Testing Roof-Installed PV Modules

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As the demand for solar energy continues to grow rapidly, so does the number of photovoltaic (PV) systems that are mounted on the roofs of commercial and residential buildings. As failure of any roof-mounted assembly can lead to extensive—if not catastrophic—damage, a lack of certifiable standards for the construction and installation of such assemblies can lead to billions of dollars in losses due to property damage and business interruption.

Courtesy of TÜV Rheinland PTL

To mitigate this damage potential, TÜV Rheinland and FM Approvals recently entered into a cooperative agreement to evaluate and certify roof-installed PV systems to two new FM Approvals standards: 4476 *Approval Standard for Flexible Photovoltaic Modules* and 4478 *Approval Standard for Rigid Photovoltaic Modules*. These additional standards will enable PV module manufacturers and others to certify their products when used as part of an FM Approvals roofing assembly.

PV systems have been tested for many years for electrical performance according to standards issued by the International Electrotechnical Commission (IEC) including IEC 61215 (crystalline silicon flat-plate modules), IEC 61646 (thin-film flat-plate modules), and IEC 62108 (concentrator modules/assemblies). Recently, these standards also have been promoted by the U.S. Department of Energy Solar ABC's Commission for adoption in the U.S. market purchase criteria.

According to the agreement, TÜV Rheinland will test for IEC 61215, IEC 61646, and IEC 62108 and the relevant PV safety standard IEC 61730 for Europe and Asia or UL1703 for North America. FM Approvals will test to the new 4476 and 4478 PV standards that feature requirements for combustibility above the roof deck, wind resistance, and hail damage resistance.

Electrical Safety and Performance

The performance and reliability standards trace their origin back to the 1970s in NASA's Jet Propulsion Laboratory. Later, the product certification of crystalline PV modules for open-air climates was adapted for terrestrial products and converted to international standards from the IEC 68 *Environmental Test Procedures* series.

Considerable preliminary work on the definition of special test procedures for PV modules was rendered by the Research Centre of the European Commission in Ispra, Italy. Test specification 503 *Terrestrial Photovoltaic (PV) Modules With Crystalline Solar Cells—Design Qualification and Type Approval* was adopted in 1993 as IEC 1215, now IEC 61215, and in 1995, ratified as the European standard EN 61215. In April 2005, a second edition of IEC 61215 was published with changes in testing conditions and pass criteria. IEC 61215 comprises the examination of all parameters responsible for the aging of PV modules and describes the various qualification tests on the basis of the artificial load of the materials.

In 1996, a comparable standard was developed for PV thin-film modules. Then in 2008, a second edition to this standard, IEC 61646 *Thin-Film Terrestrial Photovoltaic (PV) Modules—Design Qualification and Type Approval*, was released to address new developments in the thin-film technologies and reduce testing efforts.

In many aspects, the standard is identical to IEC 61215. The main difference between the two is the additional test procedures to adapt to the special properties of thin-film technologies. These additional tests take into account the degradation behavior of thin-film modules due to irradiance exposure.

Shortly after the formal adoption of these standards, a few global laboratories began offering them as a commercial service to industry clients. TÜV Rheinland in Cologne, Germany, and TÜV Rheinland Photovoltaic Testing Laboratory (PTL) were two of the three original laboratories that offered commercial service of these standards.

Both IEC 61215 and IEC 61646 list UV preconditioning of test samples. As a further option, a UV exposure test was issued in 1998 and can be utilized alternatively. IEC 61345: 1998 *UV Test for Photovoltaic (PV) Modules* stipulates higher minimum UVA and UVB doses that the modules should be exposed to.

In addition to the design-qualification and type-approval IEC standards, markets across the world require a safety standard for module construction and operation. For the United States, this standard is ANSI/UL1703; for Europe and Asia, the standard is IEC 61730. Both standards are similar and ensure that the module designs have the basic requirements for safety of operation and construction.

IEC 62108 specifies the minimum requirements for the design qualification and type approval of concentrator PV (CPV) modules and assemblies suitable for long-term operation in general open-air climates. The test sequence is partially based on those specified in IEC 61215. It determines the electrical, mechanical, and thermal characteristics of the CPV modules and assemblies and shows that they are capable of withstanding prolonged exposure in climates described in the scope.

PV/CPV systems, as the name implies, concentrate sunlight onto the PV sensor. For this reason, IEC 62108 contains additional requirements that ensure safety and integrity of the components in the optical path of the device.

A module design passes the qualification tests and is IEC type-approved if each sample meets the following criteria:

- The degradation of the maximum power output at standard test conditions (STC) does not exceed 5% after each test nor 8% after each test sequence for a crystalline silicon module design.
- 1,000 VDC plus twice the open-circuit voltage of the system at STC for 1 minute; isolation resistance times module area is >40 MΩm^2 at 500 VDC.
- No major visible damage such as broken, cracked, torn, bent, or misaligned external surfaces; cracks in a solar cell which could remove a portion larger than 10% of its area; bubbles or delaminations; or loss of mechanical integrity.
- No open circuit or ground fault during the tests.
- For IEC 61646 only, the measured maximum output power after final light-soaking shall not be less than 90% of the minimum value specified by the manufacturer.

Combustibility Above the Roof

As can be logically inferred, fire is a significant concern with regard to building safety, and numerous standards have been developed to mitigate the chances of solar-related property damage and life loss due to building fire. Both ANSI/UL 1703 and current versions of IEC 61730 contain elements of fire testing for the PV module alone.

To establish how the panel and its mounting system will impact the combustibility of an overall roof system, FM Approvals has determined that PV systems must be in accordance with ASTM E108 *Fire Test of Roof Coverings* (**Figure 1**). Specifically, for Class A, the maximum flame spread of the sample materials shall not exceed 72 inches, Class B sample materials flame spread shall not exceed 96 inches, and Class C flame spread shall not exceed 156 inches.

In addition, no flaming or glowing portion of the sample blown or falling off the test deck can continue to glow after reaching the floor. Currently, studies are being conducted in parallel by the Department of Energy to evaluate the impact of the PV and roof system in combination.

Wind Resistance

Roof damage caused by high winds offers several potential hazards. Not only does flying debris pose a risk to life and property surrounding a building, but also as rain and moisture frequently accompany high winds, damaged roofs can allow moisture infiltration leading to significant and even catastrophic structural damage.

PV assemblies traditionally are installed with the panel on the same slope as the roof or on a different slope. In each case, FM Approvals testing must be done with simulated wind uplift pressure with the module attached to a test frame using a pleated air bag and with tensile loading of the fasteners/clips. The rating assigned to the overall is the lowest rating obtained during all testing.

Membranes must not tear, puncture, fracture, or develop any through-openings or delaminate or separate from adjacent components. All adhesives must maintain full contact between all the surfaces of all components to which they have been applied without separating, delaminating, or cracking. The roof decks must maintain their structural integrity during the entire classification period and not fracture, split, or crack.

Stresses induced to steel roof decking do not exceed the allowable stresses per the latest edition of AISI S100-200 *North American Specification for the Design of Cold-Formed Steel Structural Members*.

PV modules cannot puncture, fracture, develop any through openings, delaminate, or separate from the frame. Seams, base sheets, base plies, plies, and cap plies cannot tear, puncture, fracture, disengage, dislodge, disconnect, delaminate, or develop any through openings. Insulations cannot fracture, break, or pull through/over fastener heads, plates, or battens; nor can they delaminate or separate from their facers or adjacent components to which they have been adhered.

Fasteners and stress plates must not fracture, separate, or break; must remain securely embedded into the structure to which they are fastened; and must not pull through, dislodge, disconnect, or disengage from plates, battens, seams, or substrates. The theoretical load-per-fastener (pressure x contributory area) cannot exceed the pullout resistance of the fastener per C.6.1 of FM Approvals Standard 4470.

Figure 1. A PV Panel Being Tested to ASTM E108 Fire Test at the Intended Installed Slope
Courtesy of FM Approvals

Tensile loading pullout tests for fastener/roof-deck combinations and pull-through tests for fastener/stress-plate or batten-bar combinations using tensile loading are performed in accordance with the FM Approvals *Test Procedure, Wind Uplift Tests for Rigid Mechanically Fastened Photovoltaic Modules*.

The minimum rating required for FM Approvals is Class 1 to 60, and the maximum rating is Class 1 to 990. Ratings from 1 to 60 and 1 to 990 are available in increments of 15 psf, with the final rating assigned the maximum simulated uplift resistance pressure that the assembly maintained for a full minute without failure.

The rating assigned to the assembly is the average load obtained during the tests divided by the contributory area for that fastener/clip and 80% of the maximum simulated uplift resistance pressure which the assembly maintained for 1 minute without failure rounded down to the next multiple of 15 psf. The result reported is the highest force attained by the sample during the test, and the overall sample results are based on the average of three tests. If the standard deviation of the three values divided by the mean is greater than 20%, two additional tests are required, and the results of all the tests are used to determine the final average.

Sample results from tensile testing determine the load in lbf (N). The total area of the rigid PV module is divided by the number of fasteners/clamps used to secure it, providing the contributory area for each fastener/clamp in ft^2. The FM Approvals rating is the load determined from the tensile testing divided by the contributory area, rounded down to the next multiple of 15 psf.

Hail Damage Resistance

ANSI/UL 1703 and IEC 61730 contain elements of hail testing for the module alone. In the FM Approvals standards for hail damage, resistance is tested in accordance with the test method for determining the susceptibility to hail damage of flexible PV modules but to a higher degree than those in the current PV standards. This test involves covering a sample module with crushed ice for 10 minutes and then subjecting it to 10 drops of a 2.1-inch steel ball weighing 1.19 lb (**Figure 2**).

For areas of the United States not typically subject to severe hail storm damage, Class 1-MH ratings are acceptable. The Class-1 MH test involves dropping the ball from a height of 81 inches, generating an impact energy of approximately 8 lbf over the 2-inch impact area. Areas where severe hail damage will likely occur require Class 1-SH ratings where the ball is dropped from a height of 141.5 inches, generating an impact energy of approximately 14 lbf over the 2-inch impact area.

For both the SH and MH tests, the minimum rating required by FM Approvals is Class 2, indicated by a PV module showing no signs of cracking or splitting, misaligned external surfaces, or rupture when examined closely under 10x magnification. This test is applied to both weathered and unweathered modules.

Figure 2. Hail Impact Testing on a Solar Collector
Courtesy of TÜV Rheinland PTL

Other Testing Criteria

Additional testing may be required for items such as seismic activities. Rigid PV systems must undergo seismic analysis to evaluate the metal mounting frame required for roof securement.

While details of this aspect are still under discussion, it is likely that this portion of the standard will be modeled after the seismic loading requirements included in the FM Approvals 4930 standard for cooling towers. It requires seismic analysis for cooling systems located within earthquake zones as indicated within FM Global Property Loss Prevention Data Sheet 1-2 *Earthquakes*. In addition, there also will be a standard for operations requirements including demonstrated quality-control programs, facilities, and procedures audits.

Benefits to PV System Manufacturers

As expressed by manufacturers, underwriting technical integrity is a big challenge in solar project adoption. The combination of TÜV Rheinland and FM Approvals working together makes it easier for the expected proliferation of roof-mounted PV modules to successfully occur.

About the Authors

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