



Bifacial Simulation in SAM

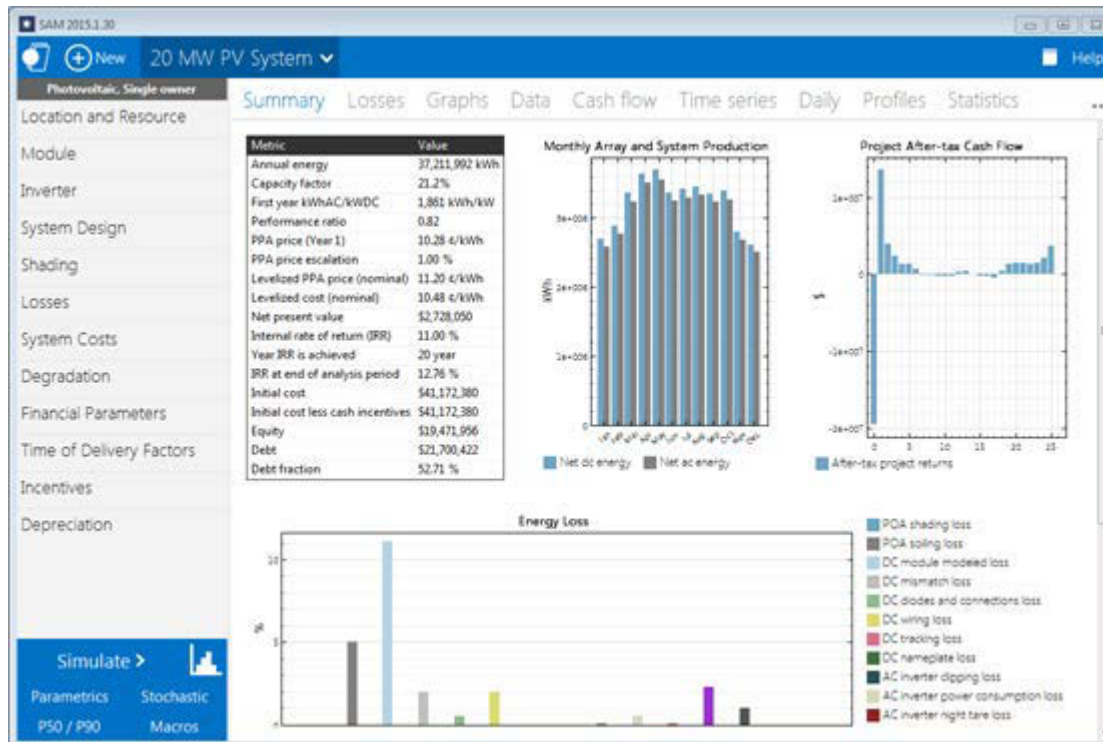
Nicholas DiOrio and Chris Deline

Bifi PV 2018 Workshop – Lakewood, Colorado
September 11, 2018

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



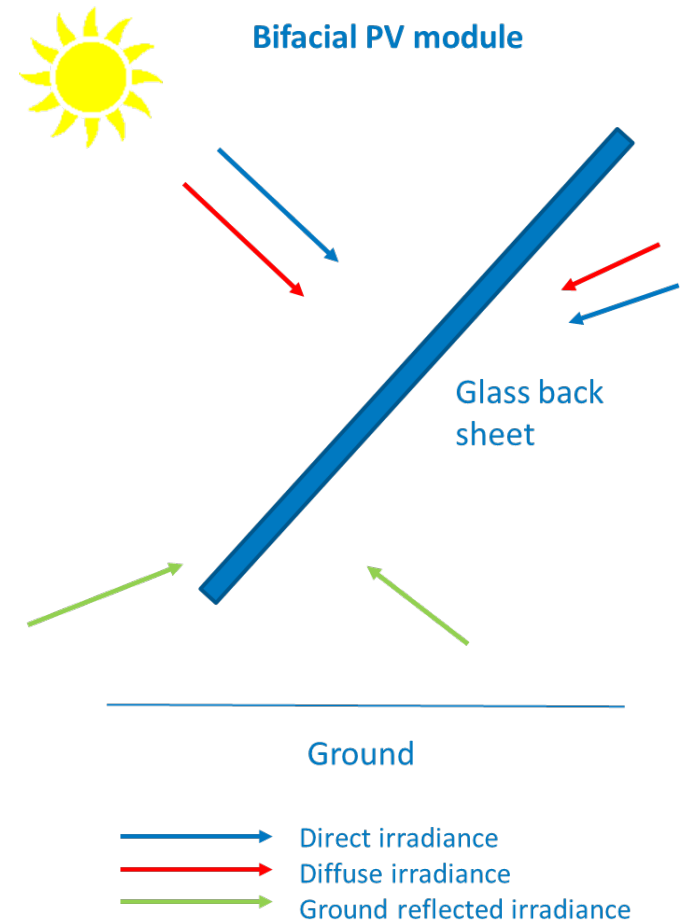
- Developed by NREL with funding from DOE
- Windows, OSX, and Linux
- One or two new versions per year
- Software Development Kit (SDK)
- Support

Download Beta version

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

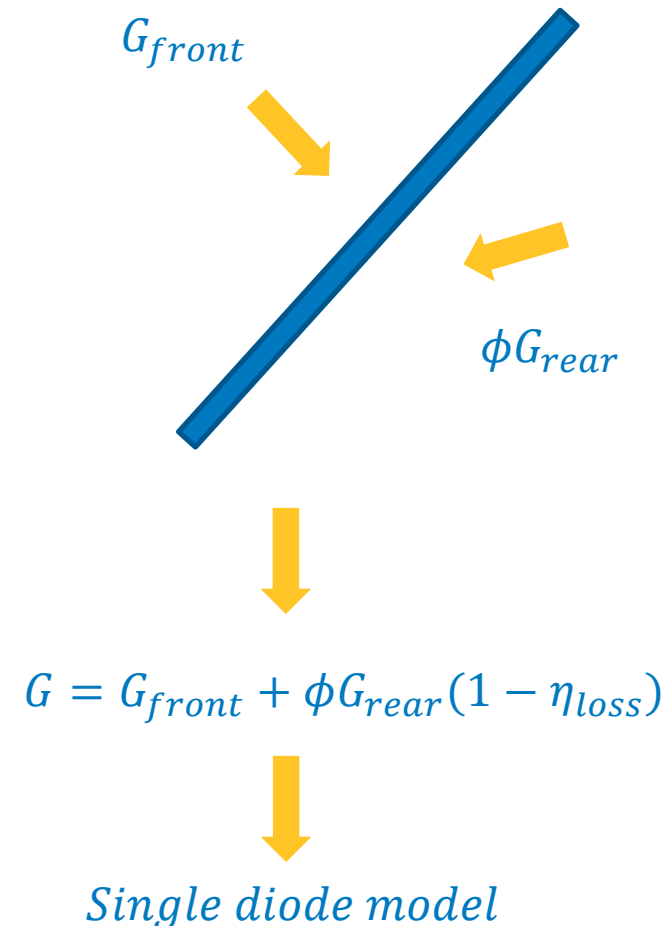
Outline

- 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



Bifacial irradiance model



A Practical Irradiance Model for Bifacial PV Modules

Preprint

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National Renewable Energy Laboratory

Amir Asgharzadeh and Fatima Toor
University of Iowa

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Sandia National Laboratories

*Presented at 2017 IEEE 44th Photovoltaic Specialists Conference (PVSC)
Washington, DC
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<https://www.nrel.gov/docs/fy17osti/67847.pdf>

SAM Implementation

<https://github.com/NREL/ssc>

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 contributor

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

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

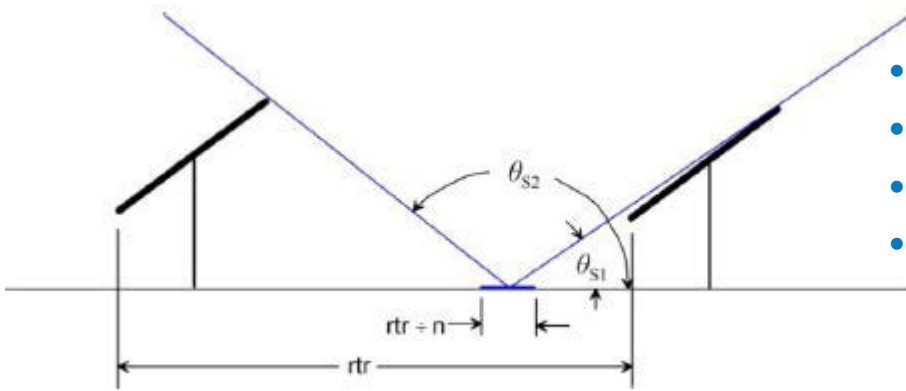
Original code by Bill Marion Python translation by Silvana Ayala Updates by Chris Deline

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>

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

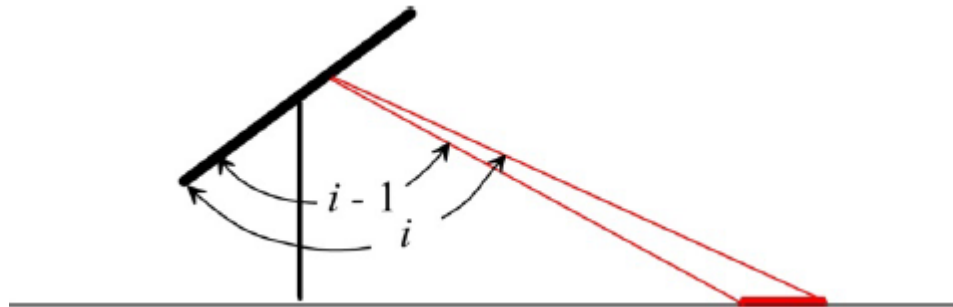
2. Determine irradiance received by the ground by accounting for shading and restricted view of the sky

- 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 $\text{AOI} < 90^\circ$



- 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

SAM 2018.8.13

File Add untitled

Photovoltaic, Residential

Location and Resource

Module

Inverter

System Design

Shading and Layout

Losses

Lifetime

Battery Storage

System Costs

Financial Parameters

Incentives

Electricity Rates

Electric Load

CEC Performance Model with Module Database

Simple Efficiency Module Model

CEC Performance Model with Module Database

CEC Performance Model with User Entered Specifications

Sandia PV Array Performance Model with Module Database

IEC61853 Single Diode Model

	V _{mp_ref}	A _c	N _s	I _{sc_ref}	V _{oc_ref}	gam
SunPower SPR-X20-327-COM	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X20-445-COM	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X21-255	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X21-335	57.3	1.631	96	6.09	67.6	-0.3
SunPower SPR-X21-335-BLK	57.3	1.631	96	6.09	67.6	-0.3

Module Characteristics at Reference Conditions

Reference conditions: Total Irradiance = 1000 W/m², Cell temp = 25 C

SunPower SPR-X21-335-BLK

Nominal efficiency 20.5521 %

Maximum power (P_{mp}) 335.205 Wdc

Max power voltage (V_{mp}) 57.3 Vdc

Max power current (I_{mp}) 5.8 Adc

Open circuit voltage (V_{oc}) 67.9 Vdc

Short circuit current (I_{sc}) 6.2 Adc

Temperature coefficients

-0.310 %/°C -1.039 W/°C

-0.250 %/°C -0.170 V/°C

0.040 %/°C 0.002 A/°C

Bifacial Specifications

Modules are bifacial

Transmission Fraction 0.013 0-1

Bifaciality 0.65 0-1

Ground clearance height 1 m

- 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

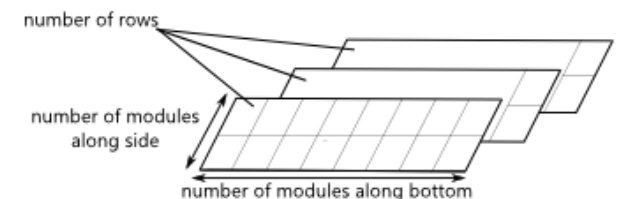
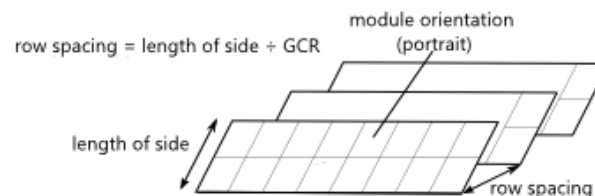
1.6305 m

Module width

1.00031 m

Module area

1.631 m²



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

Irradiance Losses

Soiling losses apply to the total solar irradiance incident on each subarray. SAM applies these losses in addition to any losses on the Shading and Snow page.

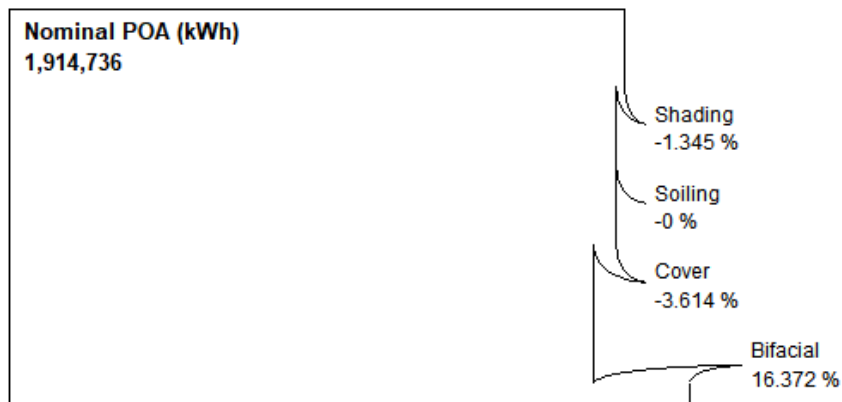
	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Monthly soiling loss	Edit values...	Edit values...	Edit values...	Edit values...
Average annual soiling loss	2	5	5	5
-Bifacial modules only-				
Average annual rear irradiance loss due to soiling, mismatch, or external shading (%)	2	0	0	0

Additional rear-side irradiance losses can input to approximate:

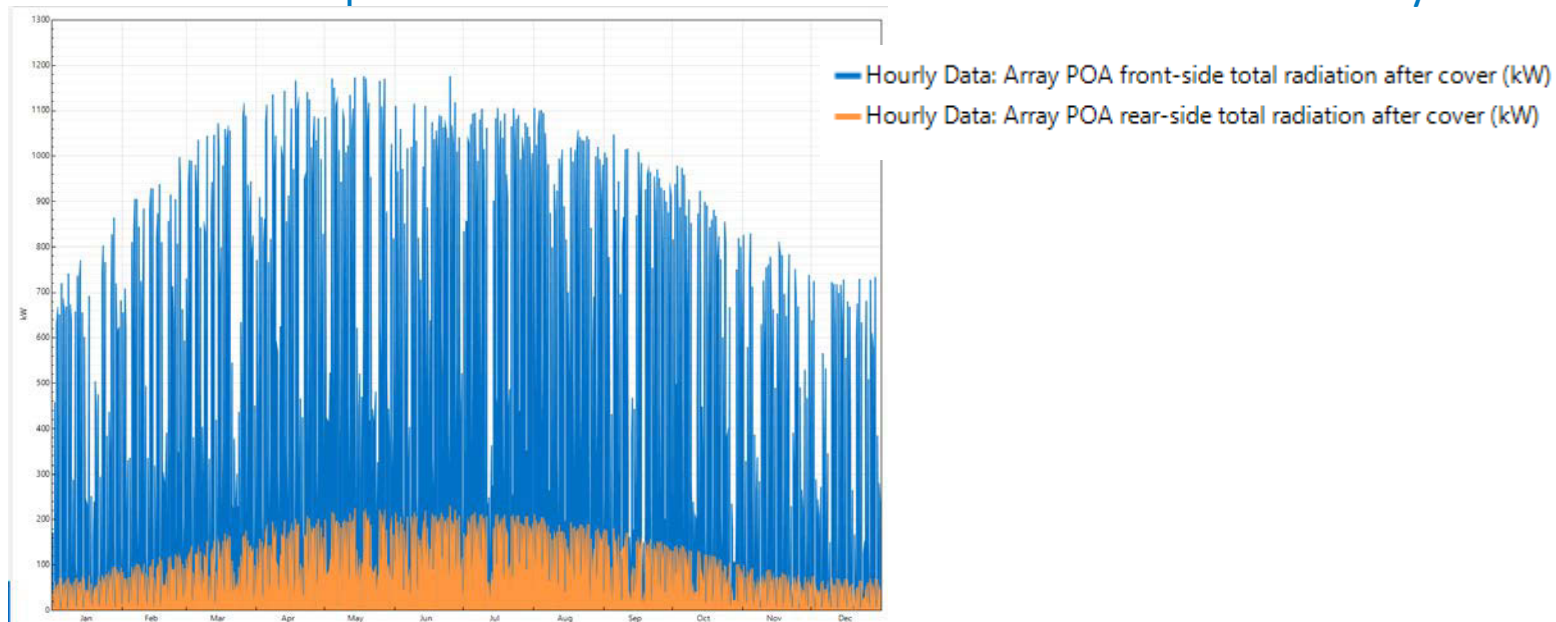
- Mismatch loss between front and rear-side
- Shading due to mounting structure or tracking system
- Soiling on the rear-side

Bifacial model outputs

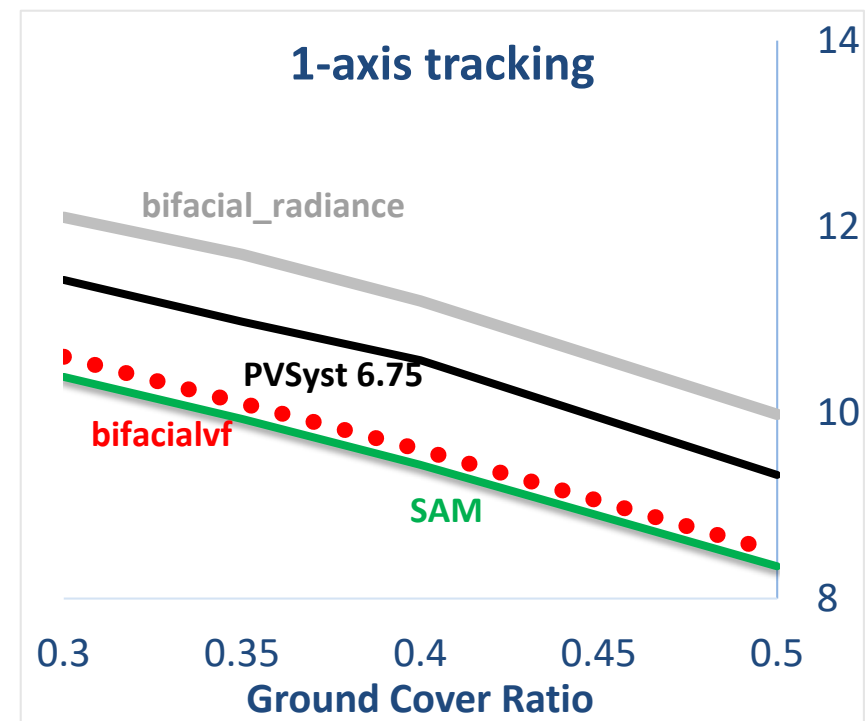
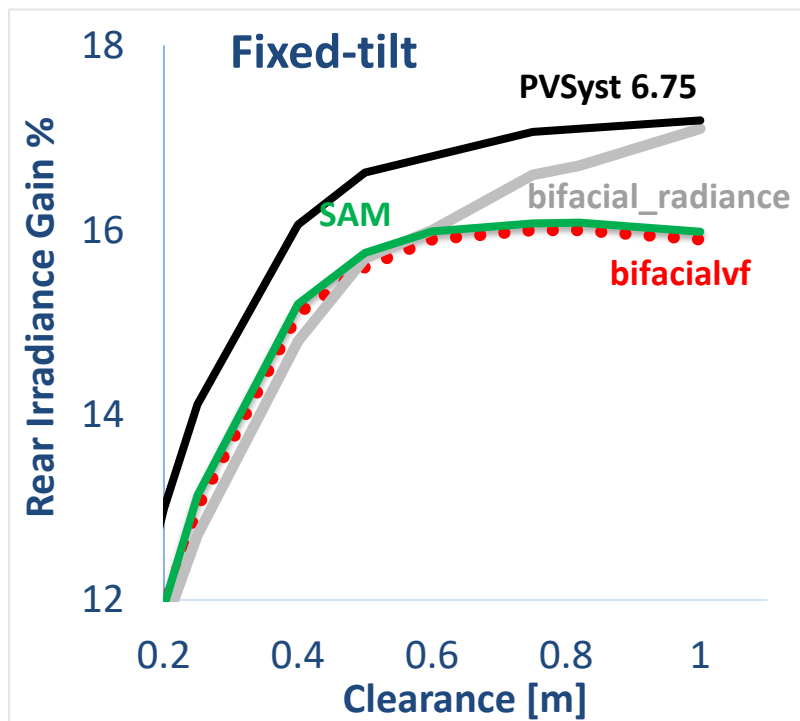
Updated loss diagram, showing bifacial irradiance gain



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



Model comparison



Preliminary results

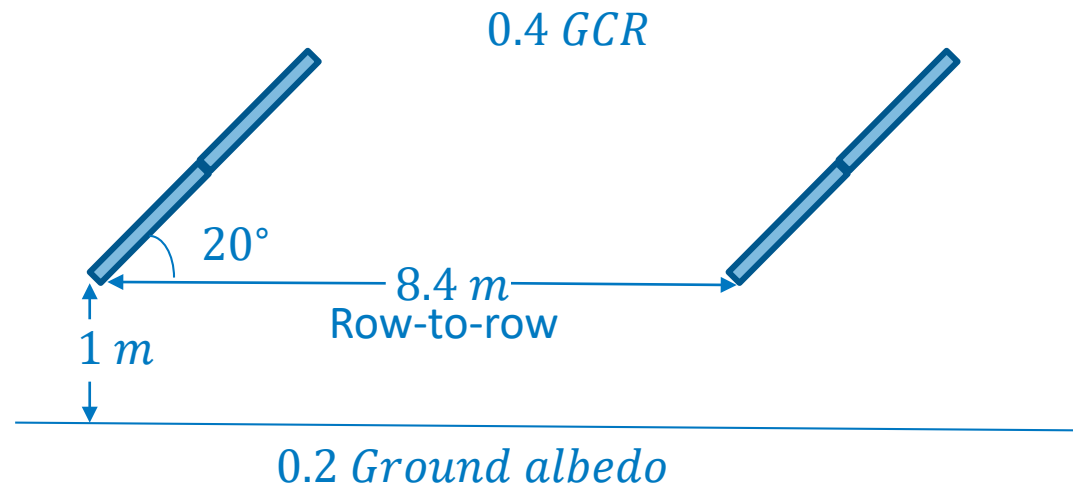
- SAM implementation closely tracks with bifacialvf prediction
- SAM tracks bifacial_radiance model at low ground clearances.
- SAM consistently predicts approximately 1-2% less rear-side irradiance than PVSyst
- For tracked systems bifacial_radiance predicts higher gain

Example analysis

- 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

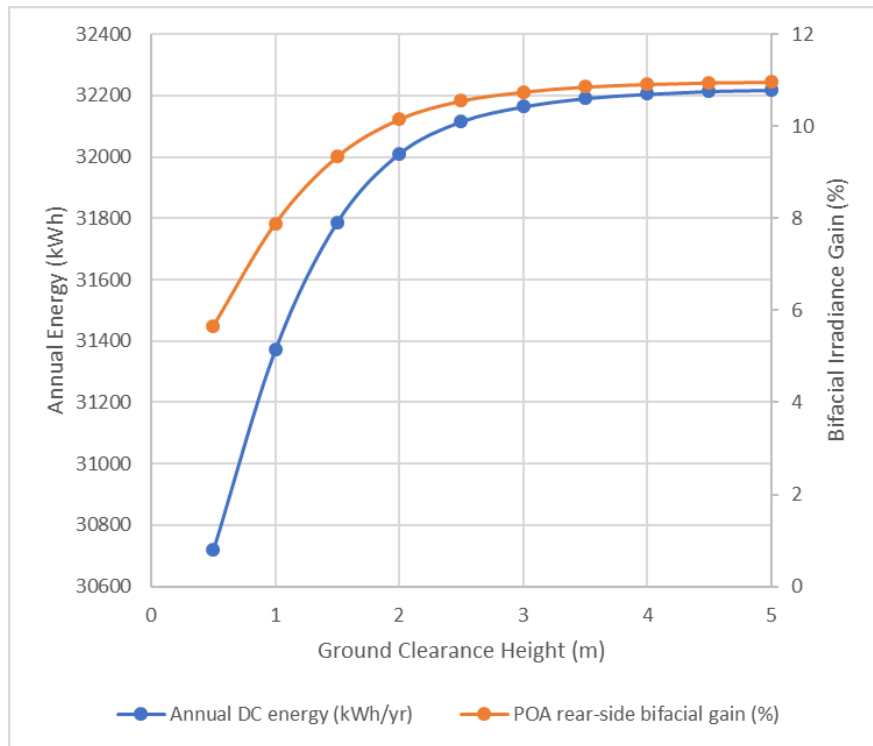
	Monofacial Fixed-tilt	Bifacial Fixed-tilt	Monofacial 1-axis track	Bifacial 1-axis track
POA Annual Irradiance (kWh)	190,961	206,030	254,943	265,187
Irradiance Gain	0%	7.9%	33.5%	38.9%
DC Annual Energy (kWh)	29,051	31,372	36,614	38,130
Energy Gain	0%	8.0 %	26.0%	31.3%

*Gains calculated relative to monofacial fixed-tilt system

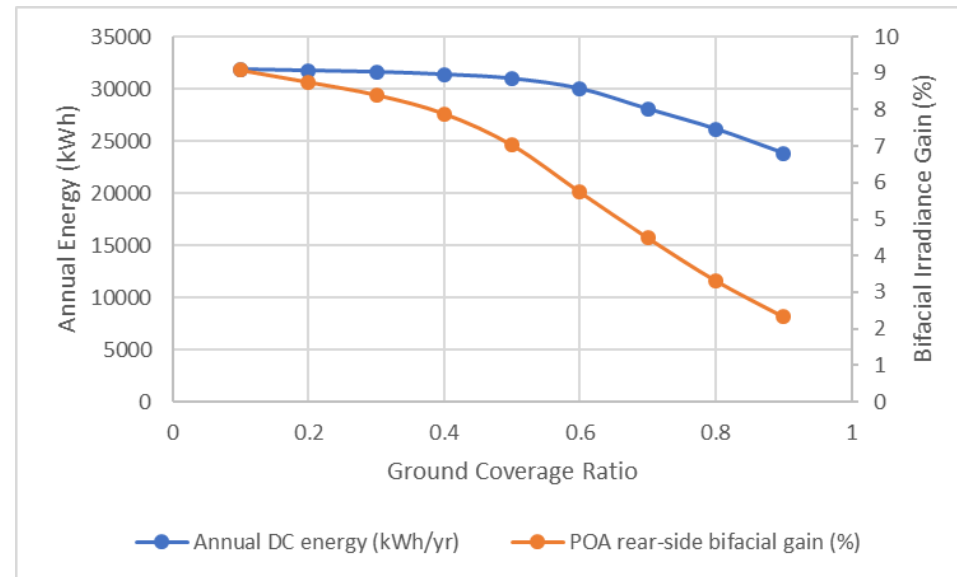
- DC energy gain is different from irradiance gain due to non-linear module response
- Installing 1-axis tracker on monofacial results in higher gain than installing bifacial (in this case).
- Installing bifacial modules with 1-axis trackers boosts annual DC energy by 31% over fixed monofacial system.

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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