Advanced Solar PV Energy Pre-Construction Losses

Losses due to uneven terrain, tracker wind stowing, and sub-hourly clipping error

Renn Darawali, Lucila D. Tafur, Alana Benson
(*renn.darawali@ul.com, lucy.tafurgamarra@ul.com, alana.benson@ul.com*)
August 23, 2022

INTRODUCTION

Several industry publications have recently reported on under-performance for some utility-scale solar projects. In response, independent engineers and energy modelers have revisited energy modeling practices to identify potential areas for refinement. This model review has focused on areas where existing modeling software programs may have inherent limitations or oversights.

UNEVEN TERRAIN LOSS

Complex terrain incurs an additional row-to-row shading loss for single axis tracker projects due to non-uniformity of adjacent tracker heights. The impact of complex terrain is a higher row-to-row shading loss commensurate with the level of sloping throughout the site. The method includes:

1. Calculate distribution of project-specific slopes based on 10m DEM data from USGS. Slopes isolated for the active PV area.
2. Calculate loss from database of reference simulations (195)
3. Uneven terrain loss is applied within the Module Quality Adjustment

Reference Simulation Description
• Region: (3) Various diffuse profiles
• Ground Cover Ratios: (5) 0.30, 0.35, 0.40, 0.45, 0.50
• West to East facing slopes: (13) -10% to +10% (increments of 2%)

Results:

1. Publicly available elevation data is utilized to characterize site terrain (10-m spatial resolution)
2. GCR and slope play a significant role in loss magnitude, with higher sensitivity in tightly packed arrays.
3. Losses can be negligible or significant (at times greater than 1%)

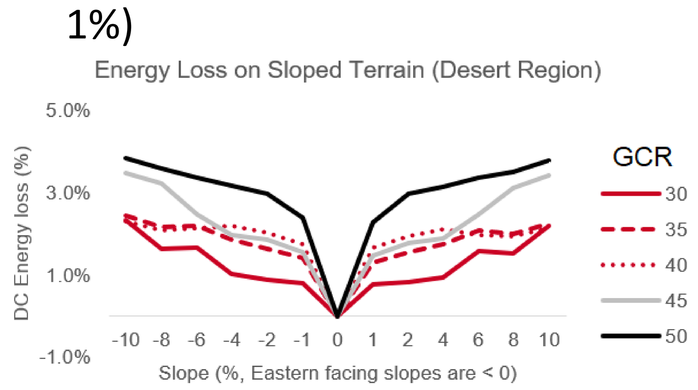


Figure 1 Simulation results after independently altering tracker row heights in PVsyst.

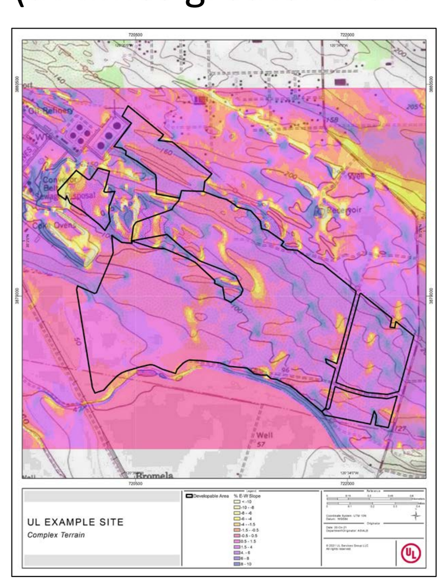


Figure 2 Example of slope characterization of a system using digital elevation data

WIND STOW LOSS

For single-axis tracking PV systems, tracker stow strategies are used to prevent structural failure or collapse during high wind events. Although in most cases system damage is avoided, there is still a loss associated with keeping a PV array in non-optimal position for the duration of a high wind event.

Methodology:

- Twenty year 10-m ERA5 timeseries data is used with the site-specific stow strategy to identify the specific hours that would trigger a stow event.
- Two twenty-year energy timeseries are compared: one for the base case scenario and one for the stow-impacted scenario.
- Difference between the base case and stow-impacted scenarios used to represent the final stow loss.

Analysis:

The methodology was tested on sites across the US in varying regions and wind regimes. All sites were assessed for 0, 30, and 60 degree stow scenarios and simulated as active stow strategies.

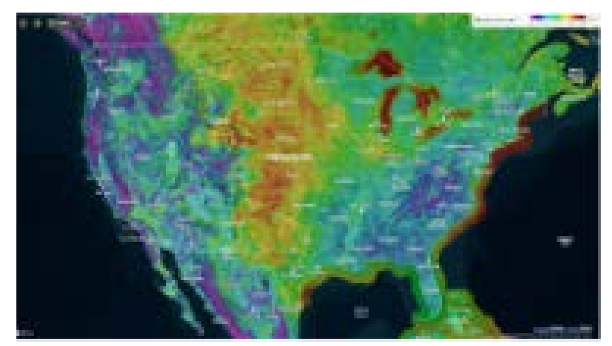


Figure 2 *Windnavigator*. Wind regimes across the continental US.

Results:

Results show that the stow loss is influenced by the following factors:

1. **Wind regime and site complexity.** A consistent source of wind speed and wind direction data is necessary to accurately capture the magnitude of this loss. The loss is higher at sites where high wind speeds occur in the direction sectors of interest (East and West).

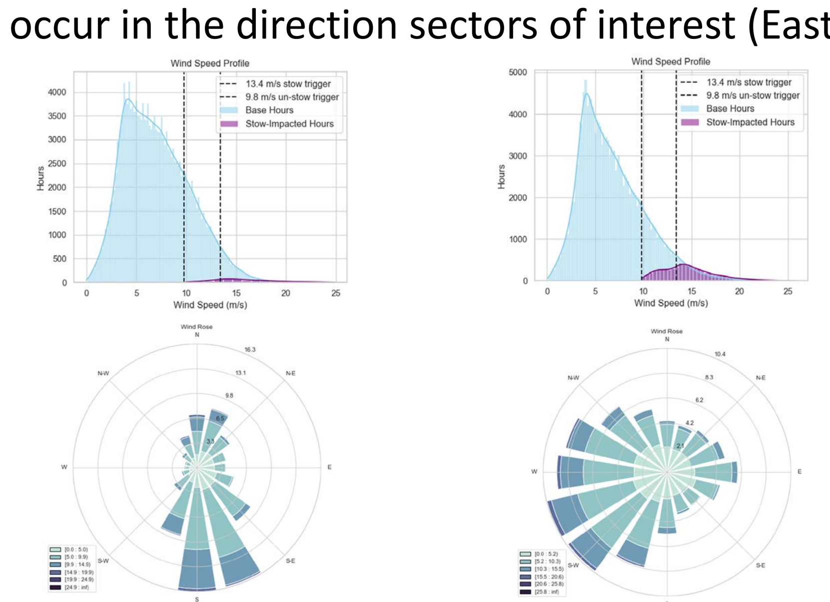


Figure 3 (Left) Wind rose and speed profile showing stow-impacted hours overlayed on total wind speed hours at Site A. (Right) Wind rose and speed profile showing stow-impacted hours overlayed on total wind speed hours at Site B. Although Site A consistently hits higher wind speeds, the wind rose is not predominantly in the East-West sectors of interest; therefore, the site experiences a much lower stow loss than at Site B.

2. **Tracker strategy**. In addition to the stow threshold, the stow angle is a secondary driver of magnitude. In most cases, higher losses are observed when stowing flat or at the maximum rotation angle.

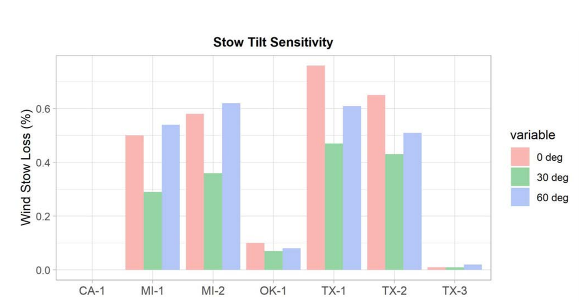


Figure 4 Stow sensitivity tests conducted across 6 sites in the US.

SUB-HOURLY CLIPPING ERROR

Industry standard solar energy modeling practices commonly rely on hourly simulation models. Due to inverter clipping events, hourly simulations may not capture the full magnitude of the inverter limitation loss that occurs in real time.

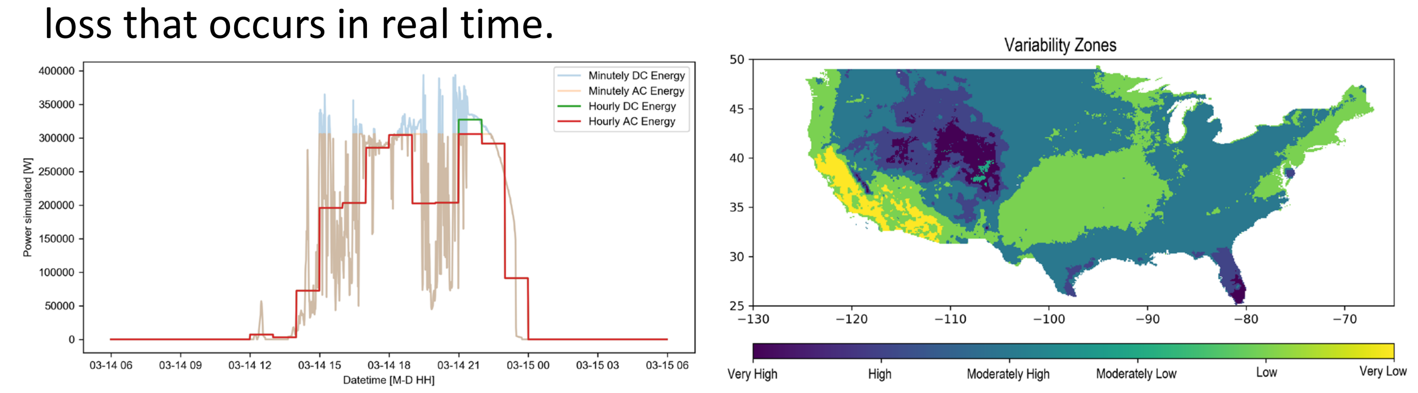


Figure 5 (Left) Example profile of minutely energy compared to its hourly averaged equivalent. (Right) Variability zones across the continental US (Lave et al. 2017) [1]

Analysis:

- For each variability zone, one-minute (1-min) frequency data from solar ground measurements is transposed to plane of array irradiance and converted to DC energy.
- The 1-min DC energy is also aggregated to an hourly timescale.
- AC and POI limitation losses applied to both 1-min and hourly records.
- The sub-hourly error is calculated from the difference between the losses calculated for the two timescales.

Results:

Effect of Variability Zone

1. Inverted CDF shows the amount of time spent above a threshold at different ratios.
2. Increased variability results in increased loss and sensitivity to error.
3. Example results for one system (1.3 DC:AC Ratio, Tracking System):

- Moderate High: ~2%
- Moderate Low: ~1.7%
- Low: ~1%
- Very Low: ~0.5%

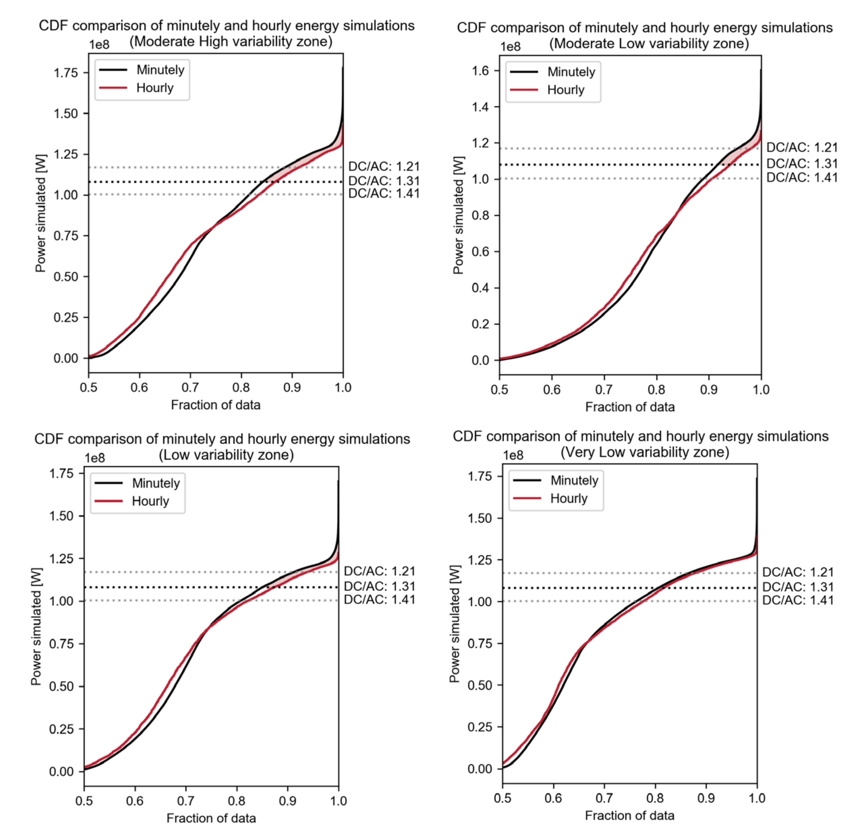
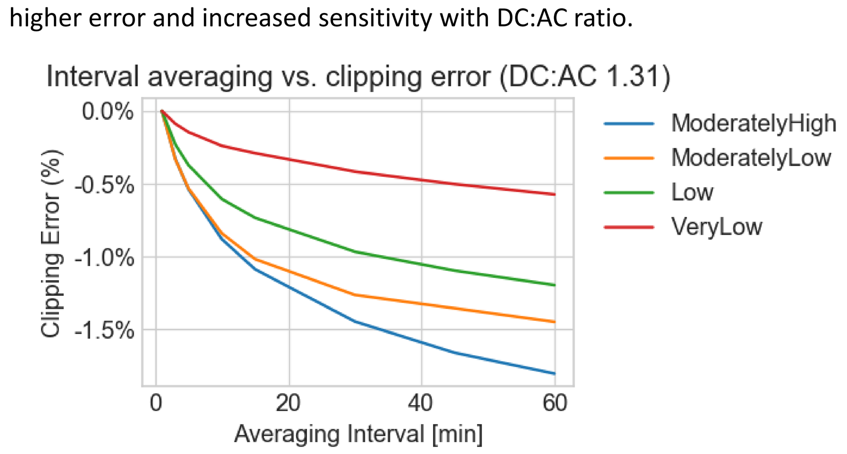


Figure 6 Inverse cumulative distributions of an example project site under a variety of variability zones conditions. VeryLow zone shows little error and low sensitivity with DC:AC ratio. ModHigh shows higher error and increased sensitivity with DC:AC ratio.

Effect of averaging interval

1. Majority of discrepancy appears within the 1-min to 15-min averaging interval.
2. Hourly-to-15-min error captures only ~30% of hourly-to-1-min error.



CONCLUSIONS

Uneven Terrain:

In order to incorporate additional shading loss due to tracker row-to-row shading, UL has developed a database of reference simulations to calculate additional shading loss.

Project-specific array layout information along with high resolution elevation data is used to calculate a project-specific loss. Depending on these inputs, the loss can range from fractions of a percent to values greater than 1%.

Wind Stow:

It is important to consider stow on a timeseries basis (rather than a typical year) in order to best capture extreme weather events.

Wind stow is a site and technology-specific loss, influenced by:

1. Wind regime and complexity of the site
2. Stow strategy – the stow angle and the stow trigger speed

Sub-hourly Clipping Error:

1. One-min observations can be used to visualize and calculate clipping loss errors, and to understand sensitivity
2. System design details (including configuration and DC:AC ratio) are drivers in loss sensitivity
3. Ground-measured 1-min irradiance data is vital in understanding sub-hourly variability, as lower resolution data may overlook a portion of the loss.

In analyzing possible reasons for under-performance in utility scale solar energy production, modelers have found several areas that may have been overlooked in previous modeling practices or simulation programs. UL is committed to continually evaluating modeling practices for a more accurate solar energy model.

REFERENCES

[1] M. Lave, R. J. Broderick, and M. J. Reno, "Solar variability zones: Satellite-derived zones that represent high-frequency ground variability," Solar Energy, vol. 151, pp. 119–128, Jul. 2017, doi: 10.1016/j.solener.2017.05.005.

[2] Uneven terrain loss: In collaboration with RB RE Consulting LLC, (contributor: Rhonda Bailey).

UL Solutions

Safety. Science. Transformation.™