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Wind Performance Results for Earth Mount Solar®

White Paper

Abstract

Hurricane-prone regions in the United States are currently underserved by the utility-scale solar market. This is due in large part to concerns that single-axis tracker systems cannot reliably survive the wind speeds generated by Category 4 and 5 hurricanes. These concerns are justified. Although some tracker plants have survived low-end Category 4 storms with little to no damage, others have experienced damage from wind speeds lower than 60 miles per hour, due to instabilities such as torsional galloping. Not only are tracker plants elevated above the earth and therefore more exposed to the wind, they also have numerous parts, each of which represents a potential point of failure. Few tracker systems to date have achieved a maximum wind rating on par with the wind speeds generated by Category 4, and none have met Category 5 speeds, making these systems a risky choice for anyone pursuing a solar plant project in a hurricane or other high-wind zone.

There is an alternative option for building solar plants that are not only robust against torsional galloping, but that can be installed in hurricane-prone and other high-wind regions. Developed by Erthos, Earth Mount Solar® PV forgoes foundations, tracking mechanisms, and mounting structures completely, opting instead to install its modules directly on the ground. This approach reduces wind force on the system and eliminates many of the potential points of failure seen in tracker arrays, leading to drastically increased stability and a much higher maximum wind rating.

To test this claim, CPP Wind Engineers developed a scale model of a standard 2MWac Earth Mount Solar system, then subjected it to a series of wind tunnel tests. The Earth Mount Solar model performed exceedingly well, exhibiting no observable movement even at the wind tunnel's maximum speed of 215 miles per hour.

In this paper, we take a closer look at these results and their implications.

Introduction

Within the U.S. solar industry, wind is the second-most frequent cause of system damage, as measured by number of insurance claims.[1] This is laregly due to the design of the systems themselves. The utility-scale solar market is dominated by single-axis and fixed-tilt tracker systems, the modules of which are elevated above the ground and attached to their mounting racks at discrete locations (rather than continuously along the frame), with numerous parts representing different potential points of failure. While such systems can be rated to withstand maximum winds of 120-140 miles per hour, observed failures have occurred in winds less than 60 miles per hour.[2, 3]

Failure at these relatively low wind speeds are often due to a phenomenon known as torsional galloping, a phenomenon consisting of "a gradual helical twisting that increases with distance from the torque motor." [4] The resulting damage can be quite significant. Consider the 55 MW Oakey 2 site in Australia, which suffered from extensive damage due to torsional galloping on October 18, 2018, when the plant was hit by a storm with measured top wind gusts of around 30 miles per hour. As described in PV Magazine (and shown in Figure 1), "Some rows have completely collapsed, with steel puncturing modules, and the whole structure resembling little more than a tangled wreckage." [5]

Figure 1 — Damaged modules at the Oakey 2 site in 2018. [5]

Cited References

1. Insurance in the Operation of Photovoltaic Plants (Link)
2. Dozens of solar panels damaged by Hurrican Dorian (Link)
3. Failure investigation of a solar tracker due to wind-induced torsional galloping (Link)
4. Torsional Instability of Single-Axis Tracker Systems (Link)
5. What Broke at Oakey (Link)

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It should be noted that the Oakey 2 site was still under construction at the time of the storm. As a result, the modules were not able to be placed in proper stow position. Fully installed and properly stowed, the system would not have experienced that level of damage from that particular storm.

However, this highlights yet another advantage of Earth Mount Solar® PV: it doesn't require stow position to survive nominal wind events, whether during or after construction. Fully installed, with mesh cables crossing through each module at perpendicular angles and terminating in a concrete perimeter block, the Earth Mount Solar® PV system has a wind rating of 194 miles per hour. Even incompletely installed, without the cables or perimeter block — with just the modules laid side-by-side on the ground — the system is rated to withstand winds up to 135 mph.[6]

For fixed-tilt and tracker systems to achieve a wind rating of 135 miles per hour — which is still below most Category 4 and all Category 5 wind speeds — they must use specialized parts such as dampeners, incorporate thicker torque tubes, employ deeper and thicker post and pier foundations, and be stowed at high-tilt angles.[a] According to the Rocky Mountain Institute's "Solar Under Storm" report, which reviewed the solar plant damage caused by Hurricanes Irma and Maria in 2017, following these and other best practices can be expected to add 5% to the cost of a tracker project. Even then, with all best practices followed and higher costs incurred, the report concluded that tracker systems should not be installed in Category 4 or higher wind zones.[7]

Earth Mount Solar® PV offers an alternative approach to utility-scale solar that promises better wind performance at a lower cost. Because Earth Mount Solar® PV systems are installed directly on the ground, with a vertical profile no taller than the module itself, they require fewer parts, with no foundations or complex stowing mechanisms — all while achieving maximum wind ratings that exceed the highest hurricane wind speed ever measured on U.S. soil.

It's worth noting that the true maximum wind rating of the Earth Mount Solar® PV system remains unknown. In wind tunnel testing performed by CPP Wind Engineering, the Earth Mount Solar® PV model exhibited "no significant movement," even at the wind tunnel's maximum speed of 215 miles per hour.

Note

a. Stowing comes with its own problems. As noted by CPP, "high tilt angles introduce greater static loads as well as increased dynamic excitation due to buffeting in the array interior."[4]

Cited References

6. CPP Project 14693: Erthos Aeroelastic Study (CPP Wind Engineering Consultants)

7. Solar Under Storm (Link)

Background

Earth Mount Solar® PV systems are installed directly on the ground, in a near-flush configuration joined together by non-tensioned 1/8”-diameter mesh aircraft cables and a concrete perimeter with a per-2MW ballast weight exceeding 45,000 pounds.

To determine how this system can be expected to perform in high-wind events, Erthos contracted with CPP Wind Engineering to provide independent, third-party testing. CPP had tested Earth Mount Solar® PV previously, but that was a stripped-down version of the system that didn’t factor in the weight of the concrete perimeter or include the mesh cables, which run in an X-Y pattern through every module frame and terminate at said perimeter. That simplified test configuration (Figure 2) achieved a wind rating of 135 miles per hour,[6] which is in line with most tracker systems installed today.

Figure 2 — Photo of the initial CPP test model of Earth Mount Solar® PV, without perpendicular mesh cables or consideration of the ballast weight of the concrete perimeter that encloses each 2 MWac block.

Cited References

6. CPP Project 14693: Erthos Aeroelastic Study (CPP Wind Engineering Consultants)

As noted by CPP, “The [original] wind tunnel study was based on a rigid model, under the assumption that the results would be used to limit applicability to geographic locations where the design wind speed was some fraction below the critical wind speed when the module was predicted to be unweighted. The present study extends the testing to investigate the behavior of the system when the wind speed exceeds the nominal unweighting speed. At this point the cable becomes critical to the integrity of the system, both aligning modules, but also restraining them if they begin to lift.”[8]

CPP’s new wind performance study tested a 1:21 scale model of the full Earth Mount Solar® PV 2MWac package, as installed in the field, which allowed for comprehensive aeroelastic analysis. It was hypothesized that this more robust test, inclusive of the mesh cabling and concrete ballast effects, would return a much-improved wind rating.

New Wind Tunnel Test Results

Test Setup

The new test of the Earth Mount Solar® PV system was conducted on a turntable in the 72-foot-long test section of CPP’s boundary-layer wind tunnel, the schematic of which is shown in Figure 3.

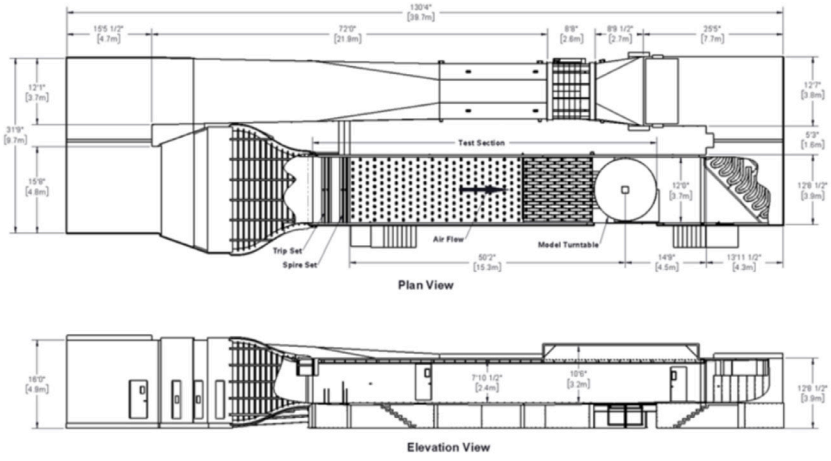

Figure 3 — Schematic of CPP’s Wind Tunnel Test Facility

Cited References

8. CPP Project 16526: Erthos Aeroelastic Study (CPP Wind Engineering Consultants)

As mentioned previously, the full Earth Mount Solar® PV 2MWac package — consisting of modules, the concrete block perimeter, and the non-tensioned mesh cables aligning the modules to each other and terminating at the concrete perimeter — was now tested as a complete system at a 1:21 scale. Utilizing the turntable, the tests were conducted for a range of wind directions within ASCE 7's Exposure C category, which assumes "open terrain with scattered obstructions having heights generally less than 30 feet."[9]

Additional details on the dimensions and characteristics of the test model — including how tension springs were used to produce the correctly scaled stiffness in the model cables — are included in CPP's final report, which is available to interested readers upon request. A general schematic overview of the model is included as Figure 4.

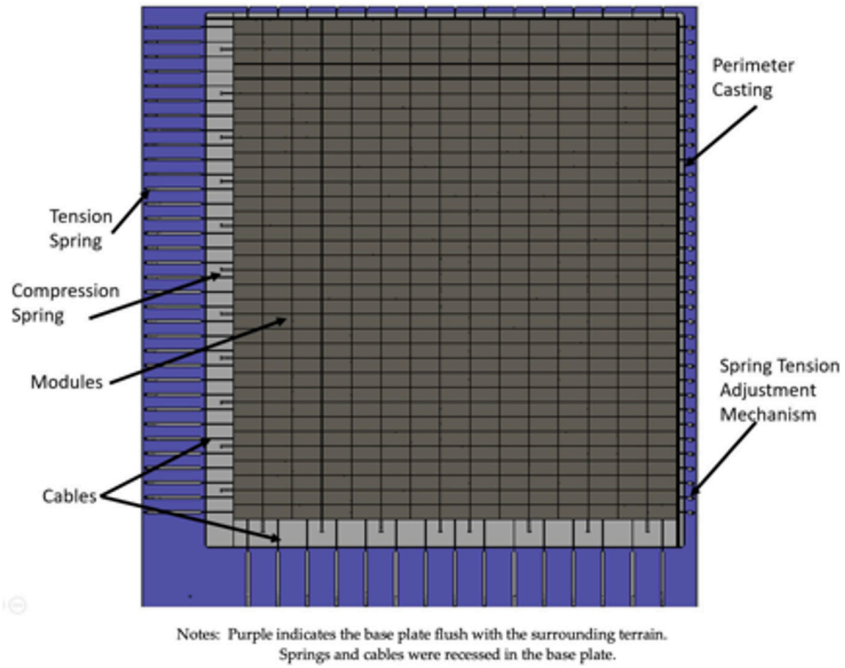

Figure 4 — Schematic of Test Model

The scale model of the Earth Mount Solar® PV package, as constructed and tested by CPP, is shown in Figure 5. High-speed, motion-capture video cameras were used to detect module movement during the test, with the white dots on top of the modules serving as tracking elements for the cameras.

Cited References

9. Minimum Design Loads and Associated Criteria for Buildings and Other Structures (Link)

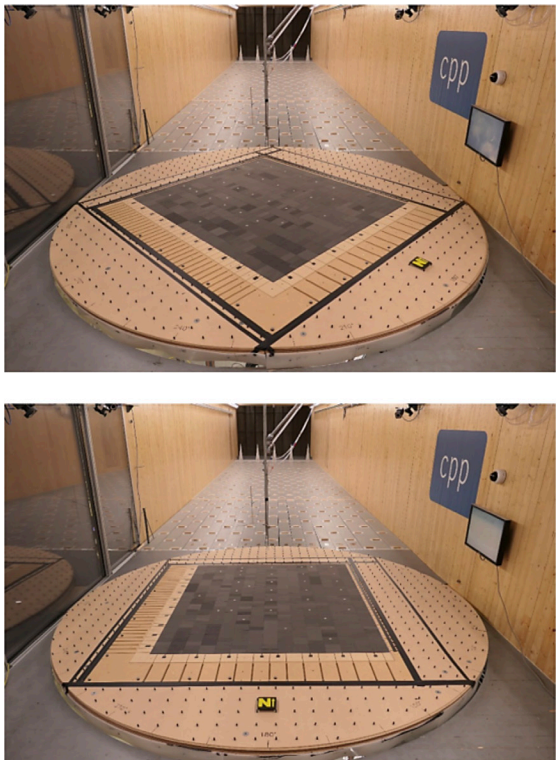

Figure 5 — The updated model inside the wind tunnel, based on a standard Earth Mount Solar® PV 2 MWac block and scaled at 1:21. Note the cables in both the X and Y directions through each module. The white dots on the modules were used for motion-capture video.

Results

The goal of the test was to determine the wind speed at which the Earth Mount Solar® PV system experiences instability. In the first test from 2020, which did not include the mesh cable array or factor in the substantial weight of the concrete perimeter, that instability happened at 151 miles per hour in the form of module liftoff. A standard 10% safety factor was applied to that number (after subtracting 1 to represent the highest speed at which full stability was present), resulting in a maximum wind speed rating of 135 miles per hour — a rating higher than those achieved by most tracker systems today.

CPP's latest test, which was completed in April 2022, more accurately modeled the Earth Mount Solar® PV system as installed in the real world. Based on this more precise approach, we hypothesized that the system would achieve a much higher maximum wind rating. This hypothesis was correct.

Once the model was constructed and the setup was complete and ready for testing, CPP gradually increased the wind tunnel speed until the modules demonstrated measurable lift. However, the tunnel's maximum speed of 215 miles per hour was reached without any such lift being detected. A standard 10% safety factor was then applied to account for any uncertainties in the model, resulting in a conservative maximum wind rating for the Earth Mount Solar® PV system of 194 miles per hour for slopes up to 5%.[b] For comparison, the highest

hurricane wind speed at landfall in U.S. history was the Labor Day Hurricane of 1935, which was estimated to have a top speed of 185 miles per hour when it hit the Florida coast.[10]

CPP devised additional test scenarios as well, including one designed to examine the system's resilience to vertical turbulence. In this scenario, "the ramp at the leading edge of the turntable was dropped down to introduce [a] large bluff edge upstream of the model. [...] In this phase of testing too, the maximum wind tunnel speed was achieved without observing any significant movement of the modules."[8]

Note

b. For slopes between 5% and 15%, CPP recommends reverting to the prior rigid model wind rating of 135 miles per hour, until more testing on these slope types can be completed.

Cited References

10. Hurricane Ida was one of the strongest hurricanes to hit US mainland. Here are some stronger ones. (Link)

8. CPP Project 16526: Erthos Aeroelastic Study (CPP Wind Engineering Consultants)

Summary

As demonstrated in the wind tunnel tests performed by CPP, the Earth Mount Solar® PV system is extremely effective at resisting module deflection — so effective, in fact, that no measurable movement of the modules occurred even at the wind tunnel's maximum speed of 215 m.p.h. After factoring in a standard 10% safety factor to account for model uncertainty, this resulted in a maximum wind rating of 194 miles per hour — the highest, by a wide margin, of any utility-scale solar power product on the market today.

Simply put, Earth Mount Solar® PV is the most wind-proof system on the market today, able to withstand even the most intense land-based wind events on record without need for special tools, parts, or procedures, all of which increase the cost of a project.

Furthermore, because Earth Mount Solar® PV plants are installed flat on the ground, they can withstand lower-speed wind events such as the storm that caused torsional galloping at the Oakey 2 site in Australia.[5] These types of events illustrate the importance of "going overboard" when evaluating how wind-resistant a plant in a given location should be, because even lower-speed wind can introduce such phenomena as torsional galloping, or can happen so quickly, as is often the case with micro-bursts, that the system is unable to assume stow position in time, leaving it vulnerable to damage at wind speeds below its maximum rating. Earth Mount Solar® PV modules, on the other hand, are not susceptible to torsional galloping and do not need to be stowed at a certain angle to maintain their rating and avoid damage.

Because of its flat installation and high wind rating, Earth Mount Solar® PV also eliminates debris risk to neighboring structures — a concern that has caused some tracker projects in storm-prone areas to face community opposition and permit denials.[2]

All considered, Earth Mount Solar® PV is the most wind-resistent solar power product in the utility market today.

Cited References

5. What Broke at Oakey (Link)

2. Dozens of solar panels damaged by Hurrican Dorian (Link)

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5. Jonathan Gifford. “Long Read: What Broke at Oakley.” PV Magazine. December 7, 2019. https://www.pv-magazine-australia.com/2019/12/07/long-read-what-broke-at-oakey/

6. Fahad Akon and Yarrow Fewless. “CPP Project 14693: Erthos Aeroelastic Study.” CPP Wind Engineering Consultants. 2020.

7. Christopher Burgess and Joseph Goodman. “Solar Under Storm.” Rocky Mountain Institute. 2018. https://rmi.org/wp-content/uploads/2018/06/Islands_SolarUnderStorm_Report_digitalJune122018.pdf

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