Bifacial PV Performance Models: Comparison and Field Results

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Outline

• Project overview
• Rear irradiance models
• Field validation
• Edge effects
• Irradiance nonuniformity
3-Yr Bifacial Research Project (2016-2018)

Collaborative project between Sandia, NREL and University of Iowa
([pvpmc.sandia.gov/pv-research/bifacial-pv-project/](pvpmc.sandia.gov/pv-research/bifacial-pv-project/))

Task 1: Measure Outdoor Bifacial Performance

- **Module scale**
  - Adjustable rack IV curves (*height, tilt, albedo, and backside shading effects*)
  - Spatial variability in backside irradiance
  - Effects of backside obstructions

- **String scale**
  - Fixed tilt rack (*tilt, mismatch effects*)
  - Single axis tracker (*investigate potential*)
  - Two-axis tracker

- **System scale**
  - String level monitoring on commercial systems (*validation data*)

Task 2: Develop Performance Models

Ray Tracing simulation

- Bifacial_Radiance software release
  [github.com/cdeline/bifacial_radiance](https://github.com/cdeline/bifacial_radiance)
- Configuration analysis publication\(^1\)
  - Effect of row spacing, tilt optimization
  - Validation of model using Sandia field data

View Factor model

- BifacialVF software release
  [github.com/cdeline/bifacialVF](https://github.com/cdeline/bifacialVF)
- Method publication\(^2\)
  - Model detail and configuration
  - Validation of model using NREL field data
- Integration with SAM software scheduled 2018

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\(^1\) A. Asgharzadeh et al, “Analysis of the impact of installation parameters and system size on bifacial gain and energy yield of PV systems”, IEEE PVSC 2017

Radiance CumulativeSky pre-processor

Typical ray-tracing approach: use Perez model to generate hourly sky description
  - Runtime = \textbf{hours} for annual simulations

\textit{CumulativeSky} approach: sum annual hourly irradiance into 145 sky patches
  - Runtime = \textbf{seconds} for annual simulation.

Robinson, Stone “Irradiation modelling made simple: the cumulative sky approach” 2004
Modeling Rear Irradiance – parameters to consider

- **Albedo**
- **Row-to-row spacing**
- **Clearance**

Other parameters:

- **Size of array / simulation**
- **Location**
- **Weather**
- **Sky Diffuse Model**
- **Tilt**
- **Others:**
  - Spacing between cells
  - Shade obstructions
Bifacial Gain Calculation

\[ E_{bifacial} = (1 + BG_E)E_{monofacial} \]

Bifacial Energy Gain =

Module Bifaciality * Rear Irradiance Ratio – Mismatch, shading loss

Bifaciality = \( \frac{P_{mp,\text{rear}}}{P_{mp,\text{front}}} \) (from single side flash data)*

Rear Irradiance Ratio

= \( f(\text{albedo, tilt, row spacing, height, racking, module transparency, climate}) \)

Our focus today

* V. Fakhfouri IEC TS 60904-1-2 ED1 (2017)
Industry Bifacial Models for comparison

PVSystems – 2D “unlimited sheds” bifacial model
  - 6.6.4 update increased bifacial response

Solar World “Boost Calculator” – web interface
  - Empirical model, not climate sensitive

PVSyst 6.6.4 bifacial interface

SolarWorld online calculator
http://www.solarworld.de/fileadmin/calculator

Loss diagram over the whole year

- 1554 kWh/m²
  - +7.3% Horizontal global irradiation
  - -1.1% Global incident in coll. plane
  - -3.4% Near Shadings: irradiance loss
  - -38.0% IAM factor on global

- 471 kWh/m²
  - -9.0% Ground reflection loss (albedo)
  - -9.0% Form Factor (reemission to sky)
  - +0.5% Sky diffuse on the rear side
  - 0.0% Shadings loss on rear side

Front Irradiance
- 1591 kWh/m² * 285 m² coll.
  - efficiency at STC = 10.79%
  - 57.13 MWh

Rear Irradiance
- Effective irrad. on the rear side (267 kWh/m²)
- Effective irradiance on collectors

PV conversion, Bifaciality factor = 1.00
Array nominal energy (at STC effic.)
Model intercomparison - height

Low tilt high albedo rooftop application
Richmond VA, 1.5m row spacing, 10° tilt, 0.62 albedo
Model intercomparison – row spacing

Low tilt high albedo rooftop application
Richmond VA, 0.15 m height, 10° tilt, 0.62 albedo

Not very good agreement
Field Validation: 3-row mock array
Adjustable spacing, tilt, height
Field Validation: 3-row mock array
Low ground clearance configuration

Front & rear irradiance sensors
Mock array configuration - 4 rear, 2 forward facing irradiance

- Tilt = 10deg.
- Slant length = 610mm
- Height = 100 - 500mm
- Row spacing = 900 - 1800mm
- Albedo = 0.62
- Compare measured with site modeled conditions

(normalized)

→ 1
→ 0.16 - 0.9
→ 1.5 - 3
Mock Array – comparison with NREL models - Height

- 2 months field data
- RayTrace model reflects finite experiment size at high ground clearance.

\[
\frac{G_{\text{rear,meas}} - G_{\text{rear,model}}}{G_{\text{rear,meas}}} < 3\%
\]
Mock Array – comparison with models – Row spacing

- OK agreement. Additional conditions under test
System Modeling – Edge Effects

Richmond VA, 1.5 m row spacing, 10° tilt, 0.62 alb. 1m landscape module width 20 modules, 3 rows default
System Modeling – Edge Effects

# Modules / row

- Height = 3 m
  - * = 1% edge effect
- Height = 1 m
  - * = 1% edge effect
- Height = 0.25 m

Total # Rows

- Height = 3 m
  - * = 1% edge effect
- Height = 1 m
  - * = 1% edge effect
- Height = 0.25 m

Richmond VA, 1.5 m row spacing, 10° tilt, 0.62 alb. 1m landscape module width 20 modules, 3 rows default
Rear Irradiance Distribution and Mismatch loss

Current models only return an average value. This doesn’t capture additional shading or distribution mismatch loss.

Spatial distribution of rear irradiance increases for low ground clearance.

Energy loss can be significant (e.g. 10% bifacial gain -> 8%)

\[
\text{Energy loss } \% = \frac{kWh_{avg} - kWh_{detailed}}{kWh_{avg}}
\]
Thank you!

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NREL View Factor Model\textsuperscript{1}

- Ground divided into $n$ segments in row-to-row direction and shading determined for each
- Irradiance on each ground segment found using view of the sky (configuration factors)
- Rear side irradiance is sum of sky, ground reflected, object reflected components
- Runtime \textbf{4 seconds} for annual simulation

\textsuperscript{1}B. Marion, “A Practical Irradiance Model for Bifacial PV Modules”, \textit{IEEE PVSC}, 2017.
Ongoing work: Single-axis tracking

Improvement: the view factor model has been extended to apply to bifacial tracking PV systems. Field validation is underway.