Analysis and Validation of Spectral Irradiance Simulations for 75kW Bifacial Solar Test Field

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Introduction

- Bifacial solar panels are photovoltaic (PV) devices that can absorb light on both the front and rear of the panel to produce electricity.
- Bifacial PV market is growing quickly, from 10% in 2020 to 35% in 2028
- The spectrum of the light incident on a solar panel is important to for its performance. Understanding this spectrum is a significant challenge particularly for rear side irradiance on bifacial modules.
- This work establishes a methodology to do spectral irradiance and albedo simulations for bifacial PV and validates it with field data for two sensors with different spectral sensitivities. An analysis to estimate the contribution of ground reflected irradiance to total rear irradiance is also presented.

Test Site

- The test field modeled is the 75 kW Bifacial Experimental Single-Axis Tracking (BEST) field located on the campus of the National Renewable Energy Laboratory (NREL). Weather data from the Solar Radiation Research Laboratory was used.
- Two rear irradiance sensors with different spectral sensitivities were modeled and compared with their recorded values. The CM11 sensor (broadband) is mounted on the eastern edge of row 3 and the LiCor (E_{bg} = 1.1um) sensor is mounted on the western edge.

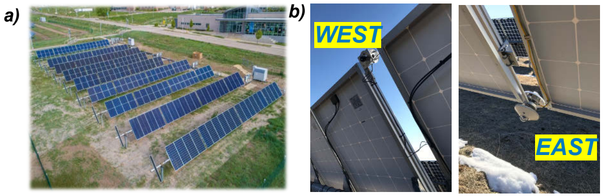
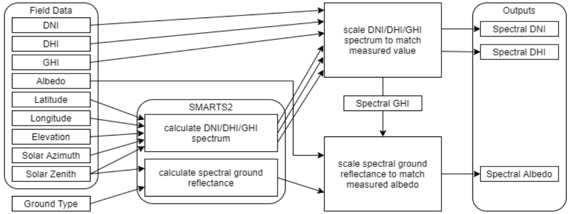


Figure 1 (a) 75kW bifacial single-axis tracked field in Golden, CO (b) Location of the sensors being modeled in the module's plane CM11 (West, broadband) and LiCor (East, narrowband)

Methodology



- Raytracing (bifacial_radiance) was used to compare **non-spectral** simulations and **spectral** simulations, and their impact on rear irradiance modeling.
- SMARTS2 was used to generate the spectral DNI, DHI, and spectral ground reflectance used for the raytracing. These were scaled by field measurements of DNI, DHI (Fig. 2), such that the integral of the spectra is equal to the measured values.
- Spectral albedo was scaled such that the weighted average of the spectral reflectance, with the GHI spectrum as the weight, equaled the measured value.
- An **estimated-spectral** rear irradiance can be obtained by doing a non-spectral simulation where the weighted albedo is calculated such that:

Modified Albedo — Spectral Ground Reflectance — Sensor's Spectral Responsivity

$$A_{mod} = \frac{\int R(\lambda) \times E_{GHI}(\lambda) \times SR(\lambda)\, d\lambda}{\int E_{GHI}(\lambda) \times SR(\lambda)\, d\lambda}$$

GHI Irradiance Spectrum

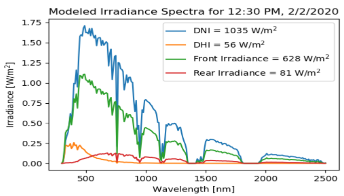


Fig. 3 - Scaled DNI and DHI spectra, and resulting raytraced front and rear irradiance spectra for the East-positioned sensor at one timestamp

Results

- **Non-spectral** simulations have an RMSE of 12-13% with measured data.
- Full **spectral** modeling provides more accuracy for non-broadband sensors such as the LiCor pyranometer. Minimal improvement is seen for broadband sensors.
- The **estimated-spectral** rear irradiance method proposed obtains a comparable improvement in rear irradiance to the spectral simulations but takes roughly 0.005% of the time.

Sensor	Measured Daily Insolation [Wh/m²]	Nonspectral Model RMSE	Spectral Model RMSE	Weighted Model RMSE
Rear CM11	517	12.18 %	11.81 %	11.90 %
Rear LiCor	536	13.27 %	10.53 %	8.25 %

Table 1 shows Daily insolation measured for 2/2/2020 with root mean square error for each methodology modeled

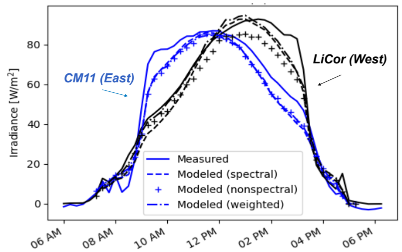


Figure 5 – Measured and modeled rear irradiances with the three methodologies (non-spectral, spectral, and estimated).

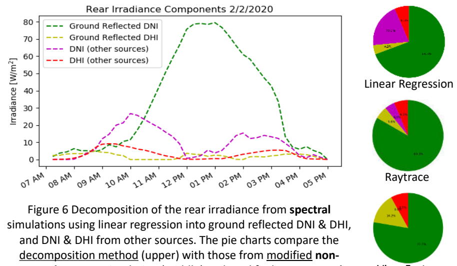


Figure 6 Decomposition of the rear irradiance from **spectral** simulations using linear regression into ground reflected DNI & DHI, and DNI & DHI from other sources. The pie charts compare the decomposition method (upper) with those from modified **non-spectral** raytrace simulation (middle) and modified **non-spectral** view factor simulation (Lower).

- A linear regression model was applied to the spectral simulation results to evaluate contributions of ground reflected DNI & DHI, and DNI & DHI from other sources (direct or reflected from other surfaces).
- DNI reflections from other sources on the scene are the most significant difference between contributions calculated by linear regression of spectral results and by modified non-spectral raytrace simulations.
- Modified non-spectral view factor simulations found a larger contribution from all DHI sources compared to both other models.

Conclusion and Future Work

- Accounting for spectral effects is important when modeling sensors and PV cells with non-broadband sensitivities, for this work decreasing RMSE from 13% to 8-11%.
- Using **estimated-spectral** irradiance simulations can provide similar results to those obtained through full **spectral** simulations in less time.
- Further validation of the **spectral** simulations should be done using a spectrophotometer to measure rear spectral irradiance for the BEST field.

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Bullet 2 of introduction from ***ITRPV. (2019). International Technology Roadmap for Photovoltaic. Itrpv, (March), 76. Retrieved from https://itrpv.vdma.org/en/ueber-uns***

Figure 1 modified from images in ***Deline, C., & Ayala, S. (2020). NREL Bifacial Experimental Single-Axis Tracking Field.***

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