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Determination of the current–voltage characteristics of concentrator systems by using different adapted conventional techniques

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ABSTRACT

The modelling of the current–voltage characteristics of HCPV (high concentrator photovoltaic) modules is fundamental for the design, monitoring and energy prediction of HCPV systems and power plants. However, the modelling of these devices is inherently different and more complex than that of conventional PV (photovoltaic) modules. Because of this, considerable efforts have been done to develop models tailored to the specific features of this technology. However, there is still a lack of studies and techniques concerning the modelling of the whole I–V curve of HCPV modules. In the present work, the possibility of obtaining the I–V curve of a HCPV module by applying common methods exploited in conventional PV technology by using the effective irradiance and cell temperature is analysed. In particular, the studied methods are: the single exponential model, the Blasser's method and the bilinear interpolation method. Every method has been adapted to be entirely function of the effective irradiance and cell temperature of the concentrator. Results show that all the methods present a good performance in the estimation of the I–V curve of a concentrator, with an average RMSE (root mean square error) ranging from 1.15% to 5.23%, and an average MBE (mean bias error) close to 0%.

1. Introduction

Nowadays, the most industrialized HCPV (high concentrator photovoltaic) module is based on monolithic lattice-matched III-V triple-junction solar cells, Fresnel lenses which concentrate the sunlight onto the solar cells surface, secondary optical elements which homogenize the light and improve the acceptance angle, and passive cooling to ensure that solar cells operate on their optimal operation range [1]. The use of optical devices and high efficiency MJ (multi-junction) solar cells allows reaching high efficiencies and reducing the amount of semiconductor material [2]. Furthermore, the efficiencies of MJ solar cells, HCPV modules and systems are expected to grow around 10% within next decade [3]. Hence, HCPV technology could be able to produce more cost-effective electricity than conventional PV (photovoltaic) technology at locations with high annual irradiation levels [4].

The electrical modelling of HCPV modules is fundamental for the design, monitoring and energy prediction concerns of these kinds of systems [5,6]. At the same time, the modelling of concentrator modules is inherently different and more complex than that of conventional PV modules. First, the use of MJ solar cells and optical elements makes the performance of these devices more sensible and complex under incident spectral variations [7,8]. Second, the electrical parameters and temperature dependencies of concentrator solar cells are significantly affected by the amount of concentrated sunlight [9,10]. Finally, the direct measurement of the cell temperature of HCPV modules is usually not possible because cells are surrounded by different peripheral elements. Because of this, different methods for indirectly estimating the cell temperature of a HCPV module have been recently proposed and discussed: methods based on direct measurements on the concentrator (electrical parameters and back surface temperature) and methods based on atmospheric parameters (air temperature, direct normal irradiance and wind speed) [11]. Taking this into account, the scientific community has devoted considerable efforts in developing

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specific models that try to quantify the phenomena commented above with different levels of complexity and accuracy, for instance [12–18]. However, these models are mainly focused on the estimation of the maximum power since it discloses the energy yield of a HCPV system, and there is a lack of studies and techniques concerning the modelling of the whole current–voltage curve of HCPV modules or systems [19].

The simulation of the whole I–V curve of a HCPV module at any desired condition is appropriate since it allows other crucial parameters such as short-circuit current, open-circuit voltage, maximum power current or voltage to be known. Moreover, it allows the association in series and/or in parallel of modules in a generator to be done, which is crucial to estimate the current–voltage characteristics of the whole system at any desired point. This is basic for detailed analysis such as the design of the electrical requirements and protections of a system or power plant, the choosing and sizing of the inverter in a grid-connected system, and also because the generator operates in different regions of its I–V curve depending on the regulation and control devices used in each installation. In addition, in an off-grid system, the battery voltage or charge regulator determines the operating point of the generator. Hence, the complete I–V curve is fundamental since the generator works in different points on its I–V curve [20–22].

An interesting approach to the modelling of HCPV devices has been previously pointed out by the authors in [23,24]. This concept is based on the idea that the electrical characteristics of a HCPV module or system can be estimated from the effective irradiance and cell temperature of the concentrator. The advantage of this method is that the amount and spectral distribution of the irradiance are quantified by only adjusting the direct normal irradiance. So that, it would allow widely known techniques for the electrical characterization of conventional PV devices to be applied. This concept has been already experimentally analysed and proved to be valid by the authors in [25]. In that prior work, an ANN (artificial neural network)-based model, previously introduced for the modelling of c-Si and thin-film photovoltaic modules [26,27], was used to simulate the I–V curve of a HCPV module by using the effective irradiance and cell temperature as input parameters. Despite the good results found, this previous work has the possible disadvantage that advanced knowledges of complex mathematical modelling techniques are required. This paper goes deep on the same approach and evaluates the possibility of obtaining the whole current–voltage characteristics of a HCPV module by using different conventional techniques based on simple analytical relationships. In particular, three commonly used methods to simulate the I–V curve of conventional PV devices are analysed: the SEM (single exponential model), the Blasser's method and the bilinear interpolation method. Every method is here adapted to be entirely function of the effective irradiance and cell temperature of the concentrator. It is also worthy to mention that a new procedure for extracting the parameters of the Shockley's equation of the SEM model, and a set of new mathematical relationships to express their dependencies with irradiance and temperature, are introduced. This offers new valuable information that contributes to the discussion of the fundamental dependencies of the parameters of concentrator MJ solar cells with light intensity and temperature [28]. Furthermore, the procedures used to predict the effective irradiance and cell temperature of the concentrator are fully based on meteorological data. The aim is to allow the application of the methods here discussed for long-term analysis at remote sites, since the methods based on measurements on the concentrator and/or specific instruments (spectroradiometers, isotype solar cells, etc.) are more appropriate for short-term field performance analysis, as discussed in [11,18].

2. Experimental procedure

To carry out this study, a HCPV module was under study for six months (July to December 2013) at the Centro de Estudios Avanzados en Energía y Medio Ambiente (CEAEMA) at the University of Jaen in Southern Spain (N 37°27′36″, W 03°28′12″), Fig. 1 (left). Jaen has a high direct annual irradiation level of more than 2000 kWh/m^2, and air temperatures that can easily reach 40 °C in summer and 5 °C in winter. Hence, this location represents an excellent place for the outdoor evaluation of concentrator systems. The module is made up of 20 triple-junction lattice-matched GaInP/GaInAs/Ge solar cells interconnected in series. The POE (primary optical elements) consist of SOG (silicon-on-glass) Fresnel lenses, and the SOE (secondary optical elements) consist of reflective truncated pyramids made up of an aluminium film layer to increase the reflectivity. The module has an optical efficiency of 80%, a geometric concentration of 700 and uses passive cooling to keep solar cells temperature on an adequate operation range (50–80 °C). Table 1 shows the main electrical parameters of the HCPV module under

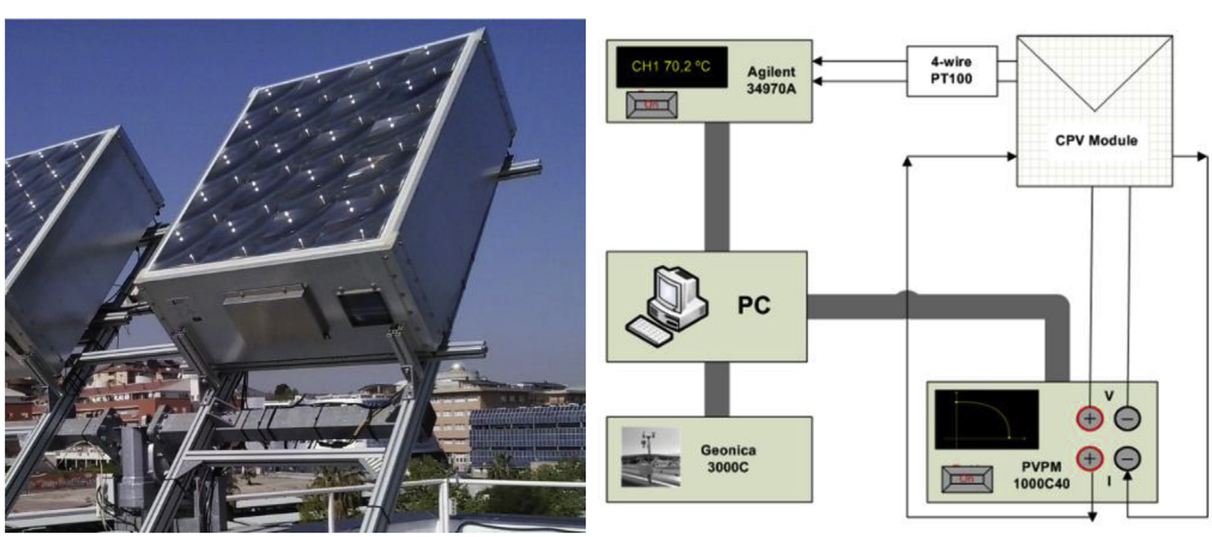

Fig. 1. Left: photograph of the HCPV module considered in this study. Right: scheme of the experimental set-up to measure the I–V characteristics of the HCPV module and the main atmospheric parameters.