GPG Outbrief 24

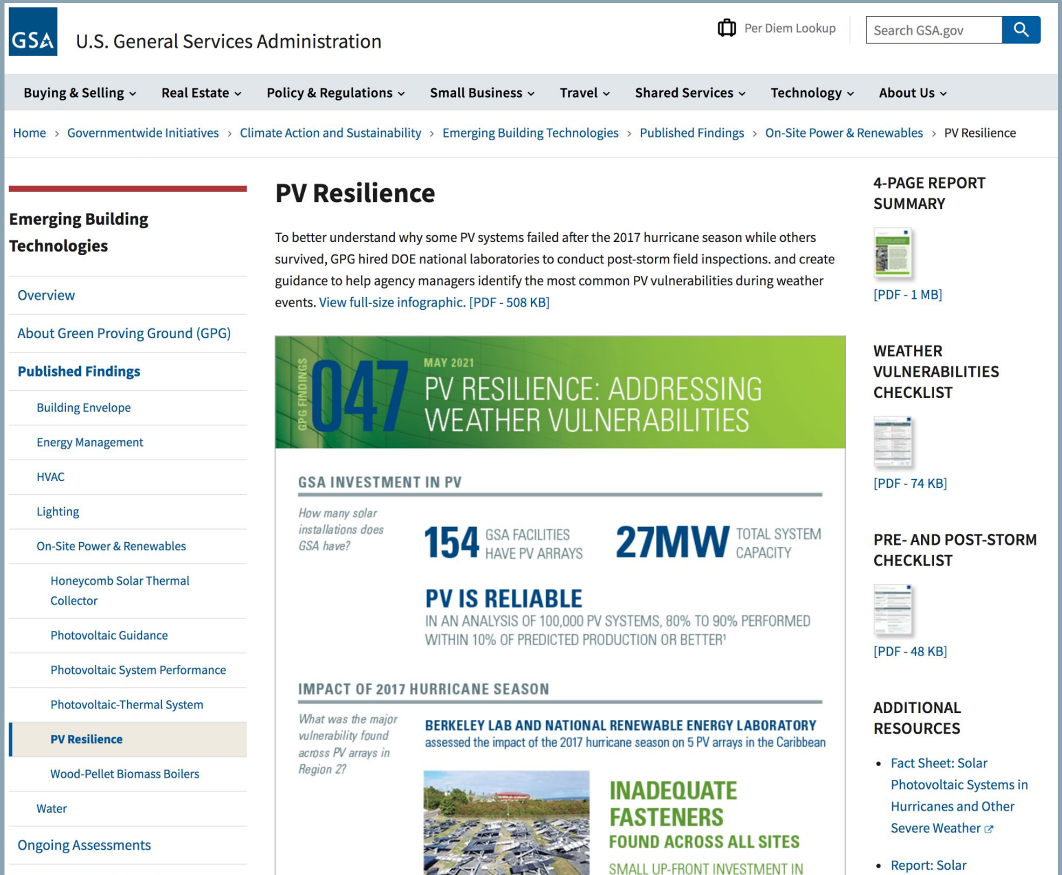
# PV Resilience: Addressing Weather Vulnerabilities in Existing Systems

Emerging Building Technologies, GPG Program | U.S. General Services Administration | June 29, 2021

GSA

# GPG-047 PV Resilience: Addressing Weather Vulnerabilities @ gsa.gov/gpg

- Infographic
- 4-page Findings
- Additional Resources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## PV Resilience

To better understand why some PV systems failed after the 2017 hurricane season while others survived, GPG hired DOE national laboratories to conduct post-storm field inspections. and create guidance to help agency managers identify the most common PV vulnerabilities during weather events. View full-size infographic. [PDF - 508 KB]

GPG FINDINGS 047 MAY 2021 PV RESILIENCE: ADDRESSING WEATHER VULNERABILITIES

GSA INVESTMENT IN PV

*How many solar installations does GSA have?*

154 GSA FACILITIES HAVE PV ARRAYS

27MW TOTAL SYSTEM CAPACITY

PV IS RELIABLE

IN AN ANALYSIS OF 100,000 PV SYSTEMS, 80% TO 90% PERFORMED WITHIN 10% OF PREDICTED PRODUCTION OR BETTER[1]

IMPACT OF 2017 HURRICANE SEASON

*What was the major vulnerability found across PV arrays in Region 2?*

BERKELEY LAB AND NATIONAL RENEWABLE ENERGY LABORATORY assessed the impact of the 2017 hurricane season on 5 PV arrays in the Caribbean

INADEQUATE FASTENERS FOUND ACROSS ALL SITES

SMALL UP-FRONT INVESTMENT IN

4-PAGE REPORT SUMMARY

[PDF - 1 MB]

WEATHER VULNERABILITIES CHECKLIST

[PDF - 74 KB]

PRE- AND POST-STORM CHECKLIST

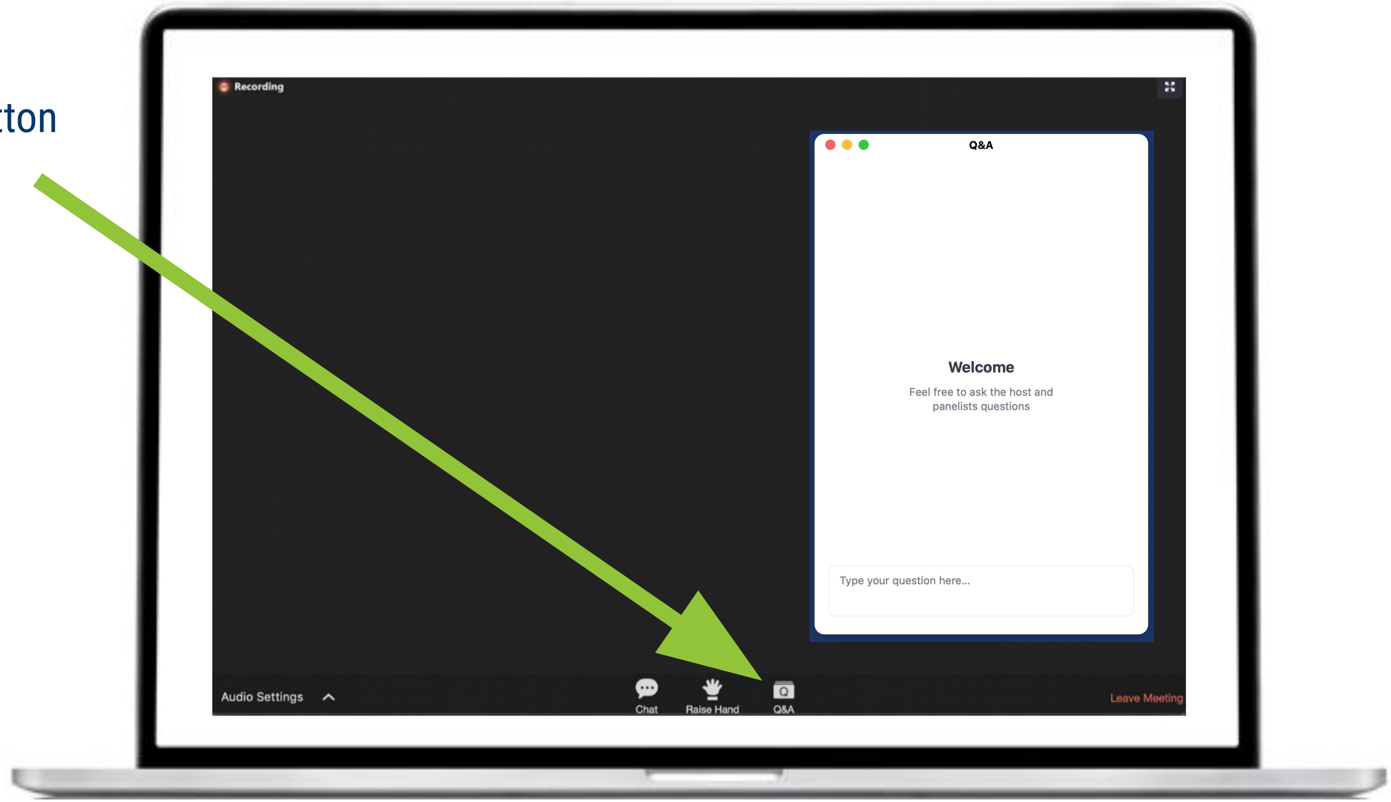
[PDF - 48 KB]

ADDITIONAL RESOURCES

- Fact Sheet: Solar Photovoltaic Systems in Hurricanes and Other Severe Weather
- Report: Solar

# How to Ask Questions

Click the Q&A button to ask questions.



# Webinar Recording and Slides Available on gsa.gov/gpg

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**Submetering & Analytics: Single-Circuit Meter**
Thursday, February 25, 2021, at 1:00 pm ET

Register now

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# Introduction

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# Webinar Agenda

- ❑ Introduction (5 minutes)
  Kevin Powell, Director, Center for Emerging Building Technologies
- ❑ PV Resilience: Addressing Weather Vulnerabilities in Existing Systems (40 minutes)
  Gerald Robinson & Kevin Watson, Lawrence Berkeley National Laboratory
- ❑ Q&A (15 minutes)

# Introduction

**Kevin Powell**
Director, Center for Emerging Building Technologies
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# PV and Resilience

**154** GSA FACILITIES HAVE PV ARRAYS

**27MW** TOTAL SYSTEM CAPACITY

## PV IS RELIABLE

In an analysis of 100,000 PV systems, 80% to 90% performed within 10% of expected production or better[1]

[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

# PV Weather Vulnerabilities & Corrective Actions

- DOE National labs conducted post-storm field inspections after Hurricanes Maria & Irma in the Caribbean
  - Some systems survived while others were destroyed in the same storm
  - All inspected systems were code-compliant
- Berkeley Lab produced guidance outlining weather vulnerabilities and corrective actions

GPG-047

# PV Resilience: Addressing Weather Vulnerabilities

General Services Administration
Public Buildings Service

GSA

GPG-047 | MAY 2021

## 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.

The GPG program enables GSA to make sound investment decisions in next-generation building technologies based on their real-world performance.

# Researchers

**Gerald Robinson**
Program Manager
Berkeley Lab

**Kevin Watson**
Research Associate
Berkeley Lab

Contributors:
James Elsworth.
National Renewable Energy Laboratory

# Market Context

## EVOLVING UNDERSTANDING

Code cycles lag field experience and solar structures present unanticipated design/assembly challenges

## Factors

- Large surface area, lightweight structures
- Static engineering—actual loading is dynamic
- Top down bolted joint assemblies
- Load paths from rack members to module mounting bolted joints
- Unique challenges for bolted joints
- Lack of failure data—siloed

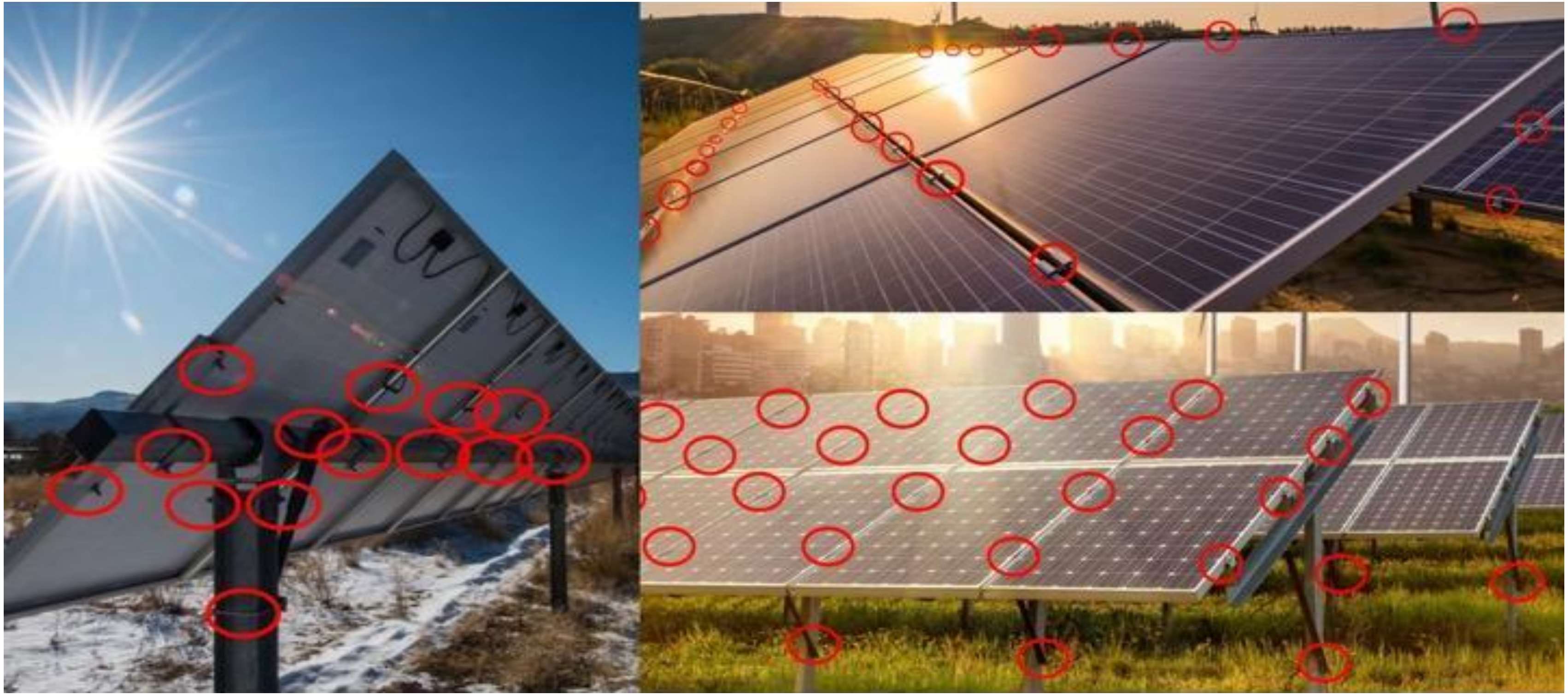
# Hurricane & Routine Weather Events—Insights

## FASTENERS ISSUES OBSERVED ACROSS ALL SITES

Critical bolted joints found in solar system present unique engineering challenges

Image Source: Gerald Robinson

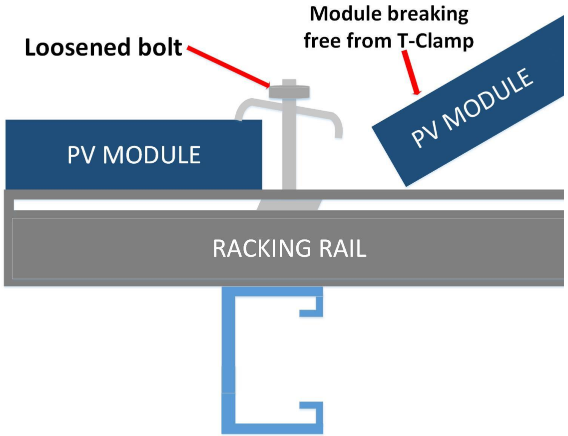
# Prevalence of Bolted Joints



# Most Common Failures in Bolted Joints

Racking Assemblies

Mechanical Attachments to Building Structures




Module Mounting

# Become Weather Aware

**Hurricanes** Eastern Seaboard, FL, TX, NC, SC, Caribbean

**Tornadoes** TX, OK, KS, NE, CO, SD and Southeast

**Earthquakes** AK, CA, NV, HI, WA, WY, ID, MT, others

**Hail** CO, WY, TX

**Flooding** FL, LA

**Wildfires** Western States

Every region in the U.S. experiences severe weather events.

When is it a force majeure event?

# 100-Year Storms—Increasing Frequency and Severity

Likely to occur in lifetime of 30-year PV system.

Failures are seen with both routine weather events as well as severe.

Image Sources: Gerald Robinson, Andy Walker

# Wind is the Most Complex and Damaging Weather Event

## Consider these wind factors when planning corrective actions

- Comparing wind speeds between different types of storms is not a useful metric.
- Need to account for other metrics like high pressure differentials (e.g. hurricane vs. tornado).
- Even F0-rated tornadoes (e.g. less than 73 mph) can easily destroy system.
- Wind damage depends on such factors like array location, tilt angle, topography, and roof/building design.

# Work with a Consulting Engineer

## Types of engineers needed

- Bolted joint engineer
- Structural engineer
- Civil engineer
- Electrical engineer

**Helpful tip:**

Engineers actively engaged in committee work and or proven record of considering the unique challenges.

# Assess Vulnerabilities

# Types of Vulnerabilities and Risks

| VULNERABILITIES | RISKS |
|---|---|
| Structural | Safety |
| Electrical | Performance |
| Site | Financial |
| Module | |

**Vulnerability 16 - Inadequate structural attachment to building**

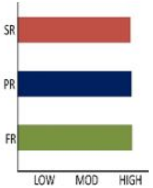
Figure 47. Ballasted roof array destroyed from high winds. Source: Renewable Energy World

Figure 48. Ballasted array, Source: Solar Power World

**Description:** On low-sloped roofs, ballasted roof arrays have become popular as a means to reduce roof penetrations. This results in less maintenance and reduces the potential for water leaks during severe weather events like hurricanes and blizzards. Ballasted PV systems use heavy blocks, typically made of concrete, to hold the array in place. This is done in lieu of mechanical attachments to the roof structure.

Unfortunately, in regions that experience moderate to severe wind events, ballasted PV systems can experience damage, and potentially cause significant property damage and pose very serious life-safety issues. The original designs did not account for powerful wind dynamics common to low-sloped roofs. Hybrid designs employing both ballasting and mechanical attachments to the building structure can be a preferable way to reduce roof penetrations while not relying solely on ballasting.

**Risk-Impact Assessment**




**Corrective Action 8**
Adding mechanical attachments to building structure to improve structural integrity

**Field Audit Instructions:**

1. Ballasted arrays are easily identifiable, as they will have rectangular blocks, usually made of concrete, in the racking assembly.
2. Look at the back of each row of modules and confirm the presence of ballasting blocks.
3. Identify if any part of the racking assembly is mechanically attached to the roof's structure.
4. Look for any signs that the PV system has moved as a result of heavy wind forces by noting any scraping that has occurred with the underlying roof.

# Safety When Working Around Solar PV Systems

## Potential shock hazards

Use qualified and trained electrical technicians. Electrical shock hazard symbols in Guide remind personnel to proceed with caution.

## Safety training required

Personnel training should match audit activities and may occur on roofs, and ladders.

# Preparing for and Conducting a Field Audit

## Collect and review documentation

- Verify that equipment installation was "as-specified" and approved
- Differences in design and as-built drawings can indicate a vulnerability

## Develop and follow a plan

- High-level assessment
- Take pictures/document everything
- Allow for adequate time
- Use of tools will depend on level of experience and personnel qualifications

**Helpful tip:** Replace missing as-built drawings (hire a consulting engineer to produce them if needed)

- Useful for the O&M contractor servicing the PV system
- Useful for the consulting engineer if any major repairs are needed

# Determine the Prevalence of a Vulnerability

Even small systems have thousands of components, exact count not practical

- Check a diverse set of areas.
- Perimeter rows may show a bias.

| Relative Prevalence | |
|---|---|
| Not Prevalent | Less than 5% |
| Prevalent | 5%–10% |
| Moderately Prevalent | 10%–20% |
| Extremely Prevalent | Greater than 20% |

# Bolted Joints are a Key Vulnerability

Identifying loose bolts by performing a torque audit is a key foundational action

Directions for a non-destructive method of torque audits are included in the guide

# Corrective Actions

# Structural Vulnerabilities/Corrective Actions

| | VULNERABILITY | CORRECTIVE ACTION |
|---|---|---|
|  | Fastener vibrational loosening | Use locking hardware |
|  | Racking clamp failure | Through-bolting |
|  | Module mounting - inadequate strength | Through bolting or upgraded top-down clamping fastener |
|  | Inadequate mechanical attachments to building structure | Add mechanical attachments |

# Electrical Vulnerabilities/Corrective Actions

| | VULNERABILITY | CORRECTIVE ACTION |
|---|---|---|
|  | Improper wire management | Support wires with purpose built clips |
|  | Inadequate electrical enclosures | Replace with appropriate NEMA-rated enclosures |
|  | Equipment located below 100-year flood level | Relocate and/or elevate equipment |
|  | Damaged and/or improperly supported conduit | Replace conduit and/or fittings that are damaged or adequate for site’s environmental conditions |

# Site Vulnerabilities/Corrective Actions

| | VULNERABILITY | CORRECTIVE ACTION |
|---|---|---|
|  | Unobstructed wind forces - “fetch” | Use a wind calming fence |
|  | Loose debris & equipment near array(s) | Secure or remove equipment/debris |
|  | Clogged drains | Clear drains of debris |
|  | Poor stormwater management | Implement better SWM features (e.g. drains, pollinator plantings, bioswales) |

# Module Vulnerabilities/Corrective Actions

| | VULNERABILITY | CORRECTIVE ACTION |
|---|---|---|
|  | Inadequate resistance to wind/snow loading and hail impacts | Test system (and modules, if necessary) for performance loss and replace if loss is significant (>20%)<br><br>Preferred modules should have uplift rating (<3,600 Pa) and resistance to hail (2 in. or greater) that match site conditions |
|  | Cracked or failed backsheets | Replace with modules that have certified BOMs that will last full system life |

# Guidance for Costing and Hiring Contractors

Use guide to ballpark recovery/rebuild costs

Hire contractors with experience in recovery/rebuild projects; unique challenges involved and skills needed

| COST | COST PER WATT | COST FOR A 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) |

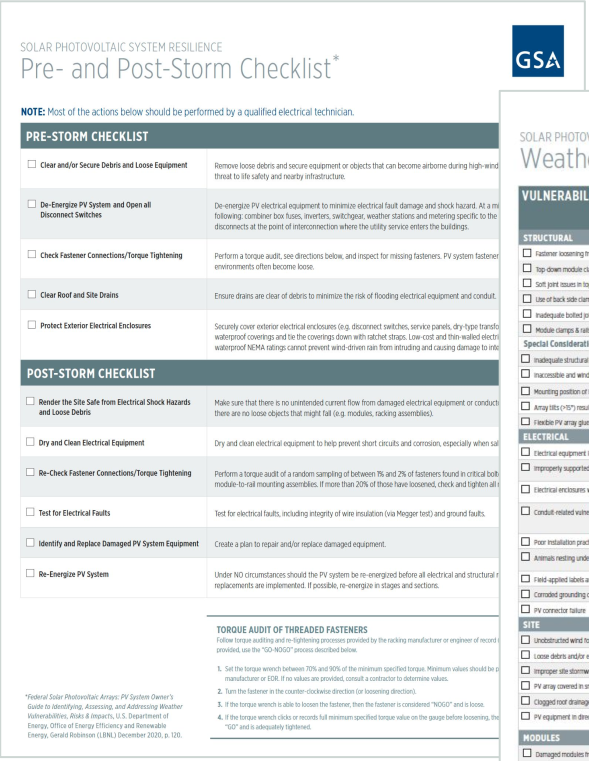
# Financing and Procurement Options

| OPTION | DESCRIPTION | FACTORS TO CONSIDER |
| --- | --- | --- |
| **Appropriations** | Use an annual funding cycle to pay repair and alteration (small) or capital construction (large) project costs. | · Easiest to implement<br>· Competes with other priorities<br>· Agency will play role of general contractor |
| **Integrate with the O&M contract** | Issue a solicitation for O&M that includes the repairs and reinforcements. | · Easy scope for O&M contractor<br>· O&M staff is skilled to undertake repair |
| **Combine with current energy project** | Integrate repair and reinforcement upgrades into an energy efficiency or renewable energy project. | · Design and skilled labor can be managed by the contractor |
| **ESPC-ENABLE for O&M** | For an array underperforming, use an ESPC-ENABLE contract to have the PV system taken over by a contractor. The agency pays on a $/kilowatt-hour (kWh) basis for refurbishing the PV system and regaining lost performance.. | · More complicated procurement pathway<br>· Contractor can manage all design and skilled labor needed to undertake project<br>· Contractor incentivized to maintain system performance, as payment is based on $/kWh delivered to agency |

# Checklists

*Pre- and Post-Storm Checklist* helps reduce storm damage and speed up recovery

*Weather Vulnerabilities Checklist* summarizes vulnerabilities and corrective actions


SOLAR PHOTOVOLTAIC SYSTEM RESILIENCE

Pre- and Post-Storm Checklist*

GSA

**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 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 mi following: combiner box fuses, inverters, switchgear, weather stations and metering specific to the 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 fastener 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 transfo waterproof coverings and tie the coverings down with ratchet straps. Low-cost and thin-walled electri waterproof NEMA ratings cannot prevent wind-driven rain from intruding and causing damage to inte |

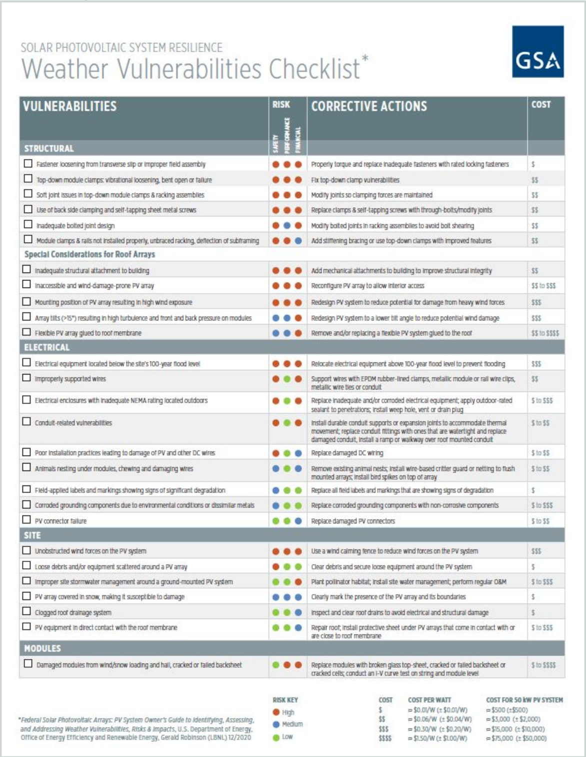
| POST-STORM CHECKLIST | |
|---|---|
| ☐ Render the Site Safe from Electrical Shock Hazards and Loose Debris | Make sure that there is no unintended current flow from damaged electrical equipment or conduct there are no loose objects that might fall (e.g. modules, racking assemblies). |
| ☐ Dry and Clean Electrical Equipment | Dry and clean electrical equipment to help prevent short circuits and corrosion, especially when sal |
| ☐ Re-Check Fastener Connections/Torque Tightening | Perform a torque audit of a random sampling of between 1% and 2% of fasteners found in critical bolt module-to-rail mounting assemblies. If more than 20% of those have loosened, check and tighten all r |
| ☐ 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 r 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 ( 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 p 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 "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.


SOLAR PHOTOVOLTAIC SYSTEM RESILIENCE

Weather Vulnerabilities Checklist*

GSA

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

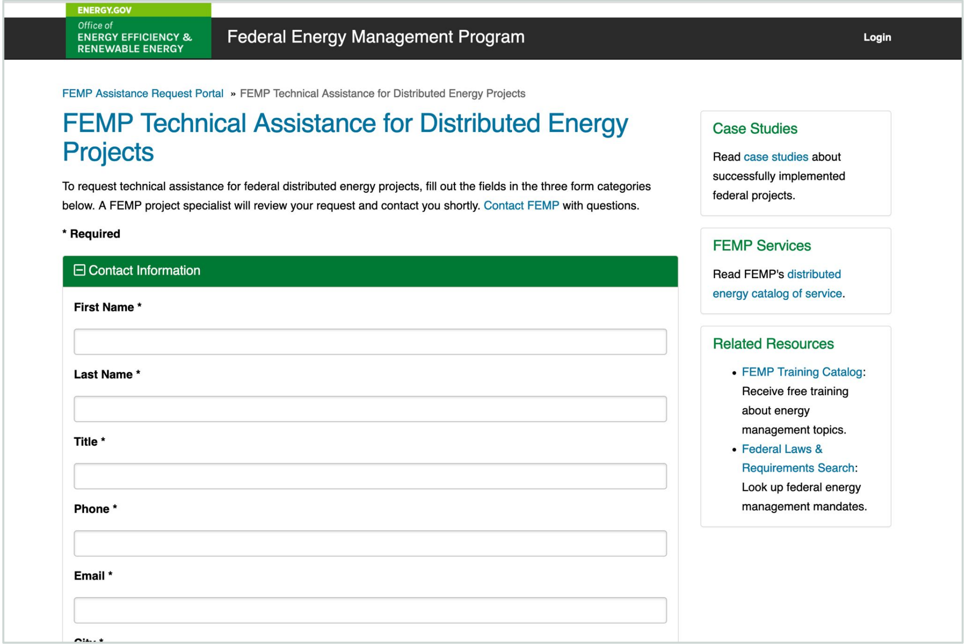
# Key Takeaways

## Use the Guide to focus upon and facilitate:

- Addressing bolted joint-assemblies as most significant vulnerabilities
- Identifying and correcting existing vulnerabilities to mitigate the severity of storm damage
- Knowing and understanding weather patterns and how weather manifests in your area
- Conducting preparatory and recovery measures before and after a weather event to reduce or avoid damage and minimize time to fully restore a system
- Understanding the importance of engaging qualified professionals that understand gaps in current codes and standards

# FEMP Technical Assistance Portal

- Federal agencies can request help!
- Fill out a quick and easy application through the FEMP portal




[FEMP Distributed Energy Portal >]

# Q & A

# Thank you

# Survey

Share experience with PV system storm damage, get technical assistance with existing arrays

## GPG Outbrief 24: PV Resilience

* Required

Email *

Your email

First and Last Name

Your answer

The information presented in the Outbrief webinar was helpful.

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Strongly Disagree | ○ | ○ | ○ | ○ | ○ | Strongly Agree |

Do you have experience with PV system storm damage that you would be willing to share?

- ○ Yes
- ○ No

Do you need technical assistance with an existing PV array?

# For more information: gsa.gov/GPG

Joe Skach, Project Manager joe.skach@gsa.gov 720.641.8891

Kevin Powell, Program Manager kevin.powell@gsa.gov 510.423.3384

# Additional Resources

- Solar Photovoltaic Systems in Hurricanes and other Severe Weather
  https://www.energy.gov/sites/prod/files/2018/08/f55/pv_severe_weather.pdf
- Solar Photovoltaics in Severe Weather: Cost Considerations for Storm Hardening PV Systems for Resilience
  https://www.nrel.gov/docs/fy20osti/75804.pdf
- Optimizing Solar Photovoltaic Performance for Longevity
  https://www.energy.gov/eere/femp/optimizing-solar-photovoltaic-performance-longevity
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