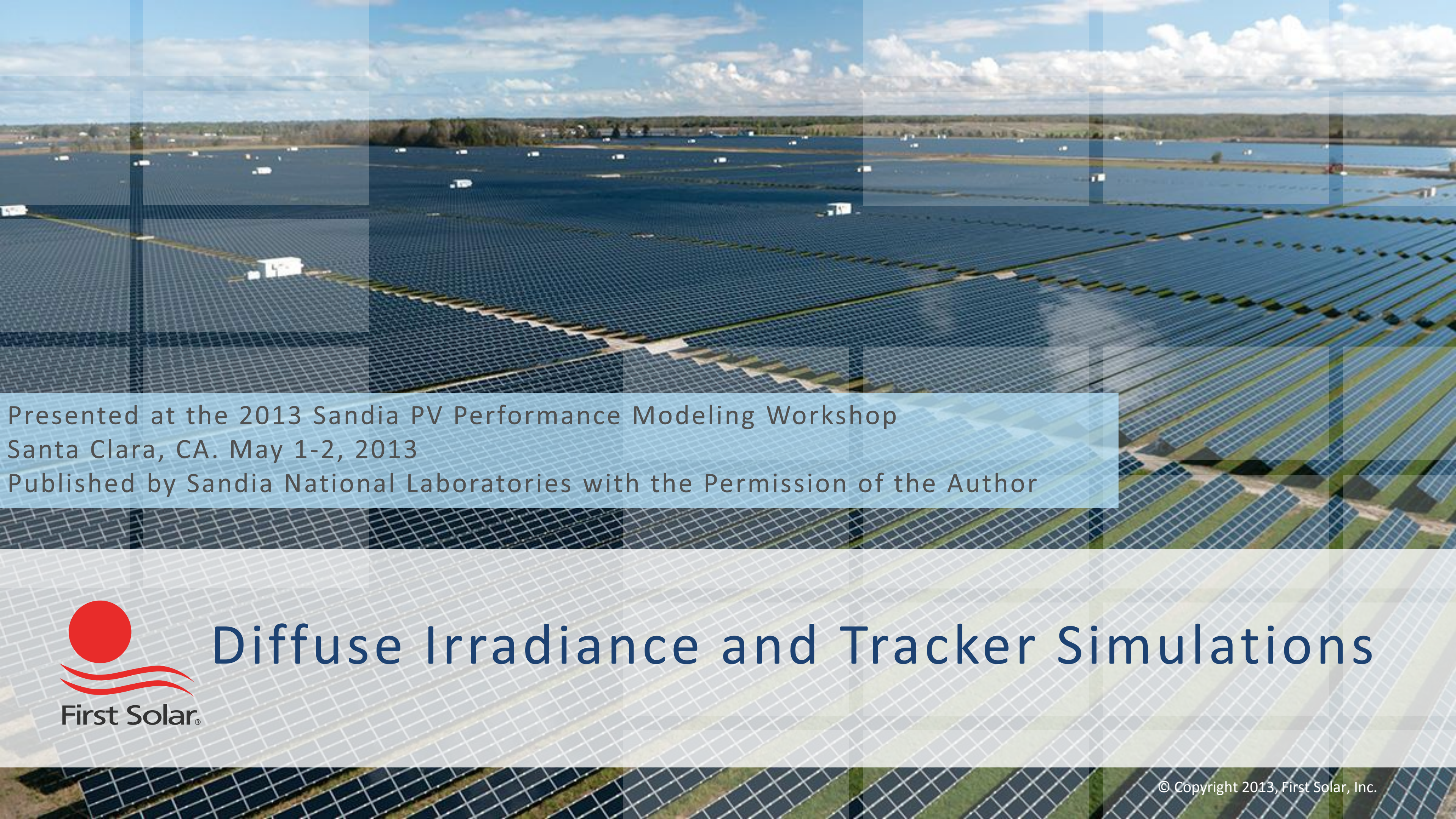

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First Solar®

Diffuse Irradiance and Tracker Simulations

Why *Are* We Backtracking?

First Solar

BACKTRACKING: A NOVEL STRATEGY FOR TRACKING PV SYSTEMS

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Advantages of Backtracking

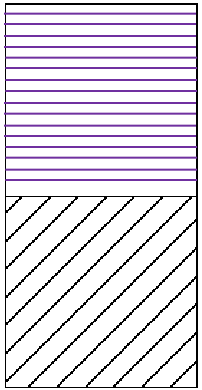
The use of backtracking can provide four main types of benefits: area-related due to closer-packed arrays; performance and reliability-related due to the elimination of inter-array shading; and design-related when used with series-configured panels.

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

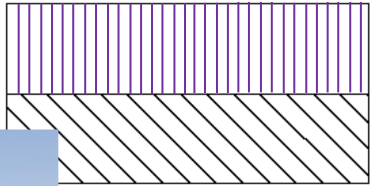
In a conventional one-axis tracking scheme, *bypass diodes conduct each day.* Long-term reliability of diodes for this application needs to be studied. It is possible that failures due to loose heat sinks or other causes could shorten diode design life, and thus leave some cell strings unprotected from reverse bias *conditions, and subject to the failures described above.* It follows that strings requiring protection most often will experience greatest diode failures, as these are conducting most frequently.

Shading Response

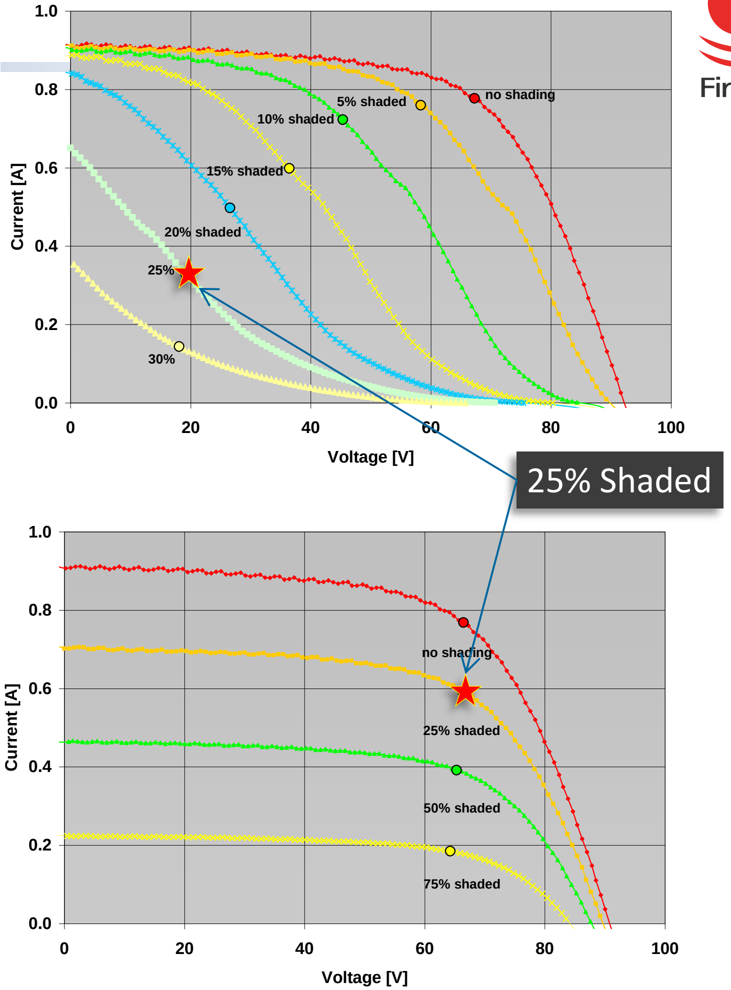
- First Solar modules are laid-out in landscape configuration
- Shadow always perpendicular to the short edge of cells
- Ignoring edge effects, shading has a similar diurnal profile on a fixed-tilt and a north-south axis horizontal tracker arrays



SHADED ALONG 600mm DIMENSION

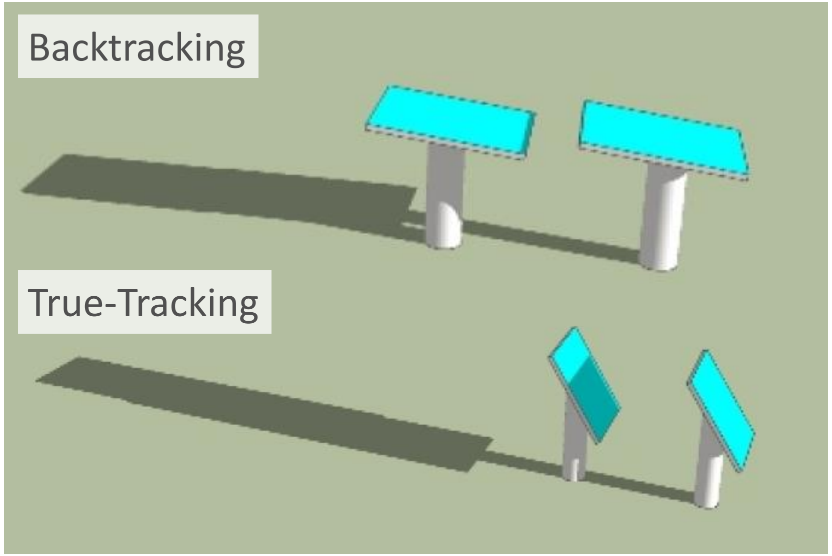


SHADED ALONG 1200mm DIMENSION



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



Images: http://www.lauritzen.biz/Solutions/backtracking.pdf

- "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

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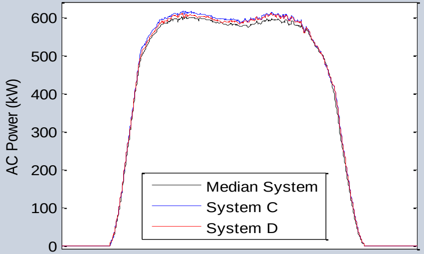
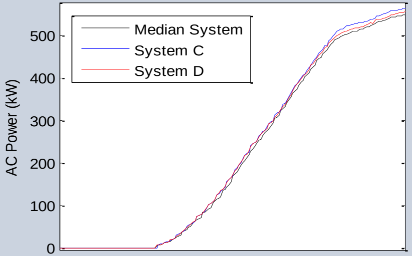
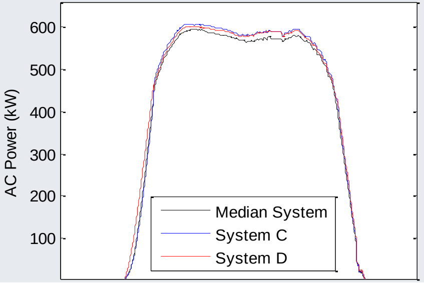
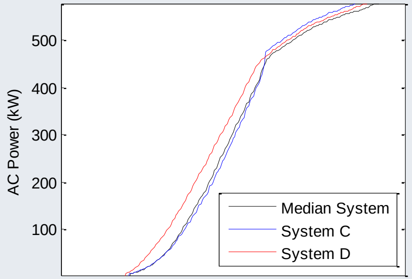
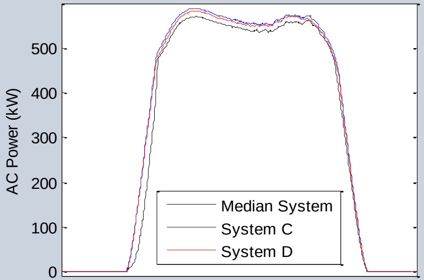
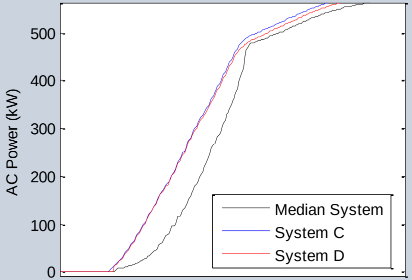
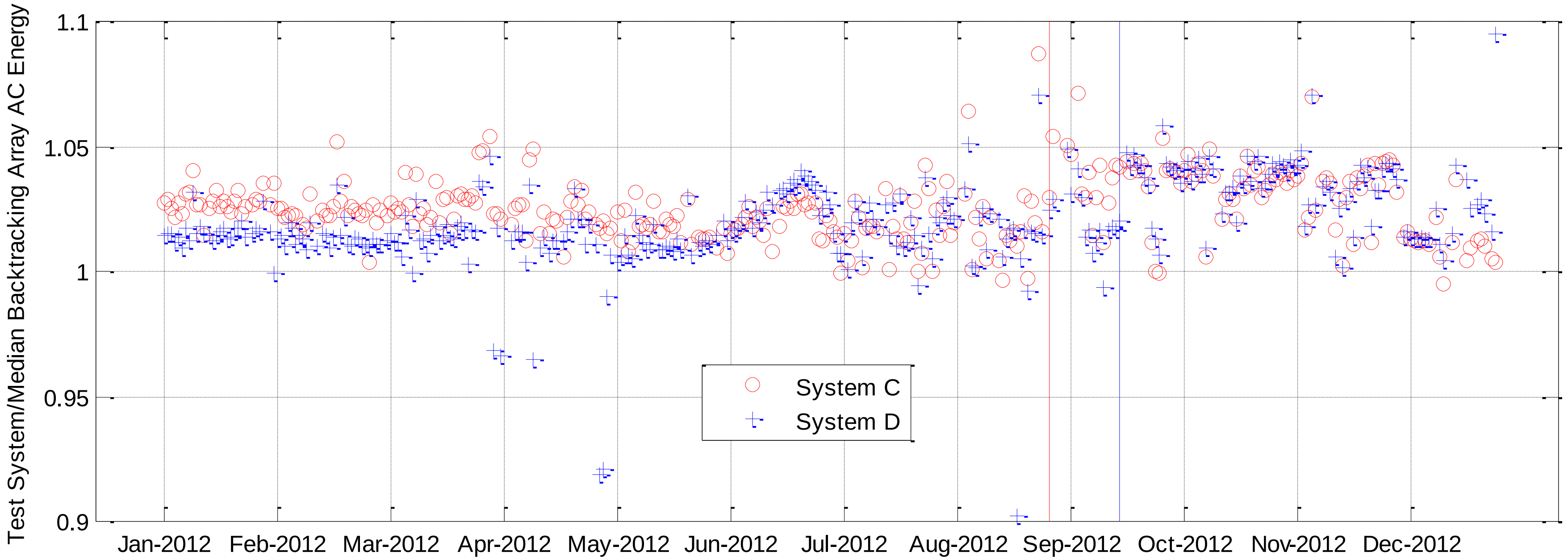
Observation	Condition	Power Profile – All Day	Power Profile – Morning Only
August 28, 2012	All systems BT		
September 9, 2012	Median System & System C BT System D TT		
September 20, 2012	Median System BT Systems C and D TT		

Backtracking vs. True Tracking over a Year



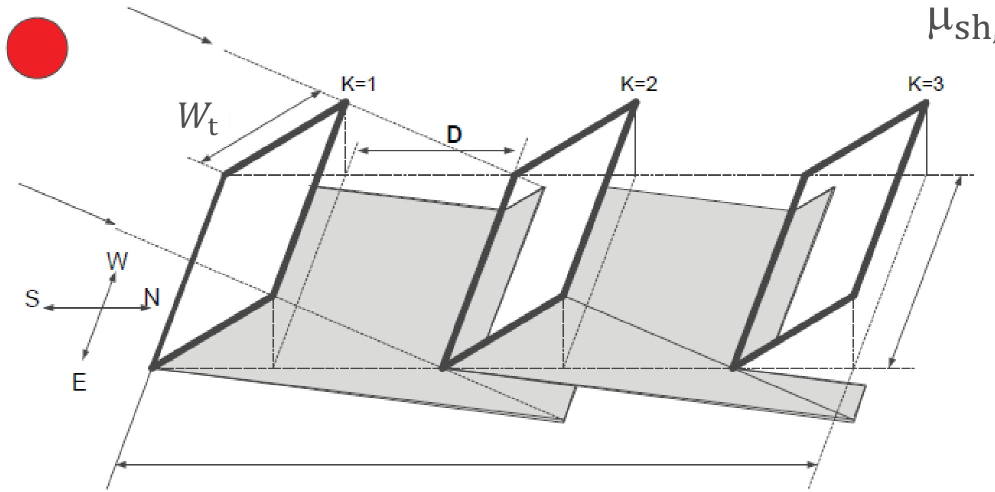
When was backtracking in Systems C & D deactivated?

Diffuse Shading Algorithm (1-D)

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

$$d = \frac{\Delta_{\mathrm{pp}} - W_{\mathrm{t}} \cos\beta}{W_{\mathrm{t}} \sin\beta} = \frac{D}{W_{\mathrm{t}} \sin\beta}$$

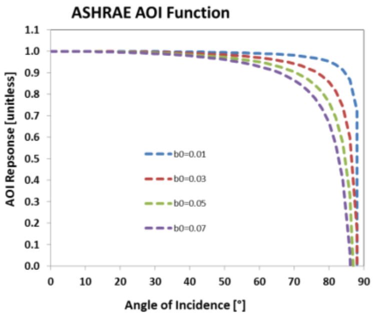
$$\mu_{\mathrm{sh,D}} = \cos^2\frac{\beta}{2} - \frac{1}{2}\left(\sqrt{d^2+1} - d\right)\sin\beta$$

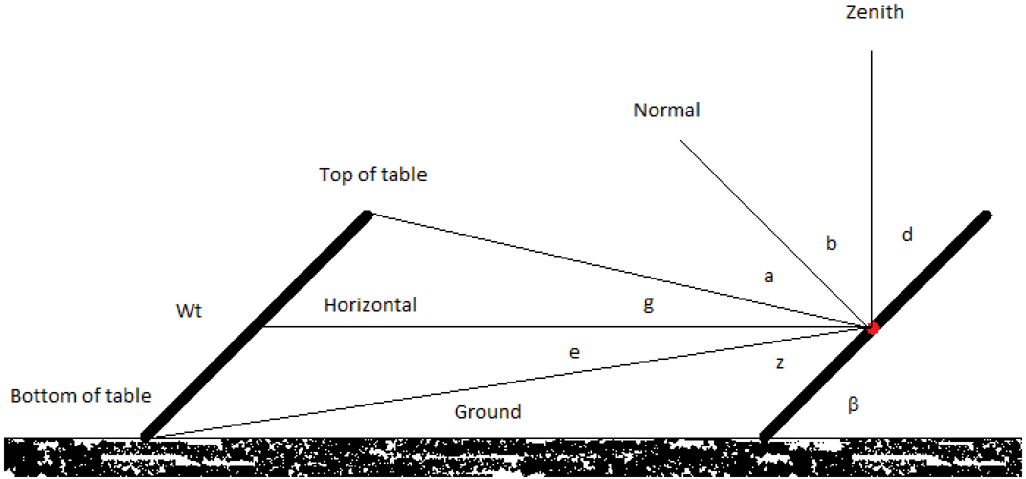


β	module tilt angle
Δ_{pp}	post-to-post spacing
W_{t}	table width

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 IAM(Θ) and the regular cosine response cos(Θ) terms due to non-normal incident irradiance

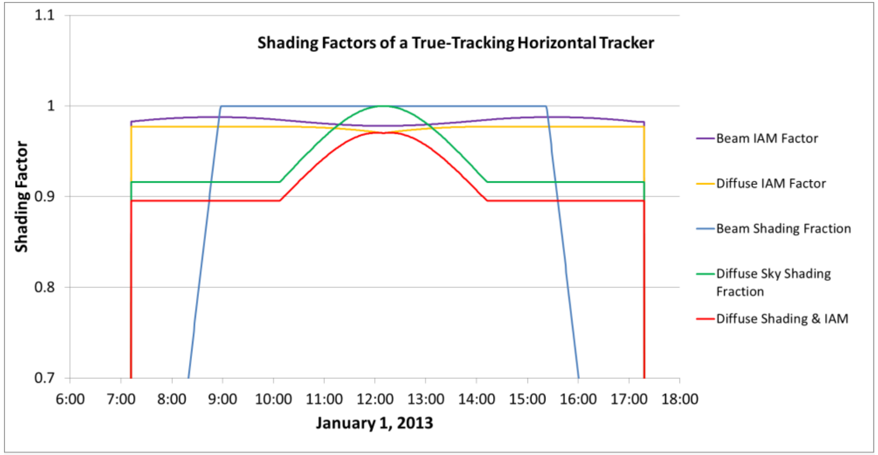


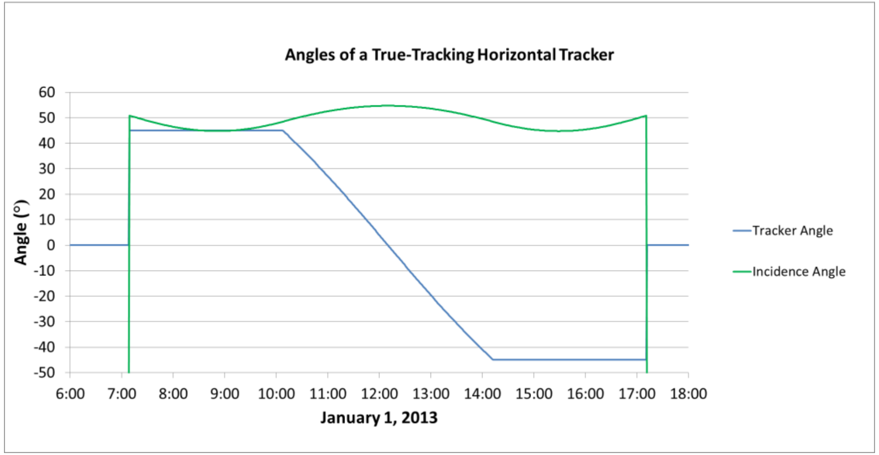


- Compute shading factors explicitly at each time step – will be static for fixed-tilt arrays, but dynamic for trackers
- Can be expanded to account for back-of-module and ground irradiance

Field of View

Example Shading Factors for a Single Day

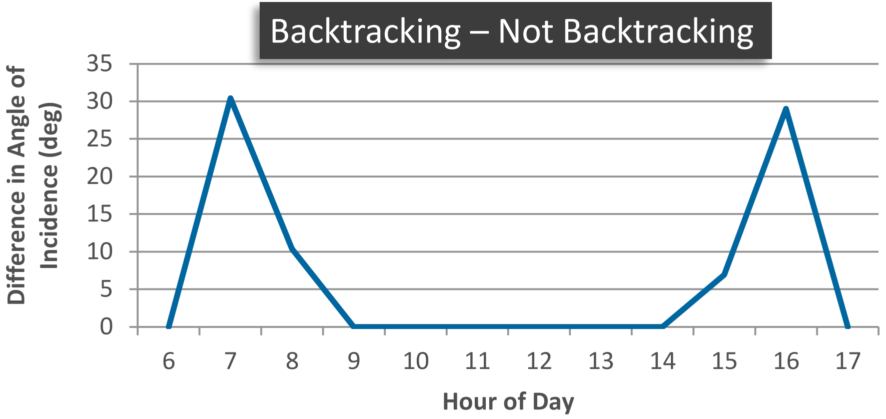


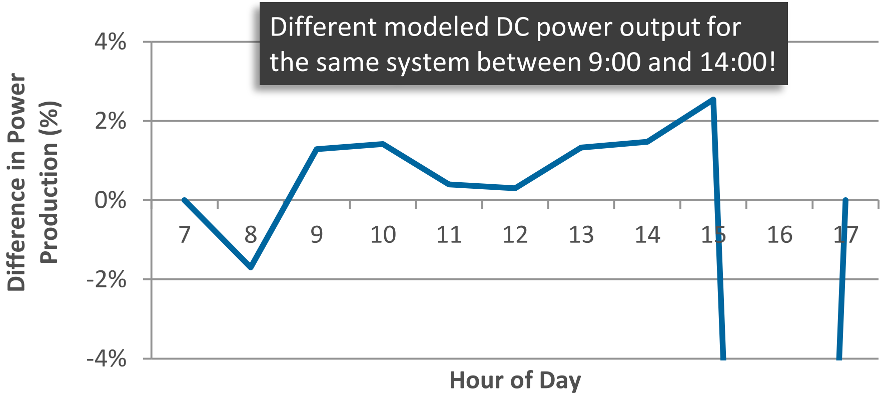


- Horizontal tracker
  - Limit angles of ±45°
  - Active area width 2.5 m
  - Post spacing 5.5 m
  - GCR 0.45
  - $\mu_{IAM,B} = 1 - b_0\left(\frac{1}{\cos\Theta} - 1\right), b_0 = 0.03$
- Diffuse shading factor is a function of array tilt and row spacing
- Beam shading factor is linear with progression 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%.
  - 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 ***truetracking***, First Solar systems will still yield more energy over an equivalent backtracking system
- Increase is about 1% - 2%





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