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A model based on artificial neuronal network for the prediction of the maximum power of a low concentration photovoltaic module for building integration

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Abstract

Low concentration photovoltaic (LCPV) modules for building integration are considered to have great potential because it offers several advantages over conventional photovoltaic technology. However, one of the problems of this technology is that as yet there are no models in the literature to directly calculate the maximum power of these kinds of systems. The development of models is an important task to promote the application of this technology because it allows the prediction of the energy yield. In this paper a model based on artificial neural networks has been developed to address this important issue. The model takes into account all the main important parameters that influence the electrical output of these kinds of systems: direct irradiance, diffuse irradiance, module temperature and the transverse and longitudinal incidence angles. The results show that the proposed model can be used for estimating the maximum power of a LCPV module for building integration with an adequate margin of error.

Keywords: Low concentrator photovoltaics; Building integration; Artificial neural networks; Maximum power prediction

1. Introduction

In recent decades there has been an increase in interest in renewable energies to reduce global warming. In this scenario, photovoltaic (PV) energy has emerged as a promising source of green energy that will play an important role in the energy generation market. However, substantial efforts are needed in terms of cost reduction in order to promote its market expansion (Razykov et al., 2011) specific to the building fenestration use. Concentration photovoltaic (CPV) systems are considered one of the most promising solutions to achieve this goal by the use of cheap optical devices to concentrate the light on a smaller solar cell (Luque et al., 2006).

The CPV systems are usually classified according to their concentration ratio as: low, medium and high (Pérez-Higueras et al., 2011). While high and medium concentration PV systems are more suitable for large scale implementations such as power plants, the use of low concentration photovoltaic (LCPV) systems is found to be suitable for stand alone systems and building integration. There are several concentrator designs for LCPV systems that have been proposed for different applications (Koltz, 1995; Maiti et al., 2012; Guiqiang et al., 2013). The LCPV systems can work either with only seasonal tracking or can function without any tracking requirements at all. Low concentrating systems have been identified by researchers

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Nomenclature

A	aperture area
θ	incidence angle
θ_T	transverse incidence angle
θ_L	longitudinal incidence angle
G_{diff}	diffuse irradiance
G_d	direct irradiance
L	path length of the light (irradiance) inside LCPV system before reaching the solar cell
n	refractive indexes of the optical materials
MBE	Mean Bias Error
MSE	Mean Square Error
P	maximum power
R^2	correlation coefficient
RMSE	Root Mean Square Error
T	module temperature
τ_r	reflective component of unpolarised light transmission
W	artificial neural network weight
η	efficiency

Terminology

ANN	artificial neural network
BICPV	building integrated concentration photovoltaic
CPV	concentration photovoltaic
DiACPC	dielectric asymmetric compound parabolic concentrator
LCPV	low concentration photovoltaic
LM	levenberg–marquardt back-propagation algorithm
PV	photovoltaic

as one of the options with most potential for building integration because it offers several advantages over conventional PV (Chemisana, 2011). This has led several researchers to design different building integrated concentration photovoltaic (BICPV) modules for maximum utilization of the potential of this technology (Bowden et al., 1993; Mallick et al., 2004; Gajbert et al., 2007; Mallick and Eames, 2007; Sellami and Mallick, 2013; Muhammad-Sukki et al., 2014). The common feature of the designs has been found to be the wide range of acceptance angle to be used as a stationary concentrator while integrated on a building façade or roof. The research trend shows that asymmetric designs of the concentrator are most suitable for LCPV modules for building integration. In recent times, the LCPV concentrator made of dielectric material has attracted the attention of the researchers, as it offers a wider range of acceptance angle and a higher concentration ratio compared to the reflective counterpart. It has been observed that the performance of stationary low concentration systems largely depends on the sun angle, module temperature and the ability to collect direct and diffuse irradiance. For stationary concentrators, the position of the sun is important as it determines the incidence angle of the solar radiation on the LCPV system. The solar incidence angle can be represented by transverse and longitudinal components (Nilsson et al., 2006), which is defined by the projection of the incidence angle on the vertical surface and horizontal surface respectively. Both the components of the incidence angle vary with the diurnal and seasonal variation of sun position and need to be treated differently. Variations in incidence angles can cause optical losses because of the range of angular acceptance of the concentrator and due to the partial reflection from the cover plate in the system. The wide range of acceptance angles of low concentrating devices enables the system to collect both direct and a large portion of diffuse irradiance. However the amount of collection of diffuse irradiance differs from the direct irradiance, so needs to be treated differently (Sarmah et al., 2011). The other parameter affecting the LCPV system is the module (or cell) temperature. It is well known that the increase in temperature of the module reduces the overall power output of the system (Green, 1982).

In spite of the work on several LCPV system designs and developments, no long term performance analysis or energy output prediction from this kind of system has been reported. As in any type of energy production system it is important to know the performance of the system in terms of energy. The development of tools to predict the energy of these kinds of systems is a key issue to promote their application. However, there is a lack of models or tools to predict the electrical output under the real operating conditions of LCPV systems. Although some models for the electrical characterization of low concentrator photovoltaic modules have been reported (Nilsson et al., 2006; Reis et al., 2010; Zahedi, 2011; Yadav et al., 2013), there are no models in the literature that allow the direct calculation of the maximum power of a BICPV module under real conditions and which take into account all the parameters which influence its electrical performance: direct irradiance, diffuse irradiance, module temperature and the transverse and longitudinal incidence angles.

Therefore, this paper aims to develop a model to accurately predict the maximum power of a LCPV module for building integration under real operating conditions. Due to the fact that artificial neural networks have proven to be very efficient in solving complex problems, a new model based on artificial neural networks (ANNs) to estimate the maximum power of a LCPV module for building integration, function of the direct irradiance, diffuse irradiance, module temperature and the transverse and longitudinal incidence angles, has been developed.

The paper is organized as follows. Section 2 describes the experimental set-up to carry out this study. In Section 3