General Services Administration
Public Buildings Service

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PV RESILIENCE: ADDRESSING WEATHER VULNERABILITIES

Small Up-Front Investments Increase Resilience

With more than 3,000 solar photovoltaic (PV) systems installed on federal property, onsite PV systems have proven to be a cost-effective, safe and reliable power source for many federal agencies. In an analysis of 100,000 commercial PV systems, more than 80% performed within 10% of predicted production or better.[1] PV systems also add resilience to the power grid and, in some cases, can provide power after a severe weather event when other grid infrastructure fails. Not all solar arrays have been built to survive severe weather events, however. After the 2017 hurricane season in the Caribbean, some PV installations in the direct path of the hurricanes failed catastrophically, while others sustained only minimal damage.

To better understand why some systems failed while others survived, the U.S. General Services Administration (GSA) hired U.S. Department of Energy (DOE) national laboratories to conduct post-storm field inspections. Based on these field inspections as well as others in the aftermath of hail storms, strong winds, and flooding, DOE laboratories and the Federal Energy Management Program (FEMP) created guidance to help agency managers identify the most common PV vulnerabilities during weather events. The guide identifies 27 vulnerabilities and prioritizes them in terms of safety, performance, and financial risks.[2] It outlines step-by-step guidance to conduct a field audit to identify vulnerabilities as well as actions that can be taken to address them. By designing, installing, and maintaining PV systems to be stronger in the face of storms, GSA can increase their value and their resilience.

INTRODUCTION

Vulnerabilities with Low-Cost Corrective Actions

Proper torquing, locking fasteners and through-bolting are all low-cost retrofits that address commonly seen vulnerabilities

Marked nut and washer for torque audit

Bolts missing because of transverse slip

Top-down clamp with T-bolt torn out of rail

STORM-HARDENING MEASURES

Estimated Costs[3]

Proper Torquing Use calibrated torque drivers & audit the results	**0.05–2.5 ¢/W**
Locking Fasteners Most common point of failure	**0.1–1.4 ¢/W**
Through Bolting More secure than top-down clamps	**0.6 ¢/W**
Three-Framed Rail System Reduces bending and twisting in high winds	**5 ¢/W**
Wind-Calming Fence Wind on perimeter rows can propagate inward	**6–14 ¢/W**
Module Selection Uplift rating should match site conditions. For hurricane-prone regions, use > 3600 Pascals	**10 ¢/W**
Tubular Steel Racking Superior to open-shaped "C" and hat channels	**12 ¢/W**

Top-Takeaways from Post-Storm Field Inspections

WITH PROPER DESIGN AND MAINTENANCE, PV CAN SURVIVE STORMS

- Causes for PV failure can easily be addressed through system design. The most common failure found during post-storm field inspections involved the use of inadequate fasteners, which can be addressed with a small up-front investment in locking hardware, clamps, and through-bolts.
- Building a system that is more likely to survive a severe storm can increase construction costs, but these costs can be recovered during the life of the system, through reduced maintenance and lifecycle costs.
- Instead of addressing isolated failure points, systems should be designed from the ground up to resist severe storms and to address location-specific conditions, such as wind speeds, loads, and topography.
- Current codes and standards are inadequate to address weather-related vulnerabilities, so it is critical to hire a consulting engineer to assist with identifying and correcting them.
- In every region of the United States, PV failures occur in response to routine as well as severe weather events. Wind is responsible for most PV system damage and is the most complex force to understand and plan for.

Resources

VULNERABILITY AND PRE-AND POST-STORM CHECKLISTS

The following page presents an at-a-glance view of the weather vulnerabilities and corrective actions identified in the DOE/FEMP guide. Note that the list has been concatenated and re-ordered from the original guide with the highest risk appearing 1st in each category. The pre-and post-storm checklists can be used to prepare a PV system to limit the damage before a storm and to safely get the system back up and running after the storm has passed.

[1] Jordan, DC, Marion, B, Deline, C, Barnes, T, Bolinger, M. PV field reliability status—Analysis of 100,000 solar systems. *Prog Photovolt Res Appl.* 2020; 28: 739– 754.

[2] *Federal Solar Photovoltaic Arrays: PV System Owner's Guide to Identifying, Assessing, and Addressing Weather Vulnerabilities, Risks & Impacts*, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Gerald Robinson (LBNL) May 2020.

[3] James Elsworth, Otto Van Geet, *Solar Photovoltaics in Severe Weather: Cost Considerations for Storm Hardening PV Systems for Resilience*, National Renewable Energy Laboratory, June 2020.

SOLAR PHOTOVOLTAIC SYSTEM RESILIENCE

Weather Vulnerabilities Checklist*

WEATHER VULNERABILITIES	RISK: SAFETY	RISK: PERFORMANCE	RISK: FINANCIAL	CORRECTIVE ACTIONS	COST
STRUCTURAL					
☐ Fastener loosening from transverse slip or improper field assembly	High	High	High	Properly torque and replace inadequate fasteners with rated locking fasteners	$
☐ Top-down module clamps: vibrational loosening, bent open or failure	High	High	High	Fix top-down clamp vulnerabilities	$$
☐ Soft joint issues in top-down module clamps & racking assemblies	High	High	High	Modify joints so clamping forces are maintained	$$
☐ Use of back side clamping and self-tapping sheet metal screws	High	High	High	Replace clamps & self-tapping screws with through-bolts/modify joints	$$
☐ Inadequate bolted joint design	High	Medium	High	Modify bolted joints in racking assemblies to avoid bolt shearing	$$
☐ Module clamps & rails not installed properly, unbraced racking, deflection of subframing	High	High	Medium	Add stiffening bracing or use top-down clamps with improved features	$$
Special Considerations for Roof Arrays					
☐ Inadequate structural attachment to building	High	High	High	Add mechanical attachments to building to improve structural integrity	$$
☐ Inaccessible and wind-damage-prone PV array	High	High	High	Reconfigure PV array to allow interior access	$$ to $$$
☐ Mounting position of PV array resulting in high wind exposure	High	High	High	Redesign PV system to reduce potential for damage from heavy wind forces	$$$
☐ Array tilts (>15°) resulting in high turbulence and front and back pressure on modules	Medium	Medium	High	Redesign PV system to a lower tilt angle to reduce potential wind damage	$$$
☐ Flexible PV array glued to roof membrane	Medium	Medium	High	Remove and/or replacing a flexible PV system glued to the roof	$$ to $$$$
ELECTRICAL					
☐ Electrical equipment located below the site's 100-year flood level	High	High	High	Relocate electrical equipment above 100-year flood level to prevent flooding	$$$
☐ Improperly supported wires	High	Low	High	Support wires with EPDM rubber-lined clamps, metallic module or rail wire clips, metallic wire ties or conduit	$$
☐ Electrical enclosures with inadequate NEMA rating located outdoors	High	Low	High	Replace inadequate and/or corroded electrical equipment; apply outdoor-rated sealant to penetrations; install weep hole, vent or drain plug	$ to $$$
☐ Conduit-related vulnerabilities	High	Low	High	Install durable conduit supports or expansion joints to accommodate thermal movement; replace conduit fittings with ones that are watertight and replace damaged conduit, install a ramp or walkway over roof mounted conduit	$ to $$
☐ Poor installation practices leading to damage of PV and other DC wires	High	Low	Medium	Replace damaged DC wiring	$ to $$
☐ Animals nesting under modules, chewing and damaging wires	Medium	Low	Medium	Remove existing animal nests; install wire-based critter guard or netting to flush mounted arrays; install bird spikes on top of array	$ to $$
☐ Field-applied labels and markings showing signs of significant degradation	Medium	Low	Low	Replace all field labels and markings that are showing signs of degradation	$
☐ Corroded grounding components due to environmental conditions or dissimilar metals	Medium	Low	Low	Replace corroded grounding components with non-corrosive components	$ to $$$
☐ PV connector failure	Low	Low	Medium	Replace damaged PV connectors	$ to $$
SITE					
☐ Unobstructed wind forces on the PV system	High	High	High	Use a wind calming fence to reduce wind forces on the PV system	$$$
☐ Loose debris and/or equipment scattered around a PV array	High	Low	Low	Clear debris and secure loose equipment around the PV system	$
☐ Improper site stormwater management around a ground-mounted PV system	Low	Low	High	Plant pollinator habitat; install site water management; perform regular O&M	$ to $$$
☐ PV array covered in snow, making it susceptible to damage	Medium	Medium	Medium	Clearly mark the presence of the PV array and its boundaries	$
☐ Clogged roof drainage system	Low	Low	Medium	Inspect and clear roof drains to avoid electrical and structural damage	$
☐ PV equipment in direct contact with the roof membrane	Low	Low	Medium	Repair roof; install protective sheet under PV arrays that come in contact with or are close to roof membrane	$ to $$$
MODULES					
☐ Damaged modules from wind/snow loading and hail, cracked or failed backsheet	Low	High	High	Replace modules with broken glass top-sheet, cracked or failed backsheet or cracked cells; conduct an I-V curve test on string and module level	$ to $$$$

RISK KEY
- High
- Medium
- Low

COST	COST PER WATT	COST FOR 50 kW PV SYSTEM
$	≈ $0.01/W (± $0.01/W)	≈ $500 (±$500)
$$	≈ $0.06/W (± $0.04/W)	≈ $3,000 (± $2,000)
$$$	≈ $0.30/W (± $0.20/W)	≈ $15,000 (± $10,000)
$$$$	≈ $1.50/W (± $1.00/W)	≈ $75,000 (± $50,000)

**Federal Solar Photovoltaic Arrays: PV System Owner's Guide to Identifying, Assessing, and Addressing Weather Vulnerabilities, Risks & Impacts*, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Gerald Robinson (LBNL) 12/2020

SOLAR PHOTOVOLTAIC SYSTEM RESILIENCE

Pre- and Post-Storm Checklist*

NOTE: Most of the actions below should be performed by a qualified electrical technician.

PRE-STORM CHECKLIST

☐ **Clear and/or Secure Debris and Loose Equipment**	Remove loose debris and secure equipment or objects that can become airborne during high-wind events and pose a threat to life safety and nearby infrastructure.
☐ **De-Energize PV System and Open all Disconnect Switches**	De-energize PV electrical equipment to minimize electrical fault damage and shock hazard. At a minimum, check the following: combiner box fuses, inverters, switchgear, weather stations and metering specific to the PV system, all main disconnects at the point of interconnection where the utility service enters the buildings.
☐ **Check Fastener Connections/Torque Tightening**	Perform a torque audit, see directions below, and inspect for missing fasteners. PV system fasteners in high-wind environments often become loose.
☐ **Clear Roof and Site Drains**	Ensure drains are clear of debris to minimize the risk of flooding electrical equipment and conduit.
☐ **Protect Exterior Electrical Enclosures**	Securely cover exterior electrical enclosures (e.g. disconnect switches, service panels, dry-type transformers) with waterproof coverings and tie the coverings down with ratchet straps. Low-cost and thin-walled electrical cabinets without waterproof NEMA ratings cannot prevent wind-driven rain from intruding and causing damage to interior components.

POST-STORM CHECKLIST

☐ **Render the Site Safe from Electrical Shock Hazards and Loose Debris**	Make sure that there is no unintended current flow from damaged electrical equipment or conductors. Also, ensure that there are no loose objects that might fall (e.g. modules, racking assemblies).
☐ **Dry and Clean Electrical Equipment**	Dry and clean electrical equipment to help prevent short circuits and corrosion, especially when salt water is involved.
☐ **Re-Check Fastener Connections/Torque Tightening**	Perform a torque audit of a random sampling of between 1% and 2% of fasteners found in critical bolted joints and module-to-rail mounting assemblies. If more than 20% of those have loosened, check and tighten all remaining fasteners.
☐ **Test for Electrical Faults**	Test for electrical faults, including integrity of wire insulation (via Megger test) and ground faults.
☐ **Identify and Replace Damaged PV System Equipment**	Create a plan to repair and/or replace damaged equipment.
☐ **Re-Energize PV System**	Under NO circumstances should the PV system be re-energized before all electrical and structural repairs and/or replacements are implemented. If possible, re-energize in stages and sections.

TORQUE AUDIT OF THREADED FASTENERS

Follow torque auditing and re-tightening processes provided by the racking manufacturer or engineer of record (EOR). If no process is provided, use the “GO-NOGO” process described below.

1. Set the torque wrench between 70% and 90% of the minimum specified torque. Minimum values should be provided by a product manufacturer or EOR. If no values are provided, consult a contractor to determine values.
2. Turn the fastener in the counter-clockwise direction (or loosening direction).
3. If the torque wrench is able to loosen the fastener, then the fastener is considered “NOGO” and is loose.
4. If the torque wrench clicks or records full minimum specified torque value on the gauge before loosening, the fastener is deemed “GO” and is adequately tightened.

Federal Solar Photovoltaic Arrays: PV System Owner’s Guide to Identifying, Assessing, and Addressing Weather Vulnerabilities, Risks & Impacts, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Gerald Robinson (LBNL) December 2020, p. 120.