ÁLVARO CASADO
AMEA Manager

DESIGN CODES AND DUE DILIGENCE FOR WIND RESILIENT PV TRACKERS
PVH: who are we?

- >3.5GW annual production
- 49 plants over 50MW
- 5.28GW worldwide
PVH: who are we?

First fixed-tilt racking in Pescopennataro (Italy) for CRS

PVH Incorporated in San Francisco (CA)

First tracker in USA, Newman (CA)

Lesele8 [80MWp] and Lottasil [80MWp] projects in South Africa

PVH opens metal work in Cheste, Valencia (Spain)

PVH opens metal work in Jundiai Sao Paulo (Brazil)

Mohammed bin Rashid Al Maktoum Solar Park (Phase III) 1054MWp in UAE

1st Middle East manufacturer with over 1GW manufactured


First single-axis tracker in Letur (Spain) for CRS

First USA project in Fallon (NV) 26MWp

AXONE single-axis tracker installed in Hyder II (AZ) 20MWp

First tracker in Central America in Zacapa Guatemala

AXONE 2.0 installed in Pheonix (AZ) 31.6MWp

AXONE 4.0 installed in Camargo (Mexico) 32MWp

First project in Australia, Ulliyale 100MWac

AXONE 1.0 in Taft Co (CA) 26MWp

Aqua Fria, Honduras 59.5MWp

NCI (NG) 33MWp

3rd PVH becomes the third tracker manufacturer in the world
PVH: who are we?

AXONE DUO, 1V
Up to 2x64 modules

Monoline 3H
90 panels per row

Monoline 2V
60 panels per row

Monoline 2V BIFACIAL
60 panels per row
PVH: who are we?

- Good sample distributed around the world. More than 5,2 Gw with different climatic conditions to have a solid knowledge database.
- A Vast experience that helps us perform proper assessments and understand where the issues might occur.
- Always improving and integrating the feedback from clients and partners. With our innovation facility our testing’s are performed fast to match the evolution of this fast-paced market.
- Technical team, required installations and best partners to check the integrity of the structures and make sure that we don’ only meet the technical requirements but warrantee the integrity of the structure.
Market overview: is code compliance enough? Other tracking system issues worldwide.

*Note: these events do not correspond to projects supplied by PVH*
Market overview: is code compliance enough?

✓ Any wind study will be enough to comply with most RFQ.
✓ There is usually no specific requirement so it’s up to tracker manufacturers to provide their studies.
✓ Wind studies have a direct impact on structural calculations.

---

Project Requirements → Tracker Compliance

- Codes and standards
  - European: EUROCODE
  - American: ASCE
  - Australian: AS-NZS etc...

Tracker Compliance → Tracker Compliance

- Wind loads calculation
- Structural calculations
- Ground reactions
Market overview: is code compliance enough?

- Some wind studies *don’t provide complete information* on tracker behaviour.
- Tracker would be *approved* but might have *issues with site conditions*.

**Project Requirements**
- Codes and standards
  - European: EUROCODE
  - American: ASCE
  - Australian: AS-NZS etc...

**Tracker Compliance**
- Wind loads calculation: *Incomplete*
- Structural calculations
- Ground reactions
Market overview: is code compliance enough?

- **There is currently an issue.** Code compliant trackers don’t warrant the integrity of the structure.
- In the past year **more than seven** large scale PV plants **had wind related issues.**
- It is only the sample to which we had access to, there were probably a lot more that weren’t brought to attention.
- Manufacturers and developers own interest play against the evolution of the market. **Lessons learnt only come with past experiences.**
DESIGN CODES AND DUE DILIGENCE
FOR WIND RESILIENT PV TRACKERS

EDUARDO CHILLARÓN
Design and Engineering Manager
Market overview: How is PVH handling the issue
Project Requirements

✓ Codes applicable to project:
  ▪ ASCE
  ▪ Eurocode
  ▪ AS-NSZ
  ▪ ...

✓ Parameters to obtain from the code:
  ▪ Basic wind pressure
    o Return period
    o Wind terms
  ▪ Topographic parameters

---

**ASCE**

1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountains terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 15% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00333, MRI = 300 Years)

\[ q_w = 0.613K_sK_vV^2 \text{ (N/m}^2\text{); } V \text{ in m/s} \]

---

**Eurocode**

\( q_w = \frac{1}{2} \rho \cdot v_w^2 \)

---

**AS-NSZ**

\( V_w = \text{ regional } 3 \text{ s gust wind speed, in metres per second, for annual probability of exceedance of } 1/R, \text{ as given in Section } 3 \)

\[ p = (0.5 \rho_w) [V_{des,0}]^2 C_{fig} C_{dyn} \]
Static Wind Study

- **Static Wind Loads**: there is a *consensus* in the market about this calculation.
  - Wind pressure *from code* in line with the wind tunnel test done
  - Static wind tunnel test to obtain \( G_{Cm} \) and \( G_{Cf} \) coefficients
  - Dynamic Amplification Factors
  - Damping factor
Aerelastic wind study

Codes do not cover the aerelastic instability check for this kind of structures. Some of them only fix the criteria of a natural frequency higher than 1Hz.
Calculation procedure for wind loads

- **Static Wind tunnel**
  - Force and moment coefficients
  - Dynamic Amplification Factors

- **Full aerelastic Wind tunnel**
  - Stow position and critical wind speeds for operational angles

- **Structural Analysis**
  - Damping factor
  - Modal frequencies
  - Stiffness
  - Mass
  - Geometry

EDUARDO CHILLARÓN  Design & Engineering Manager
DAVID BANKS
Solar Services Manager

DESIGN CODES AND DUE DILIGENCE FOR WIND RESILIENT PV TRACKERS
Regulatory context: Current codes do not have what you need

- If you make code coefficients the basis for the contract, you will only get a good design by accident.

- Then, if you have failures in a windstorm, everyone will say it was not their fault, and they will be right. The design engineer and due-diligence reviewer will have done their best to apply code provisions that were never intended for solar.
Regulatory context: Current codes do not exclude getting the right answer

CHAPTER 31
WIND TUNNEL PROCEDURE

User Note: Chapter 31 may always be used for determining wind pressures for the MWFRS and/or for C&C of any building or other structure. This method is considered to produce the most accurate wind pressures of any method specified in this standard.

- It is anticipated in the code that suitable coefficients will not be included for every possible structure.
  - ABL wind tunnel testing is the recommended recourse.
- The code provides a framework for what is needed (statics, dynamics, caution for aeroelastic).
Regulatory context: New Codes. ASCE 7-22 is expected to include static and dynamic coefficients.

- These will be conservative, due to need for brevity and simplicity.
  - For example, differences due to underside structure.
- So maybe a solar guidebook, rather than a small section in between tanks and signs?
- Better yet, what about some software from a database certified by full scale experience?
  - Careful of “sacred software”
Regulatory context: A solar wind loading standard informed by experience

- Nothing beats full-scale failure testing
  - In solar, failure information is not shared. Each owner and designer learns for themselves.
  - Consensus not needed, debate not declared.
Regulatory context: What kind(s) of solar wind loading standard(s)?

Compare to building cladding.

**Certification**

- Not done for whole building
- Cladding test facilities
Regulatory context: What kind(s) of solar wind loading standard(s)?

Compare to building cladding.

<table>
<thead>
<tr>
<th>Certification</th>
<th>Prescriptive (compliance)</th>
<th>Performance (reliability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not done for whole building</td>
<td>“Design wind pressures on C&amp;C elements of low-rise buildings shall be determined from the following equation and figures.”</td>
<td>“The building envelope shall remain attached to the structure in a 1:700 year wind event.”</td>
</tr>
<tr>
<td>Cladding test facilities</td>
<td>Limits on applicability</td>
<td>New methods extend limits</td>
</tr>
</tbody>
</table>

✓ Either way, still need due diligence
- Prescriptive can be misinterpreted, or extended outside of intended limits.
- Performance-based analysis implies wide range of possible methods.
Tracker Instability: the case for multi-row full tracker aeroelastic testing

✓ Widely accepted that full aeroelastic model is superior to section model
  ▪ Where there is disagreement, full model is more accurate.
  ▪ Section model generally intended to save money.

✓ Full ABL and relevant turbulence captured
  ▪ Turbulence larger than the tracker can trigger instability at low tilts.
  ▪ Smooth flow (typical for section model tests) is not conservative in this case.

✓ Instability is very sudden
  ▪ triggered by gusts.
  ▪ section testing often assumes mean speeds.
Tracker Instability: the case for multi-row full tracker aeroelastic testing

- The whole tracker does not twist the same to the same angle (as is the case in the section model); only the free end has the full twist. This must be accounted for by some assumptions in the section test, but it is modelled explicitly in the full tracker testing.

- Instability in one row can trigger instability in neighboring rows.
Tracker Instability: the case for multi-row full tracker aeroelastic testing

- High tilt instability behavior varies significantly with chord, span, flexibility, damping. We have tested 10 different trackers, including 3 for PVH. There is not one curve shape.
Tracker Instability: +30° tilt, 30° WD, interior-row-only instability

- At higher tilts, we have seen instability happen in the array interior at a lower speed than the first row.
- We have seen interior rows go unstable in second mode of twist, which is not modelled in the section test.
- We have seen lower instability speed for cornering winds, which cannot be modelled in a section test.
- First row sometimes twists a lot, generally sheltering downwind rows.
Advantages of full-tracker multi-row aeroelastic ABL WT testing

- Easily modify row spacing and ground clearance.
- Test rows at different tilts or heights from each other.
- Measure GCmy (tracker moment) for the deformed shape (better than static test).
- Model changes in stiffness along the span (e.g. thicker torque tube near center).
THANKS FOR YOUR ATTENTION

ÁLVARO CASADO  
acasado@pvhardware.com

EDUARDO CHILLARÓN  
echillaron@pvhardware.com

DAVID BANKS  
dbanks@cppwind.com
Regulatory context: Current Codes

BUILDING AND OTHER STRUCTURE, FLEXIBLE: Slender buildings and other structures that have a fundamental natural frequency less than 1 Hz.

... the resonant response of most buildings and structures with lowest natural frequency above 1 Hz will be sufficiently small that resonant response can often be ignored.
Avoiding aerelastic effects: Conclusions

- How aware are clients of tracker manufacturers of the problems with wind stability? What are they asking for and what should they be asking for?
- What steps does PV Hardware take to ensure each project is safe.
- Sectional vs. full aerelastic model testing, what are the fallacies and risks.
- Structure codes in the PV industry; good or bad? Why did the industry not have any so far, and what type of codes do we really want?
- How would a structure code chapter for PV help with either simplifying that process of ensuring for each client and each project that everything is safe and secure?
- How could a structure code chapter for PV help EPC or developers to identify black sheep in the industry?