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A review of standards for hybrid CPV-thermal systems

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ABSTRACT

A comprehensive review on standards for actively-cooled CPV and CPV-T systems is presented. Since these systems lack specific standardisation, this review concludes that the current standards, including the photovoltaic IEEE 1513 and IEC 62108, and the solar thermal EN-12975-2:2006 and ISO 9806-2:1995, are insufficient for qualifying these types of actively-cooled concentrator systems. Additional test specifications for adapting the IEC 62108 and EN-12975-2:2006 standards for actively-cooled CPV and CPV-T systems have been proposed.

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1. Introduction

System and component reliability are widely recognised as critical aspects of new electronic components and devices. For each component, qualification tests and other assessment procedures are usually specified in international standards, such as the IEC (International Electrotechnical Commission) or the ASTM (American Society for Testing and Materials). Similarly, qualification tests for standard or representative systems comprising these tested components are also formally specified.

When developing a new technology without associated standards, particularly at a system level, new tests must be designed in order to determine the reliability and durability of the new systems. These assessment tests are usually based on previous standards, with modifications and adaptations designed to address the specific additional requirements of the new device. A case in point is the hybrid concentrator photovoltaic-thermal (CPV-T) system, which lacks specific standards for qualification and reliability assessment. In this case, where no official standards are available to qualify this type of system, the relevant photovoltaic thermal standards must be reviewed in order to design suitable test procedures to assess the new technology.

Hybrid CPV-T receivers are neither purely photovoltaic, nor purely thermal; so special requirements for tests associated with the active cooling systems will arise when conducting the approved test sequences for solar CPV systems, such as those specified by the IEC 62108 standard. In order to verify the suitability of the IEC 62108 standard for determining CPV-T receiver reliability, the IEC 62108 tests have been analysed for applicability to actively-cooled systems. Extensions of the standard tests, and additional new tests, or modifications of existing tests where applicable, will be presented.

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Concurrently with the CPV tests, the solar thermal component of the CPV-T system must undergo a separate range of specified tests, which usually incorporates the current local standards for these applications. For this reason, standards covering domestic hot water applications and concentrator solar thermal collectors will be reviewed and incorporated in the proposed CPV-T standards in order for the hybrid system to comply with standards required for a purely thermal system.

This paper will present a combined sequence of tests, incorporating the IEC 62108 standards, under development at ANU that is designed to qualify the photovoltaic and thermal performance and reliability of an actively-cooled hybrid CPV-T system. An evaluation of the currently available standards and their considerations will be presented, along with an initial assessment of the most appropriate tests, including additional test requirements, for hybrid systems in order to guarantee their long-term electrical and thermal performance.

2. Standards for CPV systems: a review of the active cooling case

The lack of standards for CPV system qualification is not a new issue; it has been thoroughly analysed by Muñoz et al. [1] in their review on the state-of-the-art of CPV standardisation. Currently, there are only two relevant standards: the IEEE 1513 [2] and the IEC 62018 [3], with both constructed solely for CPV receivers. However, these standards are limited to three different technologies in the case of the IEEE 1513, and five technologies in the case of IEC 62108. New CPV technologies are constantly emerging, and the standards are not always appropriate for assessing the performance and reliability of the new systems.

In the case of hybrid concentrator systems that include photovoltaic as well as thermal output, one possible option is to follow the current standards as a template for defining a set of tests in order to establish the durability of the system. The main issue with this approach is the question of how to determine and analyse the suitability of the proposed tests for actively-cooled CPV and CPV-T systems. Consideration of the IEEE 1513 standard, 'IEEE Recommended Practice for Qualification of Concentrator Photovoltaic (PV) Receiver Sections and Modules', leads to the conclusion that this standard includes no special consideration for active-cooled systems. This is despite the standard including linear focus systems, which can operate with active or passive cooling, as one of the specifically described technologies.

In contrast to the IEEE 1513 standard, the new IEC 62108 standard, 'Concentrator Photovoltaic (CPV) Modules and Assemblies—Design Qualification and Type Approval', includes five distinct types of CPV systems. Of these five systems, only one, the point-focus dish PV concentrator incorporates, active cooling. Thus, it would be expected that the standard would cover this issue in detail. However, a detailed review of the standard leads to the conclusion that the lack of specifications and details leaves a very broad scope in which to interpret and conduct the different tests.

As an example, there are several tests that do not provide any reference to active cooling, such as dark I–V measurement, ground path continuity, thermal cycling test, damp heat test, humidity freeze test, bypass/blocking diode thermal test, and off-axis beam damage test. For some of these tests, such as for example the dark I–V measurement, the effect of active cooling and whether or not it is operational, would be unlikely to affect the performance. For some other tests, however, the result with and without active cooling can be dramatically different. Consider the thermal cycling test, where the standard specifies the injection of electrical cycles. In this case, passively-cooled systems have a distinct advantage over actively-cooled systems if the coolant is not flowing.

As matters presently stand, when the chamber is at a uniform temperature and current is injected into the receiver, the passive cooling system commences to function, since there is a heat focus on the cells that will be spread into the heat sink. In this case, the passively-cooled system has all the thermal mass and thermally conductive pathways required for conducting the heat, so the passively-cooled receiver will operate in a similar state to that of real operating conditions. In contrast, the actively-cooled system will be at a disadvantage if the coolant is not flowing. In this situation, the receiver will be subject to much higher localised thermal stresses, since heat conduction to the surroundings will be neither appropriate, nor realistic. In this case, the test will be unrepresentatively harsh for the actively-cooled receiver, and the results will not be useful, since the test will not be reproducing representative operating conditions. For this situation, the implementation of standards tests requires careful review of the specifications, and consideration of the test procedure limitations when using actively-cooled CPV receivers.

There are additional tests that include some considerations that are relevant to actively-cooled systems in the IEC 62108 standard. These include the outdoor side-by-side I–V measurement, the electrical insulation test, the ultraviolet conditioning test, and the outdoor exposure test. Unfortunately, the test descriptions are not always very clear, and the conditions they impose are unusually broad. For example, the ultraviolet conditioning and outdoor exposure test descriptions specify only that 'If the system requires active cooling, the cooling system should be operated during the test'. Similarly, for the outdoor side-by-side I–V measurement the test description specifies that 'If coolant is employed, monitor coolant flow rate and inlet/outlet temperatures. The coolant flow rate should not change by more than 2%, and the temperature should not change by more than 1 °C in any 5-min period'. However, the standard test description does not address the flow rate requirements of the system. The test results will be very different when using a high flow rate to that of a low flow rate, where large temperature gradients exist within the receiver. Finally, for the electrical insulation tests, which includes both dry and wet tests, the specified condition is that 'Designs that use a cooling medium should have the cooling medium present during the test, but the cooling medium circulation is not required'. The specification does not answer the question as to why the cooling medium circulation is not required.

From this review, it can be concluded that the IEEE 1513 standard is inadequate for testing actively-cooled CPV or CPV-T modules. Furthermore, although the IEC 62108 standard considers one particular actively-cooled system as one of the analysed technologies, the associated test specification is not clear and lacks procedural detail and analysis of the limitations that arise when conducting tests for other actively-cooled systems.

3. Standards for CPV solar thermal

Hybrid concentrator photovoltaic-thermal systems produce electricity as well as low-grade heat for hot water domestic applications. As solar thermal systems, they should comply with the current official standards in order to guarantee fully functional operation and durability of the thermal part. The most common standards used for solar thermal systems are the European Standard EN-12975-2:2006 'Thermal Solar Systems and Components. Solar Collectors—Part 2: Test methods' developed by AEN/CTN 94 committee [4] and the ISO 9806-2:1995, 'Test Methods for Solar Collectors—Part 2: Qualification test procedure' [5]. Both of these standards specify the tests that a solar collector should pass in order to guarantee their durability. None of these standards mention any special considerations for hybrid photovoltaic-thermal systems. The ISO 9806-2:1995 even states that it does not apply to tracking