

EXPERIENCE WITH SPECIFICATIONS APPLICABLE TO CERTIFICATION*

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Summary

The Jet Propulsion Laboratory has developed a number of photovoltaic test and measurement specifications to guide the development of modules toward the requirements of future large-scale applications. Experience with these specifications and the extensive module measurement and testing that has accompanied their use is examined. Conclusions are drawn relative to three aspects of product certification: performance measurement, endurance testing and safety evaluation.

1. Background

A number of design and test specifications for photovoltaic modules on the flat-plate solar array (FSA) project of the Jet Propulsion Laboratory (JPL) have been published over the past 6 years in support of the national photovoltaics program. The prime objective of these specifications has been to guide the development of advanced modules toward the requirements of future large-scale applications which are the main focus of the FSA's research activities.

The series of specifications published to date reflects the evolving state of knowledge within the program on these future applications and on the generic subjects of module reliability and endurance testing, and module measurement methods. The recently published block V performance requirements represent the fifth generation set of requirements and have been published in two volumes dealing separately with residential and intermediate load applications [1, 2]. Because they are designed for use with present day procurements, the specifications by necessity reflect a careful compromise between the ideal needs of future applications and the realities of present day production methods, costs and technical performance. A second

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important aspect of the specifications is that they are applied to the purchase of "general-purpose" modules within each application sector and therefore must deal with site-to-site and system-to-system differences in a generic way.

The block V specifications are targeted at typical intermediate load and residential systems situated in environments which do not involve salt fog, extreme snow loads or impact by hail greater than 1 in in diameter. However, the environmental extremes of the vast majority of sites are addressed by an extensive set of environmental qualification tests which have been updated to reflect the latest field and laboratory test experience. In particular, the thermal cycle and humidity tests have been increased in severity over previous specifications and a recently completed hot-spot endurance test has been added (Table 1).

A second important addition in these latest specifications is an extensive treatment on module safety coauthored with Underwriters' Laboratories [3].

2. Experience with module qualification

During each of the four previous block procurements, JPL has conducted qualification testing of production prototype modules to the tests outlined in the design and test specifications. Experience with module qualification can be broken down into three main categories: performance measurement, endurance testing and safety evaluation.

2.1. Performance measurement

Electrical power output represents the bottom line to the user and is therefore the key factor in characterizing module performance and assessing durability or its inverse, degradation. Because solar cell power output is dependent on a variety of parameters, including cell temperature, cell spectral response, cell irradiance level, uniformity and spectral content, accurate performance measurement requires complex procedures and equipment. Before a new module design can be measured for power output, it is first necessary to measure the spectral response of the cells and their temperature coefficient, and to fabricate or otherwise to obtain a reference solar cell with matching spectral response [4]. In order to characterize the expected field performance it is also necessary to measure the module's nominal operating cell temperature (NOCT) [4].

Experience to date indicates that methods for making the required performance measurements are well developed but require a high degree of experience and expensive equipment. Although most photovoltaic cell manufacturers have cell and module measurement facilities, nearly all manufacturers rely on JPL or the Lewis Research Center, National Aeronautics and Space Administration, for reference cell fabrication and calibration. The lack of commercially available reference cells and the high cost (U.S. $\$50 \times 10^3$ -

TABLE 1
Evolution of Jet Propulsion Laboratory endurance qualification tests

Tests	Modules					Tests levels
	Block I	Block II	Block III	Block IV residential and/or intermediate load center	Block V residential and/or intermediate load center	
Thermal cycle	100	50	50	50	200	-40 °C - +90 °C, cycles as indicated
Humidity cycle	x	5	5	5	10	5 cycles at 95% relative humidity, 23 °C - 40 °C or 10 cycles at 85% relative humidity, -40 °C - +85 °C (block I, 70 °C at 90% relative humidity, 68 h)
Mechanical loading cycle		100	100	10000	10000	2400 N m ⁻² (50 lb ft ⁻²) cycles as indicated
Wind resistance				x	x	Underwriters' Laboratories test 997 (residential only)
Twist		x	x	x	x	One corner lifted 2 cm m ⁻¹ of length
Hail impact				20	25	10 hits with ice balls, diameter (mm) as indicated
Electrical isolation		1500	1500	1500 - 2000	1500 - 3000	50 μA maximum current at voltage indicated
Hot-spot endurance					x	100 h short circuited at 100 mW cm ⁻² , NOCT

U.S. $\$300 \times 10^3$) of accurate module measurement facilities makes it difficult for users to obtain independent checks of the performance of the delivered product and makes it expensive to set up an independent certification-testing laboratory.

2.2. Endurance testing

As with performance testing, endurance (environmental) testing methods have evolved over a number of years to the comprehensive set defined in Table 1. Although many of these tests are compatible with standard temperature-humidity test chamber capabilities, a number of the tests (hail, mechanical cycling, wind resistance and hot-spot endurance) require special test facilities. A compounding factor is the desire to have electrical performance test facilities in close proximity to the endurance test facilities to allow efficient monitoring and documentation of possible performance degradation before and after exposure. The net result is increased testing expense and limited availability of facilities capable of performing the required tests and measurements.

A second complicating factor is the difficulty in quantifying pass-fail criteria for mechanical degradation such as encapsulant delamination, cell cracking and other visual defects which do not immediately affect module electrical performance. This lack of easy quantification inserts a degree of subjectiveness into the evaluation and must be addressed if multiple organizations and personnel are to arrive at equitable evaluation of competing module designs.

2.3. Safety evaluation

The most recent addition to the qualification test sequence is the evaluation of module safety features. To this end, JPL has relied on the extensive experience of Underwriters' Laboratories to define the necessary criteria and test methods [3]. Because of the extensive role of the Underwriters' Laboratories and facilities in the field of product safety testing, it is expected that they will serve as a focal point for this aspect of module evaluation in the near future.

3. Conclusions

The unique and complex nature of photovoltaic devices results in unique and complex test methods and equipment. Although these methods and equipment are well developed at this time, the large expense and specialized nature of the necessary facilities is likely to pose a significant obstacle to the ready availability of such facilities within private standards-testing laboratories.

References

- 1 Block V solar cell module design and test specification for residential applications, *Doc. 5101-162*, February 20, 1981 (Jet Propulsion Laboratory, Pasadena, CA).

- 2 Block V solar cell module design and test specification for intermediate load applications, *Doc. 5101-161*, February 20, 1981 (Jet Propulsion Laboratory, Pasadena, CA).
- 3 Interim standard for safety — flat-plate photovoltaic modules and panels, Vol. I, Construction requirements, *Doc. 5101-164*, November 30, 1980 (Jet Propulsion Laboratory, Pasadena, CA).
- 4 R. G. Ross and C. C. Gonzalez, Reference conditions for reporting terrestrial photovoltaic performance, *Proc. 1980 Annu. Meet. of the American Section of the International Solar Energy Society, Phoenix, AZ, June 2 - 6, 1980*, American Section of the International Solar Energy Society, Newark, DE, 1980, pp. 1091 - 1097.