

The Propeller Effect – Yield and Reliability Impacts on Tracker Projects

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Abstract

Azimuth Advisory Services (AAS) has developed a proprietary twist model to evaluate how tracker structural dynamics translate into module-level risk. Field analysis has demonstrated that torque tube twist is not just a structural concern but also a direct driver of forces imparted into PV modules. Excessive twist creates racking misalignment, differential loads across glass surfaces, and non-uniform support conditions that accelerate fatigue. Historically, module datasheets specified maximum allowable twist tolerances, but such guidance has largely disappeared, leaving developers and owners without a clear benchmark. This absence creates ambiguity in both warranty enforcement and performance risk assessments.

Further complicating the issue, many stakeholders conflate UL mechanical load standards with true torsional performance limits. UL certification confirms safety against specific static loads but does not define dynamic structural interaction between modules and trackers. AAS's analysis bridges this gap by quantifying how twist contributes to non-uniform shading patterns, module mismatch, and subsequent yield loss. Early findings indicate that even modest angular distortion can induce measurable reductions in energy production over the life of a plant. By combining proprietary modeling with real-world field data, AAS provides the industry with a framework to evaluate and mitigate torsional risk, ultimately preserving long-term performance and reliability.

Targeted Audience

- Project Developers
- Asset Owners and IPPs
- Engineering, Procurement & Construction (EPC) Companies
- Independent Engineering Firms (IEs)
- Tracker Manufacturers
- Structural Engineers
- Module Manufacturers
- Performance Modeling and Energy Assessment Firms
- Operations and Maintenance (O&M) Providers
- Insurance Companies
- Financiers and Tax Equity Providers
- Standards Committees
- Testing Laboratories
- Warranty and Claims Specialists
- Research Institutions
- Academia

Background: Propeller Effect & Tracker Design

Single-axis tracker rows experience torsional rotation under normal operating and wind loading conditions. This progressive twisting along the torque tube is commonly referred to as the "propeller effect," as angular distortion increases from the row center toward the free end, like the geometric twist of an aircraft propeller blade.

Azimuth Advisory Services (AAS) has documented propeller effects exceeding 20 degrees of cumulative twist from row center to row tip on utility-scale projects & technical due diligence assessments. While some degree of twist is inherent in all tracker systems, the critical issue is magnitude and its structural and performance implications.

Historically, module manufacturers included allowable twist tolerances in their datasheets. That guidance has largely disappeared, creating ambiguity around acceptable torsional exposure at the module level. Although all tracker systems exhibit this behavior to some degree, standardized limits governing cumulative twist remain poorly defined.

IEC 62817:2014 provides limited directional guidance, indicating that energy yield losses can be kept below 0.4 percent when pointing accuracy remains within ± 5 degrees of the energy-maximizing ideal. This tolerance includes both controller tracking error and physical row twist. Given that controllers typically operate within ± 1 degree, this implies that cumulative physical twist should remain within approximately ± 4 degrees along any given row to avoid measurable performance degradation.

Effects on Module Performance

The propeller effect can lead to decreased module performance on projects through two primary mechanisms:

1. Angular Misalignment and Shading Loss

Row twisting causes modules to deviate from the energy-maximizing tilt angle, directly impacting energy capture. The most visible consequence is increased shading toward row ends due to non-uniform panel orientation. Field observations have documented yield impacts exceeding 30 percent in affected sections of projects. These losses are often misattributed to errors in backtracking logic. While tracker controllers can be adjusted to mitigate shading, such adjustments do not eliminate the underlying structural distortion. A system operating with compensatory controller offsets does not perform equivalently to a system with minimal torsional deformation.

2. Cyclical Torsional Loading and Mechanical Degradation

In addition to production yield losses, repetitive torsional loading introduces potential mechanical fatigue at the module level. AAS has measured panel-level twist of up to 1.0 degree during normal tracking operation, without consideration of wind. This rotation is cyclical, occurring with every actuator movement and resulting in hundreds of thousands of loading cycles over a project lifetime. Such repeated distortion may be a primary contributor to glass cracking, cell microcracking, and long-term reliability degradation. This potential failure mode warrants controlled laboratory investigation.

Cumulative Twist Per Row

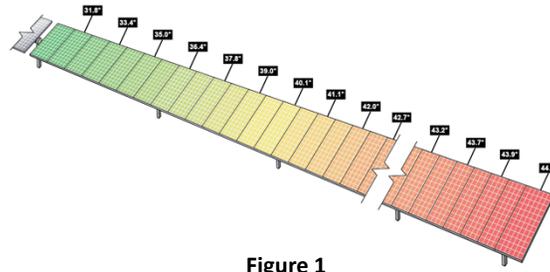


Figure 1

Figure 1 shows half of a typical ~ 112 module long row that is experiencing propeller effect. In the figure, the intended tracking tilt angle for the system is approximately 30 degrees, while the ends of the row point at 44 degrees, indicating 14 degrees of overall twist. As this is a 4-string tracker row, the image includes two full electrical strings. The inboard string includes panels tilted between 30.0 degrees and 40.1 degrees. The outboard string includes panels tilted between 40.4 degrees and 44.0 degrees, showcasing that twist along the row is not linear and each string is affected to different extents.

PV cells are current limiting devices, and this is the rationale behind including bypass diodes in their series circuitry architecture, but PV panels within a string are also largely current limiting devices and thus the string performance is impacted by the worst-case panel accuracy.

Project yield estimates typically ignore row twist, leading to overly optimistic financial projections and subpar real-world performance.

Twist Per Panel Analysis

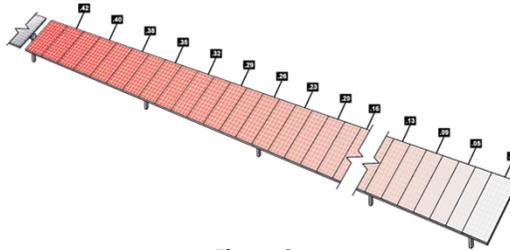


Figure 2

Figure 2 shows the twist across each individual panel within the tracker row, as predicted by the twist model. What isn't shown is the transient behavior of the row during actuation, which has been directly measured to result in approximately 100% greater peak twisting than the steady-state analysis would predict. This twisting is the physical mechanism by which the actuators move the system and so by necessity the twisting over each panel is cyclical in nature. Azimuth Advisory Services has effectively modeled this transient, cyclical response in the time-domain, though care must be taken to validate the results against real-world measurements.

The deflected shape shown in figure 2 represents a specific tracker configuration, a specific tilt angle, and a specific rotation direction of actuator travel. Other tilt angles, directions of rotation, wind effects, rain, snow, and several other site conditions will result in different deflected shapes and amplitudes of cyclical twisting. For this reason, analyzing a given tracker row for twist is a complicated undertaking. Lacking a full understanding of the yield and reliability impacts on panels, the industry should adopt and enforce the ± 5 -degree recommendation of IEC 62817:2014 for at least the worst-case operating condition without environmental loading.

AAS has observed correlation between peak panel twist and breakage rates in multiple field cases



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Effects on Overall System Yield

A first-order estimate of the pointing inaccuracy illustrated in Figure 1 indicates that the inboard string operates as though it were approximately 10 degrees off the energy-maximizing angle, corresponding to an estimated 1.5 percent yield reduction. The outboard string experiences an estimated 3.0 percent yield loss under the same conditions.

Adjusting the tracking algorithm to compensate for torsional distortion, for example advancing the tracking angle by approximately half of the total twist, or roughly 7 degrees in this case, reduces but does not eliminate losses. Even after correction, residual yield impacts of approximately 0.7 percent remain. Accurate correction requires modeling twist across all tilt angles, times of day, actuator directions, and environmental conditions. As shown in Figure 3, appropriate backtracking can eliminate visible inter-row shading; however, this does not resolve the underlying angular inefficiencies caused by cumulative torsional distortion. In practice, algorithm refinement typically stops once shading is removed.

The rapid tilt gradient across the inboard string also increases the likelihood that both strings experience inter-row shading during morning and evening backtracking. The characteristic triangular shading pattern shown in Figure 4, expanding toward row ends, indicates that torsional distortion rather than terrain variation or backtracking logic error is the dominant driver. In several documented cases, this effect has materially reduced or entirely offset the expected yield advantage of single-axis tracking relative to fixed-tilt systems.



Figure 3⁶



Figure 4⁶

Recommendations & Industry Actions

1. **Reintroduce Module Twist Specifications** - Module manufacturers should evaluate both static and dynamic torsional loading and reestablish allowable twist limits within datasheets, warranty documentation, and installation manuals. Historically, such limits were provided and served as critical design guidance.
2. **Quantify Cyclical Fatigue Exposure** - Modules may experience on the order of 500,000 torsional loading cycles over a project lifetime. The relationship between cyclical twist and glass breakage or cell microcracking requires controlled laboratory validation.
3. **Clarify Warranty Applicability** - It remains unclear whether module warranties will be honored in cases of twist-related cracking. Clear documentation and defined torsional limits would reduce ambiguity and dispute risk.
4. **Develop Standardized Twist Limits** - The industry should establish standardized module-level torsional performance criteria to complement tracker row limitations referenced in IEC 62817. Static load certification alone is insufficient to address dynamic torsional exposure.
5. **Incorporate Propeller Effect in Due Diligence** - Independent Engineers should calculate effective cumulative propeller effect during technical due diligence and communicate quantified yield impacts to developers, insurers, and financiers to strengthen financial modeling assumptions.
6. **Adopt Conservative Interim Limits** - Until validated industry standards are established, limiting individual module twist to less than 0.1 degrees and cumulative row twist to less than 4.0 degrees represents a prudent interim design approach.

More Information

Resources:

1. Anderson, K. S., and C. W. Hansen. 2024. "Simulated Performance Effect of Torque Tube Twisting in Single-Axis Tracking PV Arrays." 2024 IEEE 52nd Photovoltaic Specialist Conference (PVSC), Seattle, WA, USA, pp. 1377-1377. doi:10.1109/PVSC57143.2024.10745946.
2. IEC 62817:2014, Photovoltaic Systems – Design Qualification of Solar Trackers. International Electrotechnical Commission.
3. IEC 61215 (latest edition), Terrestrial Photovoltaic Modules – Design Qualification and Type Approval.
4. Köstner, M., et al. 2014. Review of Failures of Photovoltaic Modules. IEC-PPV Task 13 Report 13-01-2014.
5. Heckle, P., et al. 2015. "A Status Review of PV Module Reliability Testing and Standards." National Renewable Energy Laboratory.
6. Sandia National Laboratories. "Single-Axis Tracking" PV Performance Modeling Collaborative (PPVMC) Modeling Guide. Accessed 2026. <https://ppvmc.sandia.gov/modeling-guide/>
7. Silverman, T. J., E. C. Palmiotto, M. Springers, N. Bosso, M. Deegan, I. Repins, and A. Gauding. 2024. Tough Break: Many Factors Make Glass Breakage More Likely. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5K00-91695.

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