Rooftop Solar Panel Attachment: Design, Installation, and Maintenance

FEMA

HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS *Recovery Advisory 5, April 2018*

Purpose and Intended Audience

The purpose of this Recovery Advisory is to recommend practices for attachment design, installation, and maintenance of rooftop solar panels, also known as photovoltaic (PV) panels, to increase panel wind resistance in the U.S. Virgin Islands. This guidance was informed by lessons learned after Hurricanes Irma and Maria in 2017 and is primarily intended for architects, engineers, and contractors. However, it provides helpful information for building and home owners. This guidance is also helpful for manufacturers of PV panels and attachment devices.

Key Issues:

1. **Facilities in the planning stage**: Designers should calculate wind loads on the PV array, specify assemblies that have sufficient strength to resist the specified loads and specify/detail attachment of the assemblies.
2. **Commissioning:** During construction, contractors should implement quality control and quality assurance procedures to ensure that the design intent is met.
3. **Existing PV systems:** It is recommended that the building owner hire a qualified architect or engineer to perform a wind vulnerability assessment. If significant vulnerabilities are identified, a corrective action plan to mitigate the vulnerabilities is recommended.
4. **Maintenance:** It is recommended that the building owner have maintenance staff or a contractor annually check tightness of the PV array's bolted connections with a torque wrench. It is recommended that 100% of the panel clamps be checked and that spot checks be made for bolts that connect rails to clip angles or posts.
5. **Preparations prior to hurricane landfall:** It is recommended that the building owner have maintenance staff or a contractor perform the following:
    - Remove debris from roof drains, scuppers and gutters.
    - Remove loose objects such as buckets, lumber and sheet metal from the roof and surrounding areas.
    - If there is sufficient time, check tightness of the PV array's bolted connections with a torque wrench.
6. **After a severe wind storm:** It is recommended that the building owner have maintenance staff or a contractor perform the following:
    - Check the PV array for damage.
    - Remove, replace, or temporarily secure loose panels.
    - Check the roof covering for damage caused by wind-borne PV panels or other debris.
    - Check tightness of the PV array's bolted connections using the guidance given in Key Issue 4 (this task could be scheduled to occur a few months after the storm).

Terminology

External seam clamp: A clamp used to attach items to the seam (rib) of a standing seam metal roof (Figure 12).

Panel clamp: A clamp used to attach solar panels to a rail, rack, or external seam clamp (Figure 13).

Post (support stand): A device used to attach rails or racks to the roof support structure and/or roof deck. (Figure 10).

Solar array: Any number of rooftop solar panels grouped closely together (Figures 1-5).

Solar panel: A device to receive solar radiation and convert it into electricity or heat energy. Typically, this is a photovoltaic (PV) module or solar thermal panel. Panels are commonly mounted on rails or racks that are attached to the roof or are ballasted (Figure 7).

T-bolt: Bolt used to attach panel clamps to rails (Figure 8).

Wind Deflector: A component of the photovoltaic panel or racking system that is designed to turn the flow of air away from the underside of the photovoltaic panel.

This Recovery Advisory Addresses Rooftop PV Systems as They Relate to The Following:

- Facilities in the planning stage and existing facilities (including post-event repairs) including residential, commercial buildings, industrial buildings and critical facilities
- Design and construction guidance for improved wind resistance of solar panels that are mechanically attached to the roof support structure and/or roof deck[1]
- Maintenance and preparations prior to hurricane landfall

Note, this Recovery Advisory does not address electrical safety, electrical performance, or fire performance of rooftop solar panels.

For seismic considerations, see the Structural Engineers Association of California (SEAOC) report, *Structural Seismic Requirements and Commentary for Rooftop Solar Photovoltaic Arrays* (SEAOC PV1-2012).

Design and Construction Mitigation Guidance

This section provides an overview of codes, standards, and guidelines that pertain to attachment of PV arrays. It also provides examples of various levels of PV array performance and failure modes observed after the 2017 hurricanes, and it provides design and construction mitigation guidance.

Codes, Standards and Guidelines

American Society of Civil Engineers *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16, 2017): The 2016 edition of ASCE 7 added wind load criteria for rooftop solar panel systems (Chapter 29). Criteria are given for roofs that have slope angles $\leq 7^0$. Criteria are also given for roofs with other slopes, provided that the panels are parallel to the roof slope (with a tolerance of 2^0).

Repairing Wind Damaged Rooftop PV Systems on Public Facilities Using the FEMA Public Assistance (PA) Program

According to the FEMA Public Assistance Program and Policy Guide (FEMA *PAPPG*, 2018), additional grant funding may be available on eligible repairs to provide hazard mitigation against future events. For more information, see the *PAPPG,* Appendix J, Section III, B. Roof-Mounted Equipment: "Secure to rooftop via a continuous load path, using tie-downs, straps, or other anchoring systems that will resist expected wind forces."

Structural Engineers Association of California *Wind Design for Solar Arrays* (SEAOC PV2-17, 2017): The 2012 edition of SEAOC PV2 formed the basis for the new PV provisions in ASCE 7-16. The 2017 edition of PV2 references the ASCE 7-16 provisions, incorporates knowledge from research since 2012, and provides background and recommendations beyond those in ASCE 7-16. SEAOC PV2-17 also provides example problems and illustrates specific aspects of the calculation methods.

SEAOC PV2-17 includes provisions that are not in ASCE 7-16; these are intended to clarify or provide extensions to the ASCE-16 requirements. Following these more detailed provisions of PV2-17 may reduce the design wind load on portions of an array. If these load-reduction procedures are taken, it is recommended that the authority having jurisdiction approve the reduction.

[1] Ballasted solar panels, flexible PV modules (building-integrated photovoltaic [BIPV]) installed directly to the roof surface, and PV shingles were not observed by FEMA's Mitigation Assessment Team; therefore, they are not included in this Recovery Advisory.

For all regions:

- Specify PV panels that have sufficient uplift resistance to meet the calculated wind loads. Also specify the panel attachment to rails/racks, specify the attachment of rails/racks to clips or posts, and design the attachment of the clip or post to the roof support structure and/or the roof deck. If attachment is to the roof deck, verify that the deck has adequate attachment to resist the additional uplift load imparted by the clips or posts.
- Specify PV panels and rail/rack systems that have UL 1703 and UL 2703 listing (as applicable), and an ICC AC 428 evaluation report. If the building is insured by FM Global, specify that the PV system have an FM
- Specify double-nutting the panel clamp bolts. For the first nut, specify nuts that are furnished with T-bolts. For the second nut, specify a stainless-steel lock nut with a nylon insert.
- Specify that all bolted connections be made with a calibrated torque wrench and torqued as specified by the PV system manufacturer.
- Specify that PV panels are not installed over roof drains (Figure 10) and that walkways be provided to each drain so that drains can be easily checked for debris.
- Specify a walkway between rows of PV panels so that bolted connections can be checked annually (Figure 11). When panels are butted as shown in Figure 6, it is extremely problematic to check connections.
- For seismic considerations, see SEAOC PV1.

Figure 10. PV panels extended over this roof drain (yellow oval), thereby making it difficult to check for clogging and removal of debris. The red arrow indicates a rail support post.

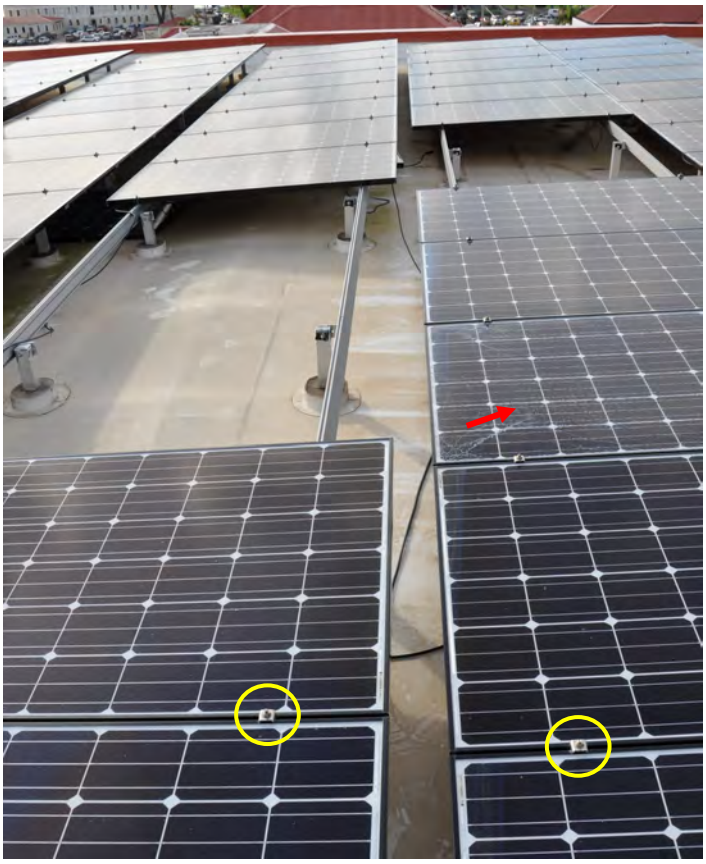

Figure 11. This array had rows between panels, which facilitate checking the tightness of panel clamps (yellow circles) and replacement of panels that were damaged by debris (red arrow) or that blew away. However, the rows were so narrow that it would have been very difficult to check the tightness of the rail/post bolts.

Involvement of a qualified roof consultant and/or a professional roofing contractor in the design and construction of the PV system is recommended. Design involvement includes providing roof system and flashing recommendations for new construction and assessing the condition of an existing roof assembly and the suitability of installing a PV array over it. Construction involvement includes having a professional roofing contractor flash penetrations through the roof covering and providing guidance for protecting the roof system during PV system installation.

PV panels may be attached to standing seam metal roof ribs with panel clamps attached to external seam clamps (Figure 12), or panels may be attached to rails that are attached to the ribs. Use of rails can result in overstressing the concealed clips that attach the metal panels. Accordingly, in lieu of rails, it is recommended that external seam clamps be used to attach PV panels to standing seam ribs. The external seam clamps should be located so that they do not interfere with the thermal expansion and contraction between the metal panels and the concealed clips.

If an array is to be attached to a standing seam metal roof that is yet to be installed, the loads on the PV panels and roof panels, and the load path from the PV panels to the concealed clips, should be considered. Prior to attaching an array to an existing standing seam metal roof, the designer should consider whether the concealed clips may be overstressed by the additional wind uplift load imparted by the PV panels.

Figure 12. These PV panels were attached directly to the standing seam ribs with panel clamps that were attached to external seam clamps (yellow arrow). Note that several panels in the foreground were damaged by wind-borne debris (reportedly a collapsed antenna).

Figure 13. View of a PV panel clip after the 2017 hurricanes. Although there was no apparent loosening of the nut, the bolt could be wobbled with finger pressure. A loose nut such as this is susceptible to further loosening and loss of the clamp's ability to keep the panels in place.

Construction Guidance

- Implement quality control and quality assurance procedures to ensure that the design intent is met.
- Use a calibrated torque wrench for all bolted connections, and torque as specified by the PV system manufacturer.
- Implement procedures during PV system application that do not damage the roof system.
- Have flashings at PV system penetrations through the roof covering flashed by a professional roofing contractor.

Post-Construction Guidance

- Annually check tightness of the PV array's bolted connections. See Key Issue 4 for specific criteria.
- Preparations prior to hurricane landfall: See Key Issue 5.
- After a severe wind event: See Key Issue 6 and Figure 13.

Water Infiltration

To avoid entrance of wind-driven rain into the building via conduits, it is recommended that electrical pull boxes and conduits associated with solar panels be specified and installed to inhibit water leakage.

References and Resources

References

American Society of Civil Engineers. 2017. *Minimum design loads and associated criteria for buildings and other structures. ASCE/SEI 7-16.* https://www.asce.org/structural-engineering/asce-7-and-sei-standards/

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UL. 2015. *Standard for Mounting Systems, Mounting Devises, Clamping/Retention Devices, and Ground Lugs for use with Flat-Plate Photovoltaic Modules and Panels, Edition 1. UL 2703.* https://standardscatalog.ul.com/standards/en/standard_2703_1

Resources

FEMA. 2018. *FEMA U.S. Virgin Islands*. Facebook page. https://www.facebook.com/FEMAUSVirginIslands

Note: this page was specifically setup for the Hurricanes Irma and Maria recovery process and is regularly updated with useful information.

For more information, see the FEMA Building Science Frequently Asked Questions Web site at https://www.fema.gov/frequently-asked-questions-building-science.

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