A Review on Suitable Standards for Hybrid Photovoltaic/Thermal Systems

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Abstract. This paper presents an evaluation of the available standards and considerations when using actively-cooled CPV systems. An initial assessment of the most appropriate tests, including additional test requirements, for hybrid Photovoltaic-Thermal (PV-T) systems to guarantee long-time electrical and thermal performance is presented.

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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 procedures are usually specified in international standards. Similarly, qualification tests exist for standard or representative systems comprising these tested components. When developing a new technology without associated standards, particularly at a system level, new tests have to be designed in order to test the reliability and durability of the new systems. These tests are usually based on previous standards, with suitable modification and adaptation designed to address the specific requirements of the new device.

One example is the hybrid Concentrator Photovoltaic-Thermal (CPV-T) system, which lacks specific standards for qualification and reliability assessment. In this case, in the absence of official standards, 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 system will arise when conducting the approved test sequences for solar CPV systems, such as those specified by the IEC 62108 standard. These tests will be analysed in order to verify their suitability for active cooled systems. Extension of the standard tests and additional new tests where applicable, will be presented. Simultaneously, the solar thermal component of the CPV-T system must be subjected to a separate range of specified tests, according to the current local standards for these applications. These standards will be reviewed and incorporated in the proposed CPV-T standards to provide uniform compliance requirements.

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

2. STANDARDS FOR CPV SYSTEMS: A REVIEW OF ACTIVE COOLING

The lack of standards for CPV system qualification is not a new issue; it has been thoroughly analysed by Muñoz et al. [1]. Currently, there are only two standards; IEEE 1513 [2] and IEC 62018 [3], both solely for CPV receivers. However, these standards are limited to three (IEEE 1513), and five (IEC 62108) technologies. New CPV technologies are constantly emerging, and the present standards are not always appropriate for the correct assessment of the performance and reliability of the new systems.

For hybrid CPV-T, one option is to follow the current standards for defining a set of tests, with the main issue with this approach being determination of suitable analysis of the proposed tests for actively-cooled systems. A study of the IEEE 1513 standard leads to the conclusion that it includes no special consideration for active-cooled systems, despite having linear focus systems as one of the described technologies.

Conversely, the new IEC 62108 standard includes five types of CPV systems; with one, the point-focus dish PV concentrator, using only active cooling. It would be expected that the standard should cover this issue in detail but a careful review reveals a lack of specifications and details, leaving a very broad interpretive scope in which to conduct the tests.

For example, tests such as dark I-V, ground path continuity, thermal cycling, damp heat, humidity freeze, bypass/blocking diode thermal test, and off-axis beam damage tests do not provide any reference to active cooling. For some of these tests, such as dark I-V measurement, the effect of active cooling might not affect the performance. But for other tests, the result can be dramatically different. Consider the thermal cycling test; when injecting the electrical cycles as the standards specifies, passively-cooled systems have an advantage over actively-cooled systems if the coolant is not flowing.

Presently, when the chamber is at a uniform temperature and current is injected into the receiver, the cooling system starts working, since there is a heat focus on the cells that has to be spread into the heat sink. In this case, the passively-cooled system has all the thermal mass required for conducting the heat, and so the receiver will operate in a similar state to that of real operating conditions. But the actively-cooled system will be at a disadvantage if the coolant is not flowing. In this situation the receiver is subjected to much higher stresses, and the results will not be useful, since the test will not be reproducing representative operating conditions. In this case, the standard tester should carefully review the specifications and limitations when using actively-cooled CPV receivers.

Some tests include considerations relevant to actively-cooled systems in the IEC 62108 standard. For example, the outdoor side-by-side I-V measurement, the electrical insulation test, the ultraviolet conditioning test, and the outdoor exposure test. However, these test descriptions are not concise and the conditions they impose are too broad. For example, they may only specify that 'If the system requires active cooling, the cooling system should be operated during the, or '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-minute period'. But the standard does not address the flow rate requirements of the system. Inappropriate flow rates can produce large temperature differences in the receiver. Finally, for the electrical insulation tests, including both dry and wet types, the specified condition that 'Designs that use a cooling medium should have the cooling medium present during the test, but the cooling medium circulation is not required' 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 is not suitable for testing CPV or CPV-T modules utilising active cooling, and that the IEC 62108, although it considers one active cooled system as one of the analysed technologies, is not clear and lacks detailed specifications and a analysis of the limitations arising for tests of actively-cooled systems.

3. STANDARDS FOR CPV-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]. 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 concentrator collectors. On the other hand, the EN-12975-2:2006 includes solar concentrator collectors, from static concentrators such as CPC's (Compound Parabolic Collectors), to high concentrator systems with two-axis tracking, but it does not specify any special requirements for tracking or non-tracking concentrator collectors.

The different tests included in these standards have been reviewed in order to determine their suitability for solar CPV systems, not only for concentrating solar thermal. The list of reliability tests for solar collectors included in the EN-12975-2:2006, which are basically the same as for the ISO 9806-2:1995, include: internal pressure, high temperature resistance, exposure, External thermal shock, internal thermal shock, rain penetration, freezing resistance, mechanical load, impact resistance, and final inspection.

Of these tests, some would not be affected by the inclusion of photovoltaic solar cells. For example, the internal pressure test, rain penetration, freezing resistance, mechanical load, or the impact resistance test. However, another group of tests including high temperature resistance, exposure, and external and internal thermal shock tests, for high solar irradiance exposure with no liquid circulation, conducted to check the high temperature resistance of the materials, could be critical when solar cells are included.

For example, the high temperature resistance test checks the collector ability to withstand high levels of solar irradiance without materials failures. For the case of hybrid CPV-T systems, this test can not be conducted as specified since the solar cells and interconnections could be damaged. The same issue applies to the exposure test with no fluid in the absorber which affects the PV components, since cells under concentration require cooling to avoid damage.

Similarly, the external and internal thermal shock tests both require no fluid inside. Both tests conflict with PV component system operation requirements, as the absorber could reach very high temperatures and lead to failure in the cells.

These solar thermal tests should be modified for those cases with high absorber temperatures that could damage the solar cells and their interconnections, by including fluid circulation, by establishing a maximum temperature during the test, or by including an off-sun fail-safe system to prevent overheating.

4. A PROPOSAL FOR ASSESSING HYBRID SYSTEMS

Hybrid system assessment requires testing the photovoltaic as well as the thermal components. An initial two-part set of tests is presented.

4.1 Photovoltaic Part

For CPV testing, a proposal is being prepared at ANU for adapting the tests from the IEC 62108 standard to actively-cooled systems. For active cooling, one of the main issues is flow-rate determination. This proposal uses a flow rate equivalent to the real flow rate in the full size system, producing a temperature drop across the receiver similar to real operating conditions.

The principle for determining when to use active cooling is rests on making the experiment as real as possible, and placing actively cooled receivers on the same footings as passive cooled receivers. Table 1 shows the variations proposed for the use of the IEC 62108 standard for actively-cooled systems.

TABLE 1. Proposed variations to the IEC 62108 for its use for active cooled modules qualification.

Test Title	Test Condition	Variation proposed for active cooled systems
Electrical performance	Outdoor side-by-side I-V with DNI > 700 W/m^2, wind speed < 6 m/s, clear sky. Dark I-V as a means to measure resistance, at least 10 points from 0.9 to 1.6 I_{sc}	Cooling system working. Flow rate calculated for a small sample as equivalent to full size module (equivalent temperature drop across the receiver).
Electrical insulation test	At ambient temperature, 25°C ± 10°C and RH < 75%, apply 2 * V_{sys} + 1000 V for 2 minutes (hi-pot); Measure R at 500 V. Coolant present, no circulation required.	Cooling circulation required. No requirements on flowrate.
Wet insulation test	Measure R at 500 V when the sample is wetted by surfactant solution with resistivity < 3500 Ωcm. Coolant present, no circulation required.	Cooling circulation required. No requirements on flowrate.
Thermal cycling test	All TC test options are from -40°C to T_{max}.Apply 1.25 * Isc when T > 25°C with cycle speed of 10 electrical/thermal.	Cooling system working only when injecting electrical cycles. Flow rate calculated for a small sample as equivalent to full size module (equivalent temperature drop across the receiver).
Bypass/blocking diode thermal test	At 75°C sample temperature, apply I_{sc} through the receiver for one hour, then measure bypass/blocking diode temperature. Apply 1.25 * I_{sc} for additional one hour.	Cooling system working. Flow rate calculated for a small sample as equivalent to full size module (equivalent temperature drop across the receiver).
Off-axis beam damage test	Aim the light on suspect locations for at least 15 minutes when DNI > 800 W/m^2; or walk-off for 3 hours.	Cooling system working. Flow rate calculated as equivalent to full size module temperature drop across the receiver.
UV conditioning test	Expose to UV accumulation of 50 kWh/m^2. Cooling system working.	Flow rate calculated as equivalent to full size module equivalent temperature drop across the receiver.

Outdoor exposure test	Expose to DNI accumulation of 1,000 kWh/m^2 when DNI > 600 W/m^2. Cooling system working.	Flow rate calculated for a small sample as equivalent to full size module (equivalent temperature drop across the receiver).

4.2 Thermal Part

For thermal component testing, it is important to limit the maximum temperature to design standards, especially the PV components. This temperature control is performed by determining the maximum temperature of the fluid in tests; or by re-defining the test considering the characteristics of the PV component. For example, CPV systems under exposure should always include fluid circulation. External thermal shock could be generated by intermittent shading. Table 2 shows the proposed modifications for the test of the thermal components of a hybrid system. These variations could be implemented in a new combined standard.

TABLE 2. Variations proposed to the EN-12975-2:2006 for its use for hybrid photovoltaic-thermal systems.

Test Title	Test Condition	Variation proposed for CPV-T Systems
High temperature resistance	Solar irradiance > 1000W/m^2 in the plane of the solar collector, Ambient temperature between 20°C-40°C, Wind speed < 1m/s, No fluid in the absorber	Define maximum temperature in the absorber on the materials in the PV receiver;or Include fluid circulation
Exposure	30 days with a minimum irradiation of 14MJ/m^2 per day 30h of at least 850W/m^2 with ambient temperature >10°C. No fluid inside the absorber.	Include fluid circulation.
External thermal shock	Initial exposure for one hour at high irradiance (> 850W/m^2), with no fluid inside. Water spray for 15min.	Include fluid circulation; or Redefine the test to CPV parameter, shadows produce thermal shock.
Internal thermal shock	Initial exposure for one hour at high irradiance (> 850W/m^2), with no fluid inside. Fluid circulated till the absorber temperature drops below 50°C.	Include fluid circulation and redefine the test including large fluid temperature changes below the maximum temperature of the materials.

4.3 PV/Thermal Integration Issues

With combined systems, it is important to identify new problems arising from the integration of the technologies, especially for system durability. For example, as with trackers for CPV, which would need their own standard [1], for hybrid CPV-T systems it is necessary to add extra tests to determine system capability for dealing with problems such as cooling system failures, or adequate system control for when the thermal storage system has reached maximum temperature. The new system would require new strategies to control and protect the photovoltaic receiver against cooling system failures, and these failures should be anticipated and checked by appropriate standards.

5. CONCLUSIONS

A thorough review has been conducted on standards for CPV-T systems in order to determine the suitability of the specified tests for actively-cooled CPV and CPV-T systems. The main conclusion is that there is a lack of specifications for qualifying actively-cooled and hybrid CPV-T concentrators in both photovoltaic and thermal standards.

Photovoltaic standards, IEEE 1513 and IEC 62108, have been reviewed as well as solar thermal standards, EN-12975-2:2006 and ISO 9806-2:1995. Variations for adapting the IEC 62108 tests and EN-12975-2:2006 tests for CPV-T systems have been proposed. Any new technology that develops between the boundaries of two existing ones should have its own standards, based on the previous experience, and leading to an improved, robust, and reliable technology.

REFERENCES

1. E. Muñoz, P.G. Vidal, G. Nofuentes, L. Hontoria, P. Perez-Higueras, J. Terrados, G. Almonacid and J. Aguilera, 'CPV standarization: An overview', *Renewable and Sustainable Energy Reviews*, Vol. 14, pp. 518-523, 2010.
2. IEEE 1513 standard, 'IEEE Recommended Practice for Qualification of Concentrator Photovoltaic (PV) Receiver Sections and Modules'.
3. IEC 62108 standard, 'Concentrator Photovoltaic (CPV) Modules and Assemblies – Design Qualification and Type Approval'.
4. European Standard EN-12975-2:2006 'Thermal Solar Systems and Components. Solar Collectors – Part 2: Test methods' developed by AEN/CTN 94 committee.
5. ISO 9806-2:1995, 'Test Methods for Solar Collectors – Part 2: Qualification test procedure', International Organization for Standardization, Geneva, Switzerland.