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A Spatial Irradiance Map Measured on the Rear Side of a Utility-Scale Horizontal Single Axis Tracker with Validation using Open Source Tools

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Abstract—This work presents measurements from 40 individual 125 mm x 125 mm crystalline silicon (c-Si) cells placed on the backside of a horizontal single axis tracker (HSAT) located in Roskilde, Denmark (55.6°N, 12.1°E). The measurements are used to validate a general set of conclusions gathered from recent literature, to compare to simulated backside irradiance results from view factor and ray-trace based methods, and to estimate the electrical losses caused by nonuniform illumination at the module and array level. In this work, all simulations are performed using the open source tools *bifacialvf*, *bifacial_radiance*, and *pvmismatch*. The tracker studied is 45 m long with 60-cell bifacial photovoltaic (PV) modules mounted “two-in-portrait” - a configuration commonly implemented in utility scale PV parks. Our measurements corroborate the conclusions from several simulation-based studies made by other authors. The measurements and simulations indicate that the irradiation-nonuniformity-induced electrical mismatch of the bifacial array is not higher than 0.25% when mounted above grass (albedo 0.22) on a clear sky day. But the array-level mismatch can go up to 3% when the PV park is *uniformly* covered by a white polymeric material (albedo 0.60). During a cloudy day, the mismatch of the bifacial system over grass is as high as 1%, but is lower than 0.25% around solar noon. Above the white ground cover on a cloudy day, the mismatch is around 1-2%, even at solar noon.

Keywords—*bifacial, electrical mismatch, single axis tracking*

I. INTRODUCTION

A well-known challenge in bifacial photovoltaic (PV) performance modeling is accounting for the spatial non-uniformity reaching the backside of the PV array. To this end, the recent years have shown several studies where view factor (VF) and/or ray-trace (RT) based methods are used to understand how the nonuniformity changes with sky conditions and with site specific criteria such as module height, tilt angle and ground reflectance (albedo) [1] - [5]. Some of these studies include model validation and report spatial rear plane of array irradiance ($G_{POA,Rear}$) measurements, typically on static tilt systems using between two and ten irradiance sensors. From these papers a few conclusions regarding the spatial distribution

of irradiance on the backside of bifacial PV arrays can be made:

1. Edge modules are brighter than inner modules.
2. Better homogeneity is observed under cloudy (high diffuse) than under clear sky conditions.
3. The closer a cell is to the tracker torque tube, the more shade loss it will experience.
4. Module-level mismatch losses are greatest in the middle of the day during a clear day, and constant over time when it is cloudy.
5. Mismatch losses are higher under high albedo than for low albedo conditions.
6. Homogeneity improves as a function of array height from the ground.

This work uses detailed $G_{POA,Rear}$ measurements collected on a two-in-portrait (2P) horizontal single axis tracker (HSAT) under clear and cloudy sky conditions and under two albedo conditions (0.22 and 0.60). With this measurement system, the aforementioned conclusions 1 - 5 can be validated in the context of Northern Europe using a HSAT configuration. We cannot validate conclusion number 6 because the tracker height is not adjustable. The movability of the sensors can also support answering open questions in the bifacial literature, such as where is the ideal location within an array to place a single backward-facing reference cell? For example, in the case of capacity testing or performance monitoring [6].

II. METHODS

The Technical University of Denmark (DTU) in partnership with European Energy A/S operates a 260 kWp bifacial test facility in Roskilde, Denmark (55.6°N, 12.1°E) [7]. The facility contains various measurement systems that investigate the parameters known to influence bifacial gain (e.g. albedo, tracker pitch, tilt angle etc.). Of these is a measurement system that provides information on the non-homogeneity of light reaching the backside of a horizontal single axis tracker (HSAT). The first measurement series begins in July 2019 and

is made above the natural grass with an albedo around 0.22. On May 9th, 2020, we mounted a white polymer sheet underneath the tracker to investigate empirically the effect of albedo on electrical mismatch. Our onsite measurements indicate that the albedo of this material is approximately 0.60. The second measurement series was acquired only from May 10th to May 25th. The installation of the white sheet was delayed due to the pandemic-related situation, and therefore reduced the data acquisition period.

A. Measurement System

The HSAT studied here is a 45 m long Soltec SF7 with a 2P module mounting configuration. The tracker is situated in the middle of an eight-tracker field, with a ground cover ratio of 0.28 (Fig. 1). The tracker has a square shape (15 cm x 15 cm) torque tube with 10 cm “z-gap” from the module plane. The tracker hub height is 1.95 m.

Fig. 1. Aerial view of the field of HSATs. The tracker under investigation is boxed in red. The orange rectangles show the most extreme distances (center and edge) tested. Views from the ground are shown in Fig. 2 and Fig. 3.

On the backside of this tracker we have mounted four custom 1x10 cell panels. These panels have been assembled by MG Solar using DTU’s PV module prototyping facilities. Each panel consists of ten 156.3 cm² mono-silicon Al-BSF cells wherein each cell’s electrical contacts are accessible through the polymeric backsheet. The low-iron glass is 3.2 mm thick and does not have an anti-reflective (AR) coating. The short circuit current (I_{SC}) of each cell within the laminate is monitored using shunt resistors with ohmic values sized for the expected cell-level current-voltage (I-V) behavior at low light conditions. The expanded measurement uncertainty was estimated at $\pm 9.3\%$ ($k = 2$). The three principal components driving the uncertainty are the lab calibration (light source irradiance), the angular response, and spectral mismatch observed in the field.

The measurement panels and Radiance renderings are shown in Fig. 2 and Fig. 3. Note the 0.5 m motor gap adjacent to the inner modules has not been replicated in the Radiance simulations. The individual cells within the panels are difficult to see because the backsheet is black. On May 9th, 2020, a white polymer sheet was mounted underneath the studied tracker and is pictured in Fig. 4. The white cover is 5 m wide with 2.5 m of material on each side of the tracker. A similar scene was simulated in *bifacial_radiance* and is visualized in Fig. 5.

To make sure that our field experiment is representative of a scene where the ground is uniformly covered by an albedo of 0.60, one additional scene is simulated in *bifacial_radiance*

where the ground albedo is set to 0.60 for the entire field surface.

Fig. 2. Two 1x10 cell panels mounted on the east and west edges of the tracker along with the cell numbering convention. The left image shows the physical panels, the right image shows the Radiance rendering with the sensor locations.

Fig. 3. Two 1x10 cell panels mounted on the east and west sides in the center of the tracker along with the cell numbering convention. The left image shows the physical panels, the right image shows the Radiance rendering.

Fig. 4. Picture of the white sheet mounted under the investigated tracker.

Fig. 5. Radiance rendering of the white polymer sheet mounted under the tracker considered from a top-view perspective.

B. Backside Irradiance and Electrical Mismatch Models

We simulate the spatial irradiance on the backside of the HSAT using two open source tools developed by the U.S. National Renewable Energy Laboratory (NREL). The first is *bifacial_radiance* [8], which is based on the Radiance ray-trace engine. The second is *bifacialvf* [9], which is a 2D VF model that implements the logic described by Marion *et al* [10]. We update the meteorological input files with 10-minute averages of onsite broadband diffuse horizontal irradiance (*DHI*), direct normal irradiance (*DNI*), global horizontal irradiance (*GHI*) recorded by spectrally flat class A sensors (per ISO 9060:2018). The onsite *GHI* - which includes all incident light - and ground reflected horizontal irradiance (*RHI*) measurements provide the albedo of the natural grass, and white surface. For each measurement series, two days are investigated: one clear sky day and one overcast day (Fig. 6 and Fig. 7). The daily clearness indexes (K_T) on the two sunny days are 0.63 and 0.67 for the first and second series, respectively. The daily K_T on the two cloudy days are 0.29 and 0.20, respectively.

Fig. 6. Broadband irradiance (*GHI*, *DHI*, and *DNI*) from a clear sky day (08/25/2019) and overcast day (09/08/2019) in the first measurement series.

Fig. 7. Broadband irradiance (*GHI*, *DHI*, and *DNI*) from a clear sky day (05/20/2020) and overcast day (05/17/2020) in the second measurement series.

The electrical mismatch losses resulting from the nonuniform illumination are calculated using the open source code *pvmismatch* developed by SunPower [11]. The mismatch calculations are performed for conventional 60-cell (1.6 m x 1.0 m) panels with three bypass diodes per substring. We assume that the rear irradiances observed in cell locations 1 through 10 are constant along the 1.0 m horizontal width of the 60-cell panels. We calculate electrical mismatch within the four modules (Edge-E, Edge-W, Inner-E, and Inner-W) using two different inputs for $G_{POA,Rear}$: the measurements from the custom panels, and the *bifacial_radiance* simulations that contain the 40 “sensors” placed in locations representative of the cells within the custom measurement panels. In all cases the electrical mismatch at each timestamp is calculated per (1).

$$Mismatch [\%] = 1 - \frac{P_{Mod}}{\sum P_{Cells}} \quad (1)$$

Where P_{Mod} is the maximum power point (P_{MP}) of the 60-cell module. This value is affected by electrical mismatch from nonuniform rear side illumination. P_{Cell} is the P_{MP} of an individual cell within the 60-cell module. For each timestamp in our *pvmismatch* model, we apply the total effective irradiance (G_{Total}) for each cell i as shown in (2). The front and rear side irradiance rear $G_{POA,Front}$ and $G_{POA,Rear,i}$ are calculated using either the field measurements or the *bifacial_radiance* simulation outputs, with $G_{POA,Front}$ assumed to be homogenous across the array. The total effective irradiance becomes:

$$G_{Total,i} = G_{POA,Front} + \phi \cdot G_{POA,Rear,i} \quad (2)$$

Where ϕ is the technology-specific bifaciality factor calculated as the ratio of backside efficiency to front side efficiency ($\eta_{STC,rear} / \eta_{STC,front}$). In this work we have used a ϕ value of 0.7, which is representative of contemporary bifacial PERC modules on the market.

We have calculated the array-level mismatch using the simplified assumption that the modules in the center of the array are illuminated by the average irradiance between the Edge and Inner cases, separated by the cell numbers, as shown in Fig. 8.

Fig. 8. Measured average $G_{Total,i}$ [$W \cdot m^{-2}$] from July to November 2019 for the south-western half of an interior row of 44 modules surrounded by 7 HSATs. The numbers 1-10 on the y-axis represent cell positions, and the numbers 1-22 on the x-axis represent module positions.

III. RESULTS

A. Rear irradiance spatial distribution over grass surface

The measured and modeled backside irradiance of the 4 different modules during the first measurement series is studied here. Fig. 9 displays the average measured rear irradiance within each module for a sunny and a cloudy day.

Fig. 9. Average rear irradiance of the ten cells measured within a module on a sunny (08/25/2019) and an overcast day (09/08/2019) over grass.

Fig. 9 confirms conclusion 1: especially during the sunny day, the edge module rear side is brighter than the inner one. On the sunny day, it is easy to see that the cells within the two

edge panels receive nearly twice as much irradiance as the cells within the two inner panels. On the cloudy day, the irradiance indeed becomes more uniform and irradiance values observed within the array are within $10 \text{ W}\cdot\text{m}^{-2}$. Hence, conclusion 1 and 2 – that the edge module rear side is brighter than the inner one and that homogeneity improves on the cloudy day – are validated.

Fig. 10. Hourly average of measured/ simulated $G_{\text{POA,Rear}}$ on the **edge** module, west side of the HSAT on a sunny and an overcast day over **grass**.

Fig. 11. Hourly average of measured/ simulated $G_{\text{POA,Rear}}$ on the **inner** module, west side of the HSAT on a sunny and an overcast day over **grass**.

Fig. 10 and Fig. 11 overlay the hourly averaged measurements, *bifacial_radiance* and *bifacialvf* simulations for the west side of the tracker at the inner and edge module locations. The *bifacialvf* results are only shown in the inner module plot, since *bifacialvf* does not consider edge effects. Ten data points are shown at each hourly timestamp and group, which represent the ten cells measured within the module.

Color shades have been applied to differentiate between cells 1 to 10. The lighter color means cell 10, which is located closest to the torque tube. The #10 cells can receive as much as 20% lower $G_{\text{POA,Rear}}$ values than the #1 cells on the sunny day and up to 10% lower on the cloudy day. This validates conclusion 3, and conclusion 2 again – that the backside irradiance is spread over a larger gradient during sunny days.

bifacial_radiance simulations reproduce well the measured inner and edge module rear irradiances. The poorest agreement of measured to modeled values is observed on the sunny day on the edge module. In the case of the west module, the model tends underestimate the irradiance in the morning, and to overestimate it around solar noon. In the morning, the error is larger than the estimated measurement uncertainty ($\pm 9.3\%$), but around solar noon the error becomes smaller than the uncertainty. During the cloudy day, the simulated absolute values are within the measurement uncertainty 76% of the time – considering all 40 sensors. Also, the model agrees with observed measurement trends such as: during the cloudy day, the module the closest to the sky receives more irradiance and

during the sunny day, the inner module the closest to the ground receives more irradiance.

A daily root mean squared error (RMSE) was calculated individually for all 40 sensors. The cloudy day RMSE is between $1\text{--}3 \text{ W}\cdot\text{m}^{-2}$ with no clear trend for higher errors occurring at any particular sensor location. The sunny day RMSE, however, is between $4\text{--}10 \text{ W}\cdot\text{m}^{-2}$ wherein the 20 inner panel sensors show a systematic trend of lowest RMSE nearest the torque tube ($4 \text{ W}\cdot\text{m}^{-2}$) and highest RMSE farthest from the torque tube ($10 \text{ W}\cdot\text{m}^{-2}$). This could be due to an imprecise definition of the tracker motor gap in the Radiance scene. The 20 sensors on the edge panels all have a sunny day RMSE between $8\text{--}10 \text{ W}\cdot\text{m}^{-2}$.

Our *bifacialvf* simulation results are slightly less accurate than *bifacial_radiance* simulations of the inner modules, which makes intuitive sense as it is a reduced order model. The VF model tends to underestimate the $G_{\text{POA,Rear}}$ irradiance during the sunny day by as much as $20 \text{ W}\cdot\text{m}^{-2}$, but the discretized mean bias error (MBE) for the 20 segments is between $-6 \text{ W}\cdot\text{m}^{-2}$ and $-10 \text{ W}\cdot\text{m}^{-2}$ on the clear sky day. The daily RMSE is $3\text{--}5 \text{ W}\cdot\text{m}^{-2}$ on the cloudy day and $8\text{--}12 \text{ W}\cdot\text{m}^{-2}$ on the sunny day. Larger errors are again observed for cells farthest away from the torque tube. The errors could be because the structural elements of the tracker are not properly accounted for in the model (e.g. shed transparency factor, structure shading factor etc.). The *bifacialvf* model is not used for the remainder of the article since it accounts for fewer geometry details and does not capture edge effects, a key element for mismatch computations.

B. Influence of albedo on the backside irradiance

In this section, the effect of the white ground cover on the backside irradiance is studied on a clear and an overcast day. The intent is to compare to the results made over low albedo grass that were shown in section A. Using *bifacial_radiance*, two different scenes are simulated: one similar to the field experiment with a 2.5 m wide white (albedo 0.60) band on grass, and one with a uniform 0.60 albedo over the entire surroundings.

Fig. 12. Hourly average of measured/ simulated $G_{\text{POA,Rear}}$ on the **edge** module, west side of the HSAT on a sunny and an overcast day over different scenarios of **white ground cover**.

Fig. 13. Hourly average of measured/ simulated $G_{POA,Rear}$ on the **inner** module, west side of the HSAT on a sunny and an overcast day over different types of **white ground cover**.

The backside irradiance levels of the edge and inner modules of the west side are displayed in Fig. 12 and Fig. 13, respectively. First, the measurements are used to validate the accuracy of *bifacial_radiance* for the high albedo condition. Indeed, the 2.5 m wide band simulation is very close to the measurement irradiance values, within 10% precision.

Now comparing the 2.5 m band case with the uniform albedo case, it appears that the band is not wide enough to be representative of a uniform 0.60 albedo. In other words, we have reason to believe that a large quantity of ground reflected light reaching the cells comes from the grass, not the white cover. Imagine a scenario early in the morning when the west module is far from the ground: At such a moment, $VF_{GND \rightarrow PV}$ on cell 1 on the tracker west side includes a considerable portion of the grass area. An additional *bifacial_radiance* simulation showed that a 5 m band ($\sim 2.5x$ torque tube height) on each side of the tracker would lead to results similar to a uniform 0.60 albedo. This much additional white cover material could not be provided nor mounted yet due to pandemic-related restrictions.

The daily RMSE of the *bifacial_radiance* simulations (2.5 m band case) are between $5-10 \text{ W}\cdot\text{m}^{-2}$ on the cloudy day and between $9-17 \text{ W}\cdot\text{m}^{-2}$ on the sunny day. We again observed that the RMSE is lower for cells nearest the torque tube as was the case in the low albedo simulations. As the outdoor measurements seem to validate *bifacial_radiance* in simulating $G_{POA,Rear}$ under different albedo conditions, we will compare the bifacial gain under both conditions. Here the RT model is used for the high albedo case because the bifacial gain observed over our white cover in the field is not truly representative of a uniformly covered field. Furthermore, the $G_{POA,Rear}$ levels in $\text{W}\cdot\text{m}^{-2}$ are not directly comparable because the daily *GHI* profiles are different between the sunny and cloudy days of the two measurement series. The average bifacial irradiance (optical) gain is defined in (3) where $G_{POA,Rear}$ stands for the average rear irradiance within a module.

$$BG_{irr} = \frac{G_{POA,Rear}}{G_{POA,Front}} \quad (3)$$

Fig. 14. Mean bifacial gain within the edge and inner modules of the west side on a sunny and a cloudy day over an albedo of 0.22 (measured, 08/25/2019 and 09/08/2019) and over albedo of 0.60 (RT model, 05/20/2020 and 05/17/2020).

The irradiance gains on the edge and the inner modules during cloudy and sunny are plotted in Fig. 14. The average bifacial irradiance gain is up to 2.5 times higher under an albedo of 0.60 than under grass albedo. As a result, the bifacial gain varies linearly with the albedo on average. Also apparent in Fig. 14 is how the bifacial gain can be overestimated by as much as 2x when edge panels - as opposed to inner panels - are used for the calculation.

C. Power mismatch losses over different ground albedos

The electrical mismatch calculated using inputs from the onsite measurements and the *bifacial_radiance* simulations during the first measurement series over grass is shown below. Fig. 15 shows electrical mismatch at the module-level and Fig. 16 at the array-level.

Fig. 15. **Module-level** mismatch losses of the west side modules using the measured and simulated rear irradiance values on a sunny and a cloudy day during the first measurement series over **grass**.

When used to estimate module-level mismatch losses, the RT model agrees very well with the measurements, except late in the cloudy day when some direct beam light was observed. The large discrepancy late in the day could be due to passing clouds and a lagged response from the thermopile (pyranometer) sensors - although the sensors implemented here do have response times < 5 seconds. During the sunny day, the module-level mismatch is lower than 0.2%. And during the cloudy day, the module-level mismatch losses are mostly lower than 0.2%, except at the beginning and at the end of the day. Conclusion 4 is validated here, since the module-level mismatch is highest in the middle of the day when it is sunny and is quite constant throughout the day if it is cloudy.

Please note that the results from the Eastern panels are not shown here to maintain clarity in the figures. An interesting observation we found when comparing East and West sides during the sunny day is that the module closest to the ground

suffers higher mismatch losses than the top module.

Fig. 16. **Array-level** mismatch losses using the measured and simulated rear irradiance values on a sunny and a cloudy day during the first measurement series over **grass**.

At the array-level now in Fig. 16, the RT model tends to overestimate the mismatch but follows the same trends as the measurements. During the sunny day, both the simulated and measured mismatch are lower than 0.25% and the mismatch losses are again highest in the middle of the day. During the cloudy day in the middle of the day the mismatch is < 0.15%, but in the morning and afternoon the mismatch increases on the array the closest to the ground up to 1% for periods with meaningful levels of irradiance ($GHI > 100 \text{ W}\cdot\text{m}^{-2}$).

Fig. 17. **Array-level** mismatch losses using the measured and simulated data points of the HSAT for a sunny and a cloudy day of the second measurement series over an albedo of 0.60. The measurement consists of two 2.5 m bands of white cover material and the RT simulations used a uniform 0.60 albedo.

The electrical mismatch calculated using inputs from the second measurement series is studied in Fig. 17. Two different conditions are compared. The measurements made over 2.5 m wide bands of white material on each side of the tracker, and the RT scene with a uniform 0.60 albedo. During the sunny day, the modeled mismatch is similar for the east and west arrays, with a significantly higher mismatch in the middle of the day. In contrast, the measurements show that the array closest to the ground experience a higher mismatch, which is likely due to the inhomogeneous albedo. For analyzing the effect of albedo on the mismatch, the RT model calculations are used instead of the measurement, since the comparison should be done over a uniform albedo for both the grass and white-cover albedo.

Fig. 17 validates conclusion 5 – mismatch losses are higher under high albedo than for low albedo conditions. Indeed, the highest array-level mismatch during the sunny day increases from 0.25% over an albedo of 0.22 to 3% over an albedo of 0.60, i.e. by an order of magnitude.

The electrical mismatch is now studied as a function of the relative standard deviation, also termed the coefficient of

variation, of the total irradiance as defined in (4) with $\mu = \text{mean}(G_{POA, \text{total}})$ from (2). A similar study has recently been carried out by *Deline et al.* [12] where RT simulations were performed of a 10° fixed tilt system above a high reflective surface and ground clearances of 0.15 m to 1.0 m. Their work resulted in a simplified model that describes electrical mismatch loss as a function of irradiance non-uniformity. *Janssen et al.* proposed a similar model in [13] for a fixed-tilt system. The module-level mismatch is shown in this section to compare our outcomes to their fitted curves. Indeed, the interpolated data used previously to calculate the array-level mismatch is not exactly true to reality. We estimate that this assumption does not affect mismatch losses much, but can significantly affect the array-level standard deviation (non-uniformity), which thus makes it unsuitable for building predictive models based on the standard deviation. Finally, only timestamps when $GHI > 150 \text{ W}/\text{m}^2$ are considered here.

$$std_r[\%] = \frac{1}{\mu} \cdot \sqrt{\sum_{i=1}^N \frac{(G_{Total,i} - \mu)^2}{N}} \cdot 100\% \quad (4)$$

Fig. 18. **Module-level** electrical mismatch vs. the relative standard deviation. Results from the measurements and Radiance simulations are shown for all 4 modules over **grass** and compared to the literature [12] [13]. Data points are filtered when $GHI < 150 \text{ W}/\text{m}^2$.

Module-level mismatch losses vs. relative standard deviation over grass is shown in Fig. 18. During the sunny day, both the measurements and the RT model fit quite well to the exponential curve of *Deline et al.* in [12] specified in (5). In fact, the edge modules are very uniform and correspond to a large amount of data points with $std_r[\%] < 0.25\%$. While the data from the inner modules best fits the *Deline* correlation (5).

$$M[\%]_{fit1} = e^{-2} \cdot std_r[\%]^{1.57} \quad (5) [12]$$

$$M[\%]_{fit2} = 0.33 \cdot std_r[\%] + 0.075 \cdot std_r[\%]^2 \quad (6) [13]$$

During the cloudy day, the correlation between mismatch and standard deviation is less obvious. Some measured data points, and even more RT modeled data points are closer to

Janssen polynomial curve [13] detailed in (6). This suggests that the effect of diffuse light ought to be accounted for when modeling mismatch losses in this range. However, one must keep in mind that the mismatch values obtained in this study are on the very low end of possible values that bifacial PV systems - particularly low ground clearance systems - can incur.

Fig. 19 again shows module-level mismatch vs. relative standard deviation, but for the second measurement series over the white cover of albedo 0.60. As a reminder, the measurements were done over a 2.5 m wide tarp under each side of the tracker, whereas the RT model considers a uniform 0.60 albedo for comparison. Both the measurements and the model fit well to the exponential curve specified in (5), for both the sunny and cloudy day. However, during the cloudy day, most of the data points are still gathered in a cluster where the relative standard deviation is lower than 1%. The sunny day data points follow the exponential curve more evenly, with relative deviations up to 3% and module-mismatch losses up to 0.9%.

Fig. 19. **Module-level** electrical mismatch vs. the relative standard deviation. Results from the measurements and Radiance simulations are shown for all 4 modules over **white cover** and compared to the literature [12] [13]. Data points are filtered when $GHI < 150 \text{ W/m}^2$.

IV. SUMMARY

We have presented high resolution irradiance measurements on the back of a 2P HSAT, compared them to VF and RT simulations and calculated electrical mismatch using open source tools. The RT and VF models has been validated during a typical sunny and cloudy day over natural grass (albedo 0.22) and over a white polymer sheet (albedo 0.60), but the VF approach is less accurate as one would expect. Moreover, the effect of albedo on the backside irradiance, bifacial gain and irradiance-nonuniformity-induced power mismatch losses have been analyzed. Please note that the mismatch results shown here are expected to be different when the torque tube shape and module gap differ significantly from the tracker studied here.

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