The Association of Professional
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APETT Technical Conference - ATC2024

Engineering Our Future: Green, Equitable, Intelligent and Integrated

RESILIENCE OF SOLAR PV GROUND-MOUNT SYSTEMS

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The Context

- Transformation from bunker C, diesel, natural gas and a small amount of hydro-power and coal to renewables
- Ambitious goals: to achieve hundred-percent, non-fosil-fuel electricity generation within a decade
- The majority of electricity will be from PV ground-mount arrays
- Concern for the resilience of such systems for the natural hazards of the Caribbean – hurricanes, torrential rainfall and earthquakes
- Relative lack of industry guidance for designing these unique types of power plants
- New construction methods, new types of structures, new manufacturing requirements new design methodologies

The Wind Hazard

St Thomas, USVI 2017

The Wind Hazard

Caribbean, 2017

The Wind Hazard

Humacao, Puerto Rico, 2017

The Wind Hazard

Humacao Waste Water Treatment Plant, Puerto Rico, 2017

The Wind Hazard

Solar panels are shattered by gusts
Isezaki, Gunma Prefecture

Understanding Dynamic Wind Effects on Solar PV Ground-mount Systems

Dynamic wind effects are crucial considerations in the design of solar PV structures, impacting their safety, efficiency, and longevity.

Key effects include resonant vibrations, torsional galloping, and flutter. These phenomena can lead to severe structural damage if not properly mitigated.

Understanding and designing for these effects ensures the resilience and stability of solar installations under damaging wind conditions.

Resonant Vibration of Solar PV Structures

Resonant frequency is when a system oscillates at its natural frequency due to periodic driving forces, potentially causing large amplitude oscillations.

It is critical to identify the natural frequencies of solar PV structures to avoid resonance with the frequencies of wind-induced vibrations.

Torsional Galloping in Solar PV Structures

Torsional galloping occurs when asymmetric aerodynamic forces induce a twisting, oscillatory motion in the structure.

This dynamic instability can lead to unexpected torsional stresses and potential structural failures, particularly in elongated components like beams and poles.

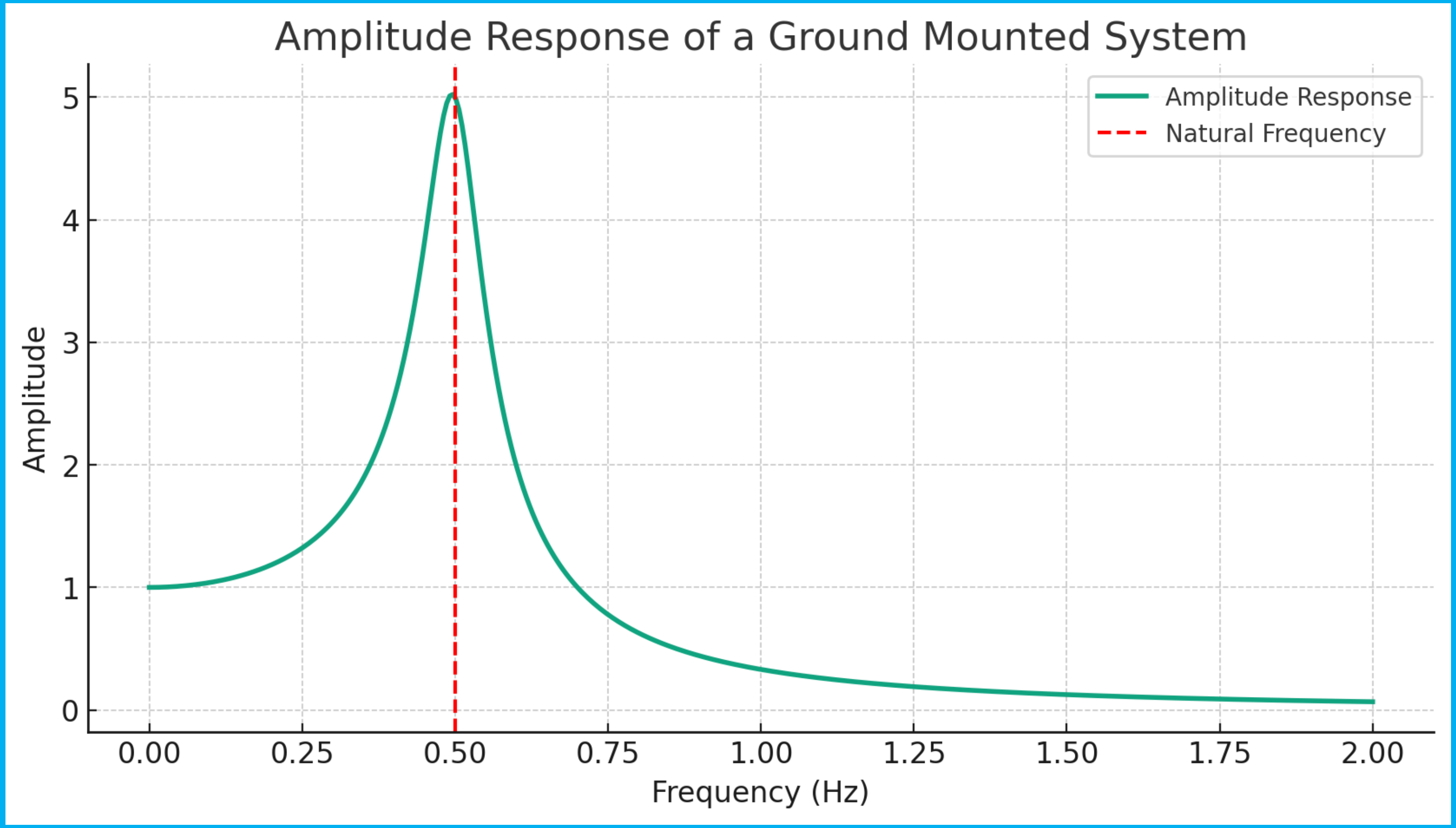
Flutter: Aeroelastic Instability in Solar PV Structures

- Flutter is a complex phenomenon where aerodynamic forces cause a structure to oscillate in a potentially destructive manner.
- It typically occurs when the structure's natural frequency aligns with the aerodynamic forces, leading to energy input that sustains the oscillation.

Key Dynamic Analysis Equations for Solar PV Ground-mount Structures

- Dynamic analysis involves several key equations to predict the behavior of structures under dynamic loads:
  - **Damping Ratio (ζ)**: $\zeta = c/(2\sqrt{mk})$, where c is the damping coefficient, m is the mass, and k is the stiffness of the structure.
  - **Natural Frequency (ω_n)**: $\omega_n = \sqrt{(k/m)}$, fundamental to predicting resonance conditions.
  - **Response to Harmonic Loading:** $x(t) = X\sin(\omega t + \phi)$, which describes the displacement over time under sinusoidal loading, where X is amplitude, ω is the forcing frequency, and ϕ is the phase angle.

Dynamic Analysis Equations for Solar PV Structures



Graph showing the amplitude response of a system across a range of frequencies, highlighting the peak at the natural frequency.

Design Strategies for Mitigating Dynamic Wind Effects in Solar PV Systems

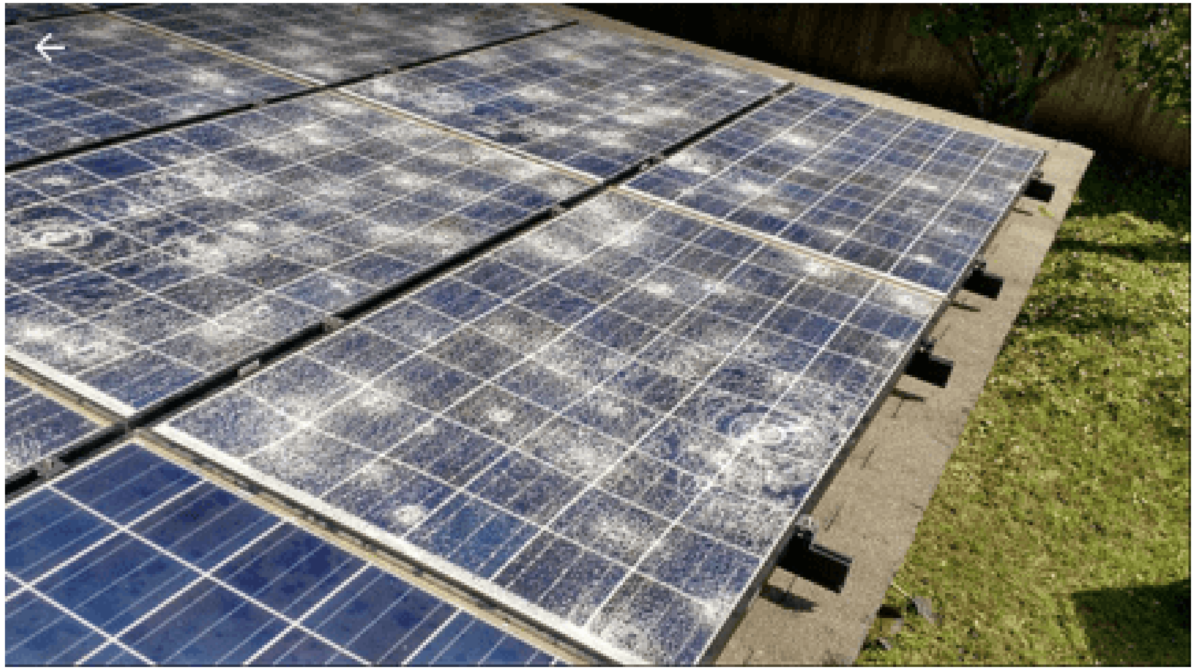
Utilization of dampers and tuned mass dampers to absorb and dissipate energy.

Aerodynamic tweaks to profiles to reduce lift and drag forces.

Selection of structural forms and materials that inherently reduce amplification of dynamic effects.

Visual Aid Suggestion: Images or diagrams of solar PV systems incorporating these technologies, showcasing practical applications of theoretical concepts.

Other Hazards – Impact from Flying Debris



How can impact damage by flying debris in a hurricane be reduced?

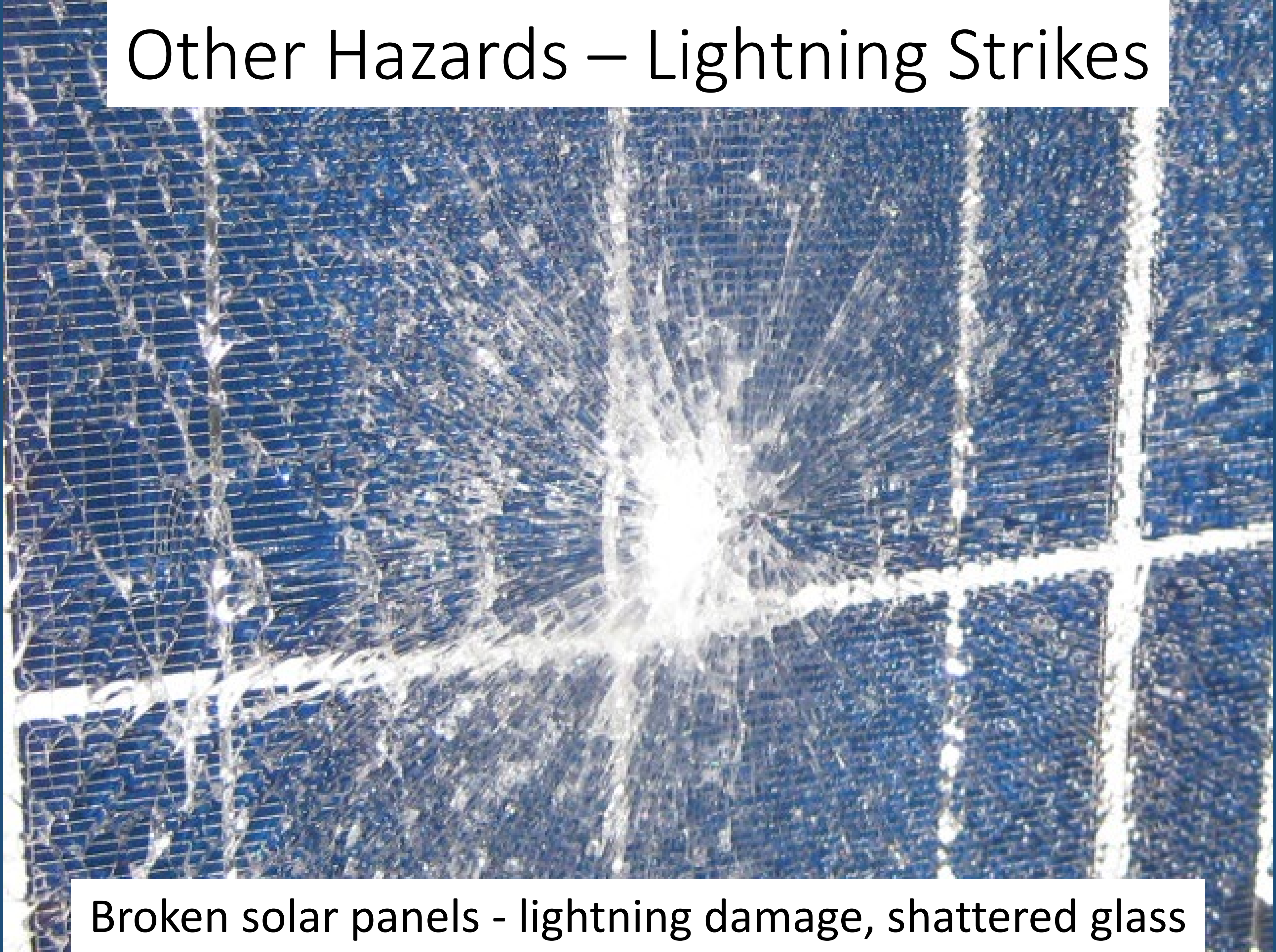
Other Hazards – Impact from Flying Debris

Caribbean, 2017

Damage Mitigation – Impact from Flying Debris

- Frangible Panels
- Strategic Landscaping
- Elevated Mounting
- Mesh Screens
- Rapid Shutdown Systems
- Redundant Panel Layout
- Impact-Resistant Panels
- Emergency Response Plan

Other Hazards – Lightning Strikes

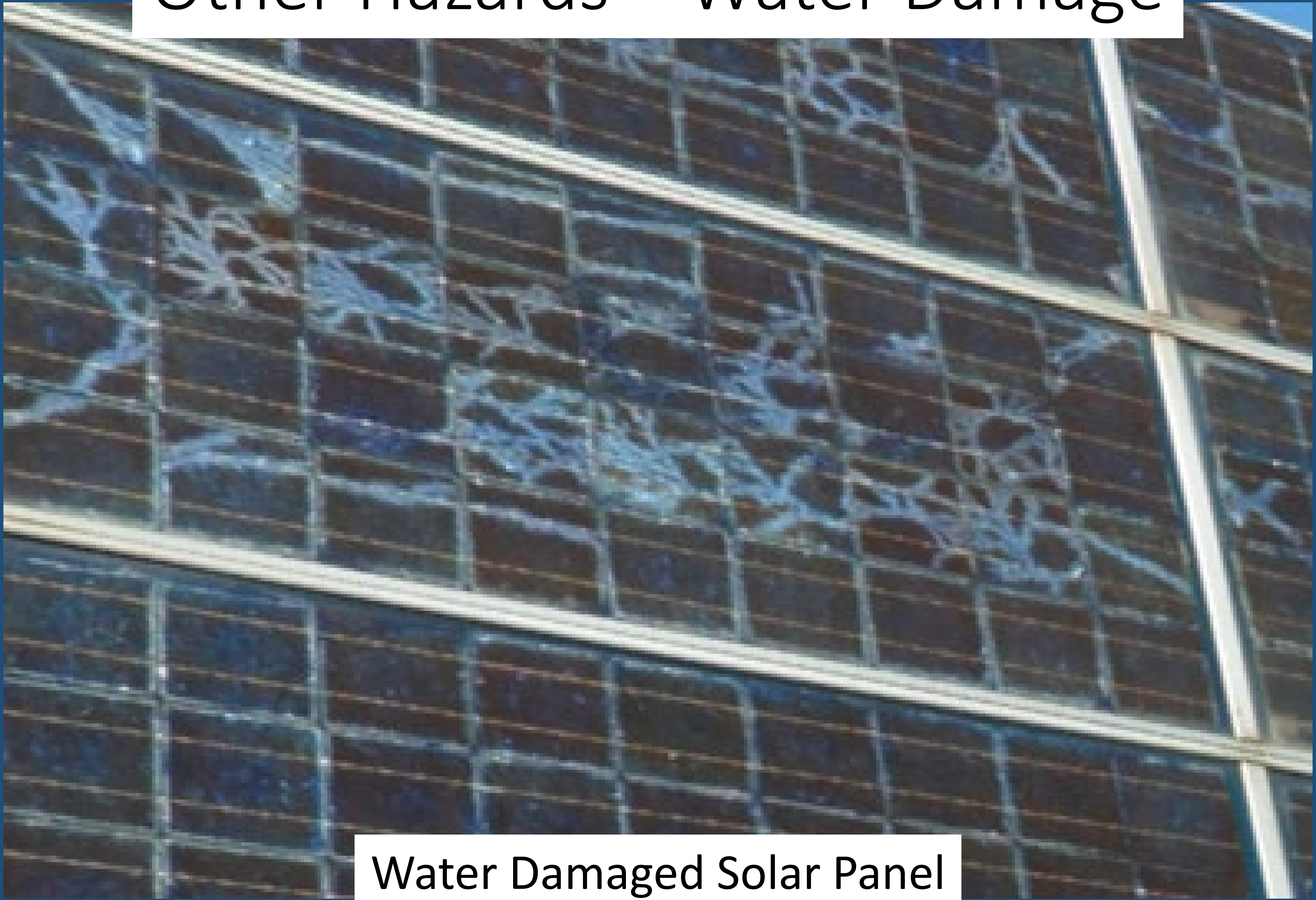


Broken solar panels - lightning damage, shattered glass

Damage Mitigation – Lightning Strikes

- ***Lightning Rods***
- ***Grounding System***
- ***Surge Protection Devices***
- ***Isolation Devices***
- ***Electrical System Design***
- ***Risk Assessment***
- ***Early Streamer Emission (ESE) Systems***
- ***Regular Maintenance***
- ***Insurance***
- ***Monitoring Systems***

Other Hazards – Water Damage



Water Damaged Solar Panel

Damage Mitigation – Water Damage 1

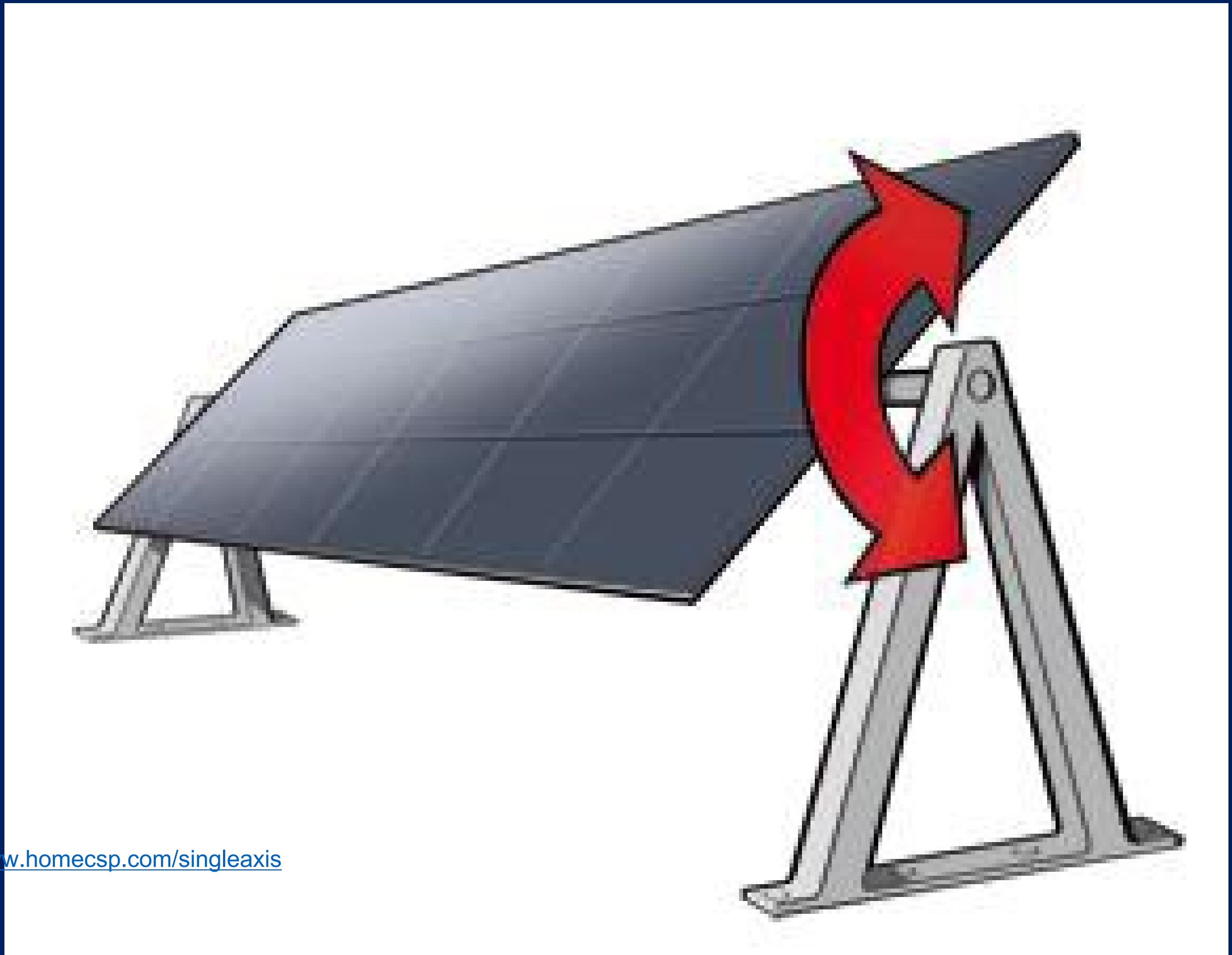
- ***Storm Damage***
- ***Poor Manufacturing***
- ***Pre-Existing Damage***
- ***Poor Sealing***
- ***Cracks or Microcracks in the Glass***
- ***Damaged Back-sheet***
- ***Faulty Junction Boxes***
- ***Regular Inspection and Maintenance***

Damage Mitigation – Water Damage 2

- ***Quality Installation***
- ***Protective Coatings***
- ***Use of Quality Materials***
- ***Proper Tilt Angle***
- ***Waterproof Junction Boxes***
- ***Warranty and Service Agreements***
- ***Preventative Measures for Microcracks***

Wind Design of Trakers – Types of Trackers 1

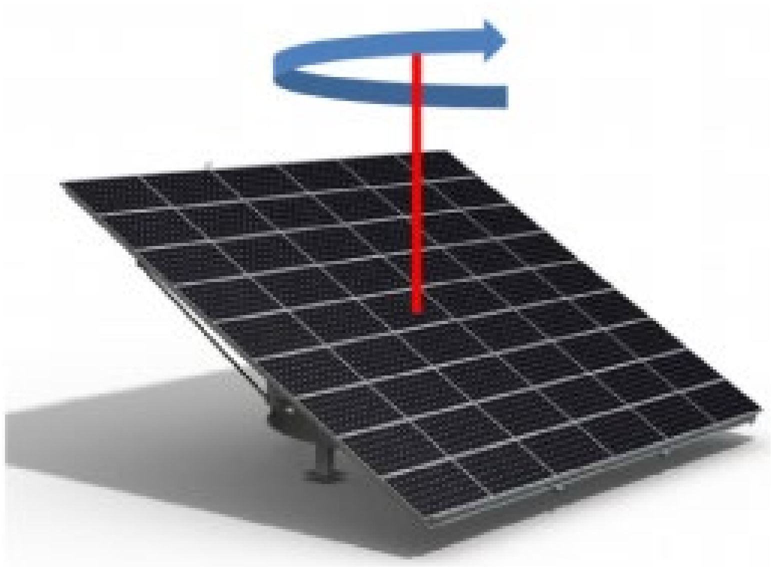
- Single Axis
  - Horizontal
    - Rotate about axis parallel to ground



http://www.homecsp.com/singleaxis

Wind Design of Trakers – Types of Trackers 2

Single Axis



Vertical Single Axis (Azimuth Tracker)

Tilted Axis

Wind Design of Trakers – Types of Trackers 3

- Dual Axis
  - Azimuth and Horizontal Rotation

cker.html

Wind Design of Trakers

- *High winds subject tracking systems to excessive vibration and twisting.*
- *Wind loads change as the shape of the tracker changes. This aeroelastic deflection can lead to a dramatic, intermittent increase in the wind loads.*
- *The motion of the tracking system can also alter wind flow patterns.*
- *The trackers can also experience displacement when a load is applied and oscillate when the load is removed. These dynamic amplification load factors include twisting about the axis of rotation.*
- ***A third-party evaluation is needed for all the wind loads – static, dynamic, and aeroelastic loading.***
- ***The wind analysis of tracker systems is quite complex and should only be undertaken by very knowledgeable and highly experienced wind engineers.***