U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Solar PV in Severe Weather Locations*: How Design, Construction and O&M Can Improve Survivability

Interagency Sustainability Working Group (ISWG)

*Best practices for solar PV in severe weather locations can be applicable to solar PV systems in non-severe weather locations as well.

FEMP
Federal Energy Management Program

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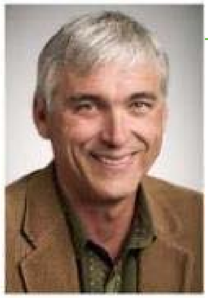

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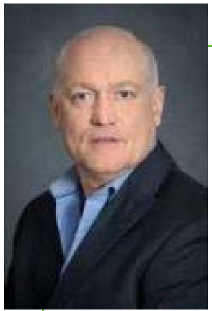

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FEMP's Distributed Energy & Energy Procurement Team

FEMP's Distributed Energy and Energy Procurement Team helps federal agencies accomplish their mission through investment in lasting and reliable energy generation projects and purchases.

Facilitate Cost Effective Distributed Energy Projects

Integrate Resilience Measures into Distributed Energy Projects

Facilitate Cost Effective Off-Site Power Purchases

Advance the Federal Workforce through Training and Resource Development

Coordinate Interagency Efforts and Provide Subject Matter Expertise to Policy Makers

Tools & Resources • Training • Project & Purchasing Assistance

PV Systems in Severe Weather Fact Sheet

- **Field examinations of hurricane-damaged PV systems identified design, construction, and operations considerations for systems in severe weather areas**
- **PV in severe weather fact sheet gives overview of recommended design specifications including:**
  - Proper torqueing fasteners
  - Through bolting
  - Proper module selection

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Solar Photovoltaic Systems in Severe Weather: Hurricanes

Field examinations of hurricane-damaged photovoltaic systems have revealed important design, construction, and operational factors that greatly influence a system's survivability of 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 will 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 2017 hurricanes. This fact sheet aims to give an overview of the upcoming additions to these design specifications. Many of these factors can apply to other severe weather events such as tornadoes.

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

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 2017 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:

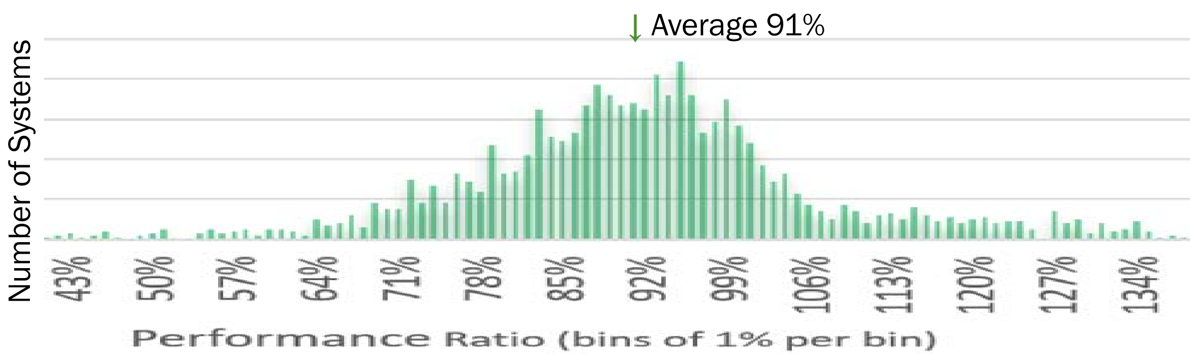
- Dry and clean all electrical systems.
- Perform a torque audit of fasteners.
- Test for electrical faults in all systems.
- Replace all damaged electrical systems before energizing.

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

https://www.energy.gov/sites/prod/files/2018/08/f55/pv_severe_weather.pdf

Performance Ratio

- PV O&M Costs vary widely, but reported between $10 and $20/kW/year
- At $15/kW/year, O&M adds about $0.01/kWh to cost of energy
- Performance Ratio = actual production/expected production
- 5% performance loss adds about $0.005 to the cost of energy
- Performance can be improved with comprehensive O&M (overall average increase from 91-95%)



Optimal (highest quartile)	Good	Average	Under-Performing (lowest quartile)
• Quality assurance in planning and construction • Comprehensive asset management • Good preventative O&M • Good corrective O&M	• Comprehensive asset management • Good preventative O&M • Good corrective O&M	• Some preventative O&M • Good corrective O&M • Can be increased from 89% to 94%	• Little or no preventative O&M • Some corrective O&M • Can be increased from 83% to 94%

Performance data from 2,200 PV system in oSPARC

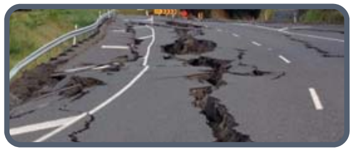
Severe Weather Events

Hurricanes

- Eastern Seaboard, FL, TX, NC, SC, Caribbean

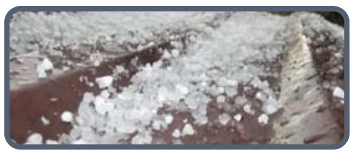
Tornadoes

- TX, OK, KS, NE, CO, SD and Southeast



Earthquakes

- AK, CA, NV, HI, WA, WY, ID, MT, others



Hail

- CO, WY

Flooding

- FL, LA

Wildfires

- Western States


Hurricane
Flooding &
Stormwater
Runoff
Hail

Special Considerations for Photovoltaics

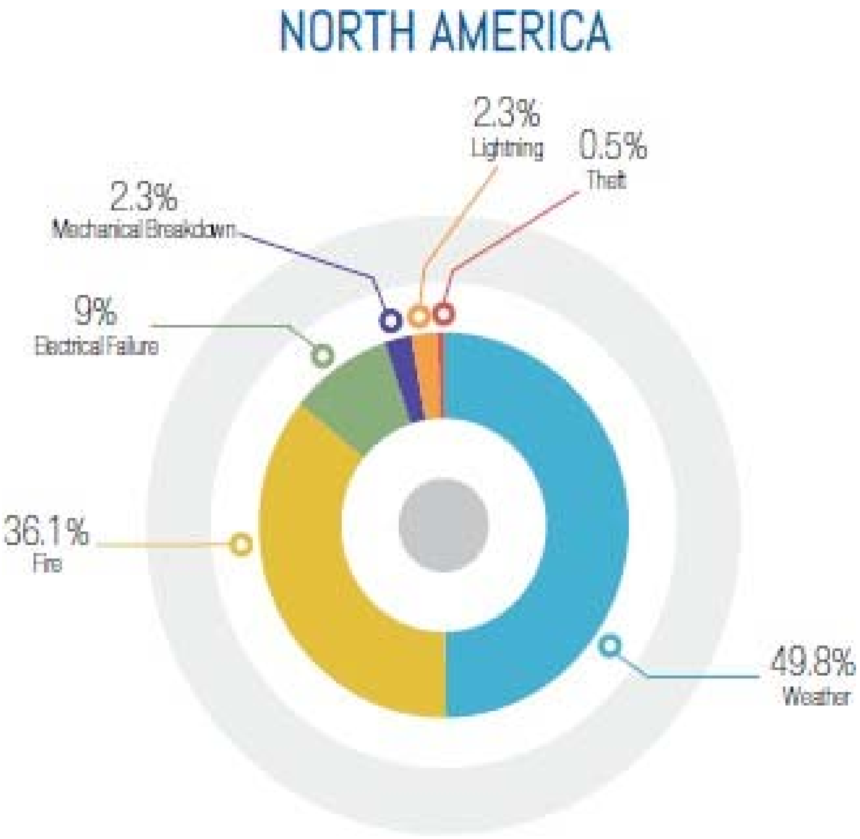
– Long term susceptibility of systems to the external environment;

  a "100 year" storm is rather likely to occur in the 25-40 year life of a PV system

– Integrated with other systems on-site (rooftop integrity, etc.)

Causes and Types of Solar PV Claims

- Causes and Types of Solar PV Claims
  - Adverse weather
  - Fire
  - Lightning
  - Mechanical breakdown
  - Electrical failure
  - (Vandalism, Theft, Transit)



11/6/2017

Severe Weather Failures

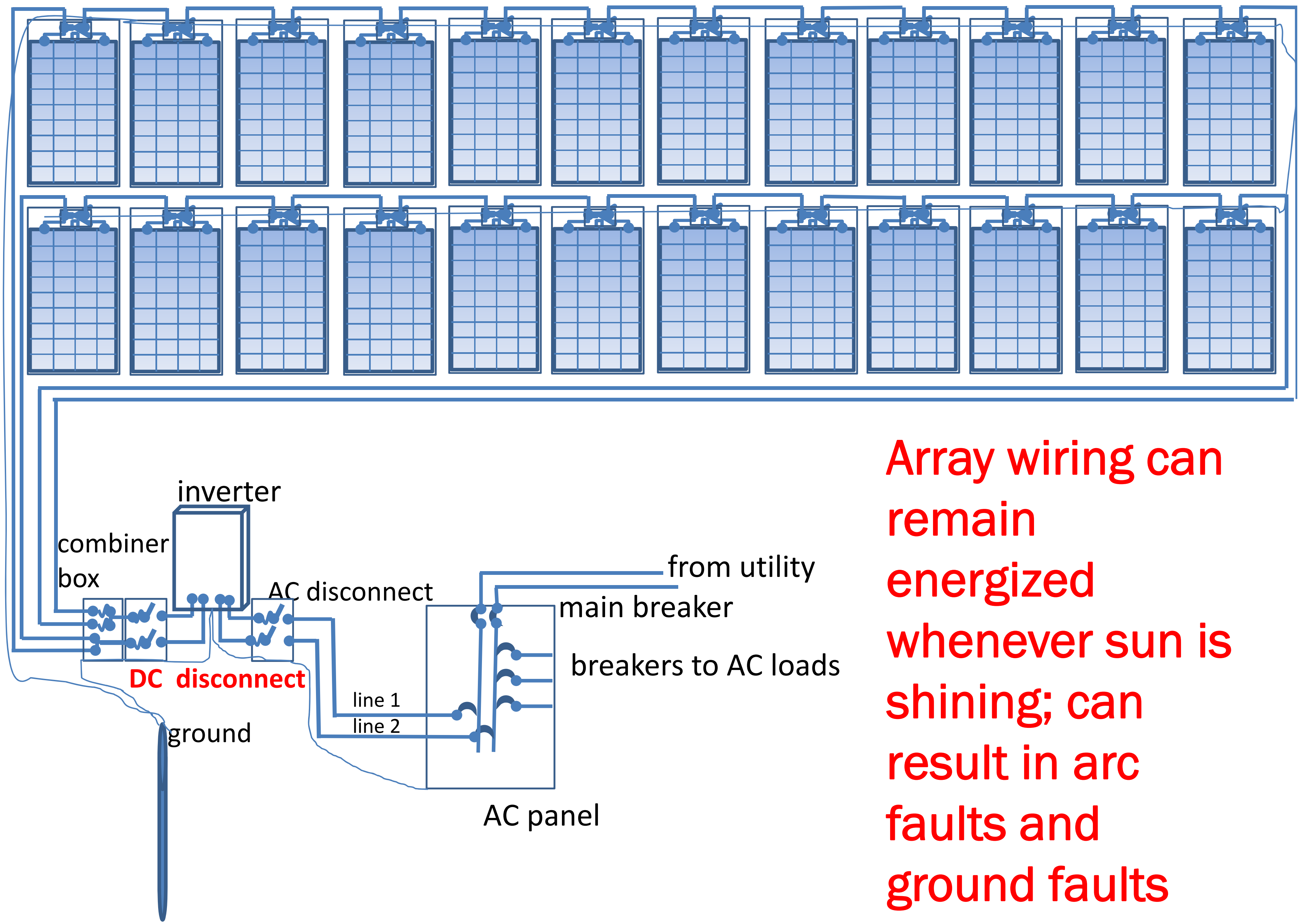
Failure
1. Structural codes/standards lag field experience
2. Construction practices – lack of training
3. Module strength ratings
3. Ineffective locking fasteners
4. Clamping fasteners - framing
5. Clamping fasteners – modules
6. Self-tapping sheet metal screws – structural applications
7. Light gauge purlins
8. Water intrusion into enclosures
9. Doors or covers coming off of enclosures
10. Overhead power lines down or fault
11. Erosion of soil around piles or equipment pads

Design Measures to Consider for New Systems

- Specify PV modules with high strength ratings (both uplift and down-force)
- Consider module-level shutoff (e.g. micro-inverters)
- Through-bolting rather than clamps (module-to-rail and rail-to-beam); avoid self-tapping screws
- Specification of bolts/washers for vibration
- Enclosures with thick rubber seals, track for seals, and multiple fasteners around door (don't just count on door handle)
- Consider underground vs above-ground utility lines
- Better wire management than plastic wire-ties
- Drains in conduit systems to avoid water in boxes
- Elevated pads for equipment enclosures
- Stormwater management system integrated into larger site/community system

Severe weather – Construction Defects

- **Inspect now for the most common construction defects**
- **May need to modify arrays now to strengthen – don’t wait**
  - Example construction defects
    - Missing or loose fasteners
    - Use of self-tapping sheet metal screws in critical structural applications
    - No true locking fasteners used
    - No torque plan followed as prescribed by product manufacturer and or structural engineer
    - Reliance on plastic wire ties to secure string wiring = wires chaffed against sharp edges and shorted



Array wiring can remain energized whenever sun is shining; can result in arc faults and ground faults

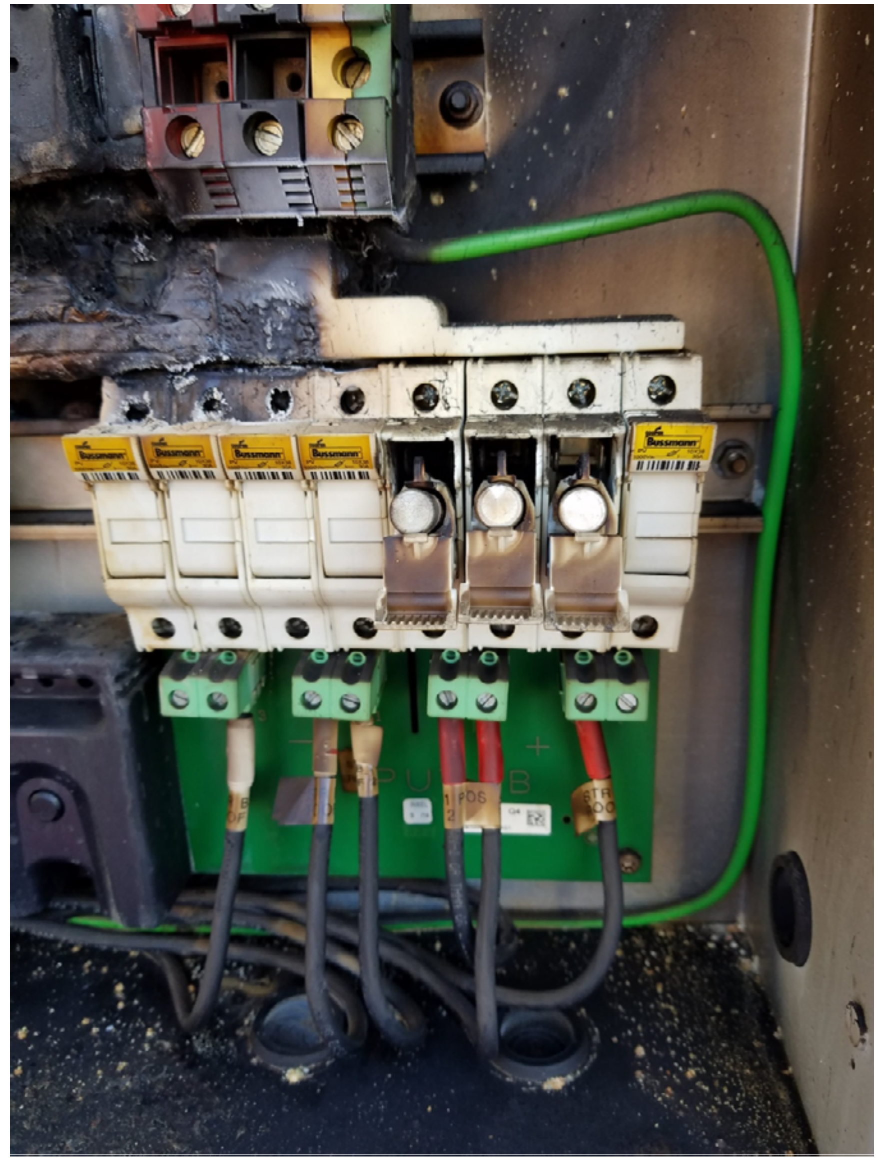
Wire Management Practices

Integrity of Enclosures

Presence and integrity of sealing gasket
Properly torque fasteners (not too loose, not too tight)

O&M: Key Role in Preventing Storm Damage

- ✓ Prep an array prior to storm arrival
- ✓ Identify and correct construction defects
- ✓ Bring array back online quickly without causing severe unintended damage to electrical system



Before The Storm Event Hits

Measure	Action(s)
Power it all down!	✓ Turn all disconnects into “open” position ✓ Use qualified and trained personnel only
Prepare site	✓ Remove debris and loose material from in and around array or lash down ✓ Remove trees and branches at risk of falling on array ✓ Ensure drains and stormwater runoff system is ready
Check fasteners and bolted joints	✓ Implement formal torque audit and take actions to tighten fasteners based on outcome ✓ Replace any missing fasteners
Electrical equipment and conduit	✓ Inspect gasketing in cabinets and make sure all equipment doors are closed with compression latches tight ✓ Remove delicate instrumentation such as pyranometer
General	✓ Replace or backup plastic wire ties with metal versions or clips and or other means for securing string wiring

After The Storm Event

Measure	Action(s)
Test before you power up!	✓ Each component of electrical system must be tested for faults, compromised wire insulation and loose lugs ✓ Megger test all wiring if possible ✓ Don't forget transformer – test for damage to windings ✓ All cabinets dried out first and if inundated with salt, cleaned by a licensed electrician ✓ Over current protection devices and disconnects may need to be serviced professionally ✓ Drain any standing water from conduit ✓ Don't forget to test power feed to meters and weathers stations
Manage array damage	✓ Remove trees and branches at risk of falling on array
Check fasteners and bolted joints	✓ Implement formal torque audit and take actions to tighten fasteners based on outcome ✓ Replace any missing fasteners
Electrical equipment and conduit	✓ Inspect gasketing in cabinets and make sure all equipment doors are closed with compression latches tight
General	✓ Replace or backup plastic wire ties with metal versions or clips and or other means for securing string wiring

Summary of Actionable Next Steps

- **Share with this FEMP team any failures**
  - Help supply more information and insight

- **Consider adapting severe weather specifications for both government and industry owned onsite systems.**

- **Industry engagement:**
  - Updates to codes and standards
  - Additional product features from manufacturers; aka: ”storm kit” for solar modules

- **Real need for more research**
  - Fully characterize the root causes of failures
  - Wind mitigating strategies for arrays

Related Resources

FEMP Severe Weather Fact Sheet

https://www.energy.gov/eere/femp/downloads/solar-photovoltaic-systems-hurricanes-and-other-severe-weather

Procurement Specifications Templates for On-Site Solar Photovoltaic: For Use in Developing Federal Solicitations

https://www.energy.gov/eere/femp/downloads/procurement-specifications-templates-site-solar-photovoltaic-use-developing

Solar Under Storm: Designing Hurricane-Resilient PV Systems

https://www.rmi.org/solar-under-storm-designing-hurricane-resilient-pv-systems/

Operations and Maintenance for Optimal Photovoltaic System Performance On-Demand Training
https://www4.eere.energy.gov/femp/training/

O&M Best Practices for Small-Scale PV Systems On-Demand Training
https://www4.eere.energy.gov/femp/training/training/om-best-practices-small-scale-pv-systems

Best Practices in PV O&M
https://www.nrel.gov/docs/fy17osti/67553.pdf

O&M Cost Model

http://apsuite.sunspec.org/

https://sunspec.org/wp-content/uploads/2016/03/SunSpecPVOMCostModelUserManual-Beta.pdf

Open Solar Performance And Reliability Clearinghouse (oSPARC)
http://sunspec.org/sunspec-osparc/