June 2004 • NREL/CP-520-35346

Conference Paper

Concentrator Photovoltaic Qualification Standards for Systems Using Refractive and Reflective Optics

Preprint

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To be presented at the 19th European PV Solar Energy Conference and Exhibition
Paris, France
June 7–11, 2004

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Contract No. DE-AC36-99-GO10337

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Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

CONCENTRATOR PHOTOVOLTAIC QUALIFICATION STANDARDS FOR SYSTEMS USING REFRACTIVE AND REFLECTIVE OPTICS

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ABSTRACT: This paper describes a proposed international qualification standard for photovoltaic (PV) systems generating electricity from concentrated sunlight. The standard's purpose is to provide stress tests and procedures to identify any component weaknesses in a system. If no weaknesses are identified during qualification, both the manufacturer and the customer can expect a more reliable product. In 2002, we began developing the standard, under the auspices of the International Electrotechnical Commission (IEC), that would describe testing procedures for concentrator PV systems using reflecting (mirrors) or refractive (lenses) optics for focusing sunlight onto solar cells. The initial draft of the IEC standard was based on the first concentrator PV qualification standard published by the Institute of Electrical and Electronics Engineers (IEEE) in the United States in 2001. Well-developed U.S. concentrator technologies use refractive optics, and the IEEE standard needed improvement for testing systems with reflective optics. Furthermore, with record III-V solar cell efficiencies above 37%, concentrator PV developers around the world would like to incorporate such cells into their next generation of technologies. The paper will highlight significant differences between the proposed IEC standard and the earlier IEEE standard.
Keywords: Qualification and Testing – 1, Concentrators – 2, Reliability – 3

1 BACKGROUND

The United States Department of Energy (DOE), through its National Renewable Energy Laboratory (NREL), has supported the development of qualifications standards for testing concentrator PV systems since 1997 [1]. Standards play an important role in the development of an emerging technology by reducing the risk for both the manufacturer and the customer through increased reliability of system components that have passed the tests in an approved qualification standard. For example, flat-plate PV qualification standards developed over the past two decades have contributed greatly to the present level of flat-plate module reliability such that some manufacturers can back their products with guarantees for as long as 20 years. Only recently, in May 2001, did the Institute of Electrical and Electronics Engineers publish the world's first concentrator PV qualification standard [2]. The IEEE working group creating the standard consisted of representatives from U.S. manufacturers, organizations who had installed and tested concentrator PV systems, and engineers from government laboratories familiar with concentrator PV technologies. The group tried to develop a standard suitable for systems using reflecting surfaces (mirrors), as well as refracting optics (lenses), for concentrating and focusing sunlight onto solar cells. However, well-developed U.S. technologies used Fresnel lenses, whereas many concentrator PV systems in other countries use mirrors.

In spring 2002, we began a series of meetings and e-mail exchanges under the auspices of the International Electrotechnical Commission (IEC) to develop an international standard with clearer and better specifications for tests for concentrator PV systems with mirrors while still providing an opportunity to review and update the IEEE standard's tests for concentrators using lenses. The IEC working group, consisting of international representatives from companies, utilities, and research organizations around the world, began with a draft based on the IEEE standard. Since then, the U.S. manufacturer, Amonix, Inc., has submitted components of its Fresnel-lens-based concentrator to the Photovoltaic Testing Laboratory at Arizona State University to become the first company with its product qualified according to the IEEE standard. In Japan, Daido Steel and Sharp are using tests in the IEEE standard to develop components of a Fresnel lens concentrator system incorporating III-V multijunction solar cells with production efficiencies above 30% and record efficiencies above 37%. Although the IEEE standard was developed with high-efficiency crystalline silicon solar cells in mind, concentrator PV companies around the world are very interested in incorporating III-V solar cells into their next generation of systems because their product's power output can increase by as much as 50% with a relatively small increase in system cost. These developments provide additional insight and impetus for a new IEC standard. The IEC working group plans to complete the balloting and publishing of the IEC standard in 2006.

In considering changes to the IEEE standard, the group found it very important to hold the IEC meetings in parts of the world where companies have well-developed technologies. The last IEC meeting was held in Melbourne, Australia, in November 2003, just prior to the International Solar Concentrator Conference held in

Figure 1: Solar System concentrator PV unit with one receiver on each unit.

Alice Springs [3]. IEC working group members had the opportunity to gather important first-hand information about the concentrator PV technology developed by Solar Systems Pty Ltd over a period of 15 years. Their system uses a dish-shaped solar concentrator with reflecting surfaces focusing sunlight onto high-efficiency crystalline silicon solar cells manufactured in the United States by SunPower Inc. (Fig. 1).

Concentrator PV systems with both reflective and refractive optics systems are now entering distributed-generation utility markets. For example, Solar Systems installed a 200-kW system in an Australian distributed-generation utility grid in 2003 and is presently installing another 720 kW in 2004. In the United States, Amonix has developed several generations of its technology, also over a period of 15 years. Amonix installed 600 kW over the past 2 years in the service territory of Arizona Public Service (Fig. 2), and both companies have indications that megawatts of their systems will be installed in 2005 [4]. These sales are small in comparison with the 740 MW of flat-plate PV systems produced throughout the world in 2003. But if the time for solar electric concentrators is finally here, international concentrator PV qualification standards will soon be available to support their penetration of the world's electricity generation markets.

2 OVERVIEW OF QUALIFICATION TEST PROGRAM

2.1 Definitions

A fundamental difference between flat-plate and concentrator PV standards is the need to differentiate between receivers and modules [1]. The IEEE standard has definitions for each that had to be substantially revised to provide a rigorous yet flexible set of definitions that apply to all types of generators as defined in the present draft of the IEC standard. The present definitions are aimed at providing clarity for simultaneously specifying tests for concentrator PV systems using mirrors or lenses. In decreasing size, the proposed standard defines a concentrator PV system, solar concentrator unit on a tracker with assemblies, assembly of receivers, receiver, and module. Figures 1 and 2 show concentrator PV systems composed of solar concentrator units with receiver assemblies using reflecting optics (Fig. 1) or refractive optics (Fig. 2). A receiver is defined as the smallest, complete assembly of one or more concentrator PV modules and secondary optics (and related components such as interconnects and mounting) that accepts concentrated sunlight. A concentrator PV module is defined as a subassembly of one or more PV cells that accepts concentrated sunlight and incorporates the means for thermal and electric energy removal. In the present draft, a manufacturer needs to provide the test laboratory with seven module sections, five receivers, one receiver assembly, and one specially constructed module if required for the intrusive bypass diode sequence.

Figure 2: Amonix concentrator PV unit with seven receivers.

2.2 Baseline tests

As in the IEEE standard, the IEC draft standard includes baseline tests for electrical performance, ground continuity, electrical isolation, and wet insulation resistance, along with visual inspections, to determine the initial status of all receiver and module sections. See Fig. 3 for the entire qualification test sequence.

2.3 Bypass diode and thermal cycle sequence

In this sequence, the draft standard specifies thermal tests for bypass diodes and test conditions for 250 or 500 thermal cycles between minimum rated temperature and 110^0C or 90^0C, depending on the design of module sections. There is a separate intrusive bypass diode thermal sequence if access to the bypass diode is not possible without compromising the integrity of the receiver.

2.4 Humidity-freeze and thermal cycle sequences

In this sequence, the draft standard specifies a different set of thermal cycle tests for modules in parallel with a similar set of tests for receivers, followed by 20 humidity-freeze cycles for both receivers and modules. This is another case where differences in the concentrator optics affect the sequence options because concentrator units with reflecting optics typically use active cooling of their receivers, whereas units with refractive optics are

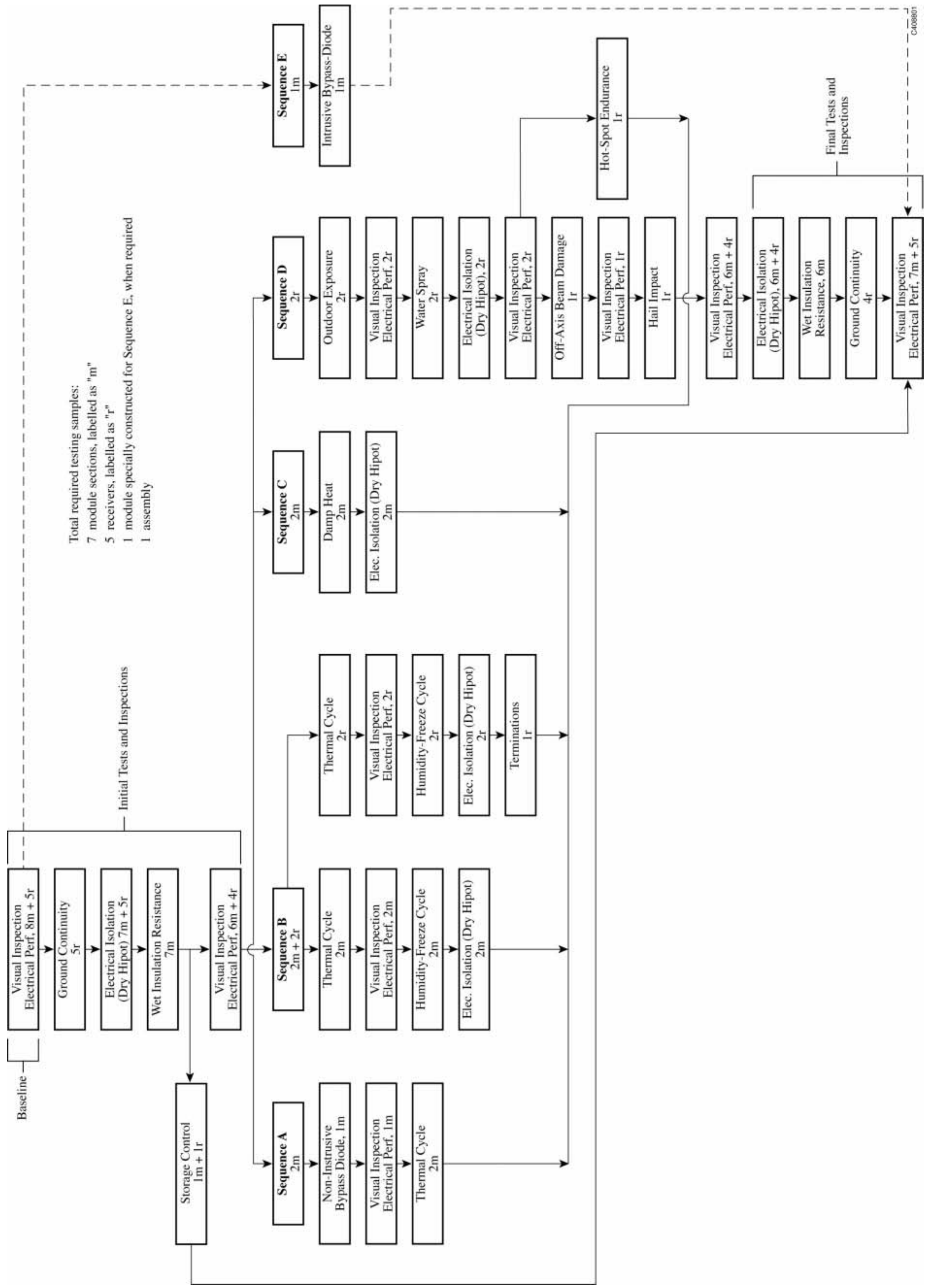

Figure 3: IEC draft concentrator photovoltaic qualification test program.

usually passively cooled. The tests are followed by electrical isolation tests.

2.5 Damp-heat sequence

In this sequence, the draft standard specifies tests for receivers in 85% relative humidity and temperatures of 85^0C for 1000 hours, followed by electrical isolation tests.

2.6 Environmental stress sequence

This is the longest sequence of tests in the standard. It specifies receiver tests for relatively short periods of outdoor exposure to identify problems that might not be seen in laboratory tests, water spray, off-axis solar beam damage, hail impact, and hot-spot endurance. Additional final tests and inspections in this sequence include visual inspection and electrical performance of receivers and modules, followed by final electrical isolation, wet insulation resistance, ground continuity, and final visual inspection and electrical performance tests.

2.7 Significant differences

We have already mentioned some significant differences between the earlier IEEE standard and the present IEC draft standard, such as new definitions for receivers and modules. The IEC draft includes test options for systems with active or passive cooling of receivers. Another significant difference arises in the specification for electrical isolation tests to determine whether or not the module or receiver is sufficiently well insulated between current-carrying parts and the frame or the outside world. The requirements in the IEEE test had a history traceable to the electrical isolation tests for flat-plate PV modules. However, as can be seen from Figs. 1 and 2, concentrator PV systems may have receivers and modules with areas significantly different than those of flat-plate systems. Concentrator PV receivers and modules may also be less accessible to personnel. The isolation resistance requirements for modules and receivers now depend on their areas. Finally, there are some differences in the specifications for electrical performance tests.

3 ELECTRICAL PERFORMANCE TESTS

A critical issue after a test or sequence of tests is the evaluation of electrical performance of the module or receiver to determine survival of the test. In the case of flat-plate PV modules, a solar simulator and reference cell provides a means to verify performance after a test sequence. This is not possible for the large systems shown in Figs. 1 and 2. The IEEE standard specified three possible tests to verify the degradation in the performance of receivers and modules. The most complex test involved outdoor baseline testing under various temperature and solar irradiance conditions to obtain an analytical expression for module and receiver performance. This option is not available in the present IEC draft due to the complexity and cost of determining the many parameters in the analytical expression for electrical performance under different outdoor conditions. The IEEE standard specified a second measurement technique to identify power degradation of a test receiver before and after stress tests by comparing its relative power with respect to a control receiver never subjected to stress tests. This method is based on the assumption that the changes in the control or reference receiver's electrical performance are negligible throughout the qualification testing period. By using this method, test condition variables are self-correcting, and the complex analytic translation procedures are eliminated. The third test in the IEEE standard is the use of dark current-voltage (I-V) measurements before and after some of the intermediate stress tests. Experience gained with the use of a control receiver has been sufficiently positive that it is the principal method in the present IEC draft standard for determining performance degradation in receivers and modules.

4 CONCLUSION

For the past couple of years, we have been developing a set of test procedures to qualify concentrator PV systems as reliable products in international markets. We are building international consensus for the new standard through a series of meetings to review successive drafts of the standard. Even though the first concentrator PV qualification standard was completed only 3 years ago, there are significant differences between it and the present proposed draft IEC standard. This appears to be in the nature of standards development activities, as new technologies appear and experience with previous standards is acquired. While the details of the tests and procedures are under consideration and modification by the IEC working group, we plan to complete the IEC balloting and publication process in 2006. A new IEC standard, suitable for international technologies and markets, will be useful as concentrator PV systems begin to emerge in the world's energy markets.

ACKNOWLEDGMENT

We wish to acknowledge the work of the IEEE Standards Association and its concentrator PV qualification working group for their efforts in developing the world's first concentrator PV qualification standard. We also acknowledge the support of the International Electrotechnical Commission and its Technical Committee No. 82 (TC 82) for Solar Photovoltaic Energy Systems. NREL's coordination of the standard's development through the IEC TC 82 Working Group 7 for concentrator PV systems is supported by DOE under Contract No. DE-AC399GO10337 and through DOE's Solar Energy Technology Program within its Office of Energy Efficiency and Renewable Energy. Finally, we acknowledge Mani TamizhMani at Arizona State University for his guidance and encouragement.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
June 2004

2. REPORT TYPE
Conference paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Concentrator Photovoltaic Qualification Standards for Systems Using Refractive and Reflective Optics: Preprint

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
R. McConnell, L. Ji, J. Lasich, and R. Mansfield

5d. PROJECT NUMBER
NREL/CP-520-35346

5e. TASK NUMBER
PVP40102

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-520-35346

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
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15. SUBJECT TERMS
PV; qualification and testing; concentrators; reliability;

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	UL		19b. TELEPONE NUMBER (*Include area code*)