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Diffuse Irradiance and Tracker Simulations
Why *Are* We Backtracking?

**Performance-related benefits.** An analysis of energy performance (see next section) demonstrates the energy collection advantages of backtracking systems versus conventional tracking. This results from the fact that the energy losses due to increased incidence angles are not as great as losses due to shading. This is especially true for non-shade-tolerant (i.e., series) panel designs and large ground cover ratios. Also, tracker...
Shading Response

- First Solar modules are laid-out in landscape configuration
- Shadow always perpendicular to the short edge of cells
- Ignoring edge effects, shading has a similar diurnal profile on a fixed-tilt and a north-south axis horizontal tracker arrays
Why Are We *Not* Backtracking?

- Backtracking “backs off” the optimum tracker tilt angle, to completely avoid tracker-to-tracker shading, which is detrimental to Si modules because the voltage contribution of entire cells is lost.

- This approach eliminates Beam (Direct) shading, *but not the other types of shading*. Diffuse sky and diffuse ground “shading” still exist, in varying amounts, throughout the day.

- “Truetracking” (not “backtracking”) with First Solar’s linear shading response (when shadow edge is perpendicular to the module’s cells) produces more energy.

- Modeling direct beam shading has good agreement with experimental data.

- Diffuse and albedo shading is sometimes ignored, especially when backtracking is activated, risking an over-estimate of the backtracking advantage.

### Backtracking Deactivation Experiment

<table>
<thead>
<tr>
<th>Observation</th>
<th>Condition</th>
<th>Power Profile – All Day</th>
<th>Power Profile – Morning Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 28, 2012</td>
<td>All systems BT</td>
<td><img src="image1" alt="Power Profile" /></td>
<td><img src="image2" alt="Power Profile" /></td>
</tr>
<tr>
<td>September 9, 2012</td>
<td>Median System &amp; System C BT</td>
<td><img src="image3" alt="Power Profile" /></td>
<td><img src="image4" alt="Power Profile" /></td>
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<tr>
<td>September 20, 2012</td>
<td>Median System BT, Systems C and D TT</td>
<td><img src="image5" alt="Power Profile" /></td>
<td><img src="image6" alt="Power Profile" /></td>
</tr>
</tbody>
</table>
When was backtracking in Systems C & D deactivated?
Diffuse Shading Algorithm (1-D)

• Diffuse shading = 1 for tilt = 0
• Normalized horizontal distance between rows
• Diffuse shading factor

\[
d = \frac{\Delta_{pp} - W_t \cos \beta}{W_t \sin \beta} = \frac{D}{W_t \sin \beta}
\]

\[
\mu_{sh,D} = \cos^2 \frac{\beta}{2} - \frac{1}{2} \left( \sqrt{d^2 + 1 - d} \right) \sin \beta
\]

\[
\beta \quad \text{module tilt angle}
\]

\[
\Delta_{pp} \quad \text{post-to-post spacing}
\]

\[
W_t \quad \text{table width}
\]

Diffuse Shading Algorithm (2-D)

- Generalized version over 2 dimensions - determine the sky field of view from observation point $g$, occluded by neighboring row.
- Calculate the integral over the solid angle subtended by the top edge of the “infinitely long” row in front, applying both the beam incidence angle modifier $\text{IAM}(\theta)$ and the regular cosine response $\cos(\theta)$ terms due to non-normal incident irradiance.
- Compute shading factors explicitly at each time step – will be static for fixed-tilt arrays, but dynamic for trackers.
- Can be expanded to account for back-of-module and ground irradiance.
Field of View
Example Shading Factors for a Single Day

- **Horizontal tracker**
  - Limit angles of ±45°
  - Active area width 2.5 m
  - Post spacing 5.5 m
  - GCR 0.45
    - \( \mu_{\text{IAM},B} = 1 - b_0 \left( \frac{1}{\cos \theta} - 1 \right) \), \( b_0 = 0.03 \)

- Diffuse shading factor is a function of array tilt and row spacing

- Beam shading factor is linear with progression of shadow after trackers have reached their mechanical stops
Conclusions – Tying It All Together

• With backtracking enabled in the simulation tool, not accounting for diffuse shading in backtracking systems can overestimate energy generation by 1%-2%.
  o Backtracking only eliminates beam shading. Other types of shading (diffuse, albedo) are still present

• Due to First Solar modules’ linear shading response, even when accounting for diffuse shading in conjunction with true tracking, First Solar systems will still yield more energy over an equivalent backtracking system

• Increase is about 1% - 2%

Different modeled DC power output for the same system between 9:00 and 14:00!
Creating enduring value by enabling a world powered by clean, affordable solar electricity.