

IEEE Recommended Practice for Qualification of Photovoltaic (PV) Modules

Sponsor

**IEEE Standards Coordinating Committee 21
on Photovoltaics**

Approved December 12, 1995

IEEE Standards Board

Abstract: Recommended procedures and specifications for qualification tests that are structured to evaluate terrestrial flat-plate photovoltaic non-concentrating modules intended for power generation applications are established.

Keywords: amorphous silicon devices, bypass diode thermal test, crystalline devices, damp heat test, dry hipot test, dynamic load test, electrical isolation test, electrical performance test, ground-continuity test, hail-impact test, hot-spot endurance test, humidity-freeze cycle test, mechanical loading test, outdoor exposure test, photovoltaic (PV) module, power generation, qualification test report, static load test, surface-cut susceptibility test, thermal-cycle test, twist test, ultraviolet conditioning test, visual inspection, wet hipot test, wet insulation-resistance test

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Copyright © 1996 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 1996. Printed in the United States of America.

ISBN 1-55937-586-8

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying all patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (508) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

[This introduction is not part of IEEE Std 1262-1995, IEEE Recommended Practice for Qualification of Photovoltaic (PV) Modules.]

This recommended practice provides qualification tests and procedures to evaluate terrestrial photovoltaic flat-plate non-concentrating modules intended for power generation applications. It is based on a Solar Energy Research Institute (SERI) interim publication. See [B3].

The intent of this recommended practice is to provide the minimum tests and inspections required to evaluate photovoltaic flat-plate non-concentrating modules and to provide a common approach (e.g., between producer and purchaser) in conducting qualification tests. The tests and procedures provided in this recommended practice may be supplemented by additional tests and procedures, established between the producer and purchaser.

Flat-plate module designs are under development, and new concepts continue to appear. This requires that qualification tests be flexible enough to allow a reasonable assessment of new designs, yet complete enough to identify weaknesses that would lead to problems in the field. Ideally, modules that experience early failures in field operation should fail qualification tests. Therefore, it is important to note that the design of this recommended practice and the tests specified were developed to eventually serve as a uniform standard for the flat-plate module photovoltaic industry.

At the time this recommended practice was approved, the Working Group on Photovoltaic Modules had the following membership:

L. Mrig, *Chair*

B. Kroposki, *Secretary*

D. Aldrich
A. J. Anderson
G. Atmaram
M. Azzam
J. Call
J. Cannon
S. Chalmers

J. Chamberlin
R. D'Aiello
R. DeBlasio
M. Flis
R. Hammond
S. Hogan
T. Lundtveit

K. Mackamul
R. Schmit
C. Osterwald
P. Taylor
R. Thompson
C. Whitaker
J. Wohlgemuth

At the time this recommended practice was completed, the Standards Coordinating Committee on Photovoltaics (SCC21) of the IEEE had the following membership:

R. DeBlasio, *Chair*

S. Chalmers, *Vice Chair*

A. J. Anderson, *Secretary**

R. Addiss
D. Aldrich
G. Atmaram
M. Azzam
J. Call
J. Chamberlin
R. D'Aiello
J. Drizos
M. Flis
D. Feder
R. Hammond

J. Hoffner
S. Hogan
W. Kaszeta
T. Lundtveit
K. MacKamul
E. Mahoney
J. McDowall
D. Meakin
L. Meisner
M. Moore
A. Nilsson

R. Rider
T. Ruhlmann
M. Russell
P. Russell
R. Schmit
R. Schmitt
P. Taylor
R. Thompson
C. Whitaker
J. Wiles
J. Wohlgemuth

* Previous Secretary—Robert J. Klein

The following persons were on the balloting committee:

R. Addiss	D. Feder	A. Nilsson
D. Aldrich	R. Hammond	R. Rider
A. J. Anderson	J. Hoffner	T. Ruhlmann
G. Atmaram	S. Hogan	M. Russell
M. Azzam	W. Kaszeta	P. Russell
J. Call	T. Lundtveit	R. Schmit
S. Chalmers	K. MacKamul	R. Schmitt
J. Chamberlin	E. Mahoney	P. Taylor
R. D'Aiello	J. McDowall	R. Thompson
R. DeBlasio	D. Meakin	C. Whitaker
J. Drizos	L. Meisner	J. Wiles
M. Flis	M. Moore	J. Wohlgemuth

When the IEEE Standards Board approved this standard on December 12, 1995, it had the following membership:

E. G. "Al" Kiener, *Chair*

Donald C. Loughry, *Vice Chair*

Andrew G. Salem, *Secretary*

Gilles A. Baril	Jim Isaak	Marco W. Migliaro
Clyde R. Camp	Ben C. Johnson	Mary Lou Padgett
Joseph A. Cannatelli	Sonny Kasturi	John W. Pope
Stephen L. Diamond	Lorraine C. Kevra	Arthur K. Reilly
Harold E. Epstein	Ivor N. Knight	Gary S. Robinson
Donald C. Fleckenstein	Joseph L. Koepfinger*	Ingo Rüsç
Jay Forster*	D. N. "Jim" Logothetis	Chee Kiow Tan
Donald N. Heirman	L. Bruce McClung	Leonard L. Tripp
Richard J. Holleman		Howard L. Wolfman

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal
Steve Sharkey
Robert E. Hebner
Chester C. Taylor

Valerie E. Zelenty
IEEE Standards Project Editor

Contents

CLAUSE	PAGE
1. Overview.....	1
1.1 Scope.....	1
1.2 Purpose.....	1
1.3 Limitations	1
2. References.....	2
3. Background and overview of qualification test	2
3.1 Background.....	2
3.2 Overview of qualification test.....	3
4. Module test and evaluation requirements	3
4.1 Test specimens	3
4.2 Initial tests and inspections	5
4.3 Final tests and inspections	5
4.4 Evaluation of qualification test results.....	6
5. Module test and inspection procedures.....	7
5.1 Visual inspection procedure.....	7
5.2 Electrical-performance test	9
5.3 Ground-continuity test	10
5.4 Electrical-isolation test (dry hipot)	10
5.5 Wet insulation-resistance test	10
5.6 Electrical-isolation test (wet hipot).....	11
5.7 Thermal-cycle test.....	11
5.8 Humidity-freeze cycle test	11
5.9 Robustness of terminations	12
5.10 Twist test.....	12
5.11 Mechanical-loading tests	12
5.12 Surface-cut susceptibility test	13
5.13 Damp heat test.....	13
5.14 Hail-impact test.....	14
5.15 Bypass-diode thermal test	14
5.16 Hot-spot endurance test.....	15
5.17 Ultraviolet conditioning test	18
5.18 Outdoor exposure test	19
5.19 Annealing procedure.....	19
6. Bibliography	19
ANNEX	
A (informative) A suggested test circuit for detecting open circuit and ground fault conditions ...	20
B (informative) Sample module qualification test report form	21

IEEE Recommended Practice for Qualification of Photovoltaic (PV) Modules

1. Overview

1.1 Scope

This recommended practice establishes recommended procedures and specifications for qualification tests that are structured to evaluate terrestrial flat-plate photovoltaic non-concentrating modules intended for power generation applications (see IEEE Std 928-1986).¹

1.2 Purpose

The qualification tests provided in this document should assist in evaluating flat-plate photovoltaic (PV) module design performance, safety, and susceptibility to known failure mechanisms.

Emphasis is placed on testing for potential degradation of module performance resulting from environmental weathering, mechanical loading, corrosion, and shadowing.

The procedures given in this recommended practice provide a common approach for conducting module qualification tests. While acceptable results from these tests should provide reasonable assurance that the modules produced by the same processes as those that pass these tests will perform reliably in the field after installation, this recommended practice does not address design, safety, or performance of PV systems.

1.3 Limitations

These qualification tests are applicable to crystalline silicon and amorphous silicon modules, and may also be applicable to modules of other photovoltaic technologies.

This recommended practice will be revised as required to incorporate the latest information on failure mechanisms and the relationships between accelerated tests and field reliability.

¹Information on references can be found in clause 2.

2. References

This recommended practice shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

ASTM E 892-87 (Reaff 1992), Standard Tables for Terrestrial Solar Spectral Irradiance at Air Mass 1.5 for a 37° Tilted Surface.²

ASTM E 927-91, Specification for Solar Simulation for Terrestrial Photovoltaic Testing.

ASTM E 1036-85 (Reaff 1993), Methods for Testing the Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells.

ASTM E 1038-93, Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls.

ASTM E 1171-93, Test Method for Photovoltaic Modules in Cyclic Temperature and Humidity Environments.

ASTM E 1462-94, Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules.

ASTM E 1596-94, Test Methods for Solar Radiation Weathering of Photovoltaic Modules.

ASTM G 53-93, Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials.

IEEE Std 928-1986, IEEE Recommended Criteria for Terrestrial Photovoltaic Power Systems (ANSI).³

UL 1703-1993, Standard for Flat-Plate Photovoltaic Modules and Panels.⁴

3. Background and overview of qualification test

3.1 Background

In developing this qualification test document, several sources of information were referenced and utilized in designing and formulating the majority of the tests given. Primary sources included UL 1703-1993, [B1], [B3], and [B4].⁵

Since the publication of these documents, photovoltaic materials technology and module development have advanced. Efforts in module reliability research have produced a better understanding of known and potential failure mechanisms associated with photovoltaic modules, especially with regard to the effects of moisture ingress. The results of these efforts and experience gained have been utilized in formulating new tests and modifying earlier tests for inclusion in this recommended practice.

²ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁴UL publications are available from Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, USA.

⁵The numbers in brackets correspond to those of the bibliography in clause 6.

3.2 Overview of qualification test

The qualification-test sequence is illustrated in figure 1. Module qualification test requirements, which provide detailed guidance and minimum requirements for the overall qualification test, are given in clause 4. Requirements and evaluation of test results necessary for passing the qualification test are provided in 4.4, and include

- a) Initial tests and inspections
- b) Sequence A through F tests and inspections which subject the modules to a specified sequence of environments and stress
- c) Final tests and inspections.

Descriptions of the required test and inspection procedures are provided in clause 5.

Initial tests and inspections (see 5.2) establish selection and acceptance of as-received modules as test module specimens. They also establish baseline visual-inspection information and electrical-performance measurement data for comparison and determination of the effects on module physical characteristics and electrical performance following exposure and endurance tests.

Nine test modules are required to complete all the specified tests. If the intrusive hot-spot test (sequence E) or intrusive bypass diode thermal test (sequence F) is to be performed, specially fabricated modules are required.

Test sequences A through F subject the modules to a specified sequence of environments and typical or accelerated stresses similar to those which final deployed modules should survive (see 4.2).

The tests and inspections (see 4.3) provide data for comparison with initial test and inspection results.

The criteria for passing the qualification tests are provided in 4.4.

4. Module test and evaluation requirements

This clause specifies the recommended tests and inspections to be performed and the required test sequence to be followed to evaluate photovoltaic flat-plate modules. The required test sequence is illustrated in the flow diagram provided in figure 1 along with designated inspection and test identification numbers corresponding to inspections and test procedures specified in clause 5.

4.1 Test specimens

A minimum of nine module test specimens of each module type representative of the modules to be deployed in the field is required to conduct all the tests specified in this recommended practice if the non-intrusive hot-spot test and non-intrusive bypass diode thermal test are performed. It should be noted that the use of the non-intrusive hot-spot test permits elimination of test sequence E and use of the non-intrusive bypass diode thermal test eliminates test sequence F. The modules should be randomly selected from a production batch or identical batches manufactured to the standard procedures and drawings, and approved by the manufacturer's quality control and conform to its acceptance procedures. Modules should not be pre-conditioned, e.g., light soaked or subject to other special procedures that are not a part of standard production. When the intrusive hot-spot test is to be conducted, an additional test module should be specially fabricated with leads brought out for accessing individual cells. When the intrusive bypass diode test is to be conducted, an additional test module should be constructed with leads brought out for accessing individual