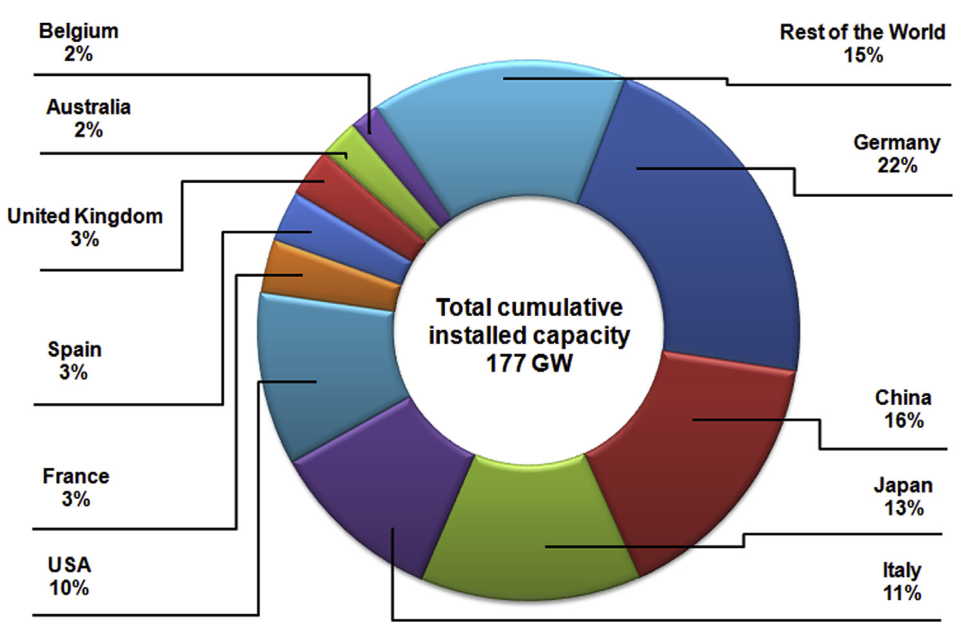

Fig. 1. Cumulative PV installed capacity in 2014. Adapted from Refs. [2,9].