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New integrated simulation tool for the optimum design of bifacial solar panel with reflectors on a specific site

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ABSTRACT

The use of a commonly available planar reflector such as a plane mirror can boost the energy output of a bifacial solar panel effectively without increasing much in the overall cost. However, the actual energy yield from the solar panel in this case is dependent on the light reflected from the reflector and surrounding objects to the rear surfaces of the solar cells. The design of the bifacial solar panel with the reflector has to be optimized in order to achieve the maximum yield on a specific site setup. Therefore, a new simulation tool consisting of several open-source software packages with the bifacial solar cell model is developed to predict the yearly yield of the bifacial solar panel with the reflector accurately. The simulation tool includes the effects of the temperature changes in solar cells and the variation in solar irradiance incident on both front and rear sides at different time in a day, the manufacturing mismatch of the solar cells, and also the reflected light from the nearby objects. The simulation tool is verified experimentally and used to determine the optimum design of a site-specified bifacial solar panel that can achieve the maximum increase of 26% in yearly yield.

1. Introduction

A bifacial solar panel can utilize both surfaces to convert sunlight into electrical energy. A simple planar reflector such as mirror had been used to boost its output by reflecting sunlight to its rear surface [1–3]. A simulation method for the bifacial solar cells with such a reflector had been reported. The optical simulation of bifacial solar cells had been done using a three dimensional Monte Carlo ray tracer with the photo-generated current output simulated by a commercial TCAD software [1]. This approach calculates the surface reflections of the solar cells accurately and predicts the photo-generated current for different types of reflectors. However, it does not take into account of the effect of installation location and environment on the performance of the bifacial solar cells. Besides, performance drop due to manufacturing mismatch and variation in reflected sunlight intensity on the solar cells from time to time is not included in the simulation too.

Performance of the bifacial solar panel with a reflector is heavily dependent on the amount of reflected light from the nearby objects on the site and the design of solar panel, or more specifically, the spacing of solar cells in the panel and the distance from the reflector. This is because the amount of sunlight reflected from the reflector to the rear surface of the panel is dependent on the sunlight direction and intensity, which is varying from time to time and dependent on the installation location. The rear surface of the bifacial solar cell can be shaded by the same solar cell or the solar cells nearby and the effect of shading is dependent on the design of solar panel. Moreover, large objects in the installation environment, such as the buildings nearby may reflect sunlight to the solar panel at a certain period of time but block the sunlight from reaching the panel at another period of time. Therefore, an accurate simulation model for the bifacial solar panel that takes into account of all the above-mentioned factors is required to simulate the output of the solar panel and predict its yearly yield accurately, so that the solar panel design can be optimized based on its yearly yield.

The solution of optimum spacing in the solar panel and distance from the reflector on a specific location that output the highest yearly yield cannot be found easily using indoor experimental approach, such as the method used in Ref. [4], since the different

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atmospheric attenuation and solar incident angle on different days cannot be reproduced easily using solar simulator. Outdoor experimental approach, on the other hand, can provide more reasonable answer but it requires a very long measurement period with numerous different solar panel setups with different spacing and distances being measured at the same time. Comparing outdoor measurement results at different times is not appropriate because the results are affected by different solar incident angles on different days. However, simulation results from a more accurate simulation model can be used as the initial value for in the outdoor experiments in order to reduce the number of solar panel setups.

A new and accurate simulation tool is therefore developed using open-source software packages, namely SMARTS [5,6], Radiance [7] and PC1D programs [8,9]. The SMARTS program is to simulate the solar irradiance on a specifically geographical location taking into account the local climate. The function of Radiance program is to simulate the reflected light from the surrounding subjects that will be received by the front and rear surfaces of the bifacial solar cells at a specific solar panel design. The PC1D programme is used to simulate the yield based on the light irradiance received by both sides of all the bifacial solar cells. Additional scripts are developed to be the interface with each program in order to facilitate the flow of input and output data between the programs as well as calculate the yield of the simulated solar panel. These three software packages are integrated to become a useful simulation tool that is able to simulate the performance of the bifacial solar panel at a particular installation location taking into account the factors mentioned above. A heat transfer model for the bifacial solar cells is developed and integrated with the software packages such that the simulation tool can determine the performance of the solar cells taking into account of the solar cell temperature.

By combining the capabilities of several software packages, it is possible to assess the solar panel outdoor performance in more details with high accuracy. Due to the complexity and a vast amount of uncertainties in the physical phenomena that happens in the real world at outdoor, exact quantitative results that can match with the outdoor measurement ones precisely is still unlikely to get from the simulation tool. However, the results can be much more useful than any rough estimate for the performance assessment of the solar panel design that heavily depends on the outdoor environment and the actual sunlight. In addition, the intermediate outputs generated from the open-source software packages can be used to analyse the performance of the solar cells in more details. Also, this simulation tool can be constantly upgraded and improved if the capabilities of these open-source packages are improved or enhanced by the developers.

This paper begins with a detailed description of the simulation program. Output from the simulation program is then verified by comparing its result to the measured current–voltage characteristic curve of a bifacial solar panel. Finally, the bifacial solar panel design is optimized based on its yearly yield that is calculated using the simulation tool.

2. Methodology

A simulation tool for a bifacial solar panel with a reflector was developed. Several experiments were conducted to obtain unknown parameters of the bifacial solar cell and verify the output from each model. The overall accuracy of the simulation model was then evaluated by comparing the simulation results with the measured current–voltage characteristic curve of the bifacial solar panel placed under the sun. Then, the yearly yield was estimated using the simulation tool. Lastly, optimization of bifacial solar panel design can be carried out to develop the design that produces the maximum yearly yield in the proposed installation location.

2.1. Overall description of the simulation tool

The operation of the simulation tool for the bifacial solar panel with a reflector can be described in three stages. The first stage takes the geographical location of the solar panel and local climate as the input data to simulate the solar irradiance at the location. The second part takes in the solar irradiance data, solar panel design and material property data to model the installation environment and simulate the actual light irradiance received by both sides of all bifacial solar cells. The light irradiance result is then used in the final part, together with the bifacial solar cell material property data, to simulate the current–voltage characteristic curve of the bifacial solar panel. Flow chart of the simulation tool is shown in Fig. 1.

2.1.1. Simulation of solar irradiance using SMARTS

The SMARTS program is an open source program written in FORTRAN. It was developed by Gueymard et al. to simulate solar irradiance spectrum for solar energy application. The spectrum simulated by the program is used as the standard AM1.5G solar irradiance spectrum [5]. It has been used extensively in numerous simulation studies for different types of solar cells [10–14].

Solar irradiance at the bifacial solar panel installation location was simulated using SMARTS. A script was written to generate the required input file, execute the SMARTS program and obtain the output spectrum from the program generated output file. Input data such as longitude, latitude and altitude of the installation location, local date and time, time zone, as well as some local atmospheric parameters are used as the input to SMARTS program.

Verification of simulation result was carried out by measuring the actual solar irradiance spectrum using a spectrometer on a sunny day in solar noon. Several consecutive solar irradiance spectrums were measured and then compared to the solar irradiance spectrum simulated by SMARTS taking in the same date and time as the input.

2.1.2. Simulation of light irradiance received by bifacial solar cells using radiance

The Radiance software, an open source program too, was developed by Ward and Shakespeare to render physically based computer image by backward ray tracing approach [7]. Different reflective or transparent materials used in the solar panel construction as well as the reflective objects found in the installation environment can be modelled easily in the software. It has also been used for solar energy application, such as the simulation of luminescent solar concentrator [15] and compound parabolic concentrator [16].

Light irradiance received by each side of a bifacial solar cell for all the solar cells in the bifacial solar panel was simulated using Radiance software. A Radiance scene template was developed to model the installation environment based on the actual dimension taken from Google Map on the installation location. Objects that are nearer to the solar cells are modelled in detail, such as the solder coated copper ribbons that join the solar cells together, the acrylic sheets that hold the solar cells and the plane mirror below the solar panel.

The components on the solar cells are necessary to be modelled in details because the rear side of the bifacial solar cell can reflect incoming light from the mirror and behaves as a secondary light source. The light emitted by the secondary light source can be reflected by the mirror again and illuminates the rear sides of the nearby solar cells or itself. Therefore, detailed modelling of the solar cells as a function of its surface reflection property is important. Besides, the thin copper ribbon joining the solar cells together blocks some sunlight from reaching the mirror, so its width is one of the factors affecting the solar panel performance. The details of