

GROUND-MOUNTED SOLAR PHOTOVOLTAIC POWER

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1.0 SCOPE

This property loss prevention data sheet presents guidelines and recommendations for the design, installation, and maintenance of solar photovoltaic (PV) systems that are mounted at ground level. Recommendations address PV arrays that are fixed as well as those that include a tracking system to follow the path of the sun. Solar power generating technologies based on roof-mounted PV systems are covered by Data Sheet 1-15, *Roof-Mounted Solar Photovoltaic Panels*. Waterborne (floating) solar generating systems are not covered by this data sheet.

1.1 Changes

July 2023. Interim revision. Minor editorial changes were made.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Construction and Location

2.1.1 General

2.1.1.1 Follow the guidance in Data Sheet 1-0, *Safeguards During Construction*, during the process of construction and alterations.

2.1.1.2 Locate and arrange emergency and standby power systems in accordance with Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*.

2.1.1.3 Locate and arrange all solar panels such that there is adequate space separation from combustible storage and construction in accordance with Data Sheet 1-20, *Protection Against Exterior Fire Exposure*.

2.1.1.4 Locate and arrange transformers in accordance with Data Sheet 5-4, *Transformers*.

2.1.1.5 Provide space separation between PV panels and fire exposures as recommended for noncombustible exposed construction for bifacial (glass-glass) panels, and for combustible exposed construction for monofacial panels. Fire exposures include transformers (see Data Sheet 5-4) and energy storage systems (see Data Sheet 5-33). See 2.1.7.3 of this document for wildland fire exposure.

2.1.1.6 Locate and arrange the electrical substation in accordance with Data Sheet 5-19, *Switchgear and Circuit Breakers*.

2.1.1.7 Construct ancillary buildings (switchgear buildings, control buildings, etc.) as firesafe buildings. See Data Sheet 1-1, *Firesafe Building Construction and Materials*.

2.1.1.8 Design the concrete foundation for the panel support framing in accordance with ACI 318, *Building Code Requirements for Structural Concrete and Commentary*, or other comparable standard outside the United States.

2.1.1.9 Refer to Data Sheet 10-6, *Arson and Other Incendiary Fires*, for information regarding protection against incendiary acts.

2.1.1.10 Provide a minimum 20 ft (6.1 m) wide access road (or as required by local code requirements) to the site and around the perimeter to ensure accessibility for firefighting apparatus to approach a fire inside the solar farm. Where row/string length exceeds 600 ft (180 m), provide additional access roads at intervals based on maximum hose length of the local firefighters. Consult the local fire department to determine if a buffer zone between the access road and exterior edge of the solar farm is needed. Also see section 2.1.6 for flood protection of access roads and section 2.1.7.3 for wildland fire protection.

2.1.1.11 Document the hail and wind design parameters and test reports. See Appendix D for recommended minimum documentation checklist.

2.1.2 Wind

2.1.2.1 Due to the considerable potential for damage due to wind pressure and windborne debris, avoid locating ground-mounted solar panels in regions prone to tropical storms (such as hurricanes, typhoons and cyclones, as defined in Appendix A) and where exposed to large windborne debris as defined below:

1. Large windborne debris is likely where the design wind speed is greater than or equal to 120 mph (54 m/s), or the design wind speed is between 110 and 120 mph (49 m/s and 54 m/s) and the location is within one mile of an ocean coast. (See also Data Sheet 1-28, *Wind Design*)

2. Small windborne debris (roof gravel) is likely where the design wind speed is greater than or equal to 100 mph (45 m/s). Refer to Data Sheet 1-28 for separation distance from buildings using roof gravel.

2.1.2.2 Where it is not practical to locate ground-mounted solar PV panels outside a region prone to windborne debris (as described in Section 2.1.2.1), separate the panels from potential windborne debris as defined in DS 1-28.

2.1.2.3 Fixed-Tilt Array

2.1.2.3.1 Design in accordance with ASCE 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* or conduct atmospheric boundary layer wind tunnel tests (BLWT) on array models to determine wind pressure coefficients and shadowing effects, when practical. BLWT tests should be conducted in accordance with ASCE 49-21, *Wind Tunnel Testing for Buildings and Other Structures*.

2.1.2.3.2 Design the solar panels and their securement for wind speeds, importance factors, and surface roughness exposures as described in Data Sheet 1-28, *Wind Design*, regardless of where they are located. Use pressure coefficients as determined in Section 2.1.2.3.1. Use an importance factor of 1.15. Typically, use Exposure C for installations in non-coastal areas. Use a minimum safety factor of 2.0 for all connections. Use recognized standards to establish safety factors for individual components and failure modes.

2.1.2.3.3 Do not use ballasted ground-mounted solar panels.

2.1.2.4 Tracker System Arrays (single and dual axis)

2.1.2.4.1 Design and install the solar array based on a third-party evaluation for wind loads and structural resistance. Address static, dynamic and aeroelastic loads appropriate for the installation site.

2.1.2.4.2 Install at least two anemometers on each side of the array.

2.1.2.4.3 Interlock movable panels to rotate to the design stow position when any site anemometer measures wind speeds 25% lower than speeds that have been determined to cause instability (torsional galloping) in the wind tunnel tests.

2.1.2.5 Elevated PV Structures (Carports)

2.1.2.5.1 Base wind loads for elevated PV structures such as carports on either wind tunnel tests or prescriptive wind loads from ASCE 7-22 for cases that represent the structure.

Prescriptive wind loads from ASCE 7-22 should consider the following:

A. For main wind force resisting systems (MWFRS) such as columns and primary and secondary roof framing, in open buildings and with mono-slope roofs with $\Theta \leq 45^\circ$, use ASCE 7-22 Figure 27.3-4.

B. For PV modules and their connections to roof framing in open structures and with mono-slope roofs with $\Theta \leq 45^\circ$, use ASCE 7-22 Figure 30.5-1.

C. Where the typical height of vehicles located below carports is $\leq 50\%$ of the mean roof height (h), use the pressure coefficients for clear (unobstructed) wind flow below the carport.

Depending on other wind related factors, the pressure resistance needed based on prescriptive coefficients for Zone 3 and, in some cases, Zone 2, may be difficult to obtain with currently available PV modules given the smaller EWA and larger associated pressure coefficients. In those wind zones, consider wind tunnel testing or use of blank panels.

2.1.3 Hail

2.1.3.1 Use PV modules that have hail resistance ratings recommended for hail-prone regions as defined in Data Sheet 1-34, *Hail Damage*. See Table 2.1.3.1 and Section 3.2.

The current test methods for solar panels used in ground-mounted applications are ANSI/FM 4473 and UL 61730/IEC 61215. When using these test methods, ensure test conditions reflect hail size and minimum impact energy according to Table 2.1.3.1.

Table 2.1.3.1. Minimum Hail Ratings for PV Modules

Hail-Prone Region	Minimum Equivalent Hail Size (in.)	Minimum Impact Energy (ft-lb)	Minimum Equivalent Hail Size (mm)	Minimum Impact Energy (j)
Moderate hail	1.5	8	38	11
Severe hail	1.75	14	44	19
Very Severe Hail	2.5	53	64	72

2.1.4 Snow, Rain, and Ice

Use solar panels and solar panel support structures that adequately support loading associated with snow, rain-on-snow surcharge, and ice accumulation. Consider both strength and stiffness of the solar panels and solar panel support structures when determining adequacy to support snow, rain, and ice loading. Adhere to the recommendations in Data Sheet 1-54, *Roof Load for New Construction*, along with the following:

- A. Assume the solar panel acts as a “cold roof” for snow accumulation purposes and when determining the slope factor C_s .
- B. Base the snow load on the lowest slope (closest to horizontal position) that is possible for the solar panel. Use the roof slope from Data Sheet 1-54, *Roof Load for New Construction*, that most closely matches the lowest solar panel slope when determining the slope factor C_s .
- C. If there are any obstructions or features that could prevent or impede snow from sliding freely off the solar panel (including any protruding panel framing or mounting hardware, or sufficiently deep ground snow or other obstruction below the panel) assume the “all other surfaces” category is representative of the solar panel when determining C_s . Otherwise, assume the “unobstructed slippery surface” category is representative of the solar panel. If it is unclear whether any obstructions or features could impede snow from sliding freely off the solar panel, assume the “all other surfaces” category is representative of the solar panel when determining C_s .
- D. Apply the rain-on-snow surcharge and ice dam loads as described in Data Sheet 1-54, *Roof Load for New Construction*.

2.1.5 Earthquake

The following recommendations are applicable to facilities located in FM Global 50-year through 500-year earthquake zones, as described in Data Sheet 1-2, *Earthquakes*.

2.1.5.1 Follow the site consideration guidance in Data Sheet 1-2, *Earthquakes*.

2.1.5.2 Design and construct all buildings and structures, equipment anchorage, support frames and foundations, tanks, piping-system bracing, and nonstructural elements to resist earthquake forces in accordance with Data Sheet 1-2, *Earthquakes*, with the following additions.

2.1.5.2.1 Assign those buildings that are critical or house equipment critical to continued operation of the solar PV power generation facility to at least Risk Category III, with a resulting seismic importance factor (I_e) of 1.25 per Tables 1.5-1 and 1.5-2 of ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures*. Increase the usual seismic design forces by a factor of I_e where the local building code is based on ASCE 7, or by an equivalent factor where design is based on a different international standard.

2.1.5.2.2 For equipment and its supports, piping, and nonstructural elements that are required to function for life-safety purposes after an earthquake or are critical to continued operation of the solar PV facility, assign a component seismic importance factor (I_p) of 1.5 per ASCE 7-10, Section 13.1.3. This includes the attachments, supports, and anchorage for the PV panels as well as other critical electrical equipment. Increase the usual seismic design forces by a factor of I_p where the local building code is based on ASCE 7 or by an equivalent factor where design is based on a different international standard.

2.1.5.2.3 Install electrical substation equipment that has been qualified through testing and/or analysis as required by IEEE Standard 693, *IEEE Recommended Practice for Seismic Design of Substations*.

- A. For facilities in FM Global 50-year and 100-year earthquake zones, use only equipment meeting IEEE 693-05, Section 8.3.1, “high seismic level.”

B. In FM Global 250-year and 500-year earthquake zones, use only equipment meeting IEEE 693-05, Section 8.3.2, “moderate seismic level,” at a minimum.

2.1.5.2.4 Install FM Approved PV panels and supports. In addition, qualify the PV panels and supports using triaxial time history shake table performance level testing per IEEE 693-05, assuming a maximum damping value of 2%. Use performance-level spectra that are twice the required response spectra (RRS) where the shake table testing is conducted using supports that are dynamically equivalent to the in-service supports, or four times the RRS where tested supports are not dynamically equivalent to the in-service supports.

A. For facilities in FM Global 50-year and 100-year earthquake zones, use only PV panel/support systems meeting IEEE 693-05, Section 8.4.1.1, “high performance level.”

B. In FM Global 250-year and 500-year earthquake zones, use only PV panel/support systems meeting IEEE 693-05, Section 8.4.1.2, “moderate performance level,” at a minimum. See Section 3.4 for additional information.

2.1.5.2.5 Locate the solar PV panel supports directly on the ground. Do not install PV panel supports in or on a building or other structure unless additional shake table testing has confirmed panel adequacy.

2.1.5.2.6 Based on results of the shake table testing, cushion any wear points to minimize abrasion of wiring and components, and provide sufficient slack and flexibility in electrical cabling and other connections between PV panels to accommodate the total differential movement expected during an earthquake.

2.1.6 Flood

2.1.6.1 Adhere to the recommendations in Data Sheet 1-40, *Flood*, regarding potential exposure to flood, including riverine, coastal or surface water runoff, as applicable. Where possible, locate the equipment 1-2 ft (0.3 - 0.6 m) above the 500-year mean recurrence interval (MRI), and direct water run-off to prevent ground scour that can disturb the equipment and support frames. If elevation is not practical, establish temporary flood protections in accordance with Data Sheet 1-40.

2.1.2.6.2 Elevate access roads 1-2 ft (0.3 – 0.6 m) above the 500-year MRI around the solar farm to ensure accessibility for maintenance and repair following a flood event.

2.1.7 Fire

2.1.7.1 Do not use solar PV systems that contain foam plastic, such as extruded foam polystyrene, unless specifically FM Approved for exterior fire exposure. See also 2.1.1.5.

2.1.7.2 Install panels having a Class A or B rating in the Spread of Flame test, and a Class A or B rating in the Burning Brand test when tested in accordance with ASTM E108, *Standard Test Methods for Fire Tests of Roof Coverings*.

2.1.7.3 Provide adequate space separation and protection from wildland fires and bushfires in accordance with Data Sheet 9-19, *Wildland Fire*, and from combustible yard storage or inadequately protected adjacent buildings in accordance with Data Sheet 1-20, *Protection Against Exterior Fire Exposure*.

2.1.7.4 Where solar farms are located in areas with vegetation, ensure adequate irrigation is provided to prevent vegetation from becoming a fire hazard.

2.1.7.4.1 Where irrigation is not practical, control growth (e.g., by mowing, cutting, or herbicide application) to prevent vegetation from exceeding 6 in. (150 mm) in height. Six inches (150 mm) is a general rule to prevent vegetation from becoming a sustained fire hazard.

2.1.7.4.2 Where mowing or cutting is used to control vegetation growth, remove cuttings from the area so that they do not pose a sustained fire hazard.

2.2 Protection

2.2.1 Electrical Protection

2.2.1.1 PV Array System and Inverter

2.2.1.1.1 Provide DC ground fault protection for grounded array systems.

2.2.1.1.2 Provide overcurrent protection on the AC and DC sides of the inverter against short-circuit faults and overload.

2.2.1.1.3 Provide overvoltage and undervoltage protection on the AC and DC sides of the inverter.

2.2.1.1.4 Provide over-frequency and under-frequency relays on the AC sides of the inverter.

2.2.1.1.5 Provide a disconnect at the output of each combiner box.

2.2.1.2 Provide electrical protection for the substation transformers in accordance with Data Sheet 5-4, *Transformers*.

2.2.2 Lightning and Transient Protection

2.2.2.1 Provide surge arrestors for the inverter on both the DC and AC sides.

2.2.2.2 Provide transient voltage surge suppression for the power electronics, control, and communication systems.

2.2.2.3 Provide lightning protection and surge protection for electric equipment and systems at the PV facility substation in accordance with Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems*.

2.2.3 Fire

2.2.3.1 Protect oil-filled transformers in accordance with Data Sheet 5-4, *Transformers*.

2.2.3.2 Protect emergency and standby power systems in accordance with Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*.

2.3 Equipment and Processes

2.3.1 Natural Hazards

Make provision in the design of the system to shield or protect the panels from abrasion during periods of wind-blown dust, dirt, sand, and debris.

2.3.2 Electrical

2.3.2.1 Provide an emergency source of uninterruptible power for the solar panel control system if loss of the control system will lead to a dangerous condition. Alternatively, provide a failsafe system that will position the panels in a safe position upon loss of power.

2.3.2.2 Provide an alternate means of power for the solar panel control system if it is critical to maneuver the panels into a safe position during a windstorm or hailstorm.

2.3.2.3 Where emergency and standby power for equipment and systems are installed, arrange them in accordance with Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*.

2.4 Operation and Maintenance

2.4.1 Perform commissioning tests to establish baseline performance of the solar farm.

2.4.2 Refer to Data Sheet 9-0, *Asset Integrity*, for general recommendations regarding establishing an asset integrity program, including maintenance and inspection programs for equipment and systems.

2.4.3 Maintain all solar PV system equipment in accordance with the manufacturers' recommendations.

2.4.4 Check all equipment for damage or required maintenance after severe wind, hail or snowstorms.

2.4.4 Test solar PV systems with moveable panels that are interlocked with anemometers at least annually. Complete this testing prior to the start of the tropical storm season each year. Verify that the anemometer initiates the shutdown mode at the proper wind speed (not to exceed 35 mph [15 m/s]) and that the panels rotate into the intended lock-down position (typically flat) they would be in prior to a major wind storm.

2.4.5 Inspect solar panel assemblies at least annually to ensure connections between the panels and support systems have not loosened or become corroded, that concrete paver blocks have not deteriorated, and that there is no damage caused by expansion and contraction due to temperature changes. Tighten connections and replace corroded or deteriorated materials as needed.

2.4.6 Test and maintain emergency power systems in accordance with Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*.

2.4.7 Test, inspect, and maintain fire detection and protection equipment in accordance with Data Sheets 2-81, *Fire Protection System Inspection*, 5-4, *Transformers*, and 5-48, *Automatic Fire Detection*.

2.4.8 Electrical Component Maintenance

2.4.8.1 General

2.4.8.1.1 Figure 2.4.8.1.1-1 shows a typical DC electrical system for a PV array. Figure 2.4.8.1.1-2 shows a typical AC electrical system for a large solar PV facility, which is composed of many PV arrays.

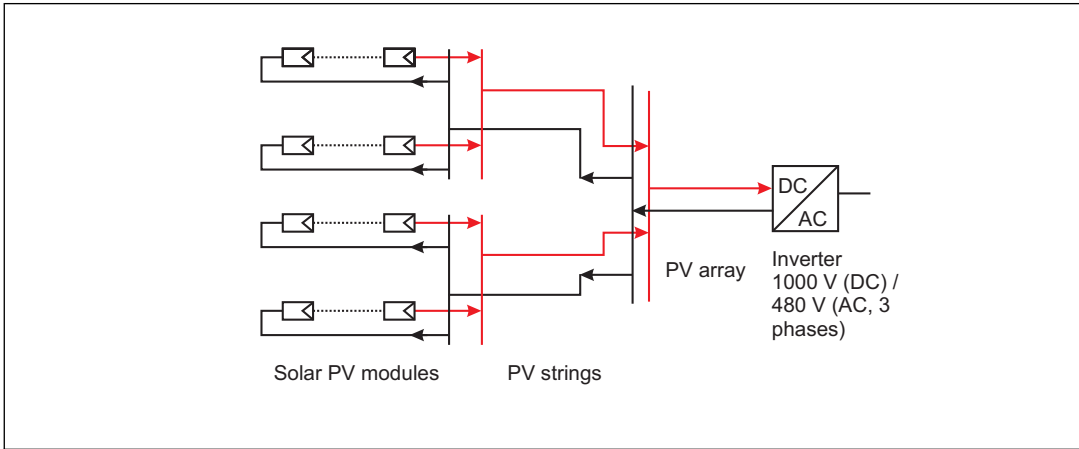


Fig. 2.4.8.1.1-1. DC electrical system for a typical PV array

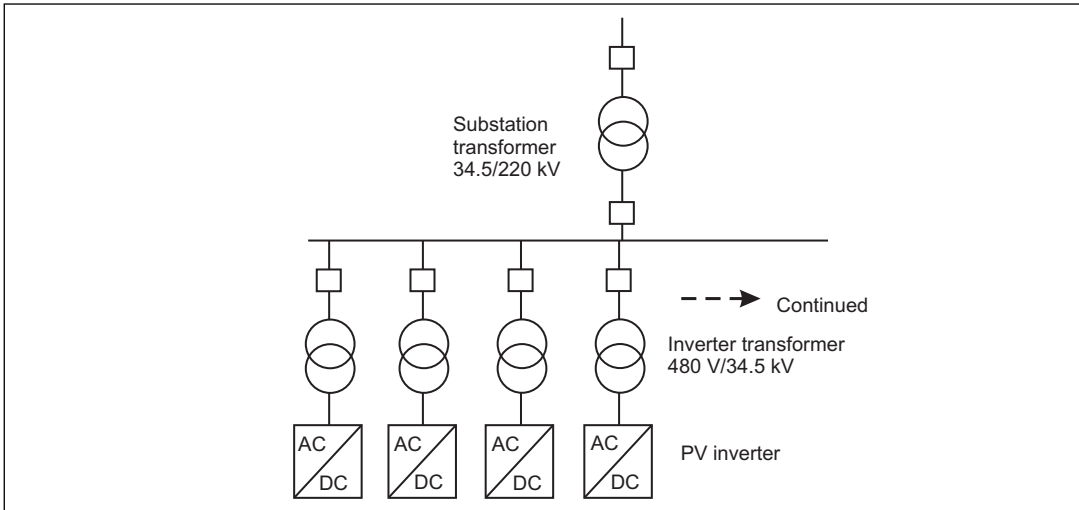


Fig. 2.4.8.1.1-2. AC electrical system for a typical solar PV power plant

2.4.8.1.2 Perform visual inspections and thermal graphic surveys for all electrical components in the PV system, including junction boxes, inverters, and source circuits in accordance with Data Sheet 5-20, *Electrical Testing*.

2.4.8.2 Array and String Cable

2.4.8.2.1 Perform PV array insulation resistance testing on a routine basis. Base the frequency of the test on site conditions and maintenance experience. As a general rule, perform the test every 3 years. Ensure the minimum insulation resistance measured with the applicable test voltage is as specified in Table 2.4.8.2.1.

Table 2.4.8.2.1. Minimum Values of Array Insulation Resistance per IEC 62446, Grid Connected Photovoltaic Systems—Minimum Requirements for System Documentation, Commissioning Tests and Inspection

Array voltage (V)	Test Voltage (V)	Minimum Insulation Resistance (MΩ)
120	250	0.5
120-500	500	1
>500	1000	1

2.4.8.2.2 Perform PV string open voltage and current tests (either short-circuit or operational current tests) on a routine basis. Compare the measured value with the expected value for systems with multiple identical strings and where there are stable irradiance conditions. Where there are stable irradiance conditions, compare measurements of current or open voltage in individual strings to ensure they are within 5% of each other.

2.4.8.3 Inverters

2.4.8.3.1 Perform periodic inspection and testing in accordance with the manufacturer's specifications to ensure correct operation of inverters.

2.4.8.3.2 Measure the contact resistance of all bolted connections and compare to the values of similar connections on a routine basis. The frequency of the test will depend on site conditions and maintenance experience. As a general rule, perform the test every 3 years.

2.4.8.4 Transformers and Switchgear

2.4.8.4.1 Test and inspect transformers and switchgear in accordance with Data Sheet 5-20, *Electrical Testing*.

2.4.8.5 Lightning and Grounding Systems

2.4.8.5.1 Test surge arrestors in accordance with Data Sheet 5-19, *Switchgear and Circuit Breakers*.

2.4.8.5.2 Inspect and test grounding and bonding systems on a routine basis. Base the frequency of testing on site conditions. As a general rule, inspect grounding and bonding systems for damage during routine electrical testing, and measure ground impedance and check continuity every 5 to 10 years.

2.4.8.6 PV Power Plant Substation

2.4.8.6.1 Perform maintenance and testing on the substation transformers in accordance with Data Sheet 5-4, *Transformers*.

2.4.8.6.2 Perform maintenance and testing on the substation switchgear and protection relays in accordance with Data Sheet 5-19, *Switchgear and Circuit Breakers*.

2.5 Human Factor

2.5.1 Emergency Response and Pre-Incident Planning

2.5.1.1 Design and institute an emergency response plan in accordance with Data Sheet 10-1, *Pre-Incident Planning*.

2.5.1.2 Include potential fire scenarios in the emergency response plan in accordance with Data Sheet 10-1, *Pre-Incident Planning*. Due to the remote location of solar power facilities, firefighting response may be delayed. Therefore, pre-incident planning with the fire service is critical.

2.5.1.2.1 Arrange and prepare documented procedures to expedite access and emergency response to events such as fire. Prepare schematics to guide responders and indicate the location of access routes throughout the facility.

2.5.1.2.2 Train and authorize designated personnel to serve as liaisons with the public fire service.

2.5.1.2.3 Provide the local fire service with sufficient knowledge of fire hazards and response procedures to aid them in conducting firefighting operations. Document this information in the pre-incident plan with the local fire service.

2.5.2 Hot Work

2.5.2.1 Establish a hot work permit and supervision program in accordance with Data Sheet 10-3, *Hot Work Management*.

2.6 Supervision of Property

Provide protection against potential theft or vandalism. This could include, but is not limited to, any of the following: the use of security fencing, exterior lighting, continuous employee attendance, and security service. The level of protection needed will vary with the value of the facility. For more information, see Data Sheet 9-1, *Supervision of Property*.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Tracker System Arrays Wind Design (Single and Dual Axis)

Tracker system arrays are design to have modules follow the sun across the sky. This maximizes the angle at which modules receive solar radiation and thus, the system's electricity output. Tracking systems can be single-axis or dual-axis as well as active or passive. A single-axis tracker moves modules on one axis of movement, usually aligned north-south to arc from east to west and track the sun as it rises and sets. A dual-axis tracker allows modules to move on two axes, aligned both north-south and east-west, which allows for maximum angle of module orientation throughout the year. Active solar trackers use a motorized tracking system powered by the solar array. Passive solar trackers move by using the heat from the sun to expand and contract a gaseous mechanical movement system. Each tracking system has variable operating temperatures, range limits, tracking accuracy and energy consumption needs for the drive system.

High winds can subject tracking systems to excessive vibration, twisting and/or unbalanced loading. If the tracker deflects significantly, the wind loads will change as the shape of the tracker changes. This aeroelastic deflection can lead to a dramatic, intermittent increase in the wind loads, which can result in significant motion, instability or modal excitation. The motion of the tracking system can also alter wind flow patterns around the tracker, which in turn alters the wind loads to subsequent or neighboring units.

Leverage wind tunnel testing, as outlined in ASCE 7-22 and ASCE 49-21, to obtain lift and drag pressure, and moment coefficients appropriate for the modules, row sections, piles, torque tubes, and drive systems. The coefficients used should consider the full range of tilt angles and worst-case wind directions. These coefficients are considered for the tracker configuration in a static state.

The trackers can also experience displacement when a load is applied and oscillate when the load is removed. The oscillations experienced by the mounting system can increase the wind load above the static loads measured in the wind tunnel study. These dynamic amplification load factors include but are not limited to twisting about the axis of rotation, piles bending east-to-west and a wavy motion along the row of modules. The amplification factors vary with the tributary area and load condition of the array. These factors should be included in the strength design.

If the tracker deflects significantly (e.g., more than 10° of twist past the nominal position), the wind loads on the tracker will likely change; because the shape of the tracker has changed. This aeroelastic deflection can lead to a dramatic, intermittent increase in the wind loads, resulting in significantly more motion, instability or modal excitation than that predicted by the dynamic amplification factors. Instability and high deflection limit-state motion can be captured with an aeroelastic model of the tracking system.

Each system will be unique, and this standard is not intended to capture all variables in the load amplification or aeroelastic design. Dynamic amplification factors, as well as the deflections experienced under the various loading scenarios are acquired from full scale testing of trackers. A third-party evaluation is needed for all the expected wind loads, including static, dynamic, and aeroelastic loading at the trackers full range of tilt angles and wind directions.

For all systems, a description of the stow strategy for high-wind conditions should be reported.

3.2 Hail

Hail stones with 2.5 in. (64 mm) diameter have approximately twice the impact energy of the 2 in. (51 mm) diameter ice balls used to obtain a Class 4 rating in ANSI/FM 4473, while 3 in. (76 mm) diameter hail stones have approximately 4.5 times the impact energy of the 2 in. (51 mm) diameter ice balls. Refer to Data Sheet 1-34, *Hail Damage*, for impact energy of other size hail stones.

3.3 Desert Locations

If solar panels are to be situated in a desert environment, fine sand and grit may be plentiful. Solar panels intended for desert locations should be tested in accordance with U.S. Department of Defense MIL-STD-810H, Test Method Standard for Environmental Engineering Considerations and Laboratory Tests and Test Method 510.4, Sand and Dust. IEC 60068-2-68 Environmental Testing - Part 2: Tests - Test L can also be used if the variable parameters meet or exceed those specified in the MIL standard as shown in Tables 3.3-1 and 3.3-2).

Table 3.3-1 Comparison of the Military and IEC Standards on Blowing Dust Tests

<i>Exposure Condition</i>	<i>The Military Standard</i>	<i>The IEC Standard</i>	<i>Equivalency Requirement*</i>
Temperature	Ambient and high operating temperature	Not exceeding the maximum operating temperature	Ambient and high operating temperature
Relative Humidity	< 30%	< 25%	Both acceptable
Air Velocity	8.9 ± 1.3 m/s	<ul style="list-style-type: none"> • 1.5 ± 0.2 m/s • 3.0 ± 0.3 m/s • 5.0 ± 0.5 m/s • 10 ± 1 m/s • 15 ± 1.5 m/s 	> 8.9 ± 1.3 m/s
Dust Composition	Red china clay or silica flour	Olivine, quartz or un-decomposed feldspar	Both acceptable
Dust Size	100% by weight less than 150 µm, with a median diameter (50% by weight) of 20 ± 5 µm	Coarse dust (< 150 µm)	Both acceptable
Dust Concentration	10.6 ± 7 g/m ³	<ul style="list-style-type: none"> • 1 ± 0.3 g/m³ • 2 ± 0.5 g/m³ • 5 ± 1.5 g/m³ • 10 ± 3 g/m³ 	> 10.6 ± 7 g/m ³
Specimen Orientation	Most vulnerable surfaces	Mounting plate to expose all sides	Most vulnerable surfaces
Test Duration	At least 6 hours at ambient temperature, and an additional 6 hours at the high operating temperature	2, 4, 8, or 24 hours	At least 6 hours at ambient temperature, and an additional 6 hours at the high operating temperature

*to make the IEC standard equivalent to the Military standard.

Table 3.3-2 Comparison of the Military and IEC Standards on Blowing Dust Tests

Exposure Condition	The Military Standard	The IEC Standard	Equivalency Requirement*
Temperature	Ambient and high operating temperature	Not exceeding the maximum operating temperature	Ambient and high operating temperature
Relative Humidity		< 25%	Both acceptable
Air Velocity	18 m/s	<ul style="list-style-type: none"> • 20 m/s • 30 m/s 	> 18 m/s
Sand Composition	Quartz sand (at least 95 percent by weight SiO ₂) of subangular structure.	Olivine, quartz or un-decomposed feldspar	Both acceptable
Sand Size	150 µm to 850 µm, with a mean of 90 ± 5 percent by weight smaller than 600 µm and larger than or equal to 150 µm, and at least 5 percent by weight 600 µm and larger	<ul style="list-style-type: none"> • < 850 µm 100 to 94.5% • < 590 µm 98.3 to 93.3% • < 420 µm 83.5 to 74.5% • < 297 µm 46.5 to 43.5% • < 210 µm 17.9 to 15.9% • < 140 µm 5.2 to 4.2% 	Both acceptable
Sand Concentration	0.18 g/m ³ , -0.0/+0.2 g/m ³	<ul style="list-style-type: none"> • 1 ± 0.3 g/m³ • 2 ± 0.5 g/m³ • 5 ± 1.5 g/m³ • 10 ± 3 g/m³ 	> 0.18 g/m ³ , -0.0/+0.2 g/m ³
Specimen Orientation	Most vulnerable surfaces	Mounting plate to expose all sides	Most vulnerable surfaces
Test Duration	90 minutes per each vulnerable face	2, 4, 8, or 24 hours	> 90 minutes per each vulnerable face

*to make the IEC standard equivalent to the Military standard.

The facility should have a response plan that includes cleaning the panels following a sand or dust storm. In addition, the abrasion of the glass surfaces may affect the voltage and current output of the panels. Arrays connected in parallel may produce unbalanced voltages, causing significant drop in total output. An FM Approved panel is not evaluated for exposure to sandstorm.

3.4 Seismic

3.4.1 Seismic Design of Structures and Typical Equipment

For buildings and most equipment (e.g., piping, tanks, boilers), analysis is used as the sole basis of design or certification for seismic resistance. For example, ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, has provisions for the design of many different building types and restraint of most common equipment items. For some items, industry standards exist that provide guidance for seismic analysis and anchorage. An example is AWWA D100, *Welded Steel Tanks for Water Storage*. A general discussion of building code seismic provisions is provided in Data Sheet 1-2, *Earthquakes*.

Building code seismic provisions for equipment anchorage are intended mainly to restrain the equipment to prevent it from movement that could cause it to become a life safety hazard in an earthquake. Fortunately, most equipment is relatively rugged and if prevented from overturning, sliding or falling, these life safety considerations will often result in equipment that is functional after an earthquake. Where equipment is critical, increasing the design forces by applying an importance factor (I_p) of 1.5 results in a high likelihood that rugged equipment will be operational after being strongly shaken in an earthquake. Similarly, applying an importance factor (I_e) greater than 1.0 for critical buildings or buildings that house critical equipment (e.g., by classifying them as at least Risk Category III per ASCE 7-10, which has an I_e of 1.25) increases the likelihood of good earthquake performance. A higher assigned building seismic design category may also result in enhancements to structural detailing requirements.

Some equipment items, however, have components that are relatively fragile and for which operability after an earthquake cannot be reliably assessed solely from analyses. For example, anchorage requirements for a transformer can be easily analyzed, but earthquake performance of the tall porcelain bushings cannot. Likewise, PV panel supports made up of standard structural shapes, as well as most anchors from the panels to the supports and from the supports to the foundation, can be designed to resist earthquake forces using standard analysis techniques. However, performance of the PV panels themselves, particularly the likelihood that they will be operable after an earthquake, is difficult to assess without actual shake table tests.

3.4.2 Seismic Qualification of Electrical Substation Equipment

A well-known method of qualifying electrical substation equipment is contained in IEEE 693, *IEEE Recommended Practice for Seismic Design of Substations*. This standard covers such items as circuit breakers, transformers and their porcelain bushings, air core reactors, circuit switches, batteries and battery racks, surge arrestors and switchboards. Depending on the item, the voltage level, the expected level of shaking and various other factors, equipment can be qualified for use in seismically active areas by IEEE 693 through several different methods. Some low voltage equipment is considered to be inherently acceptable, but for most equipment qualification is made from some combination of experience data from previous earthquakes, static analysis, static coefficient analysis, dynamic response spectrum analysis, static pull testing, sine beat shake table testing, or time history shake table testing.

IEEE 693 has three seismic qualification levels: low, moderate and high. It would be more accurate to conduct qualifications based on the site specific earthquake hazard. However, as stated in IEEE 693-05, Section 4.4, using only three qualification levels allows interchangeability should equipment be damaged or malfunction in an earthquake and need to be replaced quickly. Also, having a limited number of qualification levels makes it easier to keep track of equipment and its qualification level.

IEEE 693-05, Section 8.6.2.1, provides a method of determining appropriate seismic qualification levels based on the seismic maps in the *International Building Code*. These maps are the same as those used by ASCE 7. Generic S_{DS} and S_{D1} values based on FM Global seismic zone, which were developed in order to use ASCE 7 criteria, are provided in Data Sheet 1-2, *Earthquakes*. The values in Data Sheet 1-2 have already been adjusted for the effects of soil (i.e., Site Class). In order to convert the FM Global generic S_{DS} value to an IEEE 693 seismic qualification level, the following relationships from IEEE 693 and ASCE 7 are used:

A. $S_{DS} = 2/3 * S_{MS} = 2/3 * F_a * S_s$, therefore, $F_a * S_s = 1.5 * S_{DS}$

B. Peak ground acceleration (PGA) = $F_a * S_g / 2.5$

C. For $PGA \leq 0.1$ (g) choose low qualification level; for 0.1 (g) < $PGA \leq 0.5$ (g) choose moderate qualification level; for $PGA > 0.5$ (g) choose high qualification level.

Where:

(g) is gravitational acceleration equal to 32.2 ft/sec² (9.81 m/sec²).

Refer to Table 3.4.2 for the derivation of FM Global earthquake zones to IEEE 693 seismic qualification levels, using the relationships described above.

Table 3.4.2. Derivation of IEEE 693 Seismic Qualification Levels

FM Global Earthquake Zone	S_{DS} (see Data Sheet 1-2)	$F_a * S_s$ (= $1.5 * S_{DS}$)	PGA (= $F_a * S_g / 2.5$)	IEEE 693 Seismic Qualification Level
50-year	1.3 (g)	1.95 (g)	0.78 (g)	High
100-year	0.9 (g)	1.35 (g)	0.54 (g)	High
250/500-year	0.55 (g)	0.825 (g)	0.33 (g)	Moderate

3.4.3 Seismic Performance Shake Table Testing of Photovoltaic Panels

3.4.3.1 Qualification vs. Performance Levels

There is no category in IEEE 693 for seismic qualification or performance testing of solar PV panels. However, it is judged that the issues associated with this equipment are reasonably similar to those for high voltage (161 kV and above) transformer bushings (e.g., criticality, complexity and use of brittle materials). Therefore, provisions for seismic performance testing of high voltage transformer bushings are used to develop the suggested methodology for seismic performance testing of PV panels that follows.

In most cases, IEEE 693 time history shake table tests are conducted at what is known as a “qualification” level using a test response spectrum (TRS) derived from the time history earthquake motions that envelopes a required response spectrum (RRS) at 2% of critical damping. The RRS are given in IEEE 693-05, Figure A.1, for the high qualification level and in Figure A.2 for the moderate qualification level. This information for 2% of critical damping is included in Figures 3.4.3.1-1 and 3.4.3.1-2.

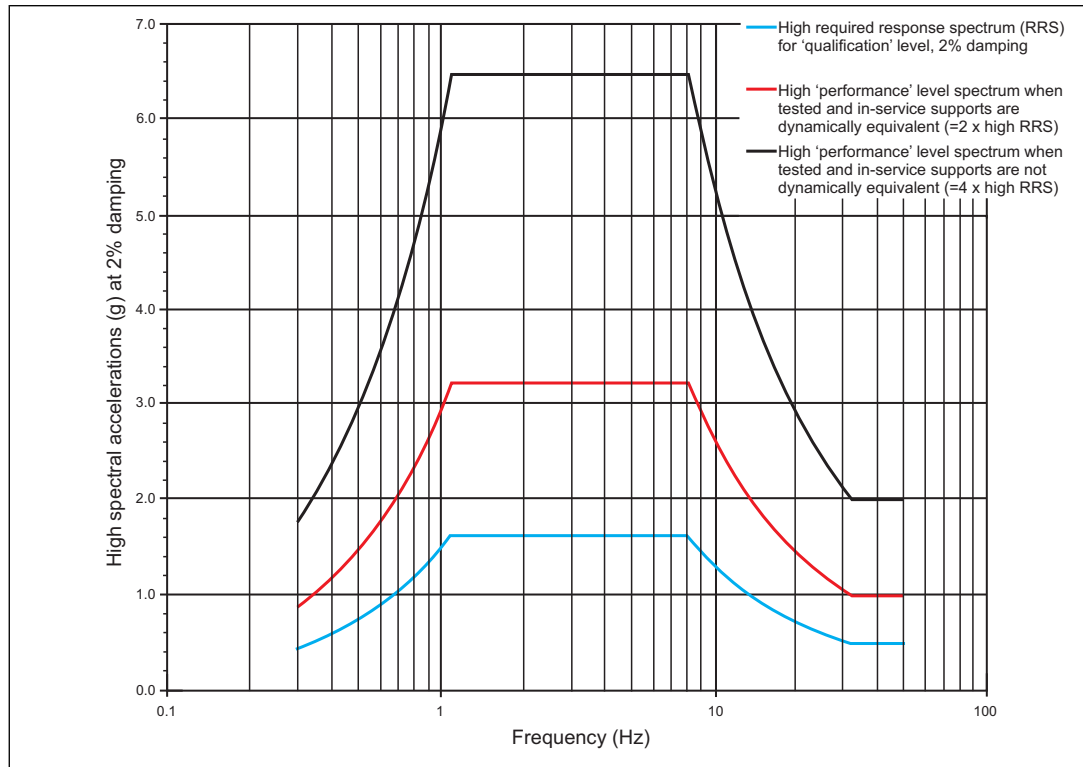


Fig. 3.4.3.1-1. High required response spectrum and high performance spectra at 2% damping

Although the figures in IEEE 693 show response spectra for other damping levels, these are not to be used unless damping is confirmed through testing (additionally, use of damping greater than 2% is not permitted for PV panels in the shake testing methodology outlined below). Equipment is tested to this lower qualification level so that it will remain undamaged and functional and thus need not be discarded, but can be installed at a facility even after testing. For most equipment, per IEEE 693-05, Section 8.2, it is anticipated that the equipment tested using the RRS at 2% damping will perform acceptably at a performance level that is twice the RRS with little or no damage, and that most equipment will continue to function. However, there are some components, such as porcelain transformer bushings and PV panels, for which testing at the higher “performance” level is justified.

According to IEEE 693-05, Section 8.4, “projecting the performance beyond the qualification level (to the performance level) is justified if the dynamic response of the equipment is generally understood, if the failure modes are known, and if the critical stress points or other critical variables associated with the failure mode are known and can be measured.” Where the results of the qualification RRS shake table tests cannot be extrapolated to the performance level, the methodology is to perform shake table tests to twice the high RRS in IEEE 693-05, Figure A.1, or twice the moderate RRS in IEEE 693-05, Figure A.2. The assembly tested must be equivalent to the in-service assembly (e.g., supports are dynamically equivalent, etc.). This equipment is then said to be qualified to the high “performance” level and moderate “performance” level, respectively. Per IEEE 693-05, Section D.4.4, projecting the performance from an RRS test is judged to be unacceptable for transformer bushings. Transformer bushing time history shake table tests are tested at four times the RRS levels shown in IEEE 693-05, Figures A.1 and A.2, to directly assess the bushing “performance” level. The multiplier of four results from a factor of two to raise the level of test from a “qualification” to a “performance” level and a second factor of two since the bushings are tested on a rigid frame that does not account for the increased accelerations due to the flexibility of the transformer itself (since bushings are located at the top of the transformer). The factor of two used to simulate transformer flexibility is slightly less than the 2.5 factor required for other types of equipment mounted without a support per IEEE 693-05, Section 5.5.4.

Time history shake table testing to a “performance” level is considered to be necessary in order to understand whether solar PV panels and their support systems will be undamaged and functional after an earthquake.

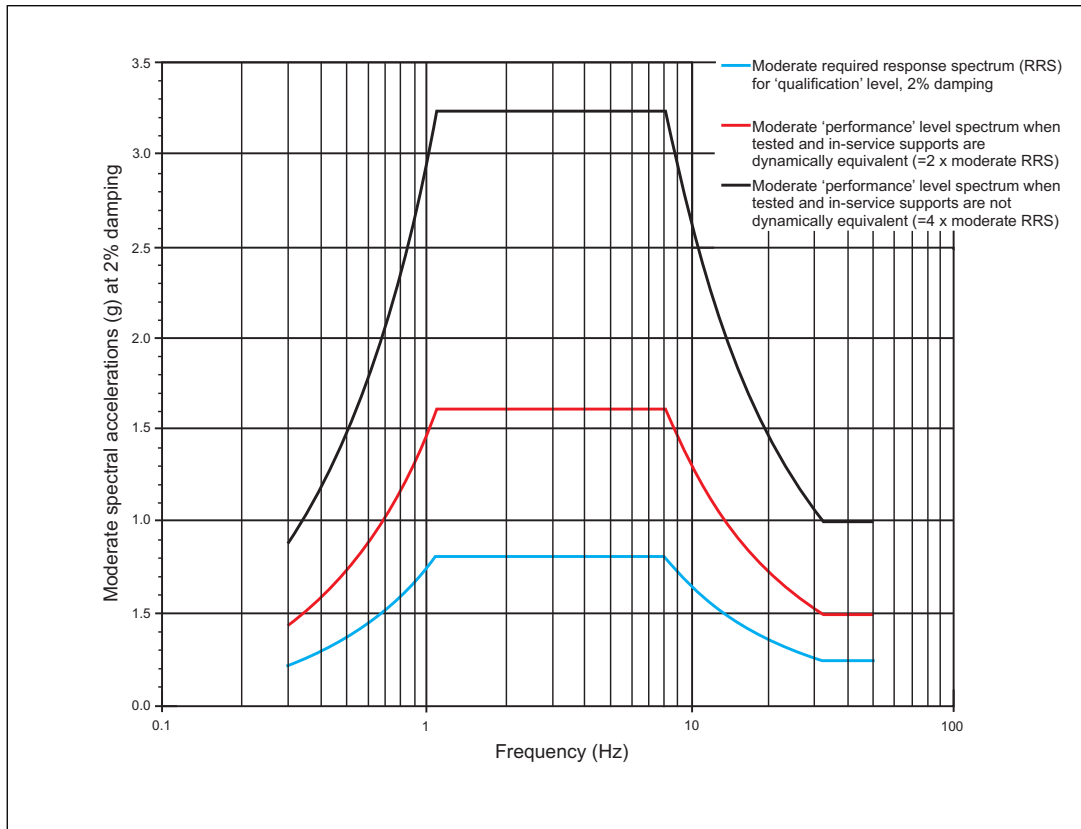


Fig. 3.4.3.1-2. Moderate required response spectrum and moderate performance spectra at 2% Damping

Although not specifically covered by IEEE 693, that standard is judged to be the most appropriate basis upon which to develop a testing program for PV panels. Other testing protocols, such as AC 156, *Acceptance Criteria for Seismic Certification by Shake-Table Testing of Non-Structural Components*, may provide additional insight regarding shake table testing. However, IEEE 693 is the basis for the shake table testing methodology presented below since it is specific to electrical equipment, it distinguishes between qualification and performance level testing, and the IEEE 693 RRS is based on 2% damping while the AC 156 RRS assumes a less conservative 5% damping.

3.4.3.2 Time History Shake Table Testing Methodology

Based on available information, the major components of time history shake table performance testing for PV panels follow. Consult IEEE 693-05 for more detailed information.

- A. The information provided here applies only to time history shake table testing of solar PV panels that are located directly at grade or on panel support structures that are founded at grade. PV panels located on roofs of buildings are not covered because ground motions will be amplified by a building and higher acceleration test levels may be necessary.
- B. Upon their arrival at the test facility, visually examine PV panels and supports to ensure that no damage has occurred during shipping.
- C. Before beginning shake tests, conduct routine production and/or quality control electrical and mechanical tests of PV panels, any mechanisms that allow the panels to track the sun, and any other applicable equipment to confirm these items are functional and electrical output is within acceptable limits.
- D. Conduct triaxial shake testing. Biaxial shake testing is not allowed because of the complexity of the system.

E. Conduct shake testing with the PV panels mounted in the identical manner as they will be in their in-service condition, including support frames, unless this is impossible due to the size of the supports or other legitimate limiting factors. Where supports can vary, use the support that is most seismically vulnerable and dynamically worst (i.e., will transmit the highest accelerations to the mounted panels and/or has a resonance frequency closest to the supported PV panels).

F. Where the PV panels cannot be mounted for testing in their identical in-service condition, an alternate support system may be used to conduct the shake table tests as long as the in-service support will be dynamically equivalent or better than the support used for testing.

G. If panels cannot be mounted as they will be in service, and dynamically equivalent supports cannot be provided, input forces will need to be adjusted to account for increased accelerations for the in-service condition vs. the tested condition (see below).

H. Provide sufficient instrumentation to monitor the shake table testing. Provide strain gauges if required to gather needed data. Provide triaxial accelerometers at a minimum on the shake table, close to the center of gravity of the equipment, at the top of the support and at the top of the panel. Measure or calculate maximum relative displacements from the base of the support to the top of the panel and from the base of the support to the locations of electrical connectors between panels.

I. Conduct a resonant frequency search test to determine the resonant frequencies and damping of the PV panel and support system.

J. Apply time history motions in the two perpendicular horizontal axes of the equipment together with a response spectrum in the vertical axis having an acceleration of 80% of that in the horizontal axes. Assume a maximum value of 2% of critical damping even if a higher value can be substantiated by testing. After a shaking ramp-up of 2-5 seconds, apply strong motion for a duration of 20-26 seconds followed by a shaking decay of 2-5 seconds.

Where panels are mounted as they will be in service or dynamically equivalent supports are provided:

1. In FM Global 50-year and 100-year earthquake zones, use input time history motions that generate a test response spectrum (TRS) that envelopes, over the frequency range from 1.0 to 33 Hz, twice the high required response spectrum (RRS) at 2% damping given in IEEE 693-05, Figure A.1. This spectrum is included in Figure 4.
2. In FM Global 250-year and 500-year earthquake zones, use input time history motions that generate a test response spectrum (TRS) that envelopes, over the frequency range from 1.0 to 33 Hz, twice the moderate RRS at 2% damping given in IEEE 693-05, Figure A.2. This spectrum is included in Figure 5.

If the PV panels are mounted without the in-service or dynamically equivalent supports, use input time history motions that generate TRS that envelope, over the frequency range from 1.0 to 33 Hz, four times the RRS at 2% damping rather than twice the RRS (see Figures 4 and 5).

K. After the time history shake table performance level tests are completed, conduct a resonant frequency search test to look for unexpected changes of system frequencies. A change of more than 20% from pre-testing resonant frequencies does not disqualify the equipment but indicates the need for a careful inspection for damage.

L. Conduct a visual inspection of the PV panels, supports, tracking mechanisms, etc. to confirm there is no evidence of significant damage such as cracked glass, broken connections, buckled members, broken bolts, etc. resulting from the time history shake table performance level tests.

M. Conduct the same routine production and/or quality control electrical and mechanical tests of panels, any mechanisms that allow the panels to track the sun, and any other applicable equipment that were performed prior to testing to confirm these items are functional and electrical output has not been reduced by more than an acceptable level as a result of the time history shake table performance level tests.

N. If the results of visual inspection and production/quality control tests confirm the panel and supports are essentially undamaged and remain functional, the panel is qualified to the high or moderate performance level (depending on the force level input).

O. Document all test configurations, input motions, output motions, visual inspections, before and after functional tests, etc., and provide a seismic-test qualification report outlining the methodology used and results obtained.

P. For other requirements not outlined above, follow the requirements of IEEE 693.

Q. Tested PV panels may be damaged and thus should not be provided to a user.

3.5 Fire

The types of materials used in ground-mounted solar panels may not necessarily be likely to propagate a fire. However, they may be damaged when exposed to fire. Such damage could occur when exposed to radiant heat or burning embers from a bush fire or wild land fire, or nearby combustible construction or outside storage. While damage may be limited to cracking of the glass covering or thermal damage to the panels below, it may prevent or limit generation of electrical power.

The ASTM E108, *Standard Test Methods for Fire Tests of Roof Coverings*, Spread of Flame test provides an indication of the ability of a solar panel to propagate fire across its upper surface. Solar panels with Class A flame spread ratings are described as “effective against severe fire exposure,” and are not capable of propagating a fire throughout the solar farm. Solar panels achieving Class A or B flame spread ratings have limited the spread of flame to a maximum of 6 ft (1.8 m) or 8 ft (2.4 m), respectively, when exposed to a 1400°F (760°C) flame for 10 minutes at a wind velocity of 12 mph (5.4 m/s).

The ASTM E108 Burning Brand test evaluates whether an external fire is capable of causing burn through of the panel. This test may replicate the exposure from a wildfire. Solar panels with a Class A Burning Brand rating are subjected to a 4.4 lb (2 kg), 12 in. by 12 in. (305 mm by 305 mm) burning wooden brand. Solar panels with a Class B Burning Brand rating are subjected to a smaller, 1.1 lb (0.5 kg), 6 in. by 6 in. (152 mm by 152 mm) burning brand. Solar panels with a Class C Burning Brand Rating are subjected to brands weighing only 10 grams (1/3 oz.), and are not considered a significant fire exposure. In all cases, the panel must not sustain burning, lateral flame spread, or formation of holes due to burn through of the burning brand.

3.6 DC Ground Fault in PV Arrays

A ground fault in PV arrays is an accidental electrical short circuit involving ground and one or more normally designated current-carrying conductors. Ground faults in PV arrays are safety concerns because they may generate DC arcs at the fault point on the ground fault path, damage surrounding insulation, and create fire hazards. The risk of fire hazards is escalated substantially if a second ground fault is developed. A DC ground fault is a common fault in PV systems and may be the result of the following:

A. Insulation failure of cables (e.g., an animal chewing through cable insulation and causing a ground fault).

B. Incidental short circuit between the normal conductor and ground (e.g., a cable in a PV junction box incidentally contacting a grounded conductor).

C. Ground faults within PV modules (e.g., a solar cell short circuiting to grounded module frames due to deteriorating encapsulation, impact damage, or water corrosion in the PV panel).

To properly protect PV arrays from ground fault damage and ensuing fire hazards, NFPA 70, *National Electrical Code*, Article 690.5(A), specifies that the ground fault protection device (GFPD) or system must be capable of detecting a ground-fault current, interrupting the flow of fault current, and providing an indication of the fault. According to recent industry experience, there are some cases where the first ground fault could not be detected by the current design GFPD (such as applying fuse in the grounding electrode). A second developed ground fault made the fault current flow in the array leading to fire incidents. Sophisticated techniques such as residual current monitoring to measure imbalance of current flow in the positive and negative feeders from the inverter to each combiner box are being developed to detect ground fault protection.

4.0 REFERENCES

4.1 FM Global

Data Sheet 1-0, *Safeguards During Construction, Alteration and Demolition*

Data Sheet 1-2, *Earthquakes*

Data Sheet 1-20, *Protection Against Exterior Fire Exposure*

Data Sheet 1-28, *Wind Design*
Data Sheet 1-40, *Flood*
Data Sheet 1-54, *Roof Loads for New Construction*
Data Sheet 2-81, *Fire Protection System Inspection*
Data Sheet 5-4, *Transformers*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*
Data Sheet 5-48, *Automatic Fire Detection*
Data Sheet 9-1, *Supervision of Property*
Data Sheet 9-19, *Wildland Fire*
Data Sheet 10-1, *Pre-Incident Planning*
Data Sheet 10-3, *Hot Work Management*
Data Sheet 10-6, *Arson and Other Incendiary Fires*

FM Approvals Standard 4478, *Approval Standard for Rigid Photovoltaic Panels*. April 2012

ANSI FM 4473, *Test Standard for Impacting Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls*. January, 2011

FM Approvals Test Procedure, *Test Method for Determining the Susceptibility to Hail Damage of Photovoltaic Modules*

The *Approval Guide*, an online resource of FM Approvals

4.2 Other

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International Electrotechnical Commission. IEC 62446, *Grid Connected Photovoltaic Systems—Minimum Requirements for System Documentation, Commissioning Tests and Inspection*. 2009.

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APPENDIX A GLOSSARY OF TERMS

Aerospace style wind tunnel: A smaller sized wind tunnel (in comparison to a boundary layer wind tunnel), which simulates horizontal wind forces acting directly on an object. It does not simulate conditions within the lower portion of the boundary layer, which is required to replicate the surface roughness exposure related to wind design of the building and rooftop equipment.

Array size: The number of interconnected PV panels (the minimum number of panels within each row), the space between rows, and the number of rows within a given array. Wind tunnel or field model tests should replicate the minimum array size to be used. All else being equal, the greater the tilt angle of the PV panels, the greater the row spacing that is required to prevent shadowing of panels in adjacent rows.

Biaxial testing: A shake table test in which accelerations are applied simultaneously in one principal horizontal axis and the vertical axis simultaneously.

Boundary layer wind tunnel: A wind tunnel which has obstructions placed on the floor of the wind tunnel that replicate the lower portion of the boundary layer and the surface roughness exposure related to wind design of the building and rooftop equipment.

Computational fluid dynamics (CFD): A form of computer modeling that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of fluids with surfaces defined by boundary conditions. Validation of wind load estimates from such software are performed using boundary layer wind tunnel experiments.

Damping: The decreasing of building or equipment earthquake motions due to dissipation of energy, for example through friction generated within the building or equipment. Damping is expressed as a percentage of critical damping, the damping at which a system would return most quickly to equilibrium without oscillating (e.g., 2% of critical damping).

FM Approved: References to “FM Approved” in this data sheet mean the products or services have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

Gravitational acceleration: The acceleration toward the earth due to gravity, represented by the variable “g”. Horizontal accelerations from earthquakes are often expressed as a fraction of “g,” for example, a 0.5g horizontal acceleration results in a horizontal force equal to half of the object’s weight.

Ground acceleration: The acceleration of the ground resulting from the motion of a given earthquake. The maximum or peak ground acceleration is the zero period acceleration (ZPA) of the ground response spectrum.

Hurricane-prone regions: Areas vulnerable to hurricanes. Areas in the United States and its territories include:

1. The U.S. Atlantic Coast and Gulf of Mexico Coast, including parts of Mexico and Central America, where the basic wind speed per Data Sheet 1-28, *Wind Design*, is greater than 90 mph (40 m/s), and
2. Hawaii, Puerto Rico, Guam, Virgin Island, and American Samoa.

For locations outside the United States, any areas that are in a “tropical cyclone” region or “typhoon-prone” region. This includes, but is not limited to, parts of Australia, Bermuda, the Bahamas, Indonesia, India, Bangladesh, the Philippines, Japan, South Korea, Hong Kong, Macau, Vietnam, and Taiwan, where the basic wind speed per Data Sheet 1-28 is greater than 90 mph (40 m/s).

Importance factor: In accordance with ASCE Standard 7, Minimum Design Loads for Buildings and Other Structures, a factor by which the usual design forces are multiplied based on the degree of hazard to human life and consequences of damage to property. Its value varies depending on the type of load (e.g., wind vs. seismic) and the item being designed (e.g., the entire building vs. a building component). Except for minor structures, the importance factor is 1.0 or greater.

Inverter: An electrical device used to convert from direct current (DC) electrical power to alternating current (AC) electrical power.

Photovoltaic cell: An electrical device that generates electricity from sunlight via the photovoltaic effect.

Photovoltaic module: An assembly of photovoltaic cells, electrically integrated in series and protected within (sandwiched between) a weather resistant enclosure. See photovoltaic panel.

Photovoltaic panel: An assembly of photovoltaic modules oriented in a single plane. Although subtle differences exist between photovoltaic modules and photovoltaic panels, the terms are used synonymously for the purposes of this data sheet.

Photovoltaic (PV) System: A system which uses an array of mechanically and electrically integrated solar panels to convert sunlight into electricity. It consists of PV panels, support framework and electrical connections and equipment to allow regulating and converting the electrical output from DC to AC.

Required response spectrum (RRS): The acceleration response spectrum that is to be met based on the standard being applied (e.g., IEEE Standard 693 or ICC Evaluation Service AC156) for a specific location, equipment type and percent of critical damping.

Resonant frequency: A natural frequency of vibration determined by the physical parameters of the object where even small periodic driving forces can produce large amplitude oscillations.

Response spectrum: A plot of the maximum response (displacement, velocity or acceleration) of a series of single-degree-of-freedom (SDOF) oscillators of varying natural frequency that are forced into motion by the same base vibration or shock. The resulting plot can then be used to determine the response of any linear system, given its natural frequency of oscillation.

Sun Shadowing: Shadows created by neighboring objects which necessitate relocation of solar panels and sometimes openings within the array. This can create wind forces on the solar panels that are immediately adjacent to the opening that are higher than those forces on the interior of the array.

Test response spectrum (TRS): The acceleration response spectrum that is developed from the actual time history of motion of the shake table test as measured by reference control accelerometers mounted on the shake table at a location near the base of the component being tested. The test response spectrum must envelope the required response spectrum, typically in the range of 1.3 to 33.3 Hz.

Triaxial testing: A shake table test in which accelerations are applied simultaneously in two principal horizontal axes and the vertical axis simultaneously.

Tropical storm-prone region: An area prone to tropical storms, such as cyclones, typhoons and hurricanes, in which winds rotate about a center of low atmospheric pressure, clockwise in the southern hemisphere and counter-clockwise in the northern hemisphere.

Typhoon-prone region: Areas including, but not limited to, the Philippines, China, Taiwan, Japan, South Korea, Hong Kong, Macau, and Vietnam.

Wind shadowing: The reduction of wind loads on solar panels inward from the perimeter due to sheltering provided by the solar panels in the perimeter.

Windborne debris: Pieces of broken material and other objects, such as roof gravel, that have become airborne projectiles due to the high winds.

Zero period acceleration (ZPA): The acceleration that corresponds to the high frequency (33 Hz or greater) on a response spectrum. This acceleration corresponds to the maximum (peak) acceleration of the time history used to derive the spectrum.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

July 2023. Interim revision. Minor editorial changes were made.

January 2023. Interim revision. Significant changes include:

- A. Added guidance for separation between solar arrays and fire exposures.
- B. Added guidance for construction of ancillary buildings.
- C. Added guidance for fire department access.

- D. Revised guidance for design wind loads for fixed tilt arrays.
- E. Added guidance for design wind loads and mitigation for variable tilt arrays.
- F. Added guidance for elevated PV structures (carports).
- G. Revised hail resistance guidance to reflect updated test methods.
- H. Revised flood guidance to ensure post-event access.
- I. Added guidance for vegetation management.
- J. Added support material for variable tilt array recommendations.
- K. Added support material for sand and dust tests.

April 2020. Interim revision. Modified guidance for hail ratings of PV panels based on changes to Data Sheet 1-15, *Roof-Mounted Solar Photovoltaic Panels*.

October 2014. Interim revision. Modified the recommendations for hail ratings of PV panels based on changes to Data Sheet 1-34, *Hail Damage*.

October 2012. This is the first publication of this document.

APPENDIX C SUPPLEMENTARY INFORMATION

C.1 General

Currently (2012), individual photovoltaic (PV) cells are constructed of a number of materials, including monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide. Individual solar PV cells are wired in series and protected within (sandwiched between) a weather resistant enclosure to form a module. The weather resistant enclosure consists of heat strengthened glass on top and tempered glass on bottom, with an anti-reflective coating provided on the top surface.

Multiple modules are assembled together in a single plane to form a PV panel. For the purposes of this data sheet, the terms module and panel are used synonymously.

An assembly of PV panels are then mechanically and electrically integrated, including a support structure and electrical connections and equipment, to form a solar array. The panels within the array convert energy from sunlight into direct current (DC) electrical power. This power is then distributed to the electrical grid. Generally, an inverter is used to convert the electric power from DC to alternating current (AC).

A well-designed and maintained PV system is expected to operate for more than 20 years. For large installations, a primary concern is the impact of various natural hazards due to an aggregation of exposures within a single location. PV systems are subjected to weather conditions such as hail, rain, snow, ice, earthquakes, wind, and storms, and the potential damage can be substantial.

Solar PV panels are generally very reliable. However, stressful environments, including desert conditions and high temperatures can cause performance degradation. The annual rate of performance degradation resulting from normal operating conditions has been estimated between 0.5 and 2%. These rates may be exceeded in the event of a severe weather condition, such as a hail or sandstorm.

C.2 Solar Photovoltaic Power Trends

Solar PV power is the world's fastest growing energy technology. Solar PV production has increased significantly over the previous decade, increasing at an average annual rate of almost 50% since the beginning of the century. The majority of this increase in capacity is the result of the installation of the large, grid connected systems that are covered in this data sheet.

Growth is expected to continue in the future, as the average installed costs decrease and various government entities provide tax credits, loan programs, and other incentives to stimulate investment in the technology. Although the rate of growth has slowed recently due to decreased government incentives, industry growth is still expected, as shown in Table C.2.

Table C.2. Worldwide Installed Solar Photovoltaic Capacity

Year	Worldwide Installed Capacity (GW)
2000	1
2005	5
2006	7
2007	10
2008	16
2009	23
2010	40
2011	53-61 (estimated)
2012	68-84 (estimated)
2013	86-115 (estimated)
2014	107-152 (estimated)
2015	131-196 (estimated)

Note: Cumulative installed capacity estimates for 2011 through 2015 are based on the European Photovoltaic Industry Association's Global Market Outlook for Photovoltaics Until 2015

Europe is the leading market in the world for solar power, led by countries such as Italy, Germany, the Czech Republic, and the United Kingdom. However, Europe's world share of installed solar power is stagnating, as countries including China, Japan, Australia, Canada, and the United States continue to install large scale solar PV facilities. In the United States, states on the east coast and in the southwest of the country are primarily responsible for the country's increased capacity. California accounts for the majority of PV installations in the United States.

C.3 Types of PV Cells

- A. Monocrystalline cells have the highest conversion efficiency. However, the manufacturing process is highly intensive and expensive.
- B. Polycrystalline cells have a lower efficiency than that of monocrystalline cells, but also have a lower manufacturing cost.
- C. Amorphous cells have a relatively simple manufacturing process, lower manufacturing cost, and lower production energy consumption. However, these cells also have a larger installation surface, lower conversion efficiency, and inherent degradation during the initial months of operation, which continues over the life span of the panels.
- D. Thin-film cell technology uses thin layers of cadmium telluride (CdTe) or copper indium diselenide (CuInSe₂). The process uses very little energy and is very economical. It has simple manufacturing processes and relatively high conversion efficiencies.
- E. Gallium-arsenide (GaAs) cell technology yields highly efficient PV cells, although the manufacturing process is very expensive. The output of GaAs cells is also relatively independent of the operating temperature and is primarily used in space programs.
- F. Multijunction cell technology employs two or more layers of PV cells, usually of the thin film type, which are layered one on top of another. Each layer extracts from a particular portion of the spectrum of the incoming light. A cell with two layers is often called a 'tandem' device.

C.4 Types of PV Systems

C.4.1 Flat-Plate PV Panels

The most common array design uses flat-plate PV modules or panels. Several solar cells are interconnected and packaged to form PV modules, which are in turn connected together into an array or panel to produce more power. Solar panels are secured on tilted structures called stanchions.

C.4.2 Concentrator Systems

In these systems, reflectors or lenses are used to concentrate the incoming solar radiation onto the cells and thus collect more energy out of a given number of PV cells. These systems generally use two-axis trackers to ensure that the cells always receive the maximum amount of solar radiation.

C.5 Mounting Structures

Photovoltaic arrays must be mounted on stable, durable structures that can support the array and withstand anticipated wind, earthquake, rain, hail, and other adverse conditions. Materials of construction may include aluminum, iron, or steel. While wood framing may be found in existing installations, combustible construction materials are not recommended. Proper protection against corrosion or deterioration must be provided.

Stationary structures are generally used with flat-plate systems. Among the choices for stationary mounting structures, rack mounting is reported to be the most versatile. It can be constructed fairly easily and installed on the ground.

In some cases, the mounting structure is also designed to track the sun. These structures tilt the PV array at a fixed angle determined by the latitude of the site, the requirements of the load, and the availability of sunlight. There are two basic kinds of tracking structures: one-axis and two-axis. One-axis trackers are typically designed to track the sun from east to west. One type of passive one-axis tracker is driven by a closed Freon system that causes the tracker to follow the sun with adequate accuracy for flat-plate PV modules. They are also used sometimes with concentrator PV systems. Two-axis trackers are used primarily with concentrator PV systems. These units track the sun's daily course, as well as its seasonal course between the northern and southern hemispheres. Generally, sophisticated systems are more expensive and usually require more maintenance.

C.6 Balance of System (BOS)

The balance of system (BOS) includes all the equipment that enables the PV-generated electricity to be properly applied to the load. It typically consists of structures for mounting the PV arrays and power-conditioning equipment that adjusts and converts the DC electricity to the proper form and magnitude required by an AC load. The BOS can also include storage devices, such as batteries, which enable PV generated electricity to be used during cloudy days or at night.

C.6.1 Power Conditioning Unit (PCU)

Power conditioning units process the electricity produced by a PV system so it will meet the specific demands of the load. PCUs may have the following functions:

- A. Limit current and voltage to maximize power output,
- B. Convert DC power to AC,
- C. Match the converted AC electricity to a utility's electrical network
- D. Provide safeguards to protect utility personnel and the network from harm during repairs

Specific requirements of PCUs depend on the type and the application of the PV system. For DC applications, the PCU consists of regulators that control output at some constant level of voltage and current to maximize output. For AC loads, the PCU must include an inverter that converts the direct current generated by the PV modules into alternating current. Inverters typically provide power (with a power factor that is very near unity) to utility grid. Inverters in current operation typically use IGBTs (insulated-gate bipolar transistors) as switching devices and also are equipped with a maximum power point tracking (MPPT) mechanism to ensure maximum net energy harvest from PV modules. They are generally not connected with batteries. However, the use of batteries can supply uninterrupted power supply (UPS) capability.

C.6.2 Batteries

Batteries provide the option to store PV electricity for later use. If connecting to the utility grid is not an option, a battery backup system is necessary for energy storage. However, batteries lower the efficiency of a PV system, because only about 80% of the energy that goes into them can be reclaimed. Like PV cells, batteries

are direct-current devices that are directly compatible only with DC loads. However, batteries can also serve as a power conditioner for these loads by regulating power. This allows the PV array to operate closer to its optimum power output.

C.6.3 Other Devices

C.6.3.1 Net Meter

This device records the generated power in an exclusive summation format. The recorded power registration is the net amount of power consumed (i.e., the total power used minus the amount of power that is produced by the solar power system).

C.6.3.2 Grid-Connection Isolation Transformer

In order to prevent transfer of power quality noises between the grid and the PV system, an isolation transformer is placed between the main service switchgear of the inverters and the grid. The delta winding of the isolation transformer, which is connected to the service bus, circulates noise harmonics in the winding and dissipates the energy as heat. Some inverter manufacturers incorporate output isolation transformers as an integral part of the inverter system, which eliminates the use of external transformation and ensures noise isolation.

APPENDIX D GROUND-MOUNTED SOLAR PV DESIGN DATA COLLECTION FOR WIND AND HAIL DESIGN

Part 1: General

<i>Geolocation (Address or Lat/Long)</i>		
Design Year		
Capacity (MW-dc)		
Total Insured Value (US\$)		
Average BI Daily Value (US\$)		
Panel Details (include all installed)	Manufacturer(s):	
	Model Number(s):	
	Spec sheet(s) attached? (Y/N):	
Sun Tracking	Fixed or Variable:	
	Number of Axes:	
	Tracker Manufacturer:	
Snow Load	Applicable (Y/N):	
	Load Tested (psf or kN/m ²):	

Part 2: Wind Design

<i>Design Wind Speed: Indicate Ultimate or Allowable (mph or m/s)</i>		
Wind Design Risk Category Per ASCE 7)		
Wind Load Testing	Test Method (e.g., UL or IEC):	
	Test Report Attached (Y/N):	
	Static Load Tested (psf or kPa):	
	Dynamic Load (Wind Tunnel) Test (Y/N):	
	Dynamic Load Test Report Attached (Y/N):	

Part 3: Hail

<i>Impact Test Completed (Y/N)</i>		
Test Agency		
Test Method (Title or Publisher Number)		
Maximum Hail Size Tested (mm or in.)		
Microcracking	Investigated (Y/N):	
	Test Report Available (Y/N):	

Part 4: Natural Hazard Mitigation

<i>Hazard Identification (as applicable)</i>	<i>Weather Service:</i>	
	On-site Sensors (type and number):	
Wind Stow Position (degree respective to horizontal)		
Hail Stow Position (degree respective to horizontal)		
Stow Position When Both Hazards Present (degree respective to horizontal)		
Initiation	Manual or Automatic	
	Proximity of Weather Event at Initiation (mi or km)	
	Stow Policy Attached (Y/N)	
Maximum Time Required to Reach Stow Position from Initiation (s)		