Best Practices for Bifacial Energy Modeling

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As the first round of utility-scale bifacial projects approach financing, developers, lenders, and stakeholders are concerned about energy modeling risk.

This presentation outlines practices for bifacial energy modeling and uncertainty associated with current approaches.
Presentation Outline

• System Design Optimization

• Solar Resource Input Data

• Energy Modeling Considerations

• Sources of Energy Uncertainty
Bifacial Design Optimization
Differences between Monofacial and Bifacial Designs

- Several design differences are common between monofacial and bifacial systems.
- For bifacial projects:
  - DC-AC ratio is lower by ~5% to achieve optimal inverter limitation loss
    \[\textit{Bifacial advantage is often realized as a combination of DC capacity cost reduction and energy gain.}\]
  - Greater row spacing (GCR reduction by ~5% absolute)
  - Tracker/mounting structure height is significant, up to a point, with increased mounting structure costs
- Optimized design is situation-dependent (considering PPA rate, land availability, climatology, etc.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Monofacial Example</th>
<th>Bifacial Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-AC Ratio</td>
<td>1.30</td>
<td>1.25</td>
</tr>
<tr>
<td>Ground Cover Ratio</td>
<td>40%</td>
<td>35%</td>
</tr>
<tr>
<td>Structure Height</td>
<td>Minimal impact on energy</td>
<td>Influences back-side irradiance</td>
</tr>
<tr>
<td>Module-to-Module Clearance</td>
<td>1-2 cm is typical</td>
<td>May be expanded for light to pass through</td>
</tr>
<tr>
<td>Mounting Structure</td>
<td>Traditional</td>
<td>Design minimizes back-side shading</td>
</tr>
<tr>
<td>Bifacial Advantage</td>
<td>3-9%, realized as DC system cost reduction and/or energy gain</td>
<td></td>
</tr>
</tbody>
</table>
Solar Resource Input Data
Contributors to Solar Resource

- Front-side global plane of array (Front POA)
  - Driven by global horizontal irradiance (GHI)
  - Influenced by diffuse horizontal irradiance (DHI)

- Back-side global plane of array (Back POA)
  - Influenced by albedo

- Total POA = Front POA + Back POA

Measurements: Reduce Uncertainty in Front and Back POA

- Redundant “Class A” GHI measurements expected
- DHI is beneficial for all sites to reduce POA uncertainty (measured DHI is twice as accurate as most models)
- Albedo measurements are recommended for bifacial
  - Modeled data sources (PSM, Meteonorm, SolarGIS) have more uncertainty
- Additional meteorological measurements
  - Temperature
  - Wind speed
  - Relative humidity
  - Precipitation
- Best practices for bifacial measurement collection are outlined in supplementary poster presentation
Albedo Measurement Considerations

- **Ground Conditions.** Prepared and maintained on a regular basis.

- **Mounting.** Proper mounting ensure that downward instrument has unobstructed field of vision. Regular levelness checks are needed.

- **Height Above Ground.** Approximate the PV array’s height. Avoid shading on upward facing instrument.

- **Azimuthal Orientation.** 180° orientation (sunward side) to prevent shadows.

- **Shadow Mitigation.** Structures to south, east, and west sufficiently far away to prevent shadows on albedometer or in field of vision.
Case Study to determine bifacial POA sensitivity to resource

- Adjust DHI in increments of 5% and re-compute POA
- Adjust Albedo in increments of 2.5% (absolute)

Results:

- Similar relationships for Texas and Illinois
- DHI has small direct impact to back-side POA
- DHI has minimal impact to total POA
  - Bifacial advantage, since there’s an inverse relationship for monofacial projects
- Albedo has meaningful direct impact on total POA
  - Modeled albedo can be 2-5% different from measured albedo (absolute)

### Site Characteristics

<table>
<thead>
<tr>
<th>Location</th>
<th>Texas</th>
<th>Illinois</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHI (kWh/m²/yr)</td>
<td>1746</td>
<td>1504</td>
</tr>
<tr>
<td>Base Case DNI (kWh/m²/yr)</td>
<td>1642</td>
<td>1488</td>
</tr>
<tr>
<td>Base Case DHI (kWh/m²/yr)</td>
<td>675</td>
<td>618</td>
</tr>
<tr>
<td>Base Case Albedo (%)</td>
<td>20.0%</td>
<td>23.2%</td>
</tr>
<tr>
<td>Average Temperature (°C)</td>
<td>21.7</td>
<td>12.1</td>
</tr>
<tr>
<td>Average Wind Speed (m/s)</td>
<td>4.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Snow</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Project Design

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Crystalline Bifacial</th>
<th>Crystalline Bifacial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>Tracking</td>
<td>Tracking</td>
</tr>
<tr>
<td>DC-AC Ratio</td>
<td>1.24</td>
<td>1.30</td>
</tr>
<tr>
<td>GCR</td>
<td>35-40%</td>
<td>35-40%</td>
</tr>
</tbody>
</table>

### Results: Summary of Energy-to-Resource Relationships

<table>
<thead>
<tr>
<th></th>
<th>DHI/Back-Side POA</th>
<th>DHI/Total POA</th>
<th>Albedo/Back-Side POA</th>
<th>Albedo/Total POA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>3.8%</td>
<td>3.5%</td>
<td>3.5%</td>
<td>3.5%</td>
</tr>
<tr>
<td></td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>
Impact of Albedo on Bifacial (Total) POA

For both sites, a 3% (absolute) increase in albedo resulted in:
- +10% increase in back POA
- +1% increase in total POA

Texas
\[ y = 0.33x + 0.00 \]

Illinois
\[ y = 0.31x - 0.00 \]
### Resource Impacts on Bifacial Energy Estimates

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Purpose</th>
<th>Measurement Accuracy</th>
<th>Percent Impact on Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHI</td>
<td>Principle measurement for solar resource assessment</td>
<td>1-2%</td>
<td>A 2% increase in GHI corresponds to about 1.5% increase in energy</td>
</tr>
<tr>
<td>POA</td>
<td>Assists with verifying POA transposition model accuracy</td>
<td>1-2%</td>
<td>A 2% increase in POA corresponds to a similar increase in energy</td>
</tr>
<tr>
<td>DHI</td>
<td>Increases accuracy of POA transposition for energy modeling</td>
<td>4-6%</td>
<td>A 5% decrease in DHI corresponds to a 1-2% increase in energy (because of DNI relationship)</td>
</tr>
<tr>
<td>Albedo</td>
<td>Improves characterization of back-side POA for bifacial projects</td>
<td>2-4%</td>
<td>For tracking system, 3% increase corresponds to about 10% increase in back-side irradiance, about 1% increase in overall energy</td>
</tr>
<tr>
<td>Temperature</td>
<td>Improves accuracy of non-STC temperature loss for PV projects</td>
<td>0.5°C</td>
<td>A 3°C increase in temperature corresponds to a loss increase of about 1%</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>Improves accuracy of non-STC temperature loss for PV projects</td>
<td>0.5 m/s</td>
<td>(Dependent on site conditions)</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>Improves accuracy of spectral performance modeling</td>
<td>3%</td>
<td>(Dependent on PV technology)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Frequency of rain/snow events for module cleaning</td>
<td>1%</td>
<td>Informsoiling and snow loss</td>
</tr>
<tr>
<td>Soiling System</td>
<td>Power loss due to dirt, debris, snow</td>
<td>(Dependent on system design)</td>
<td>Informsoiling and snow loss</td>
</tr>
</tbody>
</table>
Energy Modeling Considerations
Energy Modeling in PVsyst

- Detailed light modeling:
  - Back-side irradiance modeling
  - Front-side 3D shading losses

- Less detailed loss modeling:
  - Back-side shading (2D, simple generic factor for mounting structure impact)
  - Back-side soiling
  - Back-side condition-based “mismatch” contributors (irregular shading and soiling)
  - Correlation of monthly albedo with snow loss?
  - Bifacial degradation assumption
Sources of Energy Uncertainty
The back-side energy contribution is expected to have more uncertainty than the front side for the following reasons:

- Albedo and DHI accuracy (measured more accurate than modeled)
- Bifaciality factor uncertainty in the field
- Back-side loss modeling
- The back-side energy contribution may be between 20-40% uncertain (1σ). Examples with respect to total energy:
  - Back-side contribution of 5%, ± 1.5%
  - Back-side contribution of 8%, ± 2.4%
Summary and Conclusions

– Optimal bifacial system designs tend to have:
  • Lower DC-AC ratios and lower ground cover ratios
  • Taller mounting structures and more clearance between modules
  • Situation-specific cost-benefit analysis (ratios, structures, electrical, etc.)

– Typical bifacial advantage of 3-9%, realized as DC system cost reduction and/or energy gain

– On-site albedo and diffuse horizontal measurements can reduce uncertainty in the back-side POA
  • A 3% increase (or decrease) in albedo can result in a 1% increase (or decrease) in total POA

– In the future, bifacial energy modeling uncertainty can be reduced by the following:
  • More complex simulation and loss models
  • Field performance data to calibrate model assumptions
Thank you for your attention.

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Total megawatts assessed

500+
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