Performance of Solar Cells under Spectro-Angular Solar Irradiance

Shweta S. Pal[1], Roland Adelerhof[1], and Rebecca Saive[1,2]
[1]*University of Twente, Enschede, 7522 NB, Netherlands*
[2]*rebsaive@utwente.nl*

Abstract: Performance of solar cells is usually determined under AM 1.5 conditions rarely existing at power plant sites. We present the dependence of solar cell output on the spectro-angular solar irradiance.
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1. Introduction

The performance of solar cells usually is evaluated under standard AM 1.5 conditions, a condition that rarely exists at actual power plant sites. Taking more realistic solar irradiance conditions into account becomes particularly important in advanced solar cell technologies. Recently, several studies have been presented in which more realistic scenarios were used to improve the performance prediction of tandem [1], multijunction [2], bifacial [3-9] and spectral splitting solar cells. All these studies had to rely on available irradiance data, often provided by the baseline surface radiation network (BSRN). However, this network and other measurement stations only provide information on the global, direct and sometimes also of the diffuse component of the incident light, while solar cell performance also heavily depends on the photon wavelength and on the angle of incidence [10, 11]. Tandem and multijunction solar cells are designed to achieve current matching under standard conditions, small variations in the spectrum or angle lead to significantly lowered performance [2]. On the other hand, bifacial solar cells accept light from both sides and therefore, have twice as large of an acceptance angle which offers significant benefits for conditions in which not only direct sunlight is present. In order to quantify both, the lowered performance of tandem and multijunction solar cells as well as the increased performance of bifacial solar cells under realistic conditions, it is crucial to know these conditions with as much detail as possible. Therefore, we developed a measurement setup and procedure that allows for the measurement of spectro-angular solar irradiance [12] and have investigated spectra in different locations and different days during the year. To obtain the performance of different solar cells exposed to these spectra, we developed a computational model. In this talk we will present our computational model and the results we obtained for different solar cells under measured spectro-angular irradiance. We built a model bifacial solar cell plant for outdoor measurements and compare our computational results with experimental data from this bifacial model power plant.

2. Computational model and results

For our computations we virtually create a solar cell with a specific spectral and angular response in an environment with a given spectro-angular solar irradiance. We obtain the spectral and angular response of our solar cells from PV Lighthouse SunSolve simulations [13, 14]. An example spectrum is shown in Fig. 1 for a perovskite on silicon tandem solar cell. Whether an incident photon is absorbed by the perovskite or by the silicon is determined by the wavelength of the incident photon. Higher energy photons are absorbed by the perovskite, lower energy photons are absorbed by the silicon. The total current in the solar cell is determined by the material that absorbs less photons, therefore, the design usually aims for current matching at AM 1.5. For less steep angles of incidence the absorption decreases in both the perovskite and the silicon but with different rates which leads to current mismatch even with constant spectrum. The spectral content of diffused light and of light scattered by the surrounding varies significantly from AM 1.5 which is obvious considering for example the blue-greyish color of clouds or the green color of grass. However, we observed with our spectro-angular measurements that even the spectrum of light coming directly from the sun varies significantly depending on the time of the day/year, on the sky clearness and on the location [12]. When using our measured spectro-angular solar irradiance [12] to calculate the current, we observe a decrease in tandem cells due to spectral mismatch and an increase for bifacial solar cells due to reflection from the ground and improved absorption of light scattered on clouds. However, the changes compared to the AM 1.5 spectrum strongly depend on the cloud coverage and on the spectral albedo [7] of the surroundings and therefore, are highly dependent on location and time of the year and day. In this presentation we will also show experimental data obtained with a model power plant using bifacial silicon heterojunction solar cell and we will compare these experimental results with our simulations.

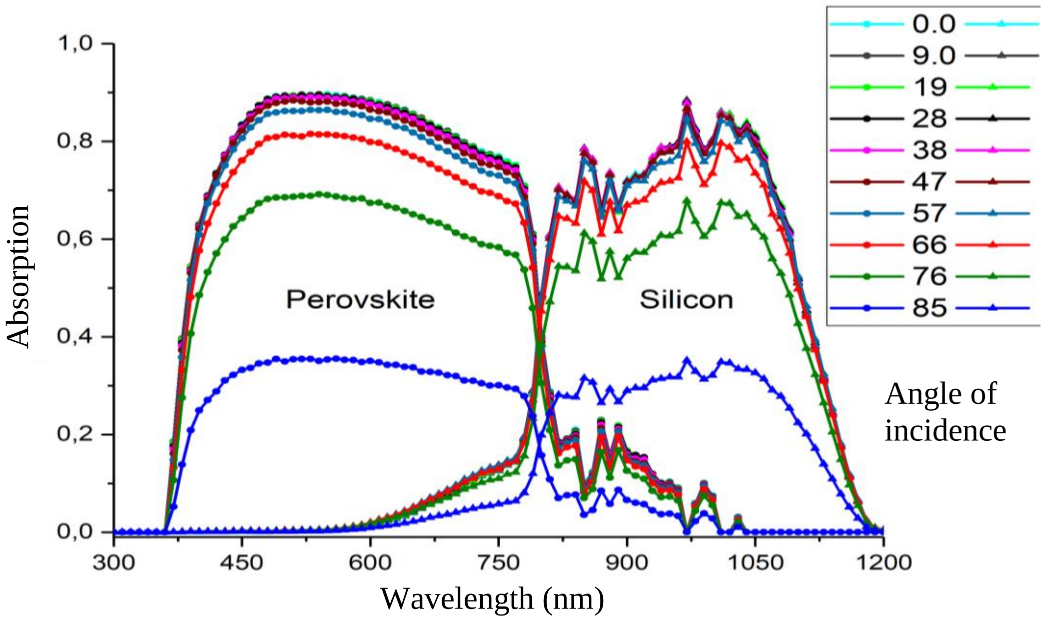

Fig. 1. Simulated absorption spectrum of the perovskite and the silicon layer in a perovskite/silicon tandem solar cell under different angles of incidence.

3. Conclusion

We have computationally investigated the performance of solar cells under measured spectro-angular solar irradiance at different locations and different times throughout the year. We observed that under realistic conditions bifacial solar cells offer an advantage over high efficiency tandem or multijunction solar cells do to their enhanced acceptance angle and less strong dependence on spectral irradiance variations. We compared our computational results with experimental data obtained from our bifacial model power plant and our spectro-angular irradiance set-up simultaneously and found good agreement.

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