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Full Scale Investigation into the Dynamic Response of Solar Trackers in high winds

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SUMMARY:
A full-scale test campaign and investigation into the dynamic response of selected solar trackers installed in a typical array configuration at the Flatirons campus of National Renewable Energy Limited (NREL), Boulder, CO, USA have been carried out over the past three years. The test array of trackers was extensively instrumented to capture a variety of structural signals including forces, pressures, accelerations, and strains on various structural and mechanical racking components, with the aim of correlating such responses with inflow wind conditions at the site. The campaign had three primary objectives: a) Test the reliability of NEXTracker's proprietary tracker designs under long term wind climate, b) Build up a reliable database of aerodynamic and aero-elastic responses of the solar trackers to help optimize the structural design process internally, and c) Facilitate fundamental understanding of fluid-structure interaction of trackers in full scale for improved aero-elastic simulation both computationally and in the wind tunnel. Selected data, collected from the campaign, will be presented in the paper with a focus on wind-induced torsional response of Single Axis Trackers (SATs), known to have been responsible for multiple wind related tracker failures. Comparisons with wind tunnel data, wherever available, will also be presented.

Keywords: Full-scale, Dynamic Response, Solar Tracker

1. INTRODUCTION AND BACKGROUND

Following on from a few years of sustained growth, the global solar tracker market size was valued at USD 3.40 billion in 2021 and is expected to expand at a Compound Annual Growth Rate (CAGR) of 20.5% from 2022 to 2030. At present, utility-scale solar provides one of the lowest Levelized Costs of Electricity (LCOE) values in the renewable energy sector. Amongst the utility scale solar installations, Single Axis Trackers (SATs), in particular, stand out due to their ability to boost energy production by about 10-30%, with respect to their fixed tilt counterpart.

The essential components of many single-axis solar tracker structure include the tracker torque tube, a drive mechanism, piers or piles, rails or purlins to support the solar modules or panels, and the solar panels themselves. These racking systems, in general, are purposely built and design optimized to be quite flexible. In most locations, the largest environmental load acting on these structures is due to the wind, inadequate design consideration of which has resulted in numerous failures of systems in the recent past (Valentín et al., 2022). Such failures have resulted in the industry turning their attention into making the systems more reliable, which in turn helped spurred the initiation of a reasonable amount of research and development effort both in academia and industry.

One of the major causes of wind-induced failures of SATs is the existence of self-excited aero-elastic effects at low to moderate wind speeds; something that perhaps has been counter-intuitive to structural engineers traditionally focused on low probability design level wind events and failures. While the aero-elastic phenomena of torsional galloping, flutter and divergence were known to bridge aerodynamicists, the propensity of solar trackers to undergo such responses, often resulting in catastrophic failures at wind speeds well below the design level event, came as a surprise to wind engineers anecdotally only a few years back. Since then, academic efforts focused on trying to model these phenomena in the wind tunnel through simplified section models as well as full-blown aero-elastic models, and in CFD, gained impetus, along with strategies to develop more practical and cost-effective design tools (such as Taylor and Browne (2020) and Martínez-García et al. (2021)).

A review of the literature indicates that while there have been some CFD (Rohr et al., 2015) and wind tunnel (Quintela et al., 2020; Rohr et al., 2015; Taylor and Browne, 2020) studies reported on analysis and quantification of flutter and divergence of SATs, few full-scale studies are available. The ones available, such as (Valentín et al., 2022) mostly focused on post damage investigation of galloping being the likely cause of tracker failures. Many of the failure investigations carried out by wind experts on behalf of tracker manufacturers are proprietary and confidential for obvious reasons. In response to such failures, current state of the art (as well as some Manuals of Practice) in tracker design requires tracker manufacturers to get their product tested in a wind tunnel for static and aero-elastic effects. These reports are again proprietary, often non-peer reviewed and, in most cases, idealized and not validated against real tracker behavior in the field. Therefore, there is a need for a comprehensive set of high resolution and reliable full-scale tests on trackers extensively instrumented in the field. A reasonably windy site is needed to capture the aeroelastic and dynamic effects. The data for such tests can be a benchmark for validation and optimization of wind tunnel and computational studies, similar to how WERFL data from Texas Tech University was used for studying wind loads on low-rise buildings.

The current full-scale campaign effort by NEXTracker, in partnership with CPP, is a step in that direction. Additionally, it helps NEXTracker to internally tune-in their structural design, calibrate risk models based on statistical inference of field data and enable CPP to optimize NEXTracker specific wind tunnel tests and loads to better reflect on-field conditions.

2. DESCRIPTION OF NREL SITE AND NEXTRACKER ARRAY SET-UP

The NREL Flatirons Campus (FC) is located approximately 8 miles south of Boulder, Colorado in the eastern foothills of Rockies. Traditionally, the site has been used for wind turbine siting and performance research. Over the last few years, however, FC has also witnessed installation of solar tracker systems to monitor their performance under adverse wind loads. The site typically experiences moderate to high downslope winds between the months of October through April with a predominant wind direction of approximately 280 degrees +/-20° relative to true north. Fig. 1a presents wind speed and wind direction statistics of peak 1-min wind speeds measured at 10m height off the ground at the site. Sustained wind speeds often exceed 30-50mph each wind season with gusts reaching 80-100 mph. Fig. 1b shows an aerial view of the site looking west into the Boulder canyon.

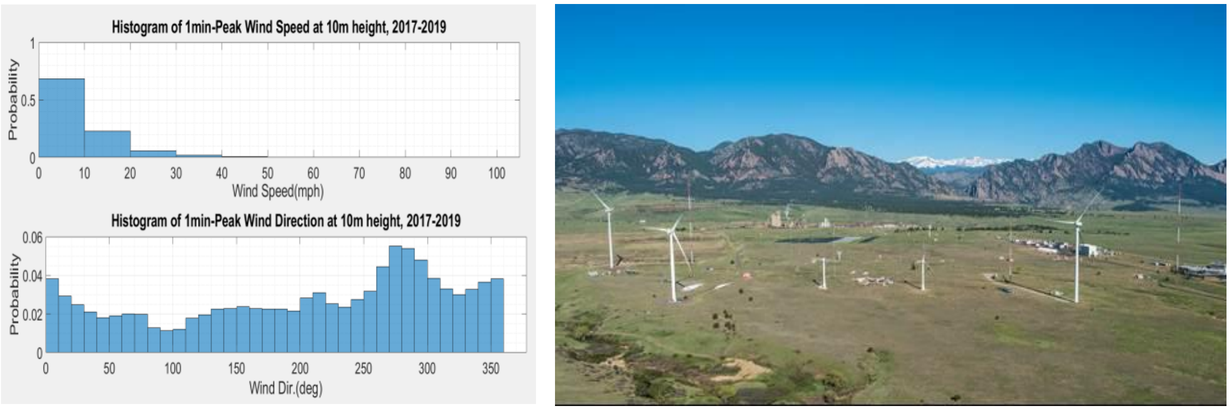

Figure 1. a) Wind Speed and Direction statistics at FC, NREL b) Aerial view of FC, NREL

NEXTracker installed two arrays, with nine rows each, of its flagship torsionally cantilevered 2-m chord system (often called a "1P" because it has one module in portrait orientation across the chord) and multi-point torsionally fixed 4m chord (two-in-portrait, 2P) system at FC. Each of the two arrays was extensively instrumented with pressure sensors, load cells, strain gauges, accelerometers and displacement transducers to capture and record various structural response signals of the trackers to oncoming wind. Fig. 2 shows a plan view of the array layout at FC along with the network of wind sensors placed along the periphery of the layout to capture inflow wind conditions. The arrays have been placed about 20° skewed off the east-west line facing the canyon, so the highest winds are expected normal to the trackers' axis. A full description of the setup, sensors and signal conditioning instrumentation will be presented in the full paper.

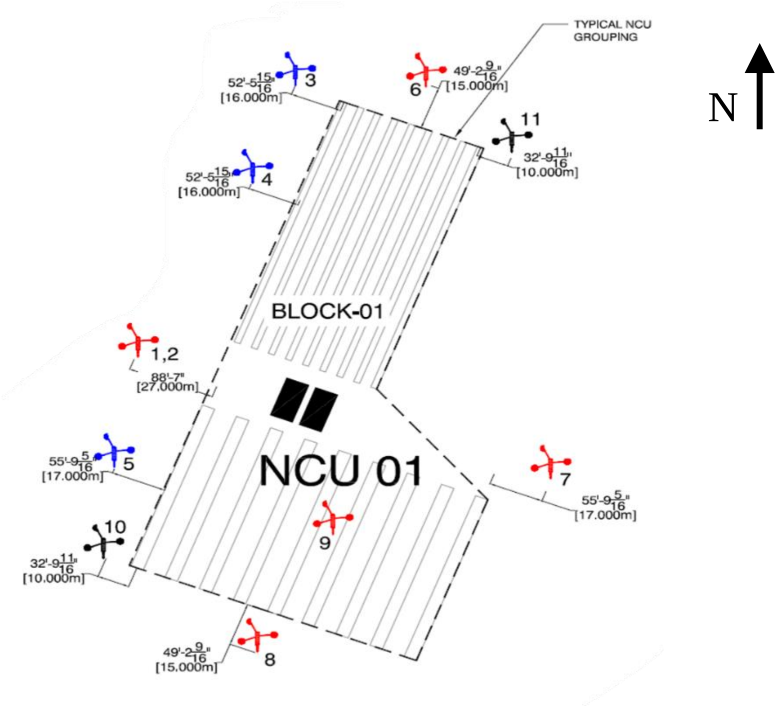

Figure 2. NEXTracker array layout at FC, NREL (red, black, and blue markers indicates wind sensors of different make and resolution at different heights off the ground). "BLOCK-01" is the 1-P tracker array

3. SELECTED RESULTS AND DISCUSSIONS

Amongst multiple signals captured and analysed as part of the campaign, of particular interest are the tests investigating the stability of the trackers parked at different tilts under different wind conditions. Accelerations are quantified using a set of high-resolution dynamic inclinometers. Example measurements in between drive piers for an exterior row of the 2-P system, obtained by double differentiating the signal conditioned angular displacement signals recorded by the sensors, is shown for four tracker tilts in Fig. 3. Results (10th and 90th percentile acceleration response at each wind speed bin) demonstrate the relative stability (smaller accelerations) of the front-winded (nose-down) tilt configurations compared to the back-winded and zero stow tilt counterparts. This is consistent with wind tunnel test outcomes (to be shared in the full paper). Further results from validated wind tunnel tests will be shared in the full paper to augment and complement gaps in full scale dataset for both 1-P and 2-P systems.

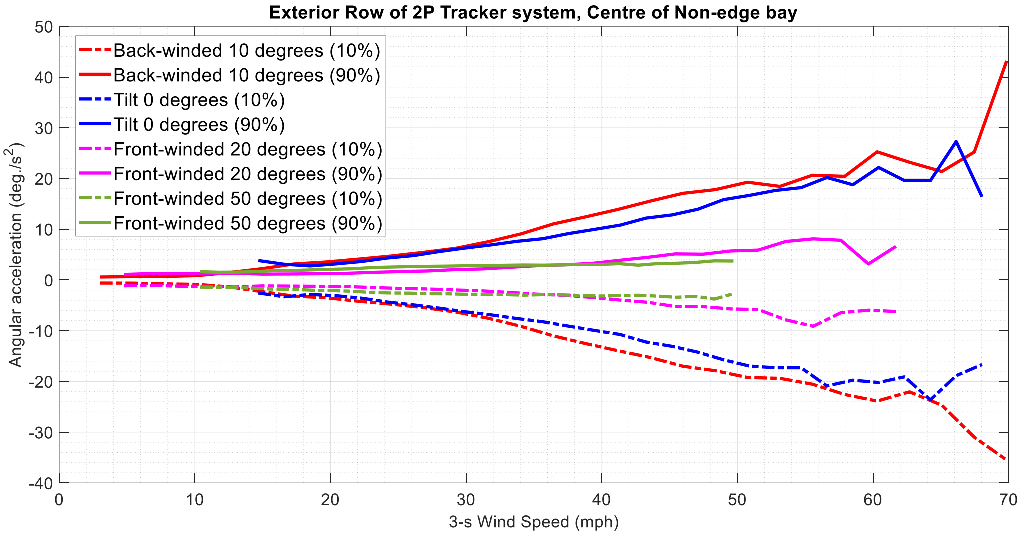

Figure 3. Wind-induced angular acceleration for a 2-P exterior row tracker parked at different stow tilts

It is worth noting that industrial design practice typically defines instability as a tracker, in whole or in part, undergoing angular motion or acceleration in exceedance of a certain threshold, rather than theoretical definition of instabilities resulting from zero stiffness or damping. As a result, an important aerodynamic design goal and control strategy is to find ways and means to prevent sudden initiation of instability. A design concession, therefore, is often to allow for certain compliance in dynamic response as a compromise between robust motion control and risk enabled value-engineering.

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