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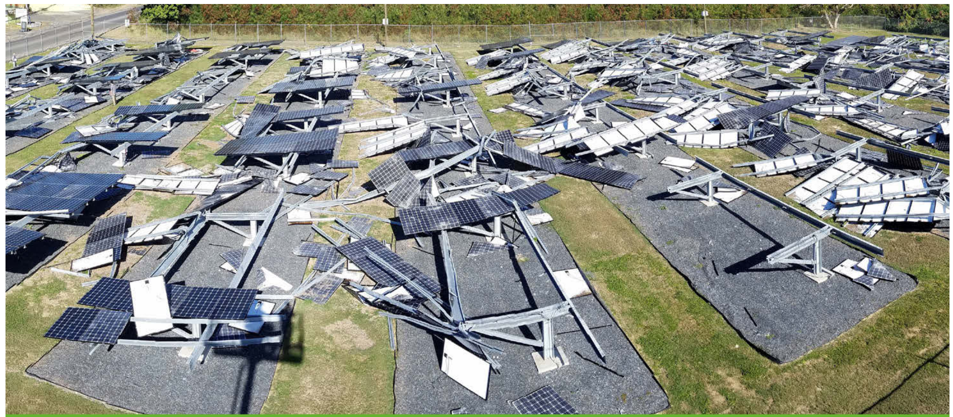

Figure 1. Unsuitable clamping fasteners lead to total photovoltaic system loss during a 2017 hurricane. *Photo by Gerald T. Robinson, LBNL.*

Solar Photovoltaic Systems in Hurricanes and Other Severe Weather

Field examinations of hurricane-damaged photovoltaic systems have revealed important design, construction, and operational factors that greatly influence a system's survivability from a severe weather event. Recent storms have not only highlighted factors contributing to survivability, but also those leading to failures. These storms also clearly demonstrated the importance of good operational and maintenance practices as a factor in survivability. For existing systems, owners can implement measures (pre- and post-storm) that can greatly minimize equipment damage and recovery time.

The U.S. Department of Energy Federal Energy Management Program (FEMP) is expanding its recommended design specifications to include factors and best practices for system survivability identified from recent hurricanes. This fact sheet provides an overview of the upcoming additions to these design specifications. Many of these factors can apply to other severe weather events, such as tornadoes.

Torqued and Locked Fasteners

Fasteners that loosened and fell out under vibration—causing photovoltaic systems to disassemble in high winds—were a common equipment loss factor identified in FEMP's analysis of recent storms. An easy, low-cost measure to prevent disassembly is to properly torque fasteners rated with true-locking capability (applicable standard: DIN 65151).

Properly torqueing a fastener involves using calibrated torque drivers and then auditing the results. Product manufacturers and consulting engineers must specify torque levels and methods for auditing results. Consider adding the audit step to the system commissioning process.

When choosing locking hardware, avoid split washers, nylon nuts (nylocks), serrated-flanged nuts, and double-nutting,[1] as these technologies are proven ineffective under Junker testing—the industry standard vibration test. Wedge-lock washers are one example of a highly effective, economical class of locking hardware.

Module Clamping Fasteners

Module clamping fasteners were also a core cause of equipment loss during the 2017 hurricane season (Figure 1). Nearly all racking manufacturers use clamps to attach modules to sub-framing, which rely on friction to hold equipment in place.

Clamping fasteners allow for fast field assembly but, as a general rule, are not adequate for photovoltaic systems in severe weather regions as they can be easily overcome in high winds. In addition, the loss of one module in a row often causes loss to all neighboring modules, since one clamping fastener is shared between two modules.

Instead of using clamping fasteners, FEMP recommends through-bolting modules with a locking fastener tightened to a specified torque rating.

Module Selection

Post-storm field inspections showed that high wind speeds caused some models of photovoltaic modules to burst from strong wind pressures. The ability of a module to withstand these wind pressures varies greatly between manufacturers.

Pre- and Post-Storm Recovery

Many actions can be taken to prepare for storm arrival and then, once passed, resume operations systematically.

Pre-storm measures:

- Perform a torque audit of all fasteners.
- Power down all components by opening breakers, fuses, and switches.
- Remove debris and tie down loose material in and around arrays.

Post-storm measures before energizing the system:

- Dry and clean all electrical systems.
- Perform a torque audit of fasteners.
- Test for electrical faults in all systems.
- Replace all damaged electrical systems before energizing.

[1] While double-nutting can be effective, it is difficult to apply in the field with predictable results.

One critical strength rating for modules is front and back pressure (Table 1). Choose modules with the highest ratings, or greatest resistance to loading. ASTM E1830-15 prescribes test parameters for loading (snow and wind) on solar modules (front and back). The test also covers several other stress factors relevant to high winds such as the "twist test." For best protection against damage from flying debris, solar modules can also be rated for "Very Severe Hail" per FM 4478.

Module Mounting

Many modules were found to be poorly supported by underlying frame elements, which led to bending and twisting and then breakage in high winds. Most solar racking systems provide two frame rails for module mounting. Consider using a three-frame rail system to provide greater rigidity and support in order to reduce bending and twisting.

Codes and Standards

The solar photovoltaic industry is changing rapidly. It takes a few years for codes and standards to keep up with the lessons learned from field experience and changing customer needs.

While there are several relevant codes, the American Society of Civil Engineers (ASCE) sponsors the main structural code, ASCE 7-16. When applying the calculation methodology outlined in the code, make sure that the gust factor used is one (1) and arrays are classified as "critical" facilities. FEMP recommends using a peer-review system that includes a structural engineering firm with wind experience.

Framing Choices

The selection of framing members comprising a racking system were another determinant of survivability. Light gauge (14–16ga), cold-rolled steel "C" or hat channels are not durable enough to survive severe weather without extreme bending and twisting. These bending forces transfer to the mounted solar modules and lead to breakage.

Table 1. Minimum Front and Back Loading on Modules

Module Side	Pascals (Pa)	Pounds per Square Inch (PSI)
Front Load (Push) Rating	5,400	113
Back Load (Pull) Rating	2,400	65

Consulting engineers need to specify frame elements that are sufficiently strong. In general, closed-form (tubular) frame elements with low drag coefficients have proven to be superior to open-shaped "C" and hat channels.

Marine-Grade Stainless Steel

Common stainless steel alloys corrode in coastal areas, leading to eventual weakening and failure. A best practice is to request 316-grade stainless steel fasteners, which are made from an alloy designed for marine environments.

Perimeter Fencing

Structural engineers experienced with wind dynamics and solar arrays have noted a highly destructive type of turbulence that acts on perimeter rows. This type of turbulence can amplify forces and lead to loss propagated from the perimeter of an array inward.

On the Western plains, wind-calming and slowing fences are used to prevent snow accumulation on highways. This same technique could be used around the perimeter of photovoltaic systems to slow damaging winds, prevent perimeter turbulence, and provide the added benefit of stopping loose debris from entering an array field.

Enclosures Rating and Maintenance

Significant damage was caused by enclosure doors opening in strong winds or by water seeping into enclosures with insufficient gasketing and latching hardware.

Specify enclosures with integrated and contiguous rubber door seals and compression latches on all sides (NEMA rated 4-R or better). Prior to a storm, maintenance personnel should ensure that seals are properly seated and fasteners are fully engaged.

Stormwater Drainage

While damage from some recent hurricanes was mainly caused by high winds, damage from other hurricanes came from localized flooding.

FEMP recommends that equipment be installed on elevated pads and entire sites have well-designed and maintained drainage systems. Avoid low spots when siting switchgear and consult with Federal Emergency Management Agency (FEMA) flood inundation maps to determine needed elevations.

For More Information

To learn more about severe weather specifications for photovoltaic systems, contact Gerald Robinson at Lawrence Berkeley National Laboratory, *gtrobinson@lbl.gov*. For FEMP assistance, contact Rachel Shepherd at the Federal Energy Management Program, *Rachel.Shepherd@ee.doe.gov*, or visit *https://www4.eere.energy.gov/femp/assistance/*. ■

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