Bifacial simulation in SAM

Bifacial Workshop 2018

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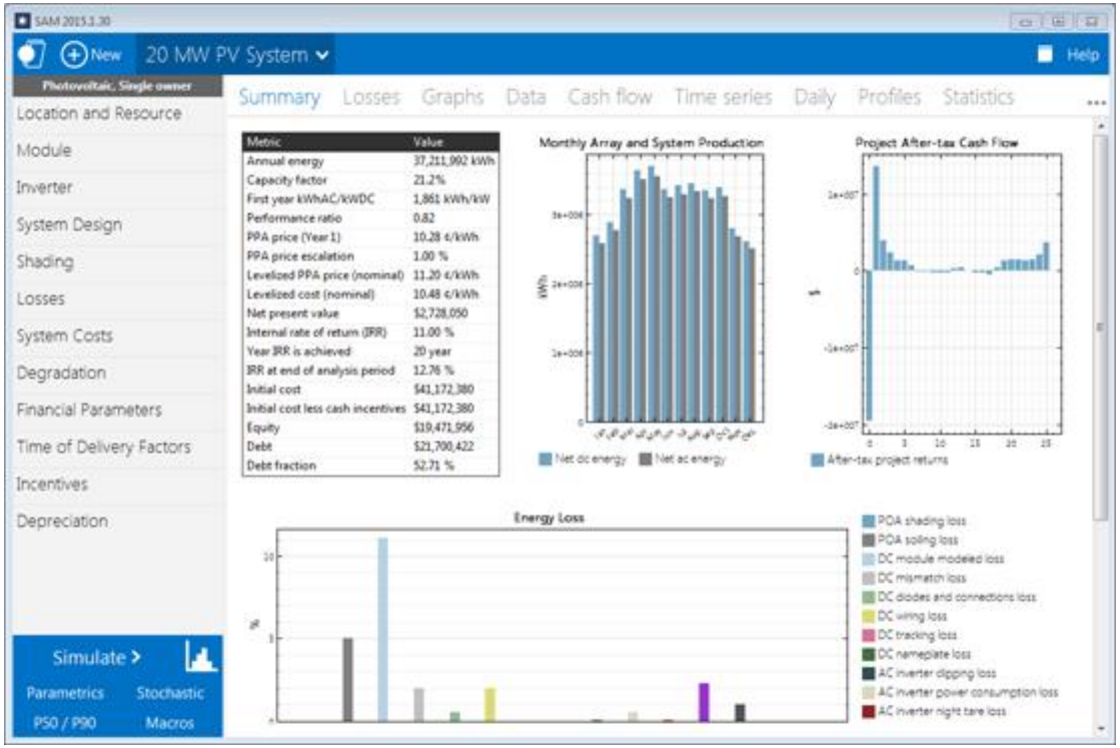
System Advisor Model (SAM)

SAM is free software for modeling the performance and economics of renewable energy projects.



http://sam.nrel.gov
github.com/NREL/SAM

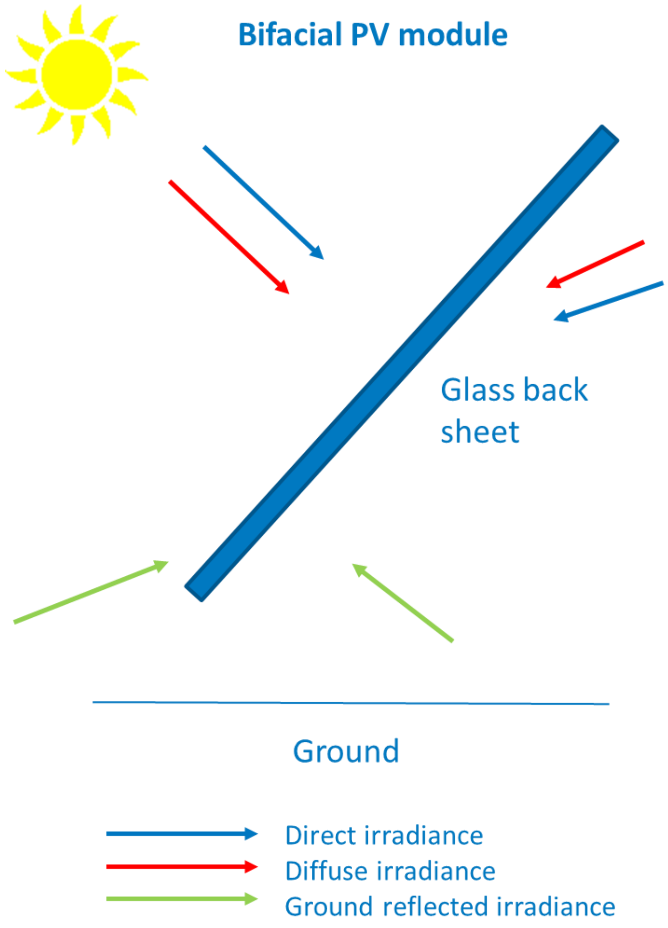
- Developed by NREL with funding from DOE
- Windows, OSX, and Linux
- One or two new versions per year
- Software Development Kit (SDK)
- Support

Download Beta version

https://sam.nrel.gov/sites/default/files/content/public_releases/sam-beta-windows-2018-9-10.exe

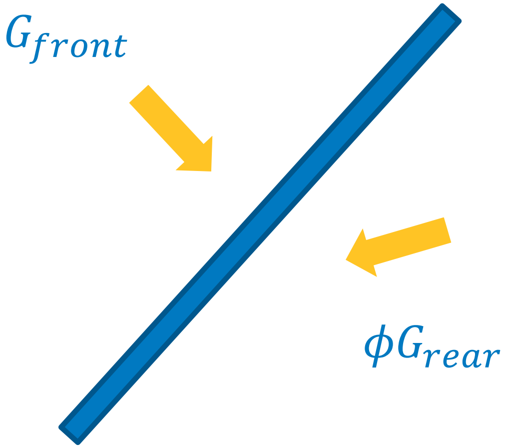
Outline

- Overview of bifacial irradiance model
- Bifacial model implementation in SAM
- Example analysis
- Some quantitative results



Model assumptions

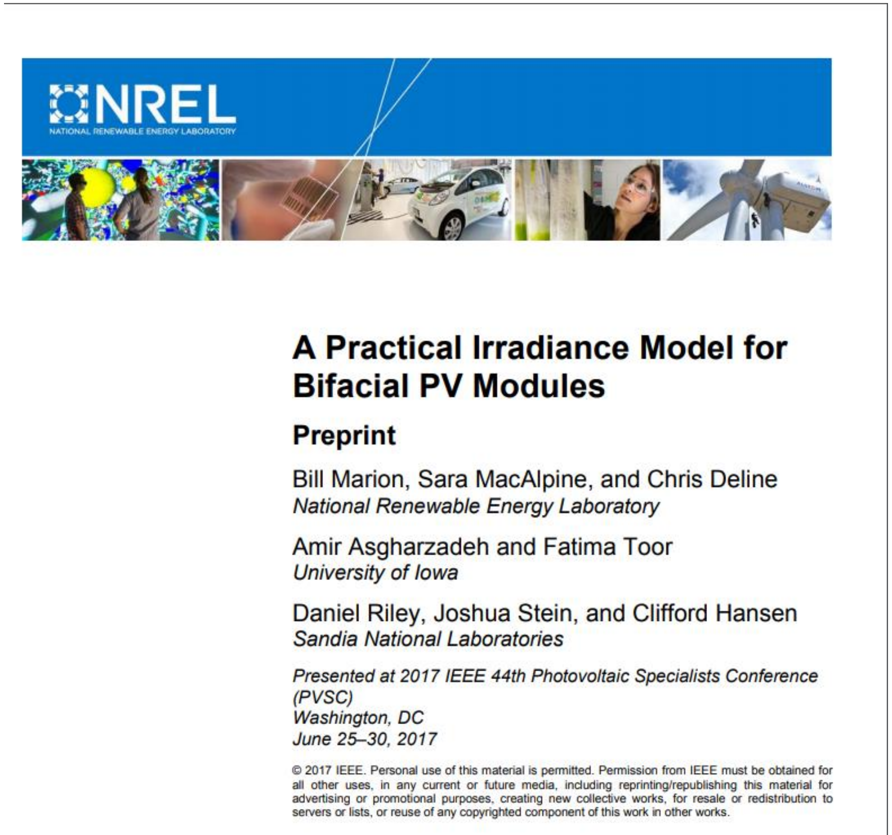
- Applicable for a row or multiple rows of PV modules, fixed tilt or 1-axis tracked.
- Calculation of configuration factors assumes isotropic radiation
- Bifacial modules are arranged in rows of infinite length (no irradiance variation along length)
- No rear mounting obstructions
- The POA rear-side irradiance (weighted by bifaciality) adds to the front-side irradiance.
- Combined irradiance is converted to DC power using single-diode model



$$G = G_{front} + \phi G_{rear}(1 - \eta_{loss})$$

Single diode model

Bifacial irradiance model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A Practical Irradiance Model for Bifacial PV Modules

Preprint

Bill Marion, Sara MacAlpine, and Chris Deline
National Renewable Energy Laboratory

Amir Asgharzadeh and Fatima Toor
University of Iowa

Daniel Riley, Joshua Stein, and Clifford Hansen
Sandia National Laboratories

Presented at 2017 IEEE 44th Photovoltaic Specialists Conference (PVSC)
Washington, DC
June 25–30, 2017

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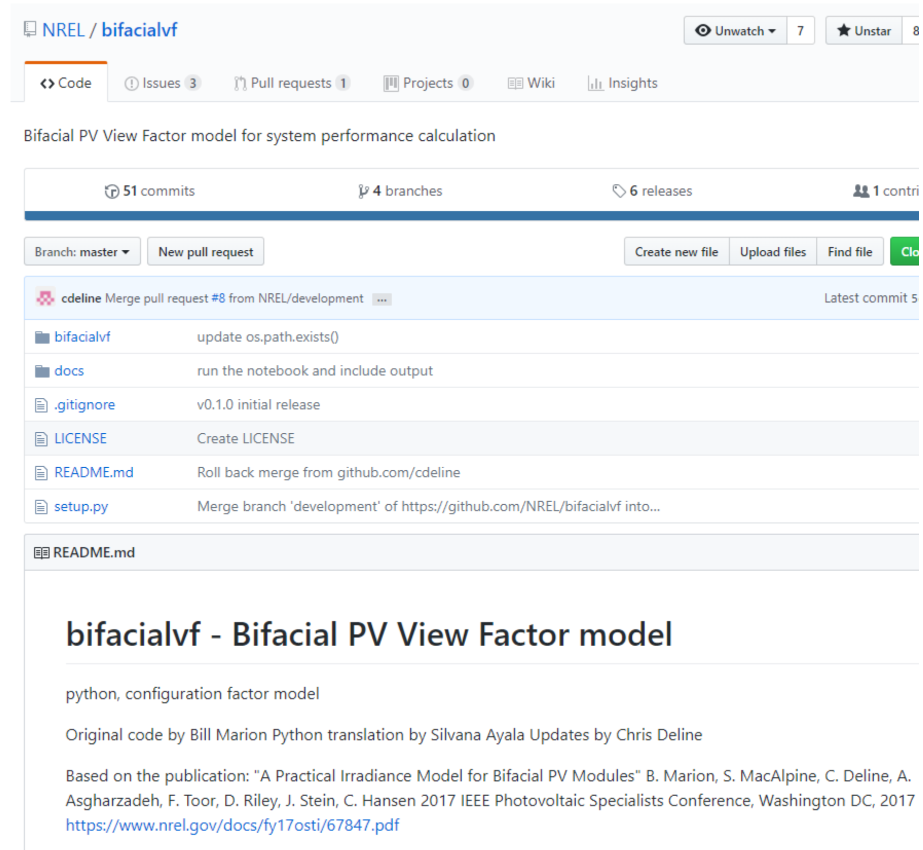
https://www.nrel.gov/docs/fy17osti/67847.pdf


NREL / bifacialvf

Unwatch 7 | Unstar 8

Code | Issues 3 | Pull requests 1 | Projects 0 | Wiki | Insights

Bifacial PV View Factor model for system performance calculation

51 commits | 4 branches | 6 releases | 1 contri

Branch: master | New pull request | Create new file | Upload files | Find file | Clo

cdeline Merge pull request #8 from NREL/development ... Latest commit 5

bifacialvf	update os.path.exists()
docs	run the notebook and include output
.gitignore	v0.1.0 initial release
LICENSE	Create LICENSE
README.md	Roll back merge from github.com/cdeline
setup.py	Merge branch 'development' of https://github.com/NREL/bifacialvf into...

README.md

bifacialvf - Bifacial PV View Factor model

python, configuration factor model

Original code by Bill Marion Python translation by Silvana Ayala Updates by Chris Deline

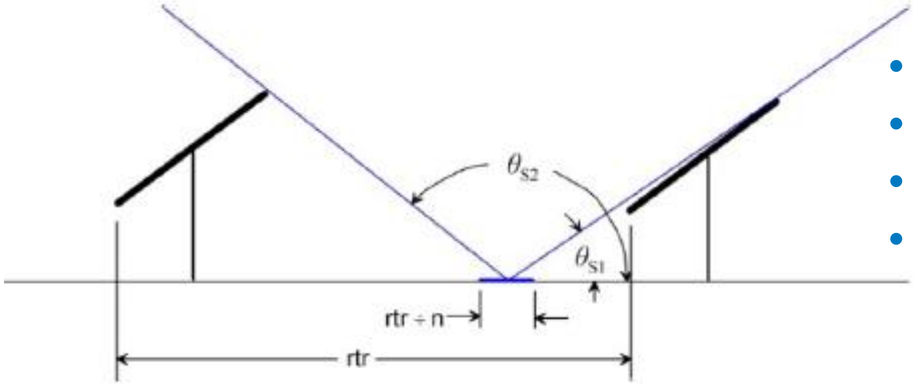
Based on the publication: "A Practical Irradiance Model for Bifacial PV Modules" B. Marion, S. MacAlpine, C. Deline, A. Asgharzadeh, F. Toor, D. Riley, J. Stein, C. Hansen 2017 IEEE Photovoltaic Specialists Conference, Washington DC, 2017 https://www.nrel.gov/docs/fy17osti/67847.pdf

https://github.com/NREL/bifacialvf

SAM Implementation
https://github.com/NREL/ssc

Bifacial Irradiance Model Steps

1. Identify ground that is shaded by the PV array



- Calculate sun position
- Project shadows into row-to-row dimension
- Divide row-to-row into n (100) segments
- Identify whether each segment is shaded or not

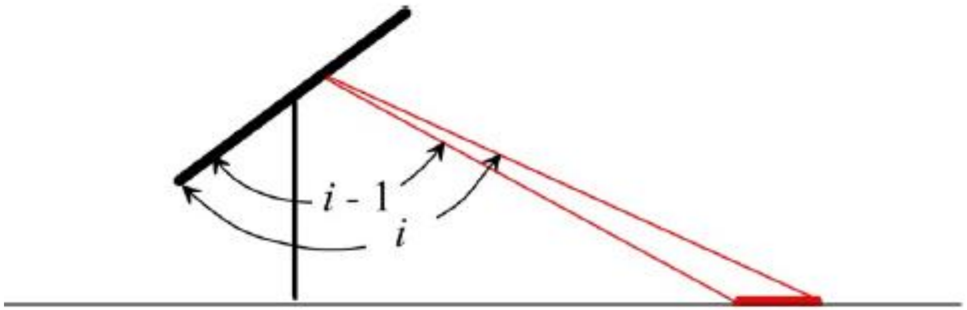
2. Determine irradiance received by the ground by accounting for shading and restricted view of the sky

- Use Perez tilted surface model with DNI and DHI to decompose DHI into circumsolar, sky and horizon components
- For each segment, compute ground irradiance

Images from "A Practical Irradiance Model for Bifacial PV Modules", Marion et al.

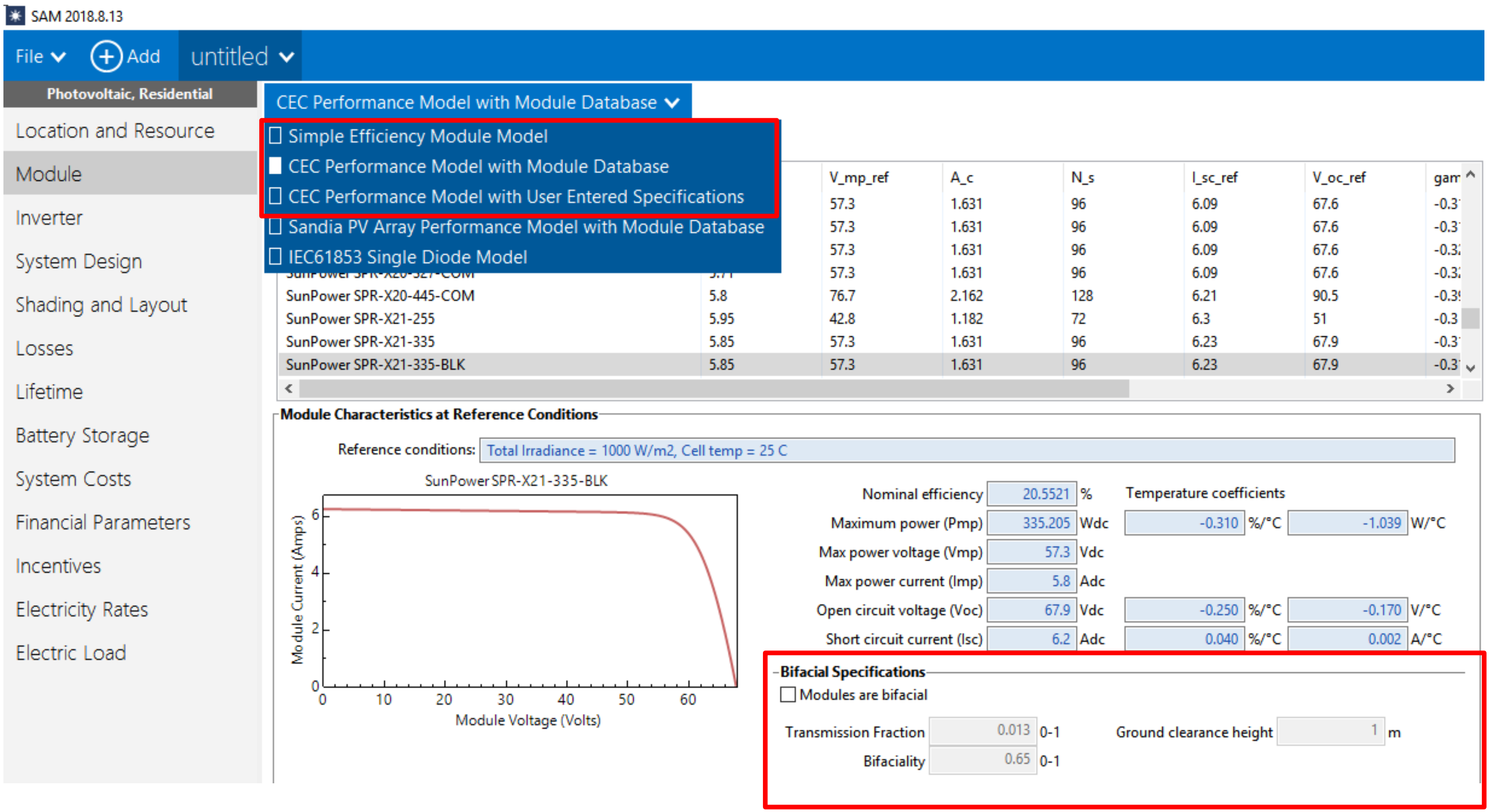
Bifacial Irradiance Model Steps

3. Determine the irradiance for the rear-side, which is a sum of:
    a. Irradiance from sky
    b. Irradiance reflected from the ground
    c. Irradiance reflected from the front surface of PV modules in the next row (considering only diffuse radiation)
    d. Irradiance from the sun and circumsolar region of the sky for AOI $< 90°$



- Diffuse irradiance for back-side is summed by dividing field-of-view into 180 one-degree segments and adding each segments contribution

Bifacial model in SAM



- Bifacial model available for module models which do not require test data

Bifacial system layout

Self Shading for Fixed Subarrays and One-axis Trackers

Self shading is shading of modules in the array by modules in a neighboring row.

Self shading	Standard (Non-line	None	None	None

Array Dimensions for Self Shading, Snow Losses, and Bifacial Modules

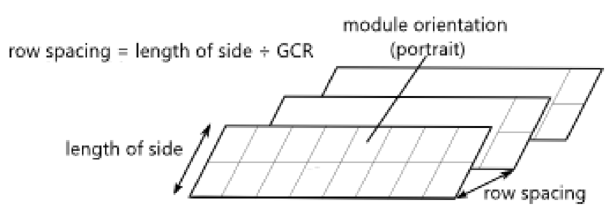
The product of number of modules along side and bottom should be equal to the number of modules in subarray.

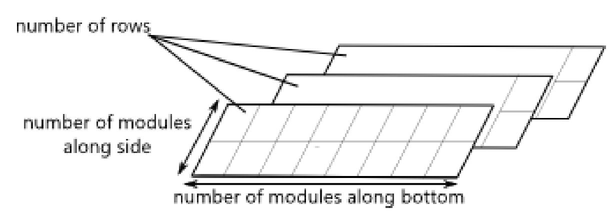
Module orientation	Landscape	Portrait	Portrait	Portrait
Number of modules along side of row	1	2	2	2
Number of modules along bottom of row	7	9	9	9

Calculated System Layout

Number of rows	100	0	0	0
Modules in subarray from System Design page	700	0	0	0
Length of side (m)	1.00031	3.261	3.261	3.261
GCR from System Design page	0.666667	0.3	0.3	0.3
Row spacing estimate (m)	1.50046	10.87	10.87	10.87

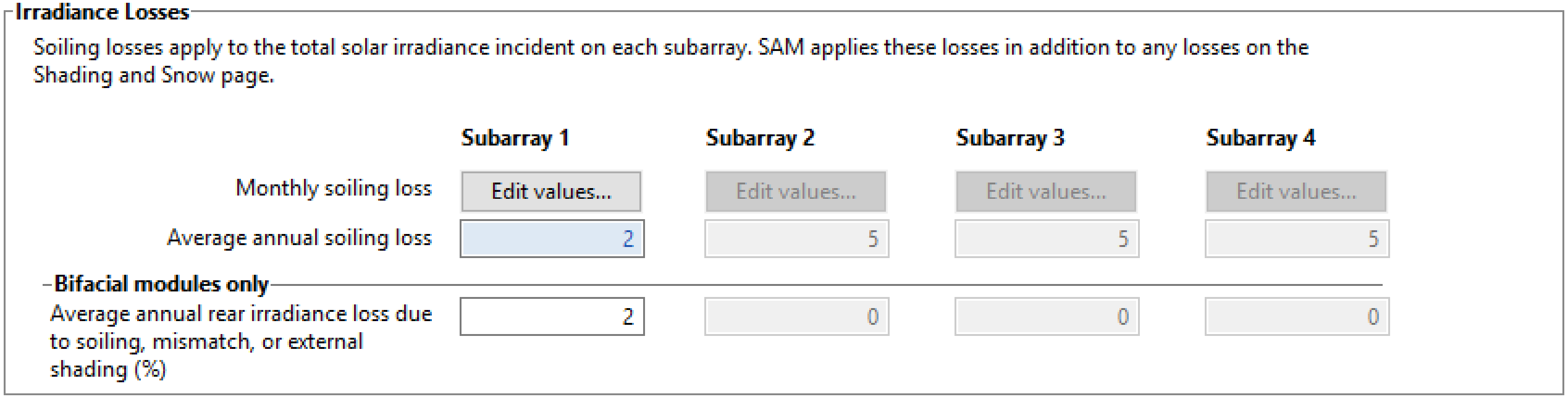
Module aspect ratio	1.63	
Module length	1.6305	m
Module width	1.00031	m
Module area	1.631	m^2





Shading and Layout – Important to turn on self-shading model and configure the geometry of the layout for correct calculation of front-side and rear-side irradiance!

Bifacial losses

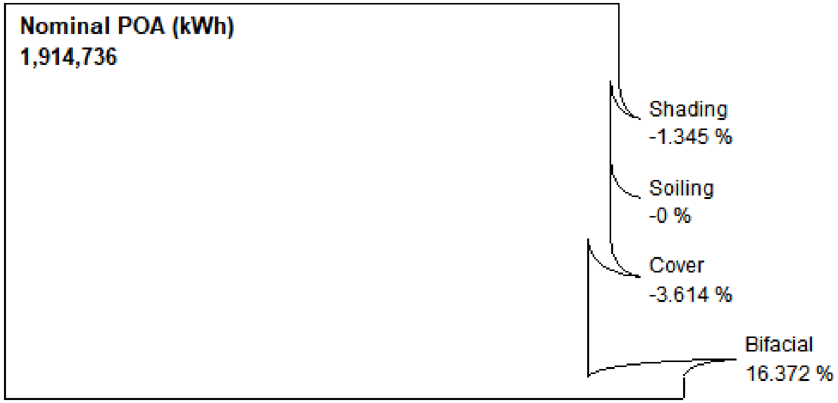


Additional rear-side irradiance losses can input to approximate:

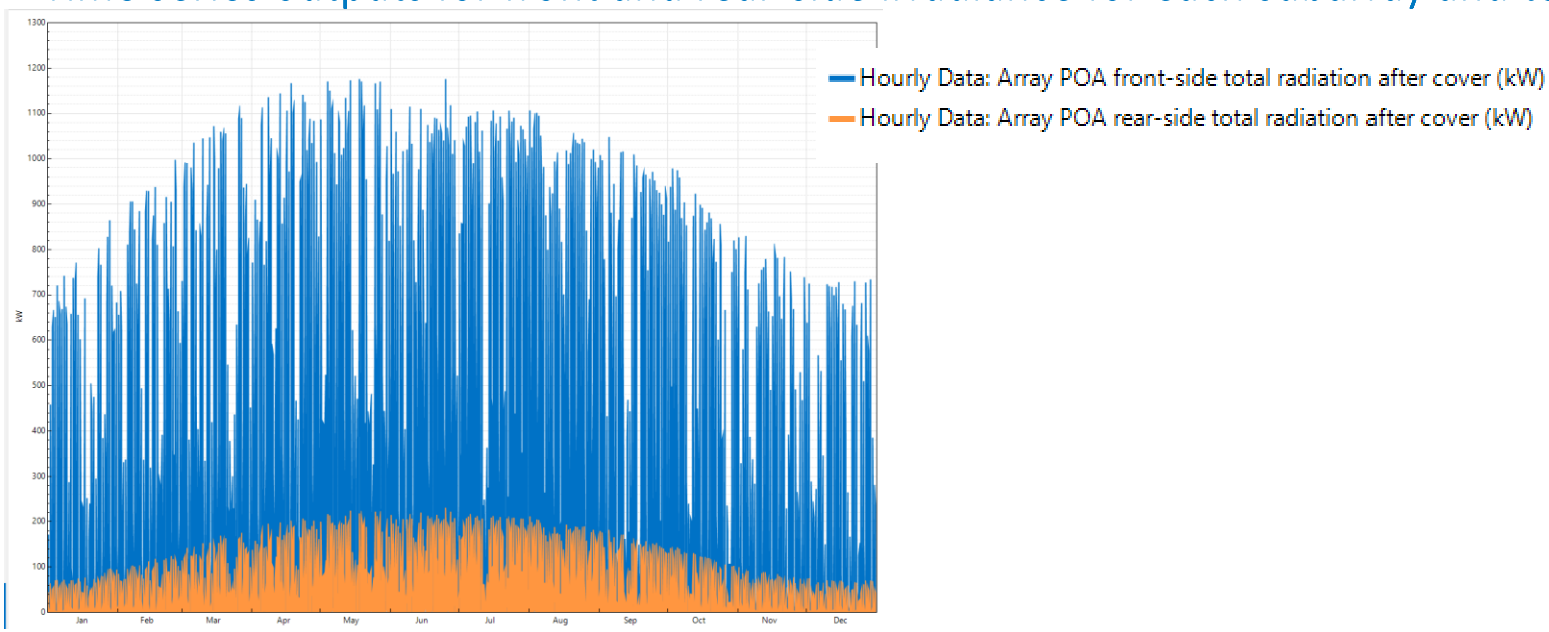
- Mismatch loss between front and rear-side
- Shading due to mounting structure or tracking system
- Soiling on the rear-side

Bifacial model outputs

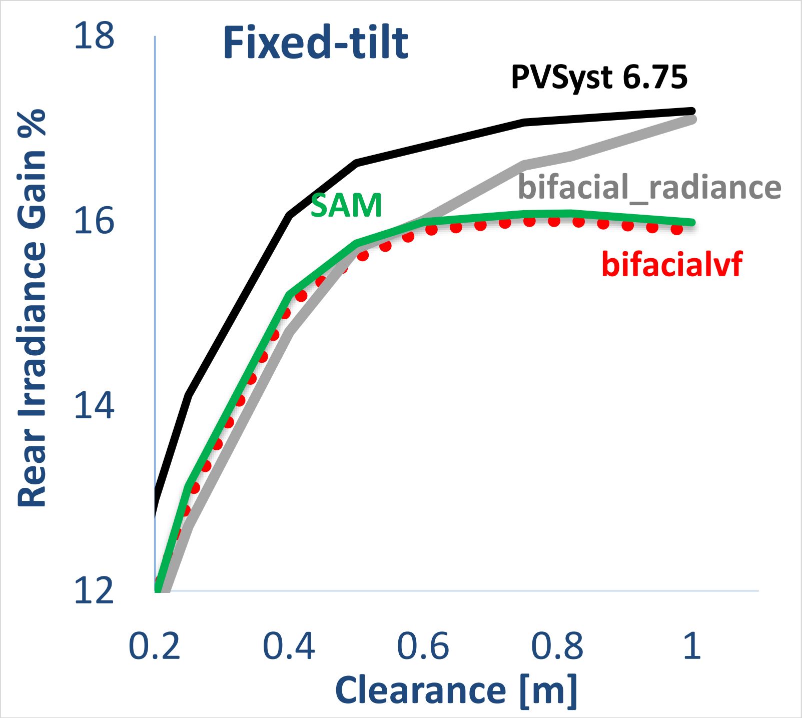
Updated loss diagram, showing bifacial irradiance gain

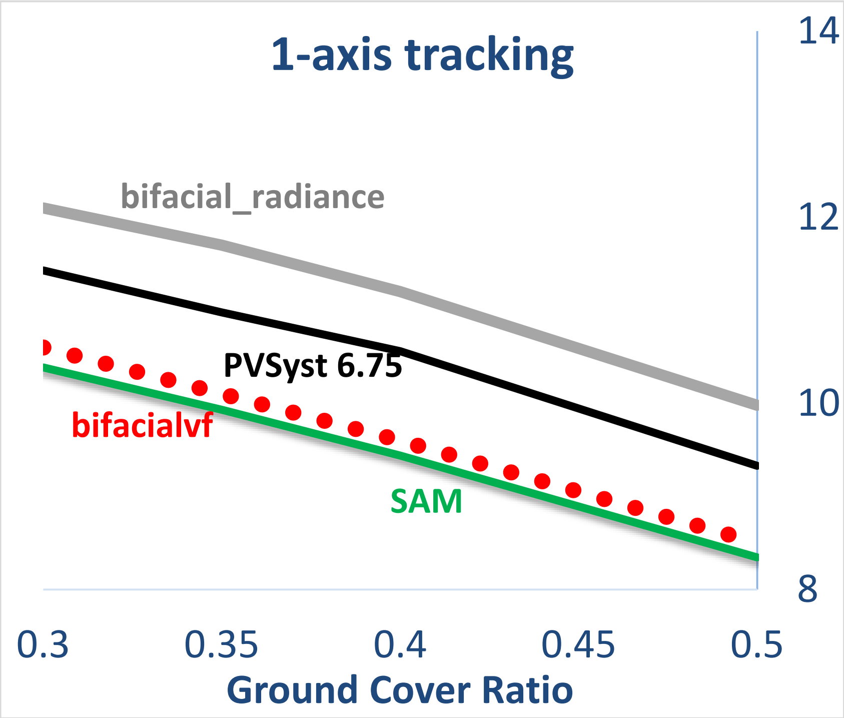


Time series outputs for front and rear-side irradiance for each subarray and total array



Model comparison

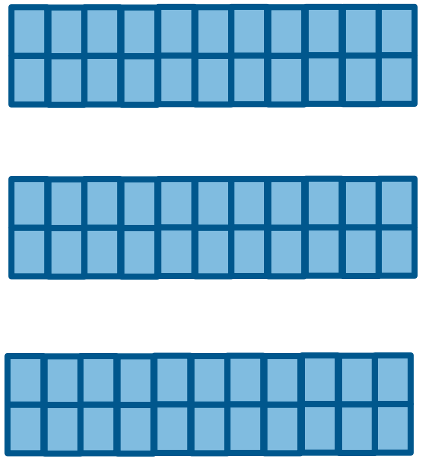




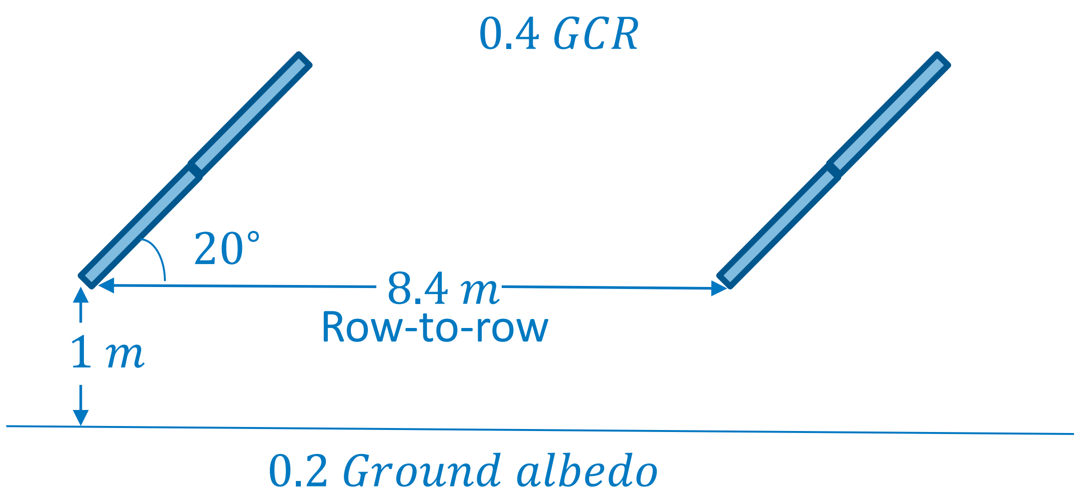
Preliminary results

- SAM implementation closely tracks with bifacialvf prediction
- SAM tracks bifacial_radiance model at low ground clearances.
- SAM consistently predicts approximately 1-2% less rear-side irradiance than PVSyst
- For tracked systems bifacial_radiance predicts higher gain

- Evaluate the boost in energy production with bifacial modules compared to monofacial modules with and without tracking systems.



3 rows of 22 modules



Example results

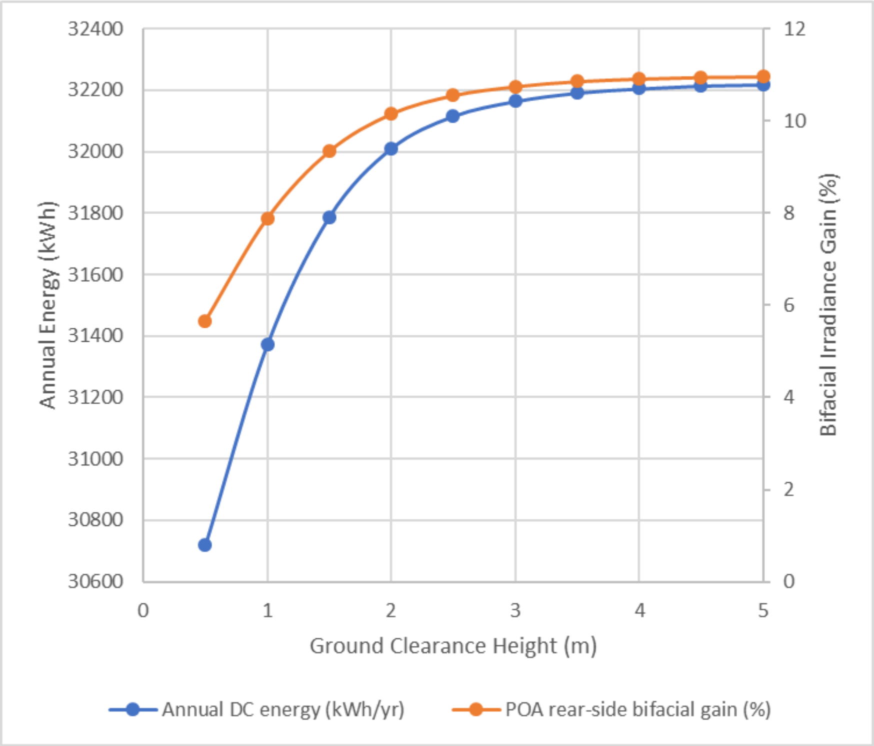
	Monofacial Fixed-tilt	Bifacial Fixed-tilt	Monofacial 1-axis track	Bifacial 1-axis track
POA Annual Irradiance (kWh)	190,961	206,030	254,943	265,187
Irradiance Gain	0%	7.9%	33.5%	38.9%
DC Annual Energy (kWh)	29,051	31,372	36,614	38,130
Energy Gain	0%	8.0 %	26.0%	31.3%

*Gains calculated relative to monofacial fixed-tilt system

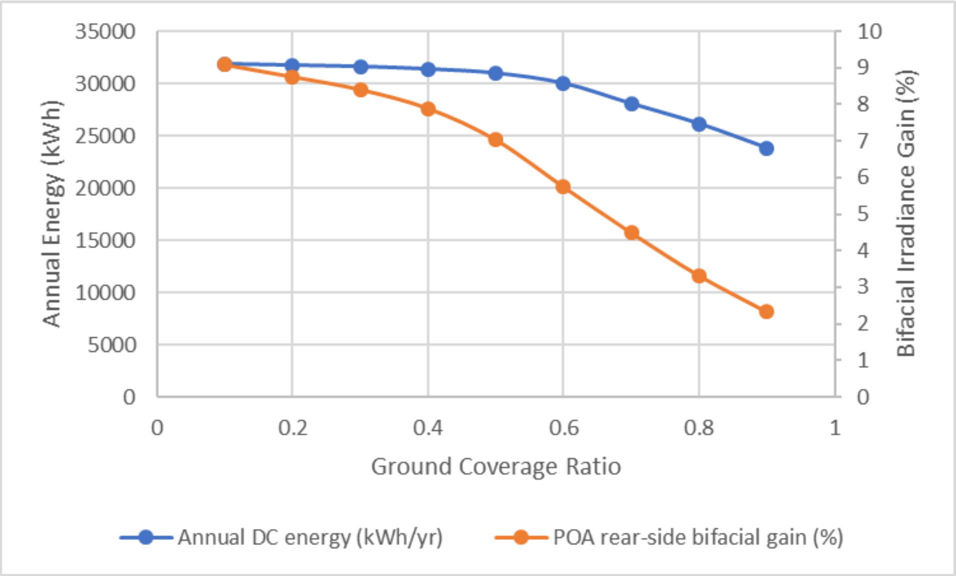
- DC energy gain is different from irradiance gain due to non-linear module response
- Installing 1-axis tracker on monofacial results in higher gain than installing bifacial (in this case).
- Installing bifacial modules with 1-axis trackers boosts annual DC energy by 31% over fixed monofacial system.

Sensitivity analysis of key variables

Ground Clearance Height



Ground Coverage Ratio



Key Variables:

- Ground Clearance Height
- Ground Coverage Ratio (row spacing)
- Albedo
- Tilt

Bifacial layout optimization

Ground clearance height (m)	Ground coverage ratio	Tilt (deg)	Annual DC energy (kWh/yr)	POA rear-side bifacial gain (%)
2	0.2	40	34221	12.226
2	0.2	45	34203	12.613
2	0.2	35	34100	12.056
1.5	0.2	45	33957	11.791
1.5	0.2	40	33949	11.323
2	0.2	30	33820	11.992
1.5	0.2	35	33803	11.068
2	0.3	40	33687	11.104
2	0.3	35	33638	11.034

Perform sweep of system layouts between:

- 0.1 – 0.5 GCR
- 15 – 45 degree tilt
- 0 – 2 m ground clearance

Sort by annual energy

Summary and Future Work

Summary

- Bifacial model added to SAM to calculate rear-side irradiance.
- Implementation tracks closely with other bifacial irradiance models

Future Work

- Model improvement and validation as part of upcoming NREL and Sandia projects:
  - NREL installation of tracked bifacial PV
  - Impacts on bifacial PV shading from rack equipment
  - Research on mismatch from rear irradiance gradient.

Thank you!

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