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Three-Prong Path to Comprehensive Technical Standards for Photovoltaic Reliability

Preprint

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***Abstract* — As the photovoltaic (PV) industry has grown, the long-term reliability of PV systems has become increasingly important. Many organizations are taking on the challenge of this multi-faceted issue. This paper describes three closely coordinated efforts that together will provide a comprehensive set of consensus standards and specifications for the technical aspects of verifying PV system quality and bankability. These three efforts are developing standards for 1) qualifying the design for the intended application (climate zone and mounting configuration), 2) quality management systems for PV module manufacturing, and 3) system-level inspections to ensure appropriate design, installation, commissioning, and operation of PV systems. A pathway has been identified for international implementation of these standards through the International Electrotechnical Commission.**

***Index Terms* — reliability, photovoltaic systems, PV, quality management, accelerated testing.**

I. Introduction

As financial incentives for photovoltaic (PV) deployment shrink, PV customers are becoming increasingly focused on the long-term reliability of PV systems. Also, because PV prices dropped by more than a factor of four from early 2009 to early 2013, module manufacturers were forced to reduce costs; concerns have been raised that some manufacturers have neglected reliability [1].

Confidence in the reliability of PV modules requires both that the module design is adequate for the use environment and that the design is consistently manufactured. In addition, reliability at the system level requires that all components have adequate quality, that all components are integrated correctly, and that the system is installed, maintained, and functioning properly.

Substantial work over the years has led to a widely accepted set of standards to guide qualification testing of modules [2-8] and balance-of-system components [9,10] and to guide the design and installation of PV systems [11-13]. Private test labs have developed a range of tests that go beyond the standard qualification testing for PV modules [8,14-25]. Additionally, multiple organizations are launching efforts to develop guidelines or standards for the design, installation, and operations and maintenance of PV systems. Each of these efforts is important for improving PV system reliability. However, there is widespread sentiment that a more comprehensive and unified approach to PV reliability is needed.

This paper describes the three-prong effort that is being pursued by the International PV Quality Assurance Task Force (PVQAT) to develop a comprehensive set of standards for ensuring the reliability of PV systems, including methods that are more comprehensive than IEC 61215 [3] for 1) qualification of the design for the intended application (climate zone and mounting configuration), 2) auditing quality management systems for PV module manufacturing, and 3) system-level inspections to ensure appropriate design, installation, commissioning, and operation of PV systems, as shown in Fig. 1.

The paper starts with a historical overview of how the effort began, then describes the status and plans for each of the three coordinated efforts, building on the existing infrastructure of the International Electrotechnical Commission (IEC). This effort is unique among the many because a pathway has been identified to reach the goal of a unified and comprehensive solution. This description is intended to facilitate coordination with other relevant efforts.

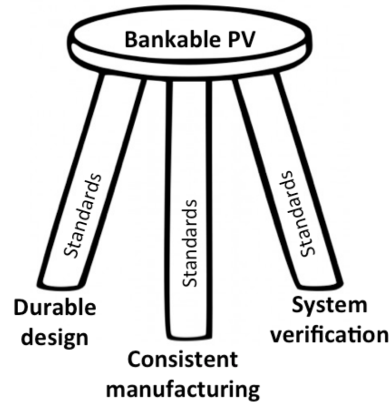

Fig. 1. Conceptual diagram of how the three-prong standards effort provides a foundation for reliable, bankable PV systems. Standards are needed to show that 1) the durability of the design meets the intended use environment, 2) the tested design is manufactured consistently, and 3) the system is appropriately designed, installed, commissioned, and operated.

II. History of Effort

In December 2010, Hironori Nakanishi of the Ministry of Economy, Trade and Industry (METI) in Japan proposed to the U.S. Department of Energy the topic of PV module reliability testing as a collaborative effort between the United States and Japan as part of the Asia-Pacific Collaboration Program. METI proposed a joint workshop in spring 2011 to discuss PV module reliability testing at an international level. At the time, METI was contemplating a PV incentive program and wished to first have confidence in the quality of the hardware.

METI and the U.S. Department of Energy approached the National Institute of Advanced Industrial Science and Technology (AIST) and the National Renewable Energy Laboratory, respectively. Michio Kondo and Masaaki Yamamichi of AIST, and John Wohlgemuth and Sarah Kurtz of the National Renewable Energy Laboratory formed a steering committee to begin preparations for the workshop. Tony Sample of the Joint Research Centre of the European Commission joined the steering committee to represent Europe.

The March 2011 earthquake in Fukushima, Japan thwarted the original plan of a May 2011 workshop in Tokyo. The workshop was quickly rescheduled with help from SEMI; the International PV Module Quality Assurance Forum was held July 15-16, 2011 in San Francisco, CA. About 150 people representing module manufacturers, equipment suppliers, test labs, and a range of other organizations attended the Forum. Presentations and breakout sessions discussed the need for taking PV reliability standards to the next level and concluded by forming the International PV Module Quality Assurance Task Force [26] to address two primary goals (Fig. 2). Initially, five Task Groups were formed, as described in Table I.

TABLE I
SUMMARY OF CURRENT TASK GROUPS

Groups for developing PV QA Testing	Date formed	Prong
1. Guideline for manufacturing consistency	July 2011	2
2. Thermal and mechanical fatigue, including vibration	July 2011	1
3. Humidity, temperature, and voltage	July 2011	1
4. Diodes, shading, and reverse bias	July 2011	1
5. UV, temperature, and humidity	July 2011	1
6. Communication of PV QA ratings to the community	Sept. 2011	1
7. Snow and wind loading	April 2012	1
8. Thin-film PV	August 2012	1
9. Concentrator PV	Sept. 2012	1
10. Connectors	May 2013	1
11. PV Systems	April 2014	3

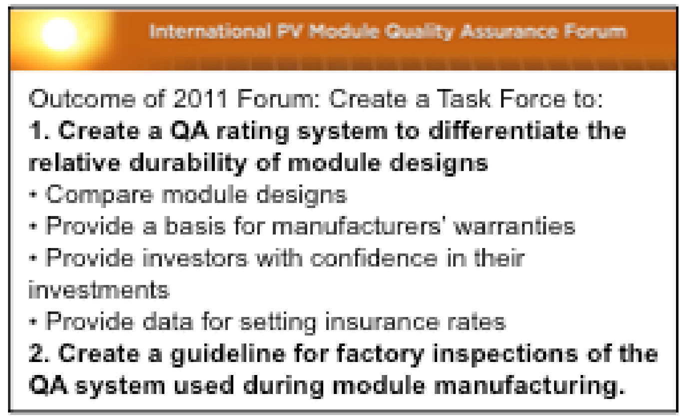

Fig. 2. The 2011 Forum was a workshop that resulted in the formation of the International PV Module Quality Assurance Task Force to address these goals.

Task Group 1 was created to address the second of the goals in Fig. 2 (prong 2); Task Groups 2-5 were created to design stress tests for the rating system, specifically for crystalline silicon modules, as in the first goal in Fig. 2 (prong 1).

A few months after the forum, Task Group 6 was formed to help ensure that the rating system could be easily communicated to stakeholders. Although there was interest in immediately starting work on thin-film and concentrator PV module standards, the complexity of the project motivated a delay of a year and Task Groups 8 and 9 were formed in summer 2012. Task Group 7 was formed in response to concerns from Australia about the need to test for cyclonic winds, but Task Group 7 has so far focused more on snow loading. Task Group 10 was later formed to address issues with connectors.

A key discussion topic for Task Group 1 was whether a guideline for PV module manufacturing should be developed and administered under IEC or ISO (International Organization for Standardization). The manufacturing process is commonly audited under ISO 9001, but there is a need to add technical aspects to the audit, implying benefit of involvement by IEC working groups. Discussions with the IEC uncovered a similar dilemma for the wind industry. In collaboration with representatives of the wind industry and the IEC, a solution was identified: IEC created IECRE [27], as discussed below.

During the 2011 Forum and subsequently, multiple individuals suggested that PV systems should be included in the goals, but initially, the Task Force focused on only PV module issues. However, in spring 2014, in recognition of the need to address system-level issues and to better support IECRE, the leaders decided to broaden the scope of the Task Force, dropping the word “Module” from the name and using the abbreviated label PVQAT. To support the IECRE in developing all the standards needed to issue a system-level certificate, Task Group 11 was formed. Because IECRE PV-system certificates will use multiple standards from IEC Technical Committee 82 (TC82) Working Groups 2, 3, and 6, Task Group 11 will provide a forum for higher-level discussions and rapid identification of solutions when a need for a more comprehensive PV-system inspection is identified. The outputs of all the PVQAT Task Groups are submitted to IEC by the appropriate IEC working group for refinement and adoption through IEC's international consensus-development process. Many individuals participate in both PVQAT and IEC, facilitating rapid adoption of the new standards. The coordination has been especially close between Task Group 5 of PVQAT and the IEC TC82 materials group, which is investigating test methods for materials including durability to ultra violet light.

The current status of the eleven task groups is briefly summarized in Table I. An analysis of the standards needed for IECRE to complete a PV-system inspection is reviewed by Kelly, *et al*. [27]. A technical description of the rating system that is being developed is described by Wohlgemuth, *et al*. [28]. The current status of the guideline for PV manufacturing consistency is described by Eguchi, *et al*. [29].

Most of the PVQAT work has been executed by telephone and web-facilitated meetings, but about two face-to-face meetings have been held each year [26].

III. Three-prong approach

Although PV system reliability is more frequently compromised by inverter failures than by other component failures [30], the PV modules represent the greatest single component risk because of the high cost associated with module replacement. Also, the modules are more directly subjected to the weather than are some other components, which may be housed in enclosures. Thus, two prongs of the three-prong approach focus specifically on the design and manufacture of the modules; the third focuses on the function of the entire system.

A. Durable design: Qualifying the design for the intended application

Qualification tests seek to identify design flaws that could lead to early failures, but PV manufacturers and customers would like to also understand the wear-out mechanisms that are likely to limit the service life of PV modules. These wear-out mechanisms usually strongly depend on the climate and mounting configuration in which the module is deployed. Most module manufacturers provide a single warranty regardless of deployment location or configuration. Some manufacturers void the warranty if the module is deployed in a marine or corrosive environment, but typically do not differentiate between hot and cold or wet and dry climates.

Historically, manufacturers have preferred to manufacture a single module design. But as the industry has grown, companies have sought to differentiate their products, sometimes within their own product line and, often, from their competitors' products. It is advantageous for manufacturers to create multiple module designs if the cost of the module can be reduced for limited markets. For example, a module deployed in a location with high snow loads may require thicker glass, frame, or support rails increasing upfront cost but decreasing levelized cost of electricity (LCOE) over modules with thinner glass that might fail in the first year [31]. As the industry matures and seeks to reduce cost, PV customers will benefit from a simple way to identify modules that meet their needs at the lowest price. Ultimately, the PV industry will reduce LCOE further if reduction in module cost is quantitatively linked to service life as a function of the use environment. The rating system that is being designed by PVQAT and implemented through IEC seeks to do exactly this by defining tests to differentiate use environments involving three climate zones (nominally, moderate, tropical, and desert climates) and two mounting configurations (open-rack and close-roof mounting) [28]. If manufacturers find that they can achieve the lowest LCOE with the same module design for multiple use environments, then fewer than six use environments may be needed.

The implementation of this rating system will be managed alongside the current international standards. This strategy was chosen over creating a new standards organization to hasten the standards creation process and minimize the need for new community education efforts.

The details of the tests that are being proposed are based on observations of the most commonly observed field failures [25,28,32-36].

B. Consistent manufacturing: Quality management systems for PV module manufacturing

Consistent manufacturing is needed to ensure that all modules replicate the intended design. Confirming that every module functions correctly at the beginning of life is straightforward; however, controlling the long-term reliability is much more challenging. Even with highly accelerated tests, it could take months to determine whether the manufacturing process has drifted out of specification.

IEC TC82 accepted "Guideline for increased confidence in module design qualification and type approval" as a new work item in January 2014. This technical specification will add PV-specific details to ISO 9001 and will be implemented through IEC TC82 and IECRE after it is published in 2015. Even before the IEC technical specification is published, the concept of a requirement for a PV-specific quality management system is being embraced in multiple locations. More than a dozen companies are already certified to the Japanese version, JIS Q8901 [37], which was used as a starting point for the international version. TÜV Rheinland, acting as a Standards Development Organization, has begun creation of a U.S. standard [38] and China has been developing guidelines for differentiating quality management systems. Eguchi, *et al*. [29] has summarized the history and status of the IEC guideline in more detail.

C. System verification: System-level inspections

Ultimately, even if the modules are perfect, a PV system may not function correctly if the system is not correctly designed, installed, and operated. Just as a restaurant or an elevator displays a certificate showing a successful inspection, each PV system can have a certification (based on an international standard) verifying that the system meets minimal safety and performance standards. This certification would be useful to:

- an insurance company determining rates
- a PV customer or the lender for a customer who wishes independent confirmation of the state of a system before investing in a plant
- an owner of a PV plant who wishes to ensure that the asset is being operated safely and effectively.

Just as an elevator is rated for the number of people it can transport, some aspects of PV system design and performance may need to be documented by the inspection. For example, some PV systems are knowingly designed to underperform because of shading or inverter clipping. It is useful to a potential customer of a system to be able to quickly quantify these.

As described above, responding to a similar need in the wind industry, in recent years IEC Technical Committee 88 began an effort to develop system-level certification of wind systems. However, conformity assessment is considered outside the scope of IEC Technical Committees and it was unclear who might have authority over a system-level certification. To fill this void, the IEC Conformity Assessment Board created IECRE in June 2013 to guide system-level inspections for all types of renewable energy systems including wind, PV, solar thermal, and marine energy. Many of the needed detailed standards for a PV-system inspection already exist. So although this organization is just starting, IECRE plans to issue the first certificates by the end of 2015. Kelly, *et al*. [27] have provided a more detailed description of the work of IECRE and the standards that will be included in the system-level inspection.

IV. Accomplishments and Plans

Since the Forum in 2011, the Task Groups have been discussing the scientific basis for the desired standards, designing experiments to answer pivotal questions, collecting the best ideas, and submitting these to the IEC TC82 consensus standards process. Some of the primary accomplishments to date (notably drafts in progress with IEC) are summarized in Table II.

Plans for implementing the three-prong effort are summarized in Table III. IECRE plans to begin issuing certificates for large PV plants in 2015. As noted above, the PV-specific reviews of quality management systems are already being done in Japan, and are expected to begin in other parts of the world in 2015. Completion of the rating system to assess durability as a function of use conditions is expected in 2016, but refinement will continue for years to come.

TABLE II
Summary of PVQAT-Supported Accomplishments and Status

IEC Designation	Title	Stage	Forecast Publication Date	Task Group
IEC 62892-1 Ed. 1.0	Comparative testing of PV modules to differentiate performance in multiple climates and applications – Part 1: Overall test sequence an method of communication	Approved work item	2015-12	2-6, 8
IEC/TS 62916 Ed. 1.0	Bypass diode electrostatic discharge susceptibility testing	Approved work item	2015-02	4
PNW/TS 82-800 Ed. 1.0	Guideline for Increased Confidence in PV Module Design Qualification and Type Approval	Approved work item	2015-10	1
IEC 62925 Ed. 1.0	Thermal cycling test for CPV modules to differentiate increased thermal fatigue durability	Approved work item	2015-8	10
PNW 82-791 Ed. 1.0	Non-uniform snow load testing for photovoltaic (PV) modules	Proposed work item	2015-12	7
Not assigned	Bypass diode thermal runaway test	Proposed work item	2016	4
	Comparative testing of PV modules to differentiate performance in multiple climates and applications – Part 2: Mechanical and Thermal Cycling Stress Testing	Draft	2016	2
	Comparative testing of PV modules to differentiate performance in multiple climates and applications – Part 3: UV and Humidity Testing	Concept	2016	3,5

TABLE III

SUMMARY OF HIGH-LEVEL PLANS FOR THREE-PRONG EFFORT

	Current Status	2014 goal	2015 goal	2016 goal
Durable Design (Comparative test)	Proposed as concept	Enumerate tests; establish framework	Submit all test procedures to IEC	Approve IEC rating system
Consistent Manufacturing (Quality Management Systems)	Revision of original proposal is resubmitted	Publish technical specification	Start use of TS in factory inspection and as part of IECRE	Revise QMS TS to reflect feed
System Verification (System-level inspection)	IECRE is being formed	Identify needed standards and create drafts as needed	Issue first certificates	Refine approach

V. SUMMARY

This three-prong path to a unified and comprehensive set of technical standards for PV-system reliability is one of many efforts underway to help PV customers, investors, and insurers easily assess PV modules and systems. It is distinguished from most other efforts underway because a pathway has been identified for how the standards will be created and implemented. Mainstream standards organizations and test laboratories will implement the new standards, providing a rapid path to unified implementation of a comprehensive treatment of PV-system reliability and quality.

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