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SIMULATION OF POA IRRADIANCE SENSOR PLACEMENT BIASES IN SINGLE-AXIS TRACKERS: A MID-LATITUDE CASE STUDY WITH OPEN-SOURCE TOOL

Summary

This study evaluates the bias introduced by plane-of-array (POA) irradiance sensor placement in single-axis tracking photovoltaic (PV) systems, with particular attention to edge effects within utility-scale tracker rows. Using the bifacial_radiance simulation tool, two sensor placement configurations were analyzed for a site in Sorocaba, Brazil. In Simulation A, a sensor was placed at the northern edge of an edge tracker, representing a worst-case placement scenario. In Simulation B, a sensor was positioned near the midpoint of a centrally located tracker, aligning with industry best practices. To establish a reference irradiance for Simulation B, hourly POA distributions from 20 virtual sensors across the central module were evaluated over a complete meteorological year. Annual results revealed that the edge-mounted sensor in Simulation A overestimated POA irradiance by 2.2% relative to the centroid-derived reference from Simulation B.

Keywords: Ray-tracing simulation, Edge effects, Single-axis trackers, POA irradiance.

1. Introduction

Accurate determination of POA irradiance is essential for evaluating PV system performance. However, such assessments are sensitive to multiple measurement and data-related biases—temporal resolution (Nascimento et al., 2019; Oliosi et al., 2024; Ransome and Funtan, 2005), data gaps (Lindig et al., 2024), and sensor placement (Korevaar and Nitzel, 2023). In particular, edge effects in tracker rows can introduce significant errors in POA readings. Korevaar and Nitzel (2023) demonstrated via ray tracing simulations that mounting sensors at row or module extremities may lead to substantial over- or under-estimation of irradiance, with direct consequences for both technical precision and financial forecasting.

In this regard, modern bifacial PV analysis using bifacial_radiance (Ayala Pelaez and Deline, 2020) leverages physically based sky models to simulate POA irradiance with high spatial resolution, potentially down to the level of individual cell facets. The method accounts for both direct and diffuse sky components as they vary throughout the day and year, capturing interrow and intramodule irradiance variations—including the effects of ground reflections and structural shading—through ray-tracing techniques. Unlike simplified methods used in tools like SAM, which apply a worst-case sky-diffuse shading approximation (e.g., the Passias model), or PVsyst, which integrates sky occlusion into aggregate loss factors, the time-varying hourly sky modeling in bifacial_radiance enables a spatially and temporally resolved representation of irradiance distribution. This approach facilitates systematic quantification of edge effects on measurement biases for front-of-module irradiance sensors in single-axis tracking systems. This modeling framework supports a rigorous evaluation of edge-induced measurement biases in front-of-module irradiance sensors under single-axis tracking, allowing for comparison between worst-case and best-practice sensor placements in Sorocaba's transitional mid-latitude environment.

2. Methodology

To quantify the irradiance difference between a module located near the center of a tracker row and one at its edge—common scenarios in utility-scale PV plants, especially in Brazil—we defined two simulation cases using bifacial_radiance. Figure 1 illustrates the layout: the red marker denotes the edge sensor location (Sim. A) and the orange marker the intermediate module (Sim. B). Table 1 summarizes all input parameters (module geometry, tracker tilt, albedo, meteorological data, etc.).

1. **Simulation A (Edge Case):**
   - Sensor placed at the north edge of the torque tube.
   - Single pyranometer positioned immediately adjacent to the tube, capturing the worst-case "edge" irradiance.
2. **Simulation B (Representative Case):**
   - Sensor at Module 13 of Row 5, corresponding to the "five-module distancing" from edge guideline (Korevaar and Nitzel, 2023).
   - Twenty virtual sensors distributed evenly across the module's L–E axis to characterize intra-module variability.

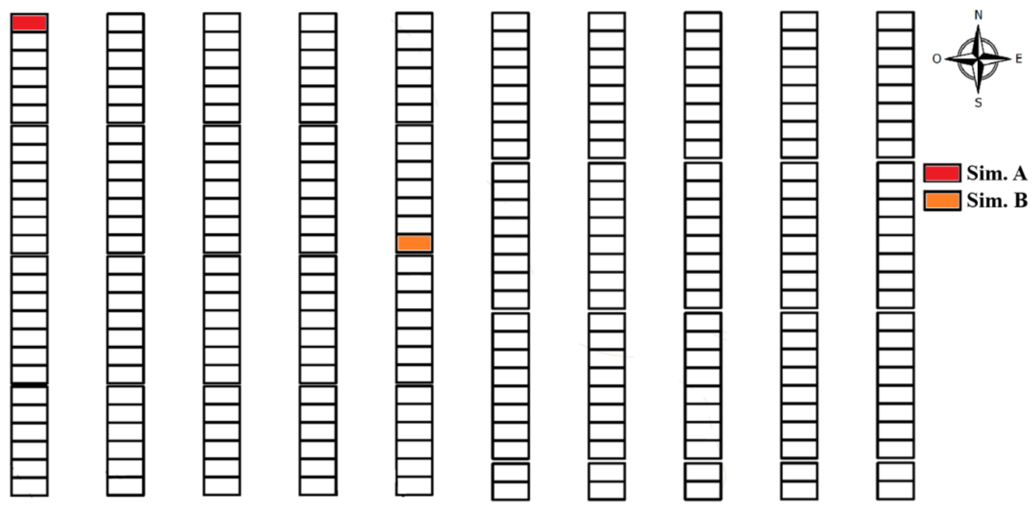

Fig. 1: Top view of the photovoltaic array highlighting the two modules where sensors were simulated

Tab. 1: Simulation parameters for the single-axis tracker array

Parameter	Value		Parameter	Value
Hub height	1.5 m		Tracker rows	10
Tilt	Backtracking on		Modules per row	26
Azimuth	N-S axis		Number of sensors	20
Ground Coverage Ratio (GCR)	0.37		Location	Sorocaba, SP
Albedo	0.2		Weather data	Energyplus.net
Module orientation	Portrait		Module dimensions	1.134 m x 2.278 m
Nr. Modules above each other	1		Torque tube	No
Type of plant	Tracked		Type of simulation	Hourly for the Whole Year
Software version: Bifacial Radiance V0.4.4				

3. Results and discussion

To evaluate POA irradiance variation between sensor locations, mean annual values were computed for each case. In Simulation A, only one sensor was modeled—located at the tracker's north edge—yielding a single annual average. In Simulation B, 20 virtual sensors were distributed laterally (east–west) across a centrally located module, and their individual annual averages were calculated. Figure 2 shows the distribution of total yearly irradiance across sensor positions on the module in Simulation B. Interestingly, the easternmost sensor produced the value closest to the overall mean of all 20 points. However, this position is not recommended for field deployment due to increased risk of shading from vegetation and/or misalignment errors caused by tracker angle calibration.

To enable a representative comparison between Simulations A and B, the seventh sensor from west to east in Simulation B was selected as the reference (it has the closest value to the POA irradiance average of the module). This position avoids edge distortion effects while maintaining proximity to the irradiance centroid. The resulting annual mean irradiance was 351.46 W/m² for Simulation A and 343.91 W/m² for Simulation B, indicating a relative bias of approximately +2.2% for the edge-mounted sensor.

Korevaar and Nitzel (2023) similarly identified two optimal POA sensor positions, but symmetrically distributed around the module center. Their study also showed that under overcast conditions, only one optimal point may exist due to the dominance of diffuse irradiance and asymmetric sky luminance.

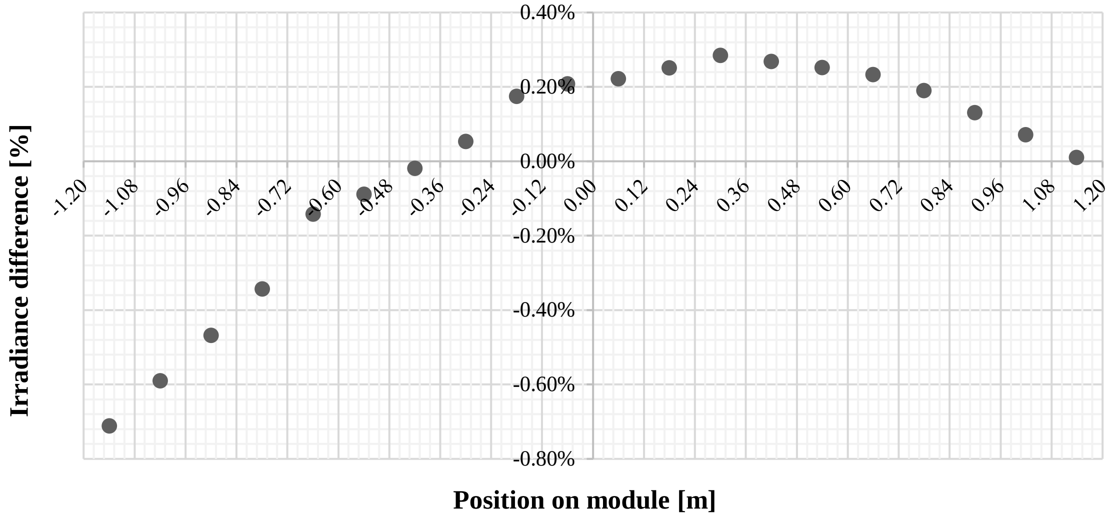

Fig. 2: Total yearly results of irradiance at different positions on the module for Sim. B

This result underscores the importance of careful sensor placement, particularly in single-axis tracking systems located at mid-latitudes. Although the bias observed in this study appears modest (~2%), such deviation may lead to overestimated performance ratios (PR) when POA measurements are used as a reference in performance assessment or contractual verification.

4. References

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