Challenges and Opportunities in Widespread Bifacial PV Adoption

Utility-scale solar development in 2020

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Bif 2019 Worksp, Amsterdam NL
AGENDA: OVERVIEW

A  IEC efforts in standardization of bifacial performance monitoring & performance testing

B  Bifacial performance models and parametric sensitivities

C  Project economics and optimization of system design
IEC EFFORTS IN STANDARDIZATION OF BIFACIAL PERFORMANCE MONITORING & PERFORMANCE TESTING
AN OVERVIEW OF THE SOLAR RESOURCE

From a bifacial point of view...

\[ G_{\text{front}} \]
\[ G_{\text{rear}} \]
\[ G_{\text{diff}} \]

(fixed tilt, summer morning/evening)
\[ G_{E_i} = 1000 \, Wm^{-2} + \varphi \cdot G_{R_i} \]  

\[ \varphi = \text{Min}(\varphi_{Isc}, \varphi_{P_{max}}) \]  

\[ G_{E_i} \quad \text{[\text{\text{-}]} \text{ Equivalent Irradiance}} \]
\[ \varphi \quad \text{[\text{\text{-}]} \text{ Bifaciality Coeff}} \]

PV Devices, Part 1-2 Measurement of I-V characteristics of Bifacial PV Devices
A. Project Team formed and tasked with defining Bifacial PV performance standard following TC82 Plenary Meeting in Busan, S. Korea (Oct. 2019)

B. Final draft edits to IEC 61724-1 complete. Project team is seeking comments by no later than 10/31/2019

C. Major overhaul to defined terms were necessary (rear-side plane-of-array irradiance, spectrally-corrected albedo, etc)

D. Expect to have IEC 61724-1 revision with bifacial system consideration committee draft (CD) submitted within the 2019 calendar year

\[
PR_{\text{annual -eq,bi}} = \left( \sum_{k} P_{out,k} \times \tau_k \right) / \left( \sum_{k} \frac{C_k \times P_0 \times G_{i,k} \times BIF \times \tau_k}{G_{i,\text{ref}}} \right)
\]
3.16 spectrally-corrected in-plane rearside irradiance ratio

\[ \rho^{\text{inc}} \]

The in-plane rearside irradiance ratio per 3.16 when both irradiance quantities are measured with a spectrally matched reference device or with the application of spectral correction factors per IEC 60904-7.

3.17 spectrally matched reference device

A reference device (such as a PV cell or module) with spectral response characteristics sufficiently close to those of the PV modules in the PV array such that spectral errors are acceptably small under the typical range of incident spectra.

3.18 in-plane rearside irradiance

\[ G^{\text{inc}}_{\text{rear}} = G_{\text{POA}}^{\text{inc}} \]

Is the sum of direct, diffuse, and ground-reflected irradiance incident on the rear side of the modules in the PV array, also known as rearside plane-of-array (POA) irradiance.

Note 1 to entry: Expressed in units of \( \text{W/m}^2 \).

Note 2 to entry (if measured via in-plane rearside irradiance ratio): \( G^{\text{inc}}_{\text{rear}} = \rho_{\text{inc}} \times G_{\text{POA}} \)

3.19 bifacial irradiance factor

BIF

A dimensionless variable that can be directly multiplied by the frontside in-plane irradiance (\( G_{\text{f}} \)) to calculate the "effective" irradiance reaching a bifacial device from both the front and rear side collectively.

Note 1 to entry: \( \text{BIF} = (1 + \psi_{\text{inc}} \times \rho_{\text{inc}}) \)

Note 2 to entry: rearside POA irradiance can be measured simultaneously with frontside POA irradiance using a bifacial reference cell. In that case, \( \text{BIF} = G^{\text{inc}}_{\text{rear}}/G_{\text{POA}} \) provided that frontside POA irradiance is measured with same type of device as the bifacial reference cell for consistency of the BIF calculation.
BIFACIAL PERFORMANCE MODELS AND PARAMETRIC SENSITIVITIES
### Commercial Bifacial PV simulation software

**Modeling assumptions in currently released versions**

<table>
<thead>
<tr>
<th>PVsyst Features</th>
<th>NREL VF</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D simulation of sheds</td>
<td>✔️</td>
</tr>
<tr>
<td>Monthly albedo values</td>
<td>✔️</td>
</tr>
<tr>
<td>Circumsolar anisotropy for back side diffuse</td>
<td>✗</td>
</tr>
<tr>
<td>IAM for backside reflections</td>
<td>✗</td>
</tr>
<tr>
<td>Diffuse shading w/trackers</td>
<td>✗</td>
</tr>
<tr>
<td>Irradiance non-uniformity</td>
<td>✗</td>
</tr>
<tr>
<td>Spectral-corrected backside irradiance</td>
<td>✗</td>
</tr>
<tr>
<td>Specular reflections</td>
<td>✗</td>
</tr>
</tbody>
</table>

- IMEC, EnergyVille, PVCase releasing performance simulation model in 1H 2020
Parametric sensitivities

Albedo, racking height (tracker)

- Albedo
- Racking height (tracker)

<table>
<thead>
<tr>
<th>Albedo</th>
<th>Racking height</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>4.0%</td>
<td>6.0%</td>
</tr>
<tr>
<td>8.0%</td>
<td>10.0%</td>
</tr>
<tr>
<td>12.0%</td>
<td>14.0%</td>
</tr>
<tr>
<td>16.0%</td>
<td></td>
</tr>
</tbody>
</table>

**Reference Solar Site (with winter snow ground cover)**

<table>
<thead>
<tr>
<th>Surface</th>
<th>Typical albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest asphalt</td>
<td>0.24%</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.18%</td>
</tr>
<tr>
<td>Bore ice</td>
<td>0.12%</td>
</tr>
<tr>
<td>Gravel frost</td>
<td>0.23%</td>
</tr>
<tr>
<td>Desert sand</td>
<td>0.35%</td>
</tr>
<tr>
<td>Bare soil</td>
<td>0.11%</td>
</tr>
<tr>
<td>Green grass</td>
<td>0.22%</td>
</tr>
<tr>
<td>Snow covered</td>
<td>0.14%</td>
</tr>
<tr>
<td>New concrete</td>
<td>0.13%</td>
</tr>
<tr>
<td>Oceanic ice</td>
<td>0.3-0.4%</td>
</tr>
<tr>
<td>Forest snow</td>
<td>0.4-0.6%</td>
</tr>
</tbody>
</table>

**REL % GAIN IN MWH/YR VS. BASECASE**

- MONO-FACIAL
- BI-FACIAL

**REL % CHANGE IN YEARLY MWH VS. BASECASE**

- TRACKER HEIGHT WHEN HZ (M) - SINGLE PORTRAIT
Parametric sensitivities
Bifaciality Factor

PERC’s bifacial capability is perhaps the key feature that will make the technology spread wider and reign longer than many anticipate…

Every 1% increase in Annual Energy Production ~1.5¢/Wp in NPV

Presented at BiFi Workshop 2018
Parametric sensitivities
*Structure shading, backside mismatch loss*

- Initial Estimates (not based on field data):
  1. 2P Tracker = 5% Mismatch/2.5% Structure Shading
  2. 1P Tracker = 10% Mismatch/10% Structure Shading

- TOTAL IMPACT OF SHADING/MISMATCH ~1.5% on MWh/yr per 10% increase
Racking type (Tracker)
1P vs. 2P (single portrait/dual portrait)

- Lower Aspect Ratio of Module Width to Tracker height produces better “ViewFactor”
- Single Portrait vs. Dual Portrait = 2% Gain in performance (fixing all other variables)
Racking type (Tracker) – Horizontal (noon)
1P vs. 2P (single portrait/dual portrait)

Racking Type | 1P vs. 2P

Single-Portrait

Dual Portrait
Racking type (Tracker) – Angled, morning/evening
1P vs. 2P (single portrait/dual portrait)

Single-Portrait

Dual Portrait
Racking type (Tracker) – Unconstrained Height
1P vs. 2P (single portrait/dual portrait)

Single-Portrait

Dual Portrait
PROJECT ECONOMICS AND OPTIMIZATION OF SYSTEM DESIGN
Bifacial – The disruptive technology of our time
PV Plant Optimization Software

*Multivariable optimization of design based on financial output*

**Major Equipment**
1. PV Modules
2. Inverter
3. Racking System

**Operating Expenses**

**Design Goals**
- DC/AC Ratio, GCR, Project Size

**Energy Production Assumptions**
- Weather model
- Loss Factors

**Site Constraints**
- Project Boundary
- Exclusion Areas
- PCC/POI

**Design Optimization**

- Manual approach to design optimization is inherently limited…

- Potential for 1000’s of combinations
- All possible designs must be constrained by project boundaries & various exclusion areas

**PV Plant Optimization Software**

Multivariable optimization of design based on financial output

- Potential for 1000’s of combinations
- All possible designs must be constrained by project boundaries & various exclusion areas
- Manual approach to design optimization is inherently limited…
BIFACIAL VS. MONOFACIAL SYSTEM DESIGN OPTIMIZATIONS

Project site in Georgia (higher DHI/GHI)
BIFACIAL VS. MONOFACIAL SYSTEM DESIGN OPTIMIZATIONS

Project site in California (lower DHI/GHI)
Modeled Bifacial gains around the U.S.

*All horizontal SAT systems (relative gains, same GCR+DC/AC ratio)*

- **Indiana**: Bifacial Gain = 6.3%
  - Bifacial yield: 1,529 kWh/kWp
- **S. California**: Bifacial Gain = 3.2%
  - Bifacial yield: 2,078 kWh/kWp
- **Georgia**: Bifacial Gain = 5.2%
  - Bifacial yield: 1,808 kWh/kWp
- **Alabama**: Bifacial Gain = 2.6%
  - Bifacial yield: 1,712 kWh/kWp
- **Colorado**: Bifacial Gain = 4.8%
  - Bifacial yield: 1,968 kWh/kWp
- **Wisconsin**: Bifacial Gain = 6.0%
  - Bifacial yield: 1,448 kWh/kWp
- **Washington**: Bifacial Gain = 6.3%
  - Bifacial yield: 1,647 kWh/kWp

Bifacial gains | Across the US

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*Silfab Solar*
Summary and Conclusions

A. Bifacial adoption is happening much faster than anticipated

B. Performance guarantees will be challenging, but international standards will be necessary to pave the way

C. Modeling energy production of bifacial systems is in very early stages, but likely on the conservative side

D. Project economics are overwhelmingly favorable, but design and optimization require new ways of thinking
THANK YOU
FOR
YOUR ATTENTION