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Outdoor performance of bifacial modules by measurements and modelling

Gaby J.M. Janssen*, Bas B. Van Aken, Anna J. Carr, Agnes A. Mewe

ECN Solar Energ,y P.O.Box 1, 1755 ZG Petten, the Netherlands

Abstract

We present the outline of a model that calculates the outdoor performance of a bifacial module including optical, electrical and thermal aspects. The *IV* curve for the total module power output is obtained by scaling or weighting the 2-diode parameters of front and rear standard test conditions (STC) module *IV* curves with the calculated front and rear irradiance. Validation and verification of the electrical model are given through simulations and measurements. Annual yield gain predictions based on measured characteristics of bifacial modules are presented and discussed for vertical, east-west bifacial modules relative to south-facing tilted monofacial modules. For a module with a bifaciality factor of 92% in a location like Amsterdam, this predicted annual yield gain is in the order of 10% at albedo 0.2 and 30% at albedo 0.5.

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1. Introduction

Bifacial PV modules and systems have the clear potential to surpass monofacial ones as there are many locations and conditions where the total amount of light on both sides of a module exceeds that of a south-facing (or north-facing in the southern hemisphere) monofacial module with optimum tilt angle. Replacement of a conventional free standing glass-backsheet module by a glass-glass module with bifacial cells can already result in 20% annual energy gain, depending on the albedo [1]. Recent studies by Yusufoglu indicated the energy gain can be further enhanced by

* Corresponding author. Tel.: +31 88 515 4803; fax: +31 88 515 8214
E-mail address: janssen@ecn.nl

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optimising the tilt angle and elevation of the module to minimise self-shading and maximise the capture of diffuse light [2]. A special case are vertically mounted modules facing east-west which produce most of their energy in the morning and the afternoon. A recent paper by Gou et al. showed that at locations with a large diffuse fraction of light or a high albedo, like most locations at latitudes > 45^o and desert areas, such modules receive more irradiation than conventional monofacial modules oriented versus the equator [1].

The development of solar cells based on n-type silicon substrates favours bifaciality since a metallisation grid can be applied at the rear instead of a full area aluminum back surface field/metallisation. Examples of such cells are the n-Pasha cell [3] developed at ECN (commercialised under the brand name PANDA by Yingli) and the BiSoN cells of ISC Konstanz [4]. Bifacial cells with a p-type substrate are also under development at ECN, as well as at Fraunhofer ISE (BOSCO concept) [5]. The bifacial concept is equally feasible for heterojunction cells, and even back contacted cells like metal wrap-through and interdigitated back-contact can be designed as bifacial cells [6-9].

Whether higher total irradiance levels can be translated into higher annual yield depends on the electrical and optical characteristics of the module. For bifacial modules a set of well-defined, widely adopted parameters that characterises the bifacial performance of a module is not yet available. Singh et al. proposed new characteristic STC parameters for bifacial cells based on measurement with illumination at front or rear with a dark back sheet [10]. At ECN a model is under development that aims to correlate data from STC measurements on bifacial modules to outdoor data. The outdoor performance of bifacial modules is measured for mini-modules and full-size modules. Irradiation of both planes of the module is measured separately, and orientation and albedo can be varied [11].

A model that correctly predicts the module performance using STC characteristics and outdoors irradiation and climate data is the basis of a reliable prediction of the annual energy production of PV systems with bifacial modules. Modelling of bifacial modules and systems is not yet as well-developed as for monofacial systems, for which well-tested and verified simulation tools like the PVSyst package [12] are available. In addition to changes in the electrical model required by simultaneous front and rear illumination, modifications are needed of the optical and thermal models for bifacial modules. Here, the outline of a comprehensive bifacial model is given. First validation results are presented as well as a comparison with a more simplified analysis using irradiance data only.

2. Bifacial model

A schematic of the bifacial model to calculate the DC output of a module is shown in Fig. 1. Only the meteorological data is the same as for monofacial modelling, all other parts are influenced by the bifacial irradiance and have to be adapted to that. The present model focusses on the DC output of the module, without effects of shading caused by the surroundings. Inverter specifications and system layout determine final AC energy yield.

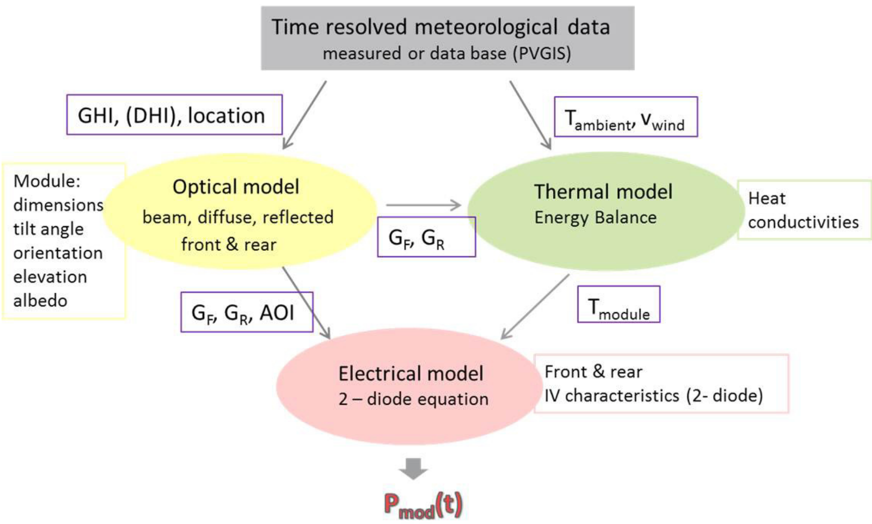

Fig.1 Schematic of the model to calculate the DC output of a bifacial module. Abbreviations and parameters are introduced in the text.