TEST METHOD FOR PHOTOVOLTAIC MODULE RATINGS

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Publication Number

FSEC-GP-68-01

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FSEC-GP-68-01
May 21, 2001

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FOREWORD

This document describes the testing and reporting requirements for certification and labeling of photovoltaic modules (PV) for their power ratings. The test methods and procedures chosen for this purpose are based on consensus standards of relevant committees of the Institute of Electrical and Electronic Engineers (IEEE), the American Society for Testing and Materials (ASTM), or the International Electrotechnical Commission (IEC).

The test method is primarily based on the PV module performance measurement in PowerMark document PV3: *Test Requirements for a Certification and Labeling Program for Photovoltaic Modules*. Some requirements are taken from IEEE 1262, UL 1703, IEC 61215 , IEC 61646 and ASTM E 1036 . Other specific ASTM test methods referenced, herein, are also incorporated as mandatory test requirements for the purposes of this document.

The test methods and procedures presented represent the minimum testing requirements for any product certification and labeling programs that may be developed for photovoltaic module power ratings. Additionally, these test procedures and the related equipment and facilities requirements represent the minimum test capabilities against which laboratories should be evaluated for testing in support of module certification and labeling programs.

This document, together with the following four documents, is intended to address the totality of the criteria and requirements for PV module power ratings certification and labeling program:

PV-1 Criteria for a Model Quality System for Laboratories Engaged in Testing Photovoltaic Modules

PV-2 Model for a Third-Party Certification and Labeling Program for Photovoltaic Modules

PV-4 Operational Procedures Manual for the Certification Body of the Photovoltaic Module Certification Program

PV-5 Application and Certification Procedures for the Photovoltaic Module Certification Program

1.0 INTRODUCTION

1.1 Background

In 1976, the Florida Legislature enacted the Solar Energy Standards Act of 1976, Section 377.705, Florida Statutes. This law, effective October 1976, directs the Florida Solar Energy Center (FSEC) to develop standards for solar energy equipment sold or manufactured in the state, establish criteria for determining the performance of solar energy equipment, and maintain a test facility for evaluating solar energy equipment performance. It provides for FSEC to charge a fee to cover cost of testing and allows the acceptance of test results from other testing organizations.

The Solar Energy Standards Act was amended in 1978 to require that after January 1, 1980, all solar systems manufactured and sold in Florida meet the standards of FSEC and must display results in a manner prescribed by FSEC. The Solar Energy Standards Act covered only solar thermal equipment and systems.

In 2001, FSEC started a voluntary program to test and certify the performance of solar photovoltaic (PV) modules. It is expected that by July 2003, the certification of PV modules will become mandatory for those sold or manufactured in Florida. This test standard and criteria were developed to meet FSEC's PV module performance certification program.

1.2 Purpose

1.2.1 The purpose of this document is to delineate the test method for determining the power ratings of photovoltaic modules for certification and labeling program.

1.2.2 These testing and reporting requirements represent the minimum requirements against which photovoltaic modules shall be evaluated in terms of their quantitative response to electrical performance-based tests.

1.2.3 These test procedures represent the minimum capabilities against which laboratories shall be assessed and accredited in accordance with Document PV-1 for testing in support of photovoltaic module certification and labeling.

1.3 Scope and Limitations

1.3.1 The testing requirements set forth in this document shall be used for determining the power ratings of terrestrial flat-plate photovoltaic (PV) modules intended for power-generating applications. These requirements are not intended for use in testing and evaluation of PV concentrator modules.

1.3.2 This document covers the requirements for both indoor testing under solar simulator and outdoor testing under natural sunlight.

1.3.3 This document is applicable to crystalline silicon and amorphous silicon modules, and other thin-film PV technologies.

1.3.4 This document does not cover the test requirements for energy ratings and/or qualification testing of PV modules.

1.3.5 This document sets forth the minimum requirements with which photovoltaic modules shall comply to demonstrate their ability to meet the requirements of the certification program for their power rating.

1.3.6 These requirements also represent the minimum standards with which laboratories selected by manufacturers shall comply and operate to demonstrate their competence to rate PV modules .

1.3.7 Guidelines for equipment and apparatus required are included in Appendix A of this document. Guidelines for the management of the testing laboratory are briefly discussed in Appendix B.

2.0 DEFINITIONS

2.1 Terms defined in this section are relevant to PV module testing. Terms defined in PV-1 and PV-2 are incorporated by reference.

2.1.1 Air Mass (AM): A dimensionless quantity equal to the ratio of (1) the actual path length of solar radiation through the atmosphere to (2) the vertical path length through the atmosphere at sea level. At sea level, for all but very large zenith angles z, AM = sec z (UL 1703).

2.1.2 AM 1.5 Standard Reference Spectrum: The solar spectral irradiance distribution (diffuse and direct) incident at sea level on a sun-facing 37 degree tilted surface from horizontal. The atmospheric conditions for AM 1.5 are: precipitable water vapor 14.2 mm, total ozone 3.4 mm, turbidity (base e, λ=0.5 μm) 0.27 (ASTM E 892).

2.1.3 I-V Data: The relationship between current and voltage of a photovoltaic device in the power-producing quadrant, as a set of ordered pairs of current and voltage readings in a table, or as a curve plotted in a suitable coordinate system (i.e., Cartesian) (ASTM E 1036).

2.1.4 Maximum Power (Pmp): The point on the current-voltage (I-V) curve of a module under illumination, where the product of current and voltage is maximum. For the purpose of this document, "rated" power is defined as Pmp at STC (UL 1703).

2.1.5 PV Module (flat-plate): The smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts, such as interconnections, terminals, (and protective devices such as bypass diodes) intended to generate dc power under unconcentrated sunlight. The structural (load carrying) member of a module can either be the top layer (superstrate), or the back layer (substrate) (UL 1703).

2.1.6 Standard Test Conditions (STC): Conditions under which a module is typically tested in a laboratory: (1) irradiance intensity of 1000 W/ m^2, (2) AM1.5 solar reference spectrum (see 2.1.2), and (3) cell/module temperature of 25 ± 2 degrees C (IEC 61215).

2.1.7 Standard Operating Conditions (SOC): Same as STC, except that the cell/module temperature is 45± 2 degrees C.

3.0 REFERENCES

ASTM E 892 Standard Tables for Terrestrial Solar Spectral Irradiance at Air Mass 1.5 for a 37 Degree Tilted Surface (Table 2).

ASTM E 927 Standard Specifications for Solar Simulation for Terrestrial PV Testing.

ASTM E 973 Standard Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell.

ASTM E 1036-96 Standard Test Methods for Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells.

ASTM E 1362 Standard Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells.

ASTM E 1799 Practice for Visual Inspection of Photovoltaic Modules.

IEC 891 Procedures for Temperature and Irradiance Corrections to Measured I-V Characteristics of Crystalline Silicon Photovoltaic Devices.

IEC 904-1 Measurement Principles of PV Current-Voltage Characteristics.

IEC 904-2 Requirements for Reference Solar Cells.

IEC 904-3 Measurement Principles for Terrestrial PV Solar Devices with Reference Spectral Irradiance Data.

IEC 904-5 Determination of the Equivalent Cell Temperature of PV Devices by the Open Circuit Voltage Method.

IEC 904-6 Requirements for Reference Solar Modules.

IEC 904-7 Computation of Spectral Mismatch Error Introduced in the Testing of PV Devices.

IEC 904-8 Guidlines for the Measurement of Spectral Response of a PV Device.

IEC 904-9 Solar Simulator Performance Requirements.

IEC 61215 Crystalline Silicon Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval.

IEC 61646 Thin-Film Silicon Terrestrial Photovoltaic (PV) Modules - Design Qualification and Type Approval.

IEEE 928 Recommended Criteria For Terrestrial Photovoltaic Power Systems.

IEEE 1262 Recommended Practice for Qualification of Photovoltaic (PV) Modules.

UL 1703 Underwriters Laboratories Inc., UL Standard 1703, Second Edition - May 7, 1993, Standard for Safety: Flat-Plate PV Modules and Panels.

4.0 SAMPLING, IRRADIANCE SOURCE AND MEASUREMENT

4.1 Sampling

A local representative designated by the laboratory (FSEC) will select at random six PV modules from the existing stock at the manufacturer's plant or distribution point. No more than two modules will be from the same production batch and/or same distributor. All six modules identified by the laboratory representative will be shipped to FSEC by the module manufacturer (or module supplier). Five of these modules will be used as the test modules, and the remaining module will be kept as the control module. After the completion of testing, the five test modules will be returned to the supplier by FSEC, if so requested.

4.2 Irradiance Source

The light source may be natural sunlight or a solar simulator. If the natural sunlight is used, the performance measurements will be conducted on each module for at least three clear days with daily plane of array (POA) insolation of at least 5.0 kWh/m^2. Only the module performance data obtained at irradiance of 800 W/ m^2 or greater and module temperature of 25°C to 60°C will be used for determining the module power rating. For the natural sunlight, the spectral mismatch error corrections shall be made to the measured data per ASTM E 973 or IEC 904-7, if a reference cell with other than identical electrical and optical properties of the test modules is used for irradiance measurement.

If a solar simulator is used as the light source, it must meet the requirements of a Class A solar simulator as specified by ASTM E 927 or IEC 904-9.

4.3 Irradiance Measurement

The measurement of the irradiance on the module surface shall be conducted with a calibrated reference cell or reference module. Reference cells used for these tests shall have the same optical and electrical properties, including the spectral response, as the modules under test. Such reference cells shall have been calibrated by a minimum of two qualified laboratories per ASTM E1362 (Standard Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells) or IEC 904-2 (Requirements for Reference Solar Cells) or IEC 904-6 (Requirements for Reference Solar Modules) using the ASTM E 892 or IEC 904-3 global reference spectrum. The calibration constants shall agree within ±2.0% of each other. If these reference cells are used at cell temperatures outside the temperature range of 23-27°C, the temperature coefficient of the calibration constant shall have also been measured by two qualified laboratories. The average value of the calibration constant and temperature coefficient measured by the qualified laboratories shall be considered the true value. An auxiliary reference cell may be used in addition to the spectrally matched reference cell for experimental purposes.

To the extent possible, FSEC owned reference cells will be used for irradiance measurement. If the module technology is different from the FSEC owned reference cells, the module manufacturer/supplier will be required to provide an environmentally capsulated reference cell, that has been calibrated by at least two qualified laboratories as discussed above.

For testing of amorphous silicon modules, the reference cell used will be stabilized prior to calibration. This reference cell will be stored in a conditioned space, except when used for irradiance measurements for outdoor testing.

5.0 TEST METHOD

The testing of PV modules for power ratings shall be performed in the following sequence:

a) Receiving Inspection
b) Determination of Temperature Coefficients and Voltage Irradiance Correction Factor
c) Measurements and Translation of Data

5.1 Receiving Inspection

On receiving the test laboratory shall visually inspect each of the modules and document their condition with appropriate sketches and photographs to show the location of defects or other irregularities. The inspection should include, but not be limited to the following:

a) Shipping damage, poor workmanship, or mechanical mounting defects.
b) Cracking, shrinkage, or distortion of polymeric material used for electrical insulation or isolation including failure of adhesive and tacky surface of plastic modules.
c) Corrosion of fasteners, mechanical members, or electrical circuit elements.

d) Bubbles, delamination, or the presence of foreign material.
e) Mechanical distortion, buckling, or evidence of yielding.
f) Broken, cracked or torn external surfaces.
g) Broken or cracked cells.
h) Cells touching one another or module frame.
i) Terminals not bonded to the module or terminal box.
j) Faulty interconnections or joints.
k) Any other condition that may affect performance.

The receiving report as shown in Table 1 will be filled out and returned to the module supplier within a week stating the expected date of delivery of the test report.

5.2 Determination of Temperature Coefficients and Voltage Irradiance Correction Factor

In case of outdoor testing in natural sunlight, the measured module performance data taken under existing irradiance levels, spectral conditions and module temperatures need to be translated to STC and/or SOC to get the nominal module rating for standardization. This requires determining the temperature coefficients of module power, current and voltage, and module voltage irradiance correction factor. It may not be necessary to determine the temperature coefficients and correction factor for every module to be tested, and the values obtained from another module of identical design and construction may be used.

For FSEC testing, the temperature coefficients and voltage irradiance correction factor will generally be measured at FSEC. In some exceptional cases, the values obtained by Sandia National Laboratories may be used (King et al., 1997[*]). The methods used for the measurement of the temperature coefficients and correction factor are described in IEC 61215 Test 10.4, ASTM E1036-96 Annex 2 and King et al., 1997. FSEC test laboratory will determine the temperature coefficients of module power, voltage and current, and voltage irradiance correction factor in accordance with ASTM 1036-96 Annex 2.

[*] King, D. L., Kratochvil, J. A., and Boyson, W. E., Temperature Coefficients for PV Modules and Arrays: Measurement Methods, Difficulties and Results, 26th IEEE Photovolltaic Specialists Conference, Anaheim, CA, September 29- October 3, 1997.

Table 1 Module Receiving Report

Module Type and Model
UL Listed and Designation
Date Received
Expected Date of Delivery of Test Report

Module Serial No.						
Shipping Damage?						
Carrier/Shipper Notified?						
Is Module Replacement Required?						
Is Module Replacement Ordered?						
Flaws in Workmanship?						
Flaws in Electrical Connectors?						
Flaws in Seals/Adhesives?						
Flaws/Voids in Encapsulant?						
Flaws/Cracks in Cells?						
Other Flaws and Damages						

Notes:

Other Comments:

Prepared by:

5.3 Measurements and Translation of Data

Purpose: The purpose of this test is to determine the PV module's rated power, Pmp, at STC and/or SOC, along with other performance parameters, Voc, Isc, Vmp and Imp, from the measurements conducted on at least five test modules -
where Voc = open circuit voltage
Isc = short circuit current
Vmp = voltage at peak power
Imp = current at peak power

Procedure: The module's optical surface shall be cleaned prior to the electrical performance measurements. The I-V curve for each module shall be measured in accordance with ASTM E 1036 or IEC 904-1. Using the procedure defined in ASTM E 1036 or IEC 891, the performance data from I-V curves will be translated to Standard Test Conditions (STC): 25°C module temperature, 1000 W/ m^2 total irradiance and AM1.5 global spectral irradiance per ASTM E 892 and IEC 904-3 and Standard Operating Conditions (SOC, same as STC except that the module temperature is 45°C).

The translated values of the performance parameters at STC are determined from the equations given below:

$Isc\ (STC) = Isc\ (1000/E) / [1+ \alpha\ (Tm-25)]$
$Voc\ (STC) = Voc / [1+\beta(Tm-25)]\ [1+\delta x \ln(E)- \delta x \ln\ (1000)]$
For all other I-V points I(STC) = I x Isc (STC)/Isc and V(STC) = V x Voc (STC)/Voc

Where E, Tm, I and V are measured values of irradiance, module temperature, current and voltage, respectively. α and β are the temperature coefficients of current and voltage, and δ is the voltage irradiance correction factor.

The translated value of the performance parameters at SOC are determined from similar equations replacing 25 by 45 as the module temperature.

From the translated data, Pmp, Voc, Isc, Vmp, and Imp at STC and SOC are determined and recorded.

(If a reference cell with other than identical electrical and/or optical properties of the test modules is used for outdoor testing, the performance data shall be corrected for spectral mismatch error per ASTM E 973 or IEC 904-7.) For outdoor testing, the translated values of Pmp (and other performance parameters) for each module determined from the selected measurements at irradiance of 800 W/ m^2 or greater and module temperature of 25°C to 60°C will be averaged.

6.0 REPORTING

Test results shall cover all of the test requirements. Initially the report shall be made available only to the manufacturer. When the manufacturer is satisfied with the results, they shall instruct the testing laboratory to send the report to the certification body.

The test report on module performance will include the following:

- Module identification and description for each of the five test modules
- Reference cell identification and description
- Irradiance source identification
- Performance parameters Pmp, Voc, Isc, Vmp, and Isc at STC and SOC for each of the five test modules and averaged for all five modules
- I-V curve of a module with Pmp closest to the average Pmp

An example of a test report is shown in the attached table.

7.0 AMORPHOUS SILICON MODULES

The power output of amorphous silicon modules is known to degrade with exposure to sunlight due to the Staebler-Wronski effect. In addition to the light-induced degradation, amorphous silicon modules power output undergoes seasonal variation of about 10% from summer to winter due to annealing effect and spectral changes. Hence, determining and reporting only initial power rating of amorphous silicon modules is not sufficient.

FSEC will determine and report the power ratings of amorphous silicon modules at four different times of sunlight exposure:

i) initial
ii) after one month of sunlight exposure
iii) after six moths of sunlight exposure
iv) after one year of sunlight exposure

The test reports will be provided to the module supplier in two stages i.e., after the determination of initial power rating and after one year of sunlight exposure.

Photovoltaic Module Performance Report

FSEC Solar Flash Simulator (SFS) Test Date: 11/19/1999

Test Module/Array Description	Reference Cell Description
Module Identification/Type **MSX**	**Description Type/Material** **Si**
Manufacturer Name **B.P. Solarex**	**Cell Identification / Serial No.** **FSEC_Spr_1**
Model No. **MSX64**	**Manufacturer** **Spire Corp.**
Semiconductor Material (Si, CIS, CdTe) **Si.**	**Calibration Laboratory (NREL, SNLA)** **NREL**
Semiconductor Structure (single/polycrystalline, amorphous) **polycrystalline**	**Calibration Procedure (E1039 , E1125, E1362)** **N/A** **See Note (1)**
Junction (single, dual, triple) **Single**	**Calibration Constant** **3.14 Amps.**
Cell Stringing (series x parallel) **36 X 1**	**Factor Spectrum (global or direct normal)** **Global**
Overall Dimensions (length x width x thickness) **43.63”x19.75”x1.97” (1108x502x50mm)**	**Spectral Response (attach table or curve)**
Weight **15.9 lbs (7.2 kg)**	**Temperature Coefficient**
Voltage Temperature Coefficient **73 mV/°C**	**Date Last Calibrated** **6/6/99**
Current Temperature Coefficient **3 mA/°C**	

Solar Simulator SPI-Sun 660
STC – Standard Test Conditions (1000 W/m^2, 25°C and Air Mass 1.5)
SOC – Standard Operating Conditions (1000 W/m^2, 45°C and Air Mass 1.5)

Module: Serial No.	**1. 8501 Date/Time 11/19/1999**		**2. 8438 Date/Time**		**3. 8439 Date/Time**		**4. 45006 Date/Time**		**5. Date/Time**		**Average**	
PARAMETER	**STC**	**SOC**	**STC**	**SOC**	**STC**	**SOC**	**STC**	**SOC**	**STC**	**SOC**	**STC**	**SOC**
Open Circuit Voltage (Voc)	20.82		20.99		21.05		21.08				20.99	
Short Circuit Current (Isc)	3.96		3.77		3.75		3.76				3.81	
Voltage at Peak Power (Vmp)	16.27		16.72		16.87		16.79				16.66	
Current Peak Power (Imp)	3.54		3.45		3.44		3.44				3.47	
Peak Power (Pmp)	57.62		57.71		57.99		57.82				57.79	
Fill Factor (FF)	0.70		0.73		0.73		0.73				0.72	
Efficiency (total area, %)	10.40		10.41		10.46		10.43				10.43	

Notes: (1) A small module was used in place of a reference cell. This module was calibrated indoors and outdoors.
Calibration Uncertainty: _ 5%.
(2) SFS Lamp Intensity. 1000 Watts/m^2 (_ 5%)
(3) Test area illumination Uniformity: _ 3%.

APPENDIX A

EQUIPMENT AND APPARATUS REQUIRED FOR CERTIFICATION OF PV MODULE POWER RATINGS

- Reference cells of single crystal silicon, polycrystalline silicon, amorphous silicon, cadmium telluride (CdTe) and copper indium diselenide (CIS) materials
- Current-Voltage (I-V) curve tester and recorder
- Thermocouples or other temperature sensors
- Digital multi-meters
- Camera for receiving inspection
- Class A Solar simulator (optional)