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Standards for PV Modules and Components – Recent Developments and Challenges

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STANDARDS FOR PV MODULES AND COMPONENTS – RECENT DEVELOPMENTS AND CHALLENGES

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ABSTRACT: International standards play an important role in the Photovoltaic industry. Since PV is such a global industry it is critical that PV products be measured and qualified the same way everywhere in the world. IEC TC82 has developed and published a number of module and component measurement and qualification standards. These are continually being updated to take advantage of new techniques and equipment as well as better understanding of test requirements. Standards presently being updated include the third edition of IEC 61215, Crystalline Silicon Qualification and the second edition of IEC 61730, PV Module Safety Requirements. New standards under development include qualification of junction boxes, connectors, PV cables, and module integrated electronics as well as for testing the packaging used during transport of modules. After many years of effort, a draft standard on Module Energy Rating should be circulated for review soon. New activities have been undertaken to develop standards for the materials within a module and to develop tests that evaluate modules for wear-out in the field (International PV Module QA Task Force). This paper will discuss these efforts and indicate how the audience can participate in development of international standards.

Keywords: PV Standards, Qualification and Testing, Safety

1 INTRODUCTION

PV is an international business in terms of supply of materials, manufacturing of products and deployment of products. If each country or region had its own set of standards it would be confusing, time consuming and expensive to participate in these markets. Imagine if a module manufacturer would have to pass different qualification test sequences or even measure their products in different ways for each national market. The result would be chaos and much higher product costs. Also imagine if a material supplier or cell manufacturer would have to meet a different specification in each market and have to provide different product specifications for each different market. One set of worldwide standards helps make PV cost effective. It also allows developers of new technologies or new materials to know what specifications and tests they are going to have to qualify to before they can commercialize those products.

The **International Electrotechnical Commission (IEC)** is the leading global organization that develops and publishes consensus-based International Standards for electric and electronic products, systems and services, collectively known as electrotechnology. There presently are 95 Technical Committees (TCs) and 80 Subcommittees (SCs) that do the standards work of the IEC. Each of these TCs and SCs is assigned a technical area in which to work. TCs and SCs actually do the work of writing consensus standards within the IEC, with representatives as assigned from the National Committees. TC 82 "Solar photovoltaic energy systems" is responsible for writing all IEC standards in Photovoltaics. TC82 has been in existence and writing standards since the early 1980's. Working Group 2 (Modules) of TC82 has been active over this entire period, developing standards for PV modules. The following is a list of the IEC standards on PV modules (and devices) published by TC82. The list includes details on which edition is now current and what year that edition was published.

IEC 60891: 2009 Ed 2, Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic (PV) devices.
IEC 60904-1: 2006 Ed 2 –Part 1: Measurements of PV current-voltage characteristics
IEC 60904-2: 2007 Ed 2 – Part 2: Requirements for reference solar devices
IEC 60904-3: 2008 Ed 2 – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data
IEC 60904-4: 2009 Ed. 1 – Part 4: Reference solar devices – Procedures for establishing calibration traceability
IEC 60904-5: 2011 Ed. 2 – Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method
IEC 60904-7: 2008 Ed. 3 - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices
IEC 60904-8: 1998 Ed. 2 - Part 8: Measurement of spectral response of a photovoltaic (PV) device
IEC 60904-9: 2007 Ed. 2 – Part 9: Solar simulator performance requirements
IEC 60904-10: 2009 Ed. 2 – Part 10: Methods of linearity measurement
IEC 61215: 2005 Ed 2 - Crystalline silicon terrestrial PV modules – Design qualification and type approval.
IEC 61646: 2008 Ed 2- Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
IEC 61730-1: 2004 Ed 1- Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
IEC 61730-2: 2004 Ed 1 - Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
IEC 61853-1: 2011 Ed 1 - Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating
IEC 62108: 2007 Ed 1 - Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval

2 STATUS OF PV MODULE STANDARDS

2.1 Measurement Principles

The initial set of standards developed by Working Group 2 involved measurement procedures for PV cells and modules. These encompassed the IEC-60904 series of standards as well as IEC 60891 which provided details on how to translate performance as a function of temperature and irradiance. This first set of standards was originally written for crystalline silicon modules, the modules that were commercially available in the timeframe of the 1980's. Subsequently it was determined that these standards covered any single junction PV device that was stable in time and whose short circuit current was linear with respect to irradiance. In the latest editions, these measurement standards have been modified to incorporate methods for measurement of thin film PV devices that are typically not linear.

At present the only active document in the measurement series is a CDV (Committee Draft for Vote) for Edition 3 of IEC 60904-8 on Measurement of Spectral Response that is circulating to National Committee with a due date of November 23, 2012. There are future plans to modify IEC 60904-3 to add the direct solar spectrum to the tables and to update IEC 60904-9 to add requirements for testing of concentrator devices, both in cooperation with WG7 on Concentrator PV.

2.2 Qualification Testing

Probably the most important set of documents to come from WG2 are the qualification test standards – IEC 61215 for Crystalline Silicon, IEC 61646 for Thin Film and IEC 61730 for PV Module Safety as well as IEC 62108 for CPV written by WG7. These standards have gone a long way to eliminate module infant mortality and therefore to help establish PV as a viable commercial business. Because of their importance to the PV industry these standards are continually being updated. Present efforts in WG 2 include work on Edition 3 of IEC 61215 and Edition 2 of IEC 61730.

Edition 3 of IEC 61215 was circulated as a CD (Committee Draft) with National Committee comments reported on March 16, 2012. Proposed changes from Edition 2 included:

1) Maximum power at STC has been made a pass/fail criterion.
2) Added retest guidelines.
3) Completely changed the hot spot test.
4) Update the other tests to be consistent with changes in IEC 61646.
5) Removed the method for measuring temperature coefficients and refer to IEC 60891.
6) Renamed NOCT as NMOT and referenced IEC 61853-2 for the test procedure.
7) Rewrote the Robustness of termination test to include evaluation of both cables and junction boxes.

WG2 will be working on responding to the National Committee comments and preparing a CDV at its October, 2012 meeting in Oslo, Norway.

Edition 2 of IEC 61730-2 was circulated as a CD with National Committee comments due on November 18, 2011. Edition 2 of IEC 61730-1 was circulated as a CD with National Committee comments due on August 10, 2012. There were so many comments to the IEC 61730-1 CD and so much overlap between the two parts that it is likely that a second CD will be circulated rather than a CDV.

Proposed changes to the second edition of Part 1 included:

1) Updated and corrected references.
2) Added a Glossary
3) Limited the documents applicability to PV modules rated for 1500 V or less maximum system voltage. Provides details on how to qualify modules at all voltages up to 1500 V.
4) Added restrictions that this standard does not cover PV modules that incorporate electronics. This will be the subject of a new standard that is now in development.
5) Application Class section was modified to provide additional guidance related to the definition of the classes based on the module's electrical output, protection requirements and intended use.
6) Reference to environmental conditions AB8 was eliminated. A PV specific range of ambient operating conditions was added.
7) Completely rewrote the polymeric materials section, defining 9 different applications for polymeric materials within a PV module. A subsection was included for each of the 9 categories.
8) RTE/RTI ratings are now required at 90 C or the maximum temperature reached in the Temperature Test, whichever is higher. RTE/RTI is only required for selected polymeric materials, namely:
   a) Enclosures for live parts
   b) Support for live parts
   c) Electric barriers
   d) Outer surface (i.e. backsheets)
   e) Frames
9) A set of requirements for encapsulants was given so that they can meet the requirements for Material Groups as defined in the Creepage and Clearance Section.
10) Added a Materials Deformation Test to be moved into IEC 61730-2.
11) Added strain relief requirements per the third edition of IEC 61215.
12) Addressed safety issues associated with open circuits (especially as they concern output leads) that can lead to arcing and fires.
13) Added grounding and earthing symbols.

Proposed changes to the second edition of Part 2 included:

1) Updated normative references
2) Rearranged test sequences
3) MST01: Visual inspection - added label requirement
4) MST11: Accessibility test - Defined force for test finger
5) MST12: Cut susceptibility test - Defined blade radius for cut test
6) MST14: Impulse voltage test - Added test voltage for a maximum systems voltage of 1500 V in table 8; changed tolerances and removed preconditioning requirement TC200 from Figure 1.
7) MST21: Temperature test - Rewrote test procedure to remove short circuit mode and allow alternative indoor test method.
8) MST23: Fire test - Section rewritten, fire test requirements related to national building codes; informative annex added.
9) MST26: Reverse Current Overload Test -Changed specification of wooden board.
10) MST32: Module Breakage Test – Defined new dimensions of the impactor to allow for it to be filled

with different material, considered a variety of mounting techniques for the test and defined the pass criteria for glass breakage based on a 450 mm drop height.

11) Removed test procedure for the Partial Discharge test, as it will be included in a proposed backsheet standard.
12) Added a retesting guideline.
13) Added a section on Recommendations for testing of modules from production.

2.3 Module Energy Rating

A series of standards is being developed for evaluating PV module performance based on power (watts), energy (watt-hours) and performance ratio (PR). It is being written to be applicable to all PV technologies, but may not work well for any technology where the module performance changes with time (e.g. modules change their behavior with light or thermal exposure), or which experience significant non-linearities in any of their characteristics used for the modeling. The first part, IEC 61853-1, which has been published, describes requirements for evaluating PV module performance in terms of power (watts) rating over a range of irradiances and temperatures. The second part, IEC 61853-2, which has been approved through the CDV stage, describes procedures for measuring the effect of angle of incidence on performance; the estimation of module temperature from irradiance, ambient temperature and wind speed; and the impact of spectral response on module performance. IEC 61853-3 will describe the calculations of PV module energy (watt-hours) ratings. IEC 61853-4 will define the standard time periods and weather conditions that can be utilized for calculating energy ratings.

3 NEW STANDARDS UNDER DEVLOPMENT

3.1 Specialized Stress Tests

A number of new specialized stress tests are under development by WG2.

IEC 61701: 2012 Edition 2 – Salt mist corrosion testing of PV modules. The second edition updated the method of test to better match the observed field corrosion of electronic devices.

IEC 62759: Transportation Testing of PV Modules. A CD has been circulating to National Committees with a due date of September 14, 2012. This document defines testing of PV modules in their shipping containers.

IEC 62782: Dynamic Mechanical Load Testing of PV Modules. This has been approved as a New Work Item. In this test the module is mechanically stressed for 1000 cycles to evaluate its susceptibility to broken cells and electrical connectors.

IEC 62716: Ammonia corrosion testing of PV modules. A CDV is circulating to National Committees with a due date for comments of November 2, 2012. This standard describes test sequences useful to determine the resistance of PV modules to ammonia (NH_3) to determine their suitability to be deployed in agricultural locations.

IEC 62804: System voltage durability test for crystalline silicon modules. This has been approved as a New Work Item. The test is designed to evaluate a module's ability to withstand exposure to high humdiity and high voltage at the same time.

3.2 PV Module Components

As PV has become a large, worldwide commercial business many PV module manufacturers are purchasing some of the components in their module from different suppliers. This has been particularly important for junction boxes, connectors and cables. In addition, more and more PV modules are being supplied with electronic components directly attached to the module. To provide assistance to module manufacturers with component purchase without the need for major retest and to provide assurance to the ultimate module customer that the purchased components are safe, WG2 has begun working on a series of standards for PV module components.

IEC 62790; Junction boxes for PV modules – Safety requirements and tests. This has been approved as a New Work Item. The IEC draft is based on modifications to CENELEC document EN 50548.

IEC TBD: Connectors for DC applications in PV Systems – Safety requirements and tests. This document is presently being circulated to National Committees as a New Work Item with a due date in December, 2012. The draft of this document was also based on modifications to CENELEC document EN 50521.

IEC TBD: PV Cables. A joint project team with WG2 and WG6 (on BOS Components) has been established to develop a standard for PV cables.

IEC 62109-3: Safety of power converters for use in PV power systems – Part 3: Particular requirements for PV modules with integrated electronics. This has been approved as a new Work Item Proposal through the efforts of WG6. WG2 is participating in the project team with the goal of writing a document that evaluates both the electronics itself as well as the electronics' impact on the module.

3.3 PV Module Materials

The initial module standards for Photovoltaics were designed to help develop a product that is safe, and able to survive reasonably long time periods when deployed in the field. To accomplish this, TC-82 developed and published the module qualification and a module safety standard. As PV has grown and the technology has become better understood, the properties of materials used in the module package play an increasingly important part in achieving long-term durability and safety. Certain basic properties are required of the materials in order for the modules to be safe and to be able to survive in the field for 25 years or more.

In 2010 Working Group 2 began an effort to develop standards for PV module materials that could serve the following two purposes:

- To develop standardized material characterization tests so that module manufacturers can select the materials that meet their packaging needs.
- To determine what material tests should be performed to ensure that PV materials can retain the important parameters required to keep PV modules safe during their lifetime.

Subcommittees were created to develop standards for the following types of PV polymeric packaging material:

1) Encapsulants
2) Back sheets and front sheets
3) Adhesives
4) Pottants
5) Edge Seals

A number of draft standards have already been approved by IEC as New Work Items.

IEC 62775: Measurement of EVA crosslink density

IEC 62788-1-2: Measurement of encapsulant and backsheet resistivity

IEC 62788-1-4: Measurement of encapsulant optical transmission

IEC 62788-1-5: Measurement of encapsulant shrinkage during processing

Two new TCO glass standards have also been approved as New Work Items.

IEC 62805-1: Measurement of haze of TCO glass

IEC 62805-2: Measurement of transmittance and reflectance of TCO glass

4 BEYOND QUALIFICATION – TESTING FOR MODULE WEAR-OUT

The commercial success of PV is based on long term reliability and safety of the deployed PV modules. Today most PV modules are warranted for 25 years with a maximum allowable degradation rate of 0.8%/year. These modules are typically qualified/certified to:

IEC 61215 for Crystalline Silicon Modules

IEC 61646 for Thin Film Modules

IEC 62108 for CPV Modules

These qualification tests do an excellent job of identifying design, materials and process flaws that could lead to premature field failures.

What we want to know is "if the PV modules purchased and deployed today will be able to survive for 25 or 30 years and how much they will degrade over that time". The question is "are the qualification tests sufficient to demonstrate this 25 year lifetime?" The answer is "no, they are not".

So what does it mean if a module type is qualified to IEC 61215, IEC 61646 or IEC 62108? Passing the qualification test means the product has met a specific set of requirements. Those module types that have passed the qualification test are much more likely to survive in the field and not have design flaws that lead to infant mortality. Most of today's commercial modules pass the qualification sequence with minimum change, meaning the qualification tests do not provide a means of ranking within the group that has passed the requirements.

How Successful are the Qualification Tests? They must be fairly successful because the PV industry has been growing rapidly. To get a feeling for the impact of the qualification tests we can look at some literature reports of Field Failures and Warranty Returns:

1) Whipple [1] reported on 10 years of field results (using data from Rosenthal, Thomas and Durand [2]) that unqualified modules suffered from 45% field failure rate while qualified modules suffered from less than 0.1% field failure rate.
2) Hibberd [3] reported on 125,000 modules from 11 different module manufacturers deployed for up to 5 years with only 6 module failures, representing a 0.005% failure rate.
3) Wohlgemuth et. al. [4] reported on Solarex/BP Solar multi-crystalline Si modules deployed from 1994-2005 with a 0.13% warranty return rate (1 failure every 4200 module years of operation)
4) Wohlgemuth et. al. [5] reported on Solarex/BP Solar multi-crystalline Si modules from 2005 to 2008 with an annual return rate of 0.01%.

By design the qualification tests have limitations. They were designed to identify early infant mortality problems, but not to:

- Identify and quantify wear-out mechanisms
- Address failure mechanisms for all climates and system configurations
- Differentiate between products that may have long and short lifetimes
- Address all failure mechanisms in all module designs
- Quantify lifetime for different applications or climates.

To address how to develop accelerated stress tests to aid in evaluating the wear-out of PV modules, NREL, AIST, JRC and SEMI hosted the International PV Module QA Forum in July, 2011. Those at the forum agreed to create the International PV Module QA Task Force with the goals of:

1. *Develop a QA rating system that provides comparative information about the relative durability of PV modules to a variety of stresses as a useful tool to PV customers and as a starting point for improving the accuracy of quantitative PV lifetime predictions.*
2. *Creating a guideline for factory inspections of the QA system used during PV module manufacturing.*

The Task Force has now been operational for more than one year. The following nine task groups have been established.

1) Guideline for Manufacturing Consistency
2) Testing for thermal and mechanical fatigue
3) Testing for humidity, temperature, and voltage
4) Testing for diodes, shading and reverse bias
5) Testing for UV, temperature and humidity
6) Communication of PV QA ratings to the community
7) Wind Loading (New group)
8) Testing of Thin Film Modules (New group)
9) Testing of CPV Modules (New Group)

Each of these international groups is working on developing specific draft standards for their area. The intial document will define how the test results from the series of tests being developed will be communicated to the industry. All task groups are still open for new members.

5 CONCLUSIONS

Working Group 2 has been active in updating its standards as well as developing new standards of interest to the PV industry. With the advent of the Materials subcommittees in 2010 participation in the development of IEC module standards has increased significantly. The International PV Module QA Task Force has attracted even more participants. While membership in WG2 is limited to those appointed by their National Committees, membership in the Materials subcommittees and in the QA Task Force are open to all who wish to participate.

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