INFLUENCE OF MODULE REQUIREMENTS ON FLAT PLATE MODULE DESIGN EVOLUTION*

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ABSTRACT

Photovoltaic module design features and performance characteristics have undergone significant evolutionary changes between pre-1975 First Generation configurations and current Third Generation design technology. A major contributor to this evolution was an iterative process of continuing design guideline and specification development for major module procurements. Module manufacturers have actively responded to these evolving requirements through progressively improving designs. This iterative/feedback process is described. Interim design guidelines and preliminary design options reflecting the LSA 1982 Module Technical Readiness Specification (November 1979) (1) are described with respect to previous design and performance requirements.

INTRODUCTION

Flat plate photovoltaic module design features and performance characteristics have undergone significant evolutionary changes between the First Generation (pre-1975) modules and current Third Generation designs. At the start of the national photovoltaic program only a few manufacturers were producing commercially available module designs based on preliminary concepts of packaging and utilizing available materials and methods. These designs have evolved into carefully engineered configurations currently being developed by a broad cross section of manufacturers producing modules for applications ranging from small remote uninterruptible power sources to residential systems, and even up to large utility connected sub-megawatt systems.

A major contributor to this evolutionary process has been the continuing development and upgrading of design and performance specifications used to purchase large blocks of photovoltaic modules. As successive revised and improved design guidelines and performance specifications have been developed, manufacturers have improved the characteristics of their modules to meet the new requirements in innovative and cost effective designs.

REQUIREMENTS DEVELOPMENT

A series of module performance and design requirements documents has been developed and issued by the Jet Propulsion Laboratory in order to support large blocks of module procurements made by the Low Cost Solar Array Project and other elements of the national program. A tabulation of these documents, their chronology and intended application, appears in Table I. The requirements incorporated in these documents have evolved through a closed-loop iterative process consisting of the steps outlined in Figure 1. The first step is identification of an important operating parameter, such as potential failure mode, interface constraint (usually application-dependent), or environmental stress. This identification comes from a variety of sources, such as review of the intended application(s), feedback of module performance results under existing qualification tests, actual field failure incidence, or potentially envisioned problems, such as hail impact, which was included as a requirement before actual field incidence.

The second step in the process incorporates two simultaneous procedures. Exploratory testing

Table I. Low-Cost Solar Array Project JPL Module Specifications

Identification	Application	Date Issued
5-342	Block I	June '75
5-342-1, Rev. B	Block II	Dec '76
5-342-1, Rev. C	Block III	May '77
5101-65	PRDA-38	Mar '78
5101-16, Rev. A	Block IV, ILC	Nov '78
5101-83	Block IV, Residential	Nov '78
5101-138	1982 MTR, ILC	Nov '79

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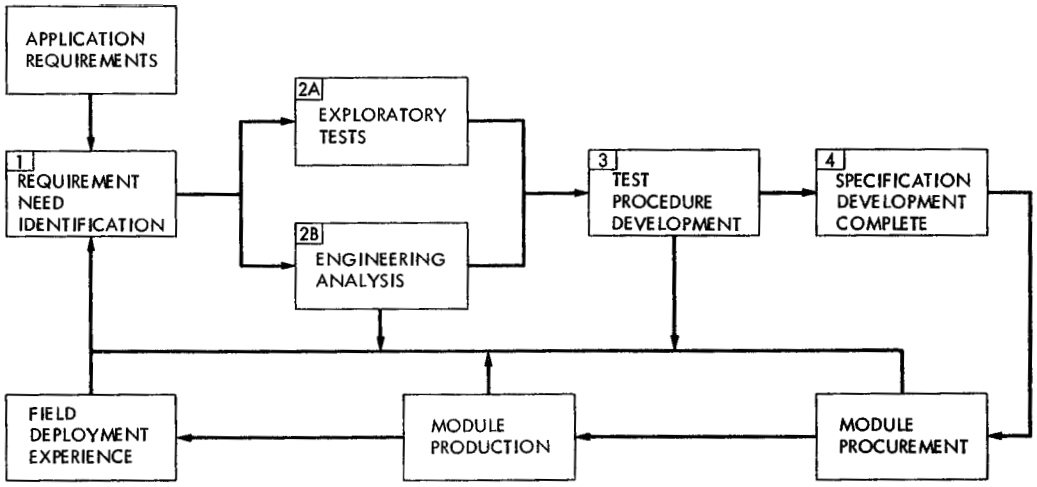

Figure 1. Specification Development Process (Closed Loop).

of existing module designs is conducted to reproduce or characterize the anticipated operating condition, or reproduce the failure mechanism. Assessment is made analytically of the probability of the problem occurrence or the conditions leading to a particular operational or failure mode.

In the third step, test procedures are developed and tests conducted to verify the validity of the test method and its associated evaluation criteria, using a sequence of exploratory tests conducted on existing hardware from previous procurements. Finally, the revised requirement is incorporated in subsequent revisions of the design and test specifications. Actual procurement, qualification, and acceptance testing of modules to the specification requirements, field performance of the modules when deployed in the field, and information obtained from manufacturers during module production provide important feedback elements in the process.

1982 TECHNICAL READINESS SPECIFICATION

The objective of the 1982 Technical Readiness Module (MTR) Design and Test Specification, JPL 5101-138, is to provide design guidelines and performance and test requirements for solar cell modules which will demonstrate a capability to meet the LSA Project 1986 goals. Modules which meet the requirements of this document will serve as pathfinder designs for the development, design and fabrication of fully automated process equipment with megawatt production capacity. Differences between the MTR specification and prior documents are summarized in Table II. In particular, the MTR specification incorporates a hot spot endurance test which reflects the potential for localized heating of individual cells under shadowing or cracked cell conditions. Analyses performed by the LSA Engineering Area and reported by Gonzalez and Weaver (2) initiated development of the test procedure. During the development activities, hot spot failures actually occurred in the field. The increased voltage isolation requirement is based on the results of studies by Bechtel indicating that system voltages for intermediate load center applications should be of the order of 1000 VDC. The efficiency requirement reflects the LSA Project 1986 goals.

As a result of the issuance of this specification it is anticipated that modules produced in the 1982-86 time frame, and meeting these design and test requirements, will be typified by the following design features:

- 1.2 meter × 1.2 meter dimensions
- Overall net module efficiency of 10% at Nominal Operating Cell Temperature
- Individual module voltages less than 30 VDC, for safety reasons
- 1000 VDC system voltage isolation capability demonstrated by a 3000 VDC hi-pot
- A high degree of circuit reliability and fault tolerance provided by appropriate levels of series/parallel connections, multiple cell contacting, and/or diode protection
- Soiling resistant front surfaces
- Structural design integrated with array support structure

CONCLUSION

The frequent reassessment of module design requirements has resulted in a continually evolving series of solar cell module design and test specifications. Module designs meeting these requirements have become successively more sophisticated and have demonstrated increasing performance capabilities in keeping with the cost and lifetime goals of the National Photovoltaic Program.

Table II. Qualification Tests Flat-Plate Modules

Tests	Modules						Test Levels
	Blk I	Blk II	Blk III	PRDA-38	Blk IV ILC/RES.	MTR '82 ILC	
Thermal Cycle	X	X	X	X	X	X	-40°C, +90°C/hr 50 Cycles (Blk I = 100 Cycles
Humidity Cycle	X	X	X	X	X	X	5 Cycles, 95%, +40°, +28°C (Blk I 90%, 70°C)
Mechanical Loading		X	X	X	X	X	±2.4 kPa, 10000 Cycles (±1.7 kPa for Residential) (Blk II, III = 100 Cycles)
Wind Resistance					X Shingles Only		UL 997
Twist		X	X	X	X	X	±2 cm/m
Hail Impact				X	X		3 Hits, 3 Places w/20 mm Ice Ball
						X	10 Hits, Sensitive Locations w/25 mm Ice Ball
Electrical Isolation		X	X	X	X	X	2 × System Voltage Plus 1000 VDC
Ground Continuity			X	X	X	X	50 Milliohm Test

REFERENCES

1. "1982 Technical Readiness Module Design and Test Specification - Intermediate Load Applications," Low-Cost Solar Array Project Document 5101-138, DOE/JPL-1012-36, November 15, 1979.

2. Gonzalez, C. and Weaver, R., "Circuit Design Considerations for Photovoltaic Modules and Systems," presented at the Fourteenth IEEE Photovoltaic Specialists Conference, San Diego, California, January 7-10, 1980.